D. Sollenberger FA

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Vol. I

Final Generic Environmental Impact Statement
on uranium milling
Project M-25

Summary and Text

September 1980

Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory Commission

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FOREWORD

This Environmental Statement was prepared by the Division of Waste Management, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission (the staff), in accordance with the Commission's regulation 10 CFR Part 51, which implements the requirements of the National Environmental Policy Act of 1969 (NEPA).

The NEPA states, among other things, that the Federal Government has the continuing responsibility to use all practicable means, consistent with the other essential considerations of national policy, to improve and to coordinate Federal plans, functions, programs and resources to the end that the Nation may:

"Fulfill the responsibilities of each generation as trustee of the environment for succeeding generations.

"Ensure for all Americans safe, healthful, productive, and esthetically and culturally pleasing surroundings.

"Attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences.

"Preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment that supports diversity and variety of individual choice.

"Achieve a balance between population and resource use that will permit high standards of living and a wide sharing of life's amenities.

"Enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

Further, with respect to major Federal actions significantly affecting the quality of the human environment, Section 102(2)(C) of the NEPA calls for the preparation of a detailed statement on:

(i) The environmental impact of the proposed action.

(ii) Any adverse environmental effects that cannot be avoided should the proposal be implemented.

(iii) Alternatives to the proposed action.

(iv) The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity.

(v) Any irreversible and irretrievable commitments of resources that would be involved in the proposed action, should it be implemented.

From time to time a generic issue must be considered in the form of a generic environmental impact statement. A public notice of intent to prepare the statement is published by the Commission. In conducting the NEPA review, the staff meets with cognizant individuals and organizations to seek new information and to ensure a thorough understanding of the issues of concern. On the basis of the foregoing and other such activities or inquiries as are deemed useful and appropriate, the staff makes an independent assessment of the considerations specified in Section 102(2)(C) of the NEPA and in 10 CFR 51.

This evaluation lead to the publication of a draft environmental statement, prepared by the NRC staff, that was circulated to appropriate governmental agencies for comment. A summary notice was published in the Federal Register, April 27, 1979, (44 FR 24963), of the availability of the draft environmental statement. In addition, proposed regulation changes implementing the conclusions of the draft environmental statement and reflecting recent legislation by the U.S. Congress (PL 95-604) were published in the Federal Register on

August 24, 1979 (44 FR 50015). Interested persons were invited to comment on the draft statement and the proposed regulations, and public hearings were held on these matters for the purpose of receiving additional public input.

The NRC is implementing the conclusions of this final statement by revising its regulations. Revised regulations incorporating the specific conclusions of this statement have been prepared and issued in the Federal Register. This statement includes: a discussion of concerns raised by the comments; a benefit-cost analysis, which considers the environmental costs and the alternatives available for reducing or avoiding them, and balances the adverse effects against the environmental, economic, technical, and other benefits; and a conclusion.

For this final Generic Environmental Impact Statement (GEIS) on Uranium Milling, the following comments may be made:

1) This action is taken in response to the Intent to Prepare Generic Environmental Impact Statement on Uranium Milling, Federal Register, June 3, 1976 (41 FR 22430), and in light of public comments received on the Draft GEIS, issued as NUREG-0511 in April of 1979.

2) The following Federal agencies have commented on the draft environmental statement:

   Department of the Army, Corp of Engineers
   Department of the Interior
   Department of Health, Education & Welfare
   Federal Energy Regulatory Commission
   Department of Energy
   Environmental Protection Agency
   Department of Agriculture

   In addition, a list of all commenters is contained in Appendix A.

3) The Draft GEIS was made available to the public, to the Environmental Protection Agency, and to other agencies in April, 1979.

4) Public meetings for the purpose of receiving additional public comments on the draft statement and proposed regulations were held in Denver, Colorado and Albuquerque, New Mexico in October 1979.

This Final Generic Environmental Impact Statement was made available to the public and to the Federal and State agencies in September 1980. Copies are available for purchase as noticed in the Federal Register, August 6, 1979, (44 FR 46005) from:

1) U.S. Nuclear Regulatory Commission
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   Springfield, VA 22161

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SUMMARY

OVERVIEW

In preparing this final generic environmental impact statement on the U.S. uranium milling industry, the staff has evaluated a wide range of issues. It has examined the problem of controlling emissions from mills during operations and the problem of mill decommissioning. The latter, of course, includes the special problem of dealing with the large volume wastes--mill tailings--produced by milling operations. These wastes will remain hazardous for very long periods of time owing to the long half-lives of radioactivity present. They emit a radioactive gas, Radon-222, which can be transported long distances exposing large populations, albeit to concentrations of radioactivity which are small increments above background. In addition to technical controls, supplementary institutional and financial arrangements for dealing with these problems have been addressed.

In formulating a position on how to deal with these problems to assure public, health and safety and environmental protection, the staff has developed a full range of perspectives and facts. It has analyzed the problems from short and long term points of view. Potential health risks to individuals living in the immediate vicinity of mills, to individuals living in mining and milling regions, to mill workers, and to large populations which can be exposed to radon, have been addressed. Potential impacts on land use, air quality, water quality, water use, biota and soils, and potential socioeconomic effects of milling operations are assessed. Alternatives for tailings disposal which have been examined have ranged from the past practice of doing virtually nothing to isolate tailings, to utilizing potential advanced treatment methods such as incorporation of tailings in a solid matrix.

It is not possible to provide a complete summary of all the information developed in this document. However a special effort has been made in preparing the Summary to refer the reader to specific sections of the main text pertinent to each issue discussed. This has been done to make it easy for readers to find and consider all of the information that has been developed, so they may draw their own conclusions about the issues addressed. Specifically, sections and chapters of the main text and appendices which provide details of material covered in the Summary are identified in parentheses, next to the topics, headings and specific material.

Specific regulatory changes found to be needed as a result of the analysis performed are being issued simultaneously with the issuance of this document. In addition, the regulations incorporate requirements of the Uranium Mill Tailings Radiation Control Act of 1978 as amended. Requirements in the regulations affecting emissions during operation will assure that exposures to individuals are within existing public health standards. Furthermore, requirements of regulations will have the effect of assuring that mill operations are performed in a manner that reduces population exposures and risks to the maximum extent reasonably achievable.

Requirements regarding decommissioning and mill tailings disposal are stated primarily as performance criteria. These criteria are intended to assure that mill and mill tailings disposal sites are returned to conditions which are reasonably near those of surrounding environs and to assure that ongoing active care and maintenance programs, to redress degradation of the tailings isolation by natural weathering and erosion forces, will not be necessary. While continued surveillance of mill tailings disposal sites is prudent in order to confirm that sites are not disrupted by unexpected natural erosion or human activity, decommissioning of remaining sections of the mill site should assure their unrestricted use. The staff has identified in its analysis a range of disposal methods, involving primarily below-grade disposal of tailings, that can meet these criteria. These include methods worked out with mill operators over the past year and represent a marked departure from previous disposal practices. Improved insight into problems of tailings disposal and decommissioning, and the best methods for solving them, will be gained as the first actual efforts of tailings disposal and mill site cleanup are undertaken at inactive sites in the next few years and as research programs of the Commission and other agencies continue. Therefore, the staff expects to reevaluate proposed criteria after remedial action has been taken at several sites, to determine if more specific criteria for tailings disposal are appropriate.

The staff is also implementing requirements for establishing financial arrangements which assure that mill decommissioning and tailings disposal are carried out in a manner consistent with the final technical criteria. In addition, it is required that mill operators contribute funds to cover the expense of ongoing site surveillance.

Finally, the staff concludes that given the highly site-specific nature of environmental impacts that can occur and in view of the importance of the tailings disposal problem, each licensing action calls for a thorough environmental assessment. The staff considers that this generic statement and associated rules can be no substitute for documented environmental assessments performed for each mill and mill tailings disposal site.

A draft of the document was issued for public comment in April, 1979 as NUREG-0511. The regulatory changes being issued were proposed in August, 1979 (44 FR 50012), and public meetings were held in October 1979 in Denver and Albuquerque, to facilitate public involvement. A very large public response occurred; private citizens, public interest groups, mill operators, trade associations and other federal and state government agencies have commented. The staff has responded to all comments received (Appendix A as summarized in Section 9 of this Summary) in finalizing this document and associated regulations.

1. PURPOSE AND SCOPE OF STATEMENT

This generic environmental impact statement on uranium milling has been prepared in accordance with a notice of intent published by the Nuclear Regulatory Commission (NRC) in the Federal Register (41 FR 22430) on June 3, 1976. As stated in the notice, the purpose of the statement would be to assess the potential environmental impacts of uranium milling operations, in a programmatic context, including the management of uranium mill tailings, and to provide an opportunity for public participation in decisions on any proposed changes in NRC regulations based on this assessment. In support of this purpose, the principal objectives of the statement have been as follow:

- To assess the nature and extent of the environmental impacts of conventional uranium milling in the United States from local, regional, and national perspectives on both short- and long-term bases, to determine what regulatory actions are needed;
- More specifically, to provide information on which to determine what regulatory requirements for management and disposal of mill tailings and mill decommissioning should be; and
- To support any rule changes that may be determined to be necessary.

Both technical and institutional issues are addressed. The major technical issues break down as follow:

- Mill tailings disposal as a long-term waste management problem. Major problems are those of isolating tailings from people for long time periods, control of persistent airborne emissions (particularly radon) and protection of groundwater quality;
- Decommissioning of mill structures and site (excluding the tailings disposal area);
- Radioactive airborne emissions during mill operations; and
- Nonradiological environmental impacts and resource use.

The major institutional questions addressed in this document include:

- Need for land use controls and site monitoring at tailings disposal sites;
- Methods of providing financial surety that tailings disposal and site decommissioning are accomplished at the expense of the mill operator; and
- Need for and methods of funding any long term surveillance which may be necessary at tailings disposal sites.

For convenience, sections, chapters and appendices providing details of material covered in this Summary are identified in parentheses. Chapter 1 contains a more complete guide to the organization of material developed in this statement.

As stated in the NRC Federal Register Notice (42 FR 13874) on the proposed scope and outline for this study, conventional uranium milling operations in both Agreement and Non-Agreement States, are evaluated up to the year 2000. Conventional uranium milling as used herein refers to the milling of ore mined primarily for the recovery of uranium. It involves the processes of crushing, grinding, and leaching of the ore, followed by chemical separation and concentration of uranium. Nonconventional recovery processes include in situ extraction of ore bodies, leaching of uranium-rich tailings piles, and extraction of uranium from mine water and wet-process phosphoric acid. These processes are described to a limited extent for completeness. They have not been evaluated in depth, since at the time the scope of this document was formulated, they were expected to produce relatively small quantities of uranium. The amount of current and projected nonconventional uranium recovery has increased since that time, as shown in Chapter 3. However, impacts from in situ extraction are almost exclusively related to groundwater and are, therefore, highly site-specific. The localized nature of this potential impact requires close examination on a case-by-case basis, which, by NRC licensing procedures and new procedures being required in Agreement States, involves preparation of independent, documented assessments of each project. Readers interested in this subject are referred to a general study of potential in situ extraction impacts on groundwater recently prepared by NRC, "Groundwater Elements of In Situ Leach Mining of Uranium."[1]

2. METHOD OF ASSESSMENT

In general, the method of assessment involves evaluation of a base case featuring a low level of environmental control, to characterize the nature and extent of potential environmental impacts from milling operations, primarily from tailings. (Chaps. 4, 5 and 6) Alternatives for mitigating these potential impacts are then evaluated. (Chaps. 8, 9, and 11) No attempt is made to analyze in detail the impacts from uranium milling which are highly specific to the site and its environs. These must be evaluated for each mill, as is done through environmental statements prepared in connection with individual mill licensing actions. In this statement, impacts that will result from a representative mill (a so-called "model" mill) are characterized to a degree sufficient to allow determining what, if any, programmatic changes are required. To evaluate potential worst-case cumulative effects that could occur in a region from milling operations, the staff examines effects of a level of concentrated mining and milling activity which might reasonably be expected to occur in a worst case in the year 2000: the equivalent of twelve 1800 metric tons (MT) per day mills in a region having an 80 km (50-mile) radius.

Cumulative impacts from the U.S. uranium milling industry were evaluated using conservative assumptions about the need for uranium until the year 2000. Nuclear energy growth projections resulting in a nuclear generating capacity of 180 GWe in the year 2000 were used in estimating U.S. uranium production necessary to meet estimated needs (Sec. 3.4). It was conservatively assumed that there would be no reprocessing of spent fuel over this time period. The resulting uranium demand would require the addition of the equivalent of about 53 additional 1800 MT per day conventional mills over this time period, assuming ore grade quality of 0.10 percent and an enrichment tails assay of 0.20 percent. It is assumed that the 23 currently required operating model mill equivalents would be retired at the rate of one per year. All the new mills are expected to be located in the western U.S. A total of about 4.7×10^8 MT of tailings, in addition to the 1.5×10^8 MT of tailings already existing at the end of 1978, is estimated to be generated by conventional uranium mills over the time period 1979 to 2000 (Sec. 3.5).

The model mill is based on an acid leach process which is common to the industry (Chap. 5). It produces 520 MT of U_3O_8 per year and about 5.6×10^5 MT/yr of mill tailings, the principal waste generated. In the base case, tailings are deposited in an above-ground tailings impoundment which comprises about two thirds of the model mill site of 150 ha. About 40 percent of the mill tailings surface is either covered or saturated with tailings solution during operation, the remainder presenting a source of radon and particulates. No steps are taken to isolate the tailings following operation. The model site is depicted in a semi-arid "model" region (80 km in radius), which is typical of actual milling regions in the western U.S. (Chap. 4). The model region is sparsely populated with an average density of 2.85 persons/km^2; the principal commercial activities are ranching and the extraction of mineral resources.

3. ASSESSMENT OF BASE CASE (Chap. 6)

3.1 General

Potential impacts in a variety of narrow categories were considered, including air quality, land use, mineral resources, water resources, soil resources, biota, community, and radiological impacts. While complete summary is not possible, the nature and extent of potential impacts are characterized by the following sections, which include selected examples identified in the Chapter 6 base case evaluation of the model mill. As previously stated, the base case features a low-level of emission control to form a basis upon which to analyze the effects of alternative control measures. Base case controls are representative mostly of past milling practice. For this reason, analysis of the base case brings into sharp focus the potential environmental and public health impacts which can occur. Impacts cited for the base case are more serious than those that would be occurring near most modern mills.

3.2 Radiological Impacts (Secs. 6.2.8, 6.3.8, 6.4)

With respect to overall health impacts, the critical mill-released radionuclides and their primary sources are, in descending order of importance: Rn-222 from the tailings pile; Ra-226 and Pb-210 from the tailings pile; and U-238 and U-234 from yellowcake operations. Health impacts from Rn-222 result from inhalation of in-grown daughters and ingestion of the ground-deposited long-lived daughter Pb-210. Because Rn-222 is released in gaseous form, it is transported long distances exposing large populations, albeit at extremely small levels above background. The impacts of Ra-226 and Pb-210, released in particulate form from the tailings pile, result primarily through ingestion pathways (dispersed Ra-226 also constitutes a secondary source of Rn-222 release). Emissions from impounded tailings materials have an enhanced importance due to their persistence beyond the operational lifetime of the mill itself. Yellowcake emissions result in significant localized impacts, primarily via inhalation, but essentially terminate when the mill shuts down.

Radiological impacts which result from mill operations under the low level of emission control assumed for the base case are summarized for various individuals and populations. In assessment of radiological impacts, the staff evaluated exposures that would occur to individuals living at several locations near the model mill. This was done to evaluate the problems of meeting applicable individual exposure limits (those of the EPA Uranium Fuel Cycle Standard, 40 CFR 190) and, in general, to state what health risks are faced by individuals living near mills. Of the several reference locations examined in the radiological assessment, a person located at a permanent residence 2 km downwind from the mill was selected to summarize the effects of mill effluents on nearby residents. (This individual is referred to as the "nearby" individual in the Summary.) To provide an additional individual health risk perspective, exposures and risks to an "average" individual living in the model region are summarized. The average individual's exposure is determined by dividing total regional population exposure by the number of people living in the model region. Contrasted with the worst case exposures received by the nearby individual, exposure to the average individual indicates the kind of risks which are faced by the broader populace of milling regions. The following also summarizes what exposures would be received by mill workers. Because mill workers will normally rotate assignments over the course of their career, exposures averaged over various locations in the mill are estimated instead of focusing on single locations. In addition to estimating "average" worker exposures and risks, cumulative industry-wide health effects are predicted. Finally, exposures and health effects to the United States and continental North American populations are summarized.

The problem of meeting 40 CFR 190 exposure limits is first discussed in the following; these limits require that exposures of whole body or any organ to any individual in the general public not exceed 25 mrem per year. Because the limits apply only to exposure to nuclides other than radon and its daughters, the first exposures discussed (referred to as 40 CFR 190 doses) do not include contributions from these nuclides. Total exposures to the individuals and populations just discussed, including doses resulting from the radon component, and health risks associated with these total exposures, are then presented.

Individual Exposure Limits - 40 CFR 190

- 40 CFR 190 limits are not met at permanent residence locations near the mill. Doses received by the nearby individual substantially exceed 25 mrem per year; 40 CFR 190 bone and lung doses are 45 and 30 mrem, respectively. Analysis indicates the limit could not be met within about three km downwind from the mill.

- The effect on the nearby resident of a potential worst case concentration of milling activity, where a cluster of 12 mills is postulated in year 2000, would be to increase 40 CFR 190 doses to bone and lung by about 15 to 20 percent. Although not a large fractional increase, this shows that the contribution from surrounding mills could be important in situations where meeting 40 CFR 190 was otherwise a borderline case.

Total Risks to Individuals

- Total exposure estimates, which include radon and daughters, indicate that radon is the greatest single contributor to risk. When total exposures are considered, the chances that the nearby individual would prematurely die from cancer as a result of living near the model mill for 20 years (a period assumed to include the full operation and decommissioning cycle of the mill) would be about 380 in a million. Because of the considerable uncertainties that exist in the health risk estimators used (risks could be one-half to two times those estimated), comparison with risks posed by background radiation provides valuable perspective. The estimated risks to the nearby individual would be an increase of about 25 percent above risks from background radiation exposures. Exposures and risks to an average individual in the region over a similar time span would be a small fraction (less than one percent) of those for the nearby individual.

- The effect of concentrated milling activity would be to increase risks to the nearby individual, as discussed above, by about 50 percent. The milling cluster would have a more dramatic effect on risks for the average individual, raising them by a factor of about ten, from three to about 30 chances in one million of premature cancer death. This risk would be about 2 percent of that faced due to natural radiation exposures.

- The risks to an average individual living in a region of maximum mining and milling activity in the year 2000 is very roughly estimated to be double those described above for milling alone. This estimate is based on recent radon measurements around open-pit and underground mines which indicate that releases from active mining will be roughly equivalent to those which would occur from tailings under the base case. (No attempt was made to study radon release from mining in detail in this study. Estimates are provided of these releases for perspective only; a comprehensive evaluation of these releases is being undertaken by NRC in separate, but related efforts to update information on environmental impacts of the uranium fuel cycle.)

Occupational Risks

- Average annual occupational exposures are estimated to be about 2000 and 7100 mrem to bone and lung, respectively. This level of exposure would lead to a lifetime risk of premature cancer death of about 30 in one thousand if the work period were about 50 years. This is about eight times risks due to natural radiation exposure. At these exposure levels, a total of about 39 potential premature deaths are estimated to occur among workers from operations of the U.S. milling industry to the year 2000. These risks are smaller than risks of death faced by workers from nonviolent causes alone, in at least several other industries, such as mining (Sec. 6.2.8.2.7).

Risks to Populations

- The most significant impact from mill operations under the base case would occur from persistent radon releases from the tailings. About 6000 premature deaths are predicted over the period 1979 to 3000 in the United States, Canada, and Mexico, from tailings which would be generated by the full operation of mills in the U.S. through the year 2000.

- These cumulative potential impacts constitute a 1.2×10^{-5} fraction of the overall U.S. incidence of cancer. Furthermore, the effects of releases from milling can be compared with those occurring from natural and technologically enhanced sources of radon. Specifically, exposures from milling radon releases would be about 0.3, 0.2, 3 and 10 percent of exposures occurring from releases from natural soils, building interiors, evapotranspiration and tilling of soil, respectively.

- The continuing annual rate of premature deaths from this volume of tailings is estimated to be about six per year. This annual rate could be used to develop estimates of health effects beyond 1000 years if this were desired; this would require making very uncertain assumptions on long-term factors such as climate, population growth, and the like.

The information just summarized about radiological impacts of the base case is tabulated in Tables 1 and 2.

3.3 Non-Radiological Impacts

Air Quality (Secs. 6.2.1, 6.3.1)

In general, the impact of mill operations on air quality occurs as a result of dust which is produced. Dusting from the tailings piles and traffic on dry ore hauling roads increases suspended particulates.

Table 1. Radiological Impacts from Radioactive Airborne Emissions for the Base Case Model Mill

Receptor	Dose Commitment[a] (mrem) Whole Body	Bone	Lung	Risk from Mill as Percentage of Risk Due to Background (%)[b,c]
Nearby Individual[d]				
Annual 40 CFR 190 doses (excluding radon)				
1 mill	3	45	30	--
Mill cluster	4	51	36	--
Total dose (including radon)				
1 mill	9.7	51	220	25
Mill cluster	13	61	340	38
Average Individual[e]				
1 mill	0.061	0.50	1.6	0.19
Mill cluster	0.66	5.8	16	1.9
Average Worker[f]				
Annual	450	2000	7100	800
Career[g]	2.1×10^4	9.3×10^4	3.3×10^5	800
Background	143	250	704	--

[a]All doses shown are total annual 15th-year dose commitments except where noted as being those covered by 40 CFR 190 limits.

[b]The range in risks due to uncertainties in health effects models extends from about one-half to two times the central value (App. G-7). This range does not include uncertainties in other areas (e.g., source term estimates and dose assessment models).

[c]Risk comparisons are presented for exposure received during entire mill life; that is, 15 years of exposure during operation of the mill, and 5 years of post-operation exposure while tailings are drying out, are considered. This value is greater than that from annual exposures presented because tailings dust releases increase in the period when tailings are drying.

[d]The "nearby individual" occupies a permanent residence at a reference location about 2 km downwind of the tailings pile.

[e]The "average individual" exposure is determined by dividing total population exposure in the model region by its population total.

[f]The "average worker" exposure is determined by averaging exposures expected at the various locations in the typical mill.

[g]The career dose is based on a person who has worked 47 years in the milling industry (that is, from ages 18 to 65).

Table 2. Potential Cumulative Somatic Health Effects from Milling Industry Mill Tailings Releases - Base Case [a,b,c]

	United States	North America
Premature cancer deaths		
1979-2100	550	610
1979-3000	5,400	6,000
Maximum premature death rate (years after 2100) - per year	5.4	6.0
Spontaneous cancer death rate - per year[d]	470,000	750,000
Fractional increase in death rate due to milling	1.2×10^{-5}	8.0×10^{-6}

[a]Uranium mines are not included in this table. It is estimated that through the year 2000, active mines would contribute about 6×10^{6} Ci which is approximately the same as the release from uncovered tailings piles through the same year.

[b]The range in risks due to uncertainties in health effects models extends from about one-half to two times the central value. This range does not include uncertainties in other areas (e.g., source term estimates and dose assessment models).

[c]Exposures in Continental Europe and Asia would add about 25 percent more health effects to the number of effects predicted for North America.

[d]"Vital statistics of the United States." See reference 2.

- In the single mill case, concentrations at a reference location nearby the mill (one km) are close to but within federal limits. An annual average concentration of 57 µg/m³ (22 µg/m³ above the background concentration of 35 µg/m³, which includes contributions from other nonmilling sources) is predicted. This compares with a limit of 60 µg/m³ existing in some states.

- Although the operation of a cluster of mills does not cause a large increase in dusting over that resulting from a single mill (about a 33 percent increase), the increment may be important in meeting allowable limits on suspended particulates near the mill. A concentration of 65 µ/m³ which would exceed some state standards is predicted for the reference location near the model mill. The relative effect of the mill cluster becomes greater as distances from the model mill increase (a doubling of suspended particulate concentration contributed by mills occurs at a distance of 40 km), but total concentrations (37 µg/m³) are within allowable limits.

<u>Land Use</u> (Secs. 6.2.2, 6.3.2)

Land use impacts from milling operations and tailings disposal are both direct and indirect. The most significant impact is permanent commitment of land to tailings disposal.

- Approximately 150 ha are devoted to milling and allied activities during operations at the model mill. During a brief period of mill construction, a total of 300 ha may be impacted.

- Deposition of windblown tailings may restrict use of land near tailings. Levels of contamination extend several hundred meters beyond the model site boundary in the prevailing wind direction affecting an area of 25 ha. Experience at inactive sites and ongoing field studies at active mills confirm the potential for such land contamination.

- In the multiple mill case, indirect impacts on land use occur; for example, the need for housing and other services for incoming workers divert a small amount of fertile land in the model region to urban uses.

The major potential land use impact is permanent commitment of 100 ha of semi-arid land for tailings disposal and restricted use of adjacent land that is contaminated by continued blowing of tailings dust from the poorly controlled mill tailings pile in the base case.

Groundwater (Secs. 6.2.4.2, 6.3.4.2, App. E)

Tailings solutions contain a wide range of trace metal, radioactive and chemical contaminants in concentrations significantly above existing state and federal water quality limits. Seepage of such solutions can potentially adversely affect groundwater aquifers and drinking water supplies.

- About 50 percent of tailings solutions, or about 600 MT per day, are disposed of by seepage in the base case.
- Transport of contaminants is a complex function of parameters such as conductivity and dispersivity of subsoils and underlying strata, hydraulic gradients of underlying groundwater formations, ion-exchange and buffering capacity of subsoils, and amounts of precipitation and evaporation. In general, natural subsoil conditions will tend to remove many heavy metals and radionuclides such as radium and thorium from the tailings seep. This will occur primarily as a result of chemical precipitation and sorption processes.
- Some heavy trace metals such as selenium, arsenic, and molybdenum may form ions which behave similarly to anion contaminants such as sulfates which do not tend to be removed by sorption.
- Using conservative assumptions about transport parameters, seepage in the base case results in contamination of the underlying aquifer, and eventually nearby wells, with concentrations of selenium and sulfate significantly above established limits. Radium and thorium are predicted to be retained by underlying soils.
- Following operation, rainfall may cause a continued, small amount of seepage from the tailings area.

Surface Water (Secs. 6.6.4.1, 6.2.4.2)

There are no direct discharges from tailings impoundments to surface streams. Minor impacts could occur indirectly from contaminated groundwater formations which intercept surface streams.

Water Use (Secs. 6.2.4, 6.3.4)

Water used in the mill process typically comes from deep-lying aquifers. About 1260 MT of solution will be deposited in the mill tailings disposal area per day. Tailings solutions will be disposed of by evaporation and seepage. 1240 MT of solution (which includes moisture from both the mill and rainfall) evaporate from the tailings per day. In some areas, where concentrated uranium development in conjunction with other heavy mining activity occurs, evaporative losses could result in temporary lowering of water wells tapping affected aquifers.

Soils and Terrestrial Biota (Secs. 6.2.5, 6.2.6, 6.3.5, 6.3.6)

Generally, impacts on soils supporting growth of vegetation and on terrestrial biota will be minor and localized. On the other hand, what impacts occur may be important because of the slow rate of soil formation in arid and semi-arid regions of the West.

- 150 to 300 ha of soils and wildlife habitat will be destroyed directly by construction and operation of the mill and mill tailings disposal site.
- Indirect impacts occur from seepage and spread of windblown particulate from the tailings pile. These lead to soil salinization, and contamination of soils and vegetation, with toxic elements. The extent of impacts would increase over the long term as tailings continued to blow.
- In the multiple mill case, impacts on biota of the region resulting from overgrazing might be evident.

The amount of land potentially disturbed is relatively small. Only a few tenths of a percent of primary and secondary productivity in the model region (80 km radius), typical of sparsely populated and semi-arid western milling areas, would be affected even in the multiple-mill case.

Socioeconomics (Secs. 6.2.7, 6.3.7)

In an effort to assess the socioeconomic impacts from uranium mining and milling, the following areas were examined: 1) demography and settlement patterns; 2) social, economic and political systems; 3) archeological and historical resources; and 4) esthetics and recreational resources. Negative socioeconomic impacts in the case of an isolated mill would be minor in terms of regional impact. Cumulative impacts might occur where multiple mills are located in a region. However, it is extremely difficult, in most cases, to isolate the effects of uranium milling and mining from effects occurring as a result of other mineral resource exploitation and industrial developments which could be occurring in a region, such as coal mining. In addition, it is difficult to project the level of these other industrial activities. In any case, the severity of impacts that can occur as a result of uranium milling and related mining activities would depend upon several factors, including the proportion of the population and regional economy that would be devoted to these activities, as well as the general social, economic and political characteristics of the area. Generally speaking, the potential socioeconomic impacts from uranium mining and milling are not unlike those occurring as a result of other similar-sized industrial developments.

3.4 Variants Examined

The staff evaluated the potential difference which could occur in impacts for two situations which vary from routine operation of the 1800 MT/day, acid leach mill: operation of alkaline leach mills and operation of much larger (7200 MT/day) mills. These different situations were considered in proposing the regulatory action summarized in Section 6 of the Summary.

Alkaline Leach Mill (App. H)

The model mill is an acid leach mill; however, 20 percent of the conventional milling industry utilizes the alkaline leach process. Radioactive exposures would be virtually the same for acid and alkaline mills. The major differences between impacts of alkaline and acid leach mills are:

- Water requirements of and, hence, seepage at the alkaline mill are 30 to 80 percent of an acid mill.
- Concentration of contaminants will be generally less in the alkaline leach mill. However, toxic anionic salts such as selenium and arsenic will tend to be present in greater concentrations.

Large Mills (App I)

General conclusions drawn from the comparison of large (7200 MT/day) and average size (1800 MT/day) mills are:

- Combined capital and operating costs of the 7200 MT/day mill are about 70 percent of those for the 1800 MT/day model mill, per unit of ore processed.
- For comparable siting situations, total population exposures will not significantly change, per unit of mill throughput.
- Problems of meeting individual limits will be more difficult at large mills, since emissions will increase with mill size.
- Factors offsetting increased emissions might be increased operating efficiency of control devices and greater management attention to emissions controls which could be afforded as a result of large mill economic efficiencies.
- Larger mills would reduce the number of separate sites being committed to mill tailings, and hence reduce the long-term problem of site surveillance.

3.5 Accidents (Chap. 7)

The effects of accidents associated with milling and mill tailings disposal were considered, including those associated with shipment of ore and yellowcake.

Generally, total releases, radiation exposures, and environmental impacts from accidents will be small fractions of routine releases from the mill.

The most severe potential accidents are those involving shipment of yellowcake. Under a worst case accident scenario in a relatively populated area, total exposures are predicted to be as much as about ten times what would occur from a single mill's annual operation.

4. ALTERNATIVES EVALUATED (Chap. 8)

4.1 General

Alternatives for mitigating potential environmental impacts were divided into three major groups: (1) alternative controls of airborne emissions during mill operation, including those from the tailings pile; (2) tailings disposal alternatives, including measures to control long-term airborne emissions (particularly radon) and to protect groundwater; and (3) alternative decommissioning modes for the mill site and structures.

4.2 Alternatives for Airborne Emission Control (Sec. 8.2)

Radioactive emissions during operations are effectively limited by the EPA's recently developed Uranium Fuel Cycle Standard (40 CFR 190), which limits annual dose commitments to offsite individuals, excluding contributions from radon and its daughters, to 25 mrem. Since NRC has responsibility for implementing this standard which takes effect in 1980, emphasis is on identifying steps that should be taken to control particulate emissions so this standard is met.

The major airborne control options identified as being available are:

- Water cover, sprinkling and chemical sprays to control diffuse sources of dust, such as the tailings, roads and ore storage areas.
- Devices for wind shielding and dust collecting hoods, such as may be applied in ore storage, handling, and crushing areas.
- Stack controls, including wet scrubbers and dry filters.
- Process modifications, such as wet, semi-autogenous grinding of ore, which can eliminate dry crushing of ore, and elimination of yellowcake drying operations, by shipping product as a moist cake or slurry.
- Progressive reclamation of tailings disposal areas.

With the exception of the two process modifications which are relatively recent developments, specific types of control equipment and methods were not evaluated in detail. Instead, the mitigative effects of several increasing control increments above the base case, which are representative of what could be provided by various available controls, were examined. An evaluation of emissions controls to establish new dose standards has not been conducted. The staff has evaluated the problems of meeting the newly established EPA fuel cycle dose limits, primarily focusing on the major mill emission sources--the yellowcake dryer and the tailings impoundment.

In general, methods used to suppress particulate dusting from exposed tailings surfaces during operation will not effectively suppress radon emissions. Saturation of the pile with tailings solution will be most effective in radon control; however, this method of emission control exacerbates problems involved in final reclamation. Progressive reclamation of a series of smaller tailings cells (contructed, filled and reclaimed in sequence) offers greatly enhanced radon emission control over the conventional single large impoundment scheme. This is the only effective and practicable alternative identified which effectively reduces tailings radon emissions during mill operation, the primary source of operational radiation risk to off-site individuals and populations.

4.3 Tailings Disposal Alternatives (Secs. 8.3, 8.4)

There are at least four, interdependent aspects of a tailings disposal program for which options can be identified. These relate to tailings treatment, disposal location, tailings area preparation, and tailings stabilization and covering. The following summarizes these options:

Tailings Treatment

Nitric acid leaching of ore to remove residual radioactivity from tailings
Segregation of slimes from sands for separate treatment
Neutralization
Barium chloride treatment
Removal of toxicants by ion-exchange
Dewatering of tailings by filtration devices in the mill process, by impoundment underdrains, by thermal evaporators, or by solar drying
Fixation of tailings in asphalt or cement

Disposal Location

Above grade
Below grade, near surface
Far below surface

Tailings Area Preparation

None
Soil compaction
Clay liner
Synthetic liner

Tailings Stabilization and Isolating Cover

None
Soil and overburden
Vegetation
Rock, gravel or riprap
Artificial covers and sealants
Combinations of above, in varying thicknesses

An extremely large number of tailings disposal programs could be constructed from these options. However, the staff selected a limited range of alternative disposal programs for detailed examination. The range of disposal programs was selected to be broad enough to feature each of the major options listed above in at least one of the programs considered. (Sec. 8.4, Table 8.1)

The alternative programs all address, to some degree, concerns of reducing airborne radioactive emissions (particularly radon), and the potential for groundwater contamination; however, there are major differences among them. The programs can be categorized according to the degree of tailings isolation provided and the associated levels of ongoing care and monitoring required. The three categories or modes assessed are referred to as: (1) the active care mode; (2) the passive monitoring mode; and (3) the potential reduced care mode.

Active Care Mode

This mode encompasses those alternatives which would require extensive active care and maintenance indefinitely to ensure continued isolation of the tailings. Although the tailings would be covered with overburden and soils, the isolation area would be susceptible to natural erosion capable of causing relatively rapid deterioration of an unmaintained pile. One tailings disposal program is described to illustrate this level of protection (Alternative 1).

Passive Monitoring Mode

Tailings would be isolated from erosional forces to eliminate or reduce to negligible levels the need for ongoing care. Five alternatives are described to illustrate the several, basic approaches which can be taken to achieve this level of protection. These alternatives primarily involve below-grade, near-surface burial of the tailings (Alternatives 2-5); however, one case (Alternative 6) constitutes an above-grade disposal scheme whereby selection of proper siting and design features would result in protection nearly equivalent to that provided by below-grade disposal. The below-grade alternatives include use of available open pit mines (Alternatives 2 and 3), or excavation of special pits for disposal (Alternatives 4 and 5).

Potential Reduced Care Mode

This mode (Alternatives 7, 8 and 9) is a loose collection of alternatives that represent departures from current technology or practice. To one degree or another, they have the potential of providing an added measure of isolation and protection, as well as a reduced level of ongoing care, beyond that provided by the two other categories. Unique features of the alternatives in this category are (1) disposal of tailings in relatively deep locations, (2) fixation of tailings slimes in asphalt or concrete, and (3) nitric acid leaching of ore.

4.4 Decommissioning of Mill Site and Structures (Sec. 8.5)

Two basic modes of mill decommissioning are considered, both of which would permit unrestricted use of the site (excluding the tailings pile) following operation. Alternatives are:

- The retention and use of some or all of the buildings and equipment after decontamination, and;

- The complete removal and burial in the tailings disposal area of all buildings, foundations, and equipment, with the restoration of the site to its original state.

Cleanup of ground contamination at the site would occur in either case.

5. BENEFIT-COST DISCUSSION AND CONCLUSIONS (Chap. 12; Chaps. 9, 11)

5.1 Radioactive Airborne Emissions during Operation (Secs. 12.3.7, 9.2.8)

Evaluation of emission controls indicates that compliance with the 25 mrem per year dose limit of 40 CFR 190, which does not pertain to radon releases, indicates that a high degree of control of particulate dusting from exposed tailings surfaces must be maintained. Compliance with 40 CFR 190 for a nearby individual at a 2-km distant permanent residence location requires that base case tailings dust emissions be reduced by 50 percent, as a minimum. Because only 63 percent of the tailings area is available for dusting in the base case, due to water cover or moisture saturation, an overall control level of about 70 percent is required. By itself, this level of control would create a borderline compliance situation, without any margin for increase in releases due to processing higher grade ore, or allowance for other mills in the area.

Table 3 illustrates the general effects on radiological exposures and risks of implementing available state-of-the-art emission controls. The effects of different levels of controls are illustrated. Level 1 includes the 50 percent reduction in tailings particulate emissions necessary to meet 40 CFR 190, and reductions in ore and yellowcake emissions as well, to provide sufficient margin of compliance. Level 2 includes a higher level of control of tailings particulates, and Level 3 illustrates the advantages of progressive reclamation of exposed tailings surfaces. Table 3 indicates the following with respect to resulting exposures and risks:

- Those controls necessary to meet 40 CFR 190 for the model mill processing 0.10 percent ore (Level 1) reduce risk to the nearby individual by less than 30 percent while reducing risk to the average individual by just over 20 percent. (These risk reductions accrue primarily from the 20 percent reduction in tailings radon releases associated with the water sprays postulated to achieve a 50 percent reduction in tailings particulates.)

- Compliance with 40 CFR 190 could be established even for mills processing much higher grade ore or located in areas near several other mills, by implementing available control technology (Level 2).

- Risks to nearby individuals are small in relation to those from background radiation and those to an average individual are smaller still, by over a factor of 100. Milling would contribute risks to an average individual amounting to less than 2 percent of those from background, even in the worst case mill cluster situation.

- Risks to the nearby individual and to the population of the region would not be greatly reduced by those controls necessary to meet 40 CFR 190, since the primary risk source, radon from tailings, would be largely unaffected.

- Risks to the nearby individual and the regional population could be substantially reduced by employing a scheme of progressive reclamation of exposed tailings areas (Level 3).

Table 3. Impacts from Pre-Reclamation Airborne Radioactive Emissions with Controls Applied[a]

Receptor		Dose During Operation, (mrem/yr)[b] Whole Body	Bone	Lung	Risk from Milling as Percent of Risk Due to Background[c] (%)
Nearby Individual[d]					
Annual 40 CFR 190 doses					
1 Mill:	Base Case	3.5	45.	30.	--
	Level 1	1.6	21.	6.9	--
	Level 2	0.68	8.9	4.3	--
	Level 3	0.26	3.5	3.1	--
Mill cluster:	Base Case	4.2	51.	36.	--
	Level 2	0.82	10.	5.2	--
Annual total doses					
1 Mill:	Base Case	9.7	51.	220.	25.
	Level 1	5.0	24.	160.	18.
	Level 2	2.8	11.	200.	22.
	Level 3	0.99	4.2	67.	5.6
Mill cluster:	Base Case	13.	61.	340.	38.
	Level 2	5.4	16.	310.	34.
Average Individual[e]					
Annual total doses					
1 Mill:	Base Case	0.061	0.50	1.6	0.19
	Level 1	0.041	0.31	1.2	0.15
	Level 2	0.040	0.28	1.5	0.18
	Level 3	0.014	0.099	0.53	0.046
Mill cluster:	Base Case	0.66	5.8	16.	1.9
	Level 2	0.40	3.4	16.	1.8
Average Mill Worker[f]					
Base Case		450.	2000.	7100.	800.
With Semiautogenous Grinding[g]		400.	730.	5700.	640
With Wet Product Shipment[h]		430.	1600.	4800.	570.

[a]Impacts to offsite individuals are given for four different combinations of emission control. Control Levels 1, 2, and 3 all differ from the base case in that particulate releases from the ore pad, and ore crushing and grinding operations are reduced by 40 percent, and base case yellowcake drying and packaging releases are reduced by 90 percent. Level 1 includes the use of water sprays or a multi-spigotted tailings discharge to reduce tailings particulate dusting by 50 percent and tailings radon releases by 20 percent. Level 2 includes the use of chemical stabilizing agents to reduce tailings dusting by 80 percent (radon is assumed unaffected). Level 3 includes progressive reclamation and use of chemical stabilizers; tailings dusting is reduced by 93 percent and radon emissions are reduced by 67 percent. (See Sec. 9.2)

[b]All doses shown are those occurring during the 15th and final year of mill operation and are rounded to two significant digits. Doses from radon and radon daughters are not included in 40 CFR 190 doses shown (40 CFR 190 exposure limits do not apply to radon releases.)

[c]Risk comparisons shown are for a total 20-year period which includes 15 years of operation plus a 5-year drying period. These risk increments are higher than occur on an annual basis during operation because post-operational annual doses are higher. Releases of particulates and radon increase in this period as the tailings dry out.

[d]The nearby individual is located at a permanent residence 2 km downwind of the center of the mill complex.

[e]Doses to the average individual are obtained by dividing the annual population doses received by all people within 80 km (50 miles) by the number of people in this area.

[f]Doses shown for the average mill worker are averages for different mill work stations; periodic rotation is assumed over a 47-year working lifetime.

[g]Semi-autogenous grinding is a wet process that virtually eliminates dust problems of more conventional dry ore crushing and grinding.

[h]Shipment of yellowcake product in wet form, as a slurry or moist cake, eliminates yellowcake inhalation exposures associated with normal product drying and packaging.

These risks are those associated with levels of control which would be very significant improvements over the base case, which represents past practice for most mills. However, notwithstanding the fact that the risks estimated would be very small compared to those occurring as a result of background radiation, and individual dose limits are met, the fact that any potential health effects can occur calls for reducing emissions to as low as reasonably achievable (ALARA). For example, holding releases to ALARA levels for new facilities would likely involve the use of progressive reclamation which, as indicated in Sec. 9.2, would substantially reduce radon emissions from tailings and result in the saving of 0.6 premature cancer deaths over a 20-year period prior to reclamation. This is also necessary to minimize the spread of ground contamination, which will lead to problems of final site decommissioning and cleanup. Since tailings dust controls are not automatic, constant vigilance and management attention to the status of tailings surfaces will have to be exercised to meet offsite dose limits.

Although the EPA limits can be met with effective stack controls, yellowcake emissions could be virtually eliminated by shipment of moist product from the mill. Also, eliminating the yellowcake dryer would reduce occupational exposure at mills, as shown in Table 3. Despite these potential benefits of the wet shipment option, the staff does not consider that wet shipment can be required because of the projected high cost of this shipment mode and insufficient capacity of UF_6 conversion facilities to handle wet cake. In fact, the process at one conversion plant is a "dry" process and is incompatible with the wet yellowcake shipment option. Modifying the process would require a dryer at the receiving end and thus, in this case, would only transfer associated problems from one location to another with higher population densities. Furthermore, that facility enjoys only a very small margin of compliance with 40 CFR 190 and could not continue to operate if it were required to dry wet yellowcake shipments onsite.

As illustrated in the base case, emissions from ore crushing and handling operations are relatively minor. Nevertheless, the wet, semi-autogenous ore grinding process offers significant advantages. It will virtually eliminate what ore crushing emissions do occur. Most significantly, worker exposure is estimated to be reduced by nearly 25 percent if this process is utilized, as shown in Table 3. For this reason, use of the semi-autogenous grinding process should be evaluated as a substitute for dry crushing operations for new mill operations.

In general, methods to control each of the mill emissions evaluated in this study are employed in the industry at the present time. Controls can be accomplished by using available technology at reasonable costs. It is essential that parameters which determine performance of effluent control devices be frequently checked to assure optimum performance; this can be done at little cost. Utilizing best available equipment, including semi-autogenous grinding equipment, would result in total lifetime costs of about $1.3 million dollars at the model mill. This would constitute a very small fraction of product price (about 0.2 percent).

5.2 Tailings Disposal (Sec. 12.3)

The base case and alternative tailings disposal programs were evaluated in terms of a series of very narrow environmental impact areas; that is, impacts on air quality, water quality, soils, biota, etc. It is difficult to summarize and quantify the severity of each of these impacts and, conversely, the degree to which they can be avoided by the alternative mitigative measures evaluated. However, the extent to which these impacts will occur over the long-term relates primarily to the following:

- Extent of airborne emissions (particulates and radon gas) from mill tailings pile, and
- Extent of seepage of tailings solutions.

Therefore, in its benefit-cost evaluation of long-term disposal alternatives, the staff narrowed the range of concern to reducing airborne emissions and seepage and assuring long-term stability. Generally, the staff has weighed alternatives in terms of a broad criterion that tailings should be isolated so that conditions at disposal sites will be reasonably near those of surrounding environs, and so that the need for ongoing active care and maintenance programs, to redress degradation of the tailings isolation by natural weathering and erosion forces, can be eliminated.

General staff conclusions regarding the tailings disposal modes evaluated are first presented. These are formed primarily by considering the long-term stability offered by each, overall costs and technological limitations. The matters of covering tailings areas to control airborne emissions and protecting groundwater from contaminated seepage are then discussed in turn.

5.2.1 General Conclusions on Disposal Modes (Secs. 12.3, 12.3.3, 9.4.1, 11.2)

Active Care Mode

Tailings disposal programs which require ongoing active maintenance to preserve the tailings isolation are unsound. Although a program may involve taking some steps to control airborne emissions and seepage to groundwater, which would be an improvement on past practice, the active care situation is unacceptable. It commits future generations to an ongoing obligation to care for wastes generated to produce benefits which those generations will receive only indirectly, if at all.

Passive Monitoring Modes

Disposal alternatives of this mode illustrate how tailings can be disposed of in a manner which provides reasonable assurance that ongoing active care and maintenance to redress natural disruptive forces can be avoided. The degree of isolation provided by this mode constitutes a minimum acceptable degree of protection.

A systematic evaluation was made to describe the kind of naturally caused "failure" events occurring over long periods of time that could breach the tailings isolation. (Sec. 9.4.1) The purpose of the evaluation was to identify potential failure mechanisms and the associated natural processes that should be considered in developing a tailings disposal program. On the basis of this, the staff concludes that below-grade disposal would provide the greatest potential for eliminating exposure to surface weathering and erosion processes which would disrupt the tailings and require continuing maintenance. The staff also concludes that, with proper siting and design measures, the tailings can be disposed of above grade in a manner which provides nearly equivalent protection to that provided by below-grade disposal. In any case, good siting is of overriding importance in isolating the tailings and associated hazards; inadequate siting cannot be overcome by design.

Table 4 presents the range of costs for the various tailings disposal modes examined. Costs associated with below-grade burial will vary, but will be reasonable in any case. Where open mine pits are available to receive tailings, no large excavation costs will be incurred, although such disposal may require that greater areas be lined with impermeable materials for groundwater protection than would be necessary for above-grade disposal schemes. Total costs for the open pit disposal alternatives examined range from about $11 million to a bit over $13 million (1800 MT per day model mill operating for 15 years). The costs for open-pit alternatives making up the lower end of this range are not much greater than costs for the above-grade alternative representing the Active Care Mode of tailings disposal. Where pits are excavated for the purpose of providing below-grade burial, excavation costs will result in an increase in total costs beyond those experienced for open pit disposal. The range of costs for special pit disposal alternatives examined is about $6 to $21 million, which is about two to three times costs for the Active Care Mode alternative examined. The above-grade disposal alternative evaluated under the Passive Monitoring Mode would be comparable in cost to the open pit program examined. The staff considers that the costs of this mode of disposal, which for the model mill will range from 2.2 to 4.1 percent of mill product price, are reasonable in view of the significant long-term benefit provided.

Potential Reduced Care Mode

While alternatives in this mode provide an added measure of isolation above that provided by previous modes, the staff concludes that none of them can reasonably be required because of uncertainty about the value of incremental benefits, uncertainty about technological feasibility, and because of their high cost.

Table 4. Total Costs of Alternative Disposal Modes at Model Mill[a,b]

Disposal Mode	Approximate Total Lifetime Costs ($1000)	Percentage Price of U_3O_8[c] (%)
Base Case	900	0.17
Active Care Mode	8,800	1.7
Passive Monitoring Mode		
Below Grade		
· Open Mine Pit	11,300-13,200	2.2-2.6
· Special Excavation	16,600-21,100	3.8-4.1
Above Grade	12,500-13,000	2.4-2.5
Potential Reduced Care Mode		
Fixation		
· Cement	71,000-140,000	13.7-21.1
· Asphalt	126,000-196,000	24.5-38
Nitric Acid Leaching	93,000	18

[a]Taken from Table 12.1.

[b]Costs are for model mill processing 1,800 MT per day of ore and operating for a 15-year period in a representative uranium development region. Costs in other regions may be somewhat different. These estimates are minimal in the sense that it was assumed that no untoward difficulties (e.g., excavating in hard rock) would be encountered. Contingency costs could be as much as 15-20% of quoted costs. Certain highly variable indirect costs such as taxes and indirect costs could add as much as 30%. Total costs could be as much as 50% less if the mine/mill operator performed work himself as opposed to contracting it. (Appendix K-8)

[c]Based on assumed market price of $30/lb and ore grade of 0.1 percent U_3O_8.

The alternatives involving fixation of the slimes portions of tailings in either cement or asphalt suffer from several drawbacks. First, fixation of tailings by cement or asphalt is not a commercially developed technology. There is also uncertainty as to the long-term stability of bonding between the tailings and the cement or asphalt. Furthermore, minimum costs for fixing the tailings would be about $70 million in the case of cement fixation. Total costs for the fixation alternatives exceed the upper range of costs for below-grade disposal alternatives by at least $50 million and by as much as $175 million. These alternatives do provide an added measure of isolation for the tailings and contribute to more than just the long-term objective. But the costs for the incremental benefit do not appear to be warranted, especially in light of the technological uncertainties involved.

Nitric acid leaching offers some potential for reduction of the radiological hazard of the tailings. Radium and thorium are removed from the ore during the same leaching process that removes the uranium. However, several problems remain. Laboratory studies to date indicate that residual radium and thorium concentrations in the tailings of a nitric acid leach process are still significantly above background concentrations. Therefore, isolation of the tailings in a manner similar to that provided for conventional tailings would still be required. Nitrates formed from the nitric acid leach process also pose a more severe environmental problem than anion species formed from conventional sulfuric or alkaline leach processes. Costs are high. The incremental lifetime costs of the nitric acid leach process (compared with conventional mill operation and tailings disposal by the most expensive passive monitoring mode alternative) would be about $70 million. Finally, there is still a problem of disposing of the radium and thorium concentrates (about 25 nCi/g each of Ra-226 and Th-230) from this process. In this study, these wastes are assumed to be solidified in a cement or asphalt matrix and buried 10 m (30 ft) below grade. They are, however, not unlike other alpha-emitting wastes from the fuel cycle, for which a final disposal mode is yet to be established.

Comparison with Disposal of Other Alpha Emitting Wastes

On the basis that mill tailings contain alpha emitting elements similar to those present in spent fuel and transuranic (TRU) wastes, some have raised the question of whether or not mill tailings should be disposed of with the same care as these other wastes. Actinides in spent fuel will accompany the high-level wastes being disposed of in the deep repository. Portions of TRU wastes may also be disposed of there.

Although the radioactive elements in mill tailings are similar to the actinides present in spent fuel (i.e., they are long lived, alpha emitters), mill tailings are a completely different kind of waste than spent fuel. Actinides in the fuel are 20 million times more concentrated than are the alpha emitters in mill tailings. The radioactivity in mill tailings is dispersed in a sand matrix which makes them much more like the earth's crust, phosphate mine tailings, fertilizer and coal ash than spent fuel carrying actinides. Radium concentrations in uranium mill tailings are on the average only about 500 times those in common soil, and as little as 10 times those of some of the other materials mentioned. Exposure to the actinides in spent fuel, and the fission products which are bound up with them, would result in immediate and acute health effects; long and sustained exposure to mill tailings would be required before any perceivable health effects would occur. Mill tailings have many times the volume of spent fuel (they would be 10,000 times more voluminous). Therefore, not only would it be unnecessary, but it would also be impracticable to dispose of tailings in deep locations similar to spent fuel disposal.

It is difficult to compare disposal of mill tailings with TRU wastes. With regard to TRU wastes, there is: (a) uncertainty about their exact total volume and concentrations; (b) variability in their form; and (c) uncertainty about the method that will be used to dispose of them. Some of the TRU waste may go to a deep repository. However, the concentrations involved would certainly have to be greater, and volumes less, than those of mill tailings for this to be necessary or practicable.

Different methods of disposing of the actinides in spent fuel, TRU, and mill tailings are called for. This is not to say that great care should not be taken in tailings disposal. Disposal methods must reflect the long-lived nature of the hazards present. The staff considers that the alternatives falling under the Passive Monitoring Mode of disposal will provide the long-term isolation of tailings wastes that is needed.

5.2.2 Tailings Cover and Radon Control (Secs. 12.3.4, 9.3.8, 11.2)

The staff evaluated a range of airborne emission control levels. This is primarily a matter of deciding what limits should be placed on radon flux, since direct gamma emissions can be reduced to essentially background and windblown particulates eliminated with very little cover material applied.

Using as a guiding principle the objective of returning tailings disposal sites to conditions which are reasonably near those of surrounding environs upon completion of milling operations, and which minimize the degree of long-term site surveillance which would be required, the staff concluded that a limit on radon emissions from buried tailings of 2 pCi/m^2/sec, and a minimum cover thickness of three meters, should be specified in regulations for tailings disposal.

In addition to the proposed action, the staff examined several alternative levels of isolation. Alternatives for controlling radon are as follow:

- At much higher levels: for example, 10 to 100 pCi/m^2/sec, or no control at all,
- At levels near but different from the proposed level: for example, 3 to 5 or 1 pCi/m^2/sec,
- Virtual elimination of the radon source.

Also considered was the alternative of requiring no minimum thickness of tailings cover.

The proposed limit on radon flux of 2 pCi/m^2/sec provides for a radon exhalation rate that will be within the observed range of variability of natural flux rates. Beyond this, the proposed limit was selected in consideration of several additional factors, no single one of which, by itself, leads conclusively to the proposed level of control, but which taken together support the requirements as being reasonable ones.

- Risk to Individuals (Sec. 12.3.4.3): The specified radon exhalation limit is one which would, in a worst case land use scenario of individuals occupying a structure on the tailings disposal area, result in exposures which are comparable to, but less than, limits specified by the U.S. Surgeon General for remedial actions at sites where tailings were used for construction of homes and other inhabited structures. They are also compatible with similar standards recently proposed by the U.S. EPA (4SFR 27370).

- Population Exposures (Sec. 12.3.4.4): Population doses and health effects calculated for the United States resulting from radon releases (under the proposed limit) from the accumulation of tailings in year 2000 would be an indistinguishable fraction of effects resulting from releases from natural soils (about 0.002 percent) and several other technologically enhanced sources. Table 5 shows estimated potential health effects resulting from uranium mill tailings controlled at the proposed level in relation to other natural and technologically enhanced sources of radon.

- Total Costs (Sec. 12.3.4.5): Costs to attain the proposed level of control appear reasonable. For cover with a common soil, resulting costs would be about 0.5 percent of the price of yellowcake ($30 per lb. and 0.1 percent ore grade assumed) or about $5 million to $7 million at the model mill. Costs would vary depending upon many factors such as type of soils, surface areas of tailings impoundment, type of earthwork procedures involved in adding cover, etc.; but in the worst case, costs should still be less than about 1.5 percent of the price of yellowcake. Evaluation of factors which will vary from site to site reveals that no undue economic burden is expected to be suffered at any particular site in meeting the proposed generic limits.

- Long-Term Physical Isolation and Stability (Sec. 12.3.4.7): In general, providing cover over the tailings provides physical isolation and protection of the tailings pile to assure stability over the long term. In addition to reducing radon, the tailings cover provides a measure of protection against disruption of tailings by such things as erosion, root penetration, burrowing animals and human intrusion. Specifying a minimum thickness of cover assures that undue reliance is not placed on thin coverings, which at least, for a short time, may reduce radon flux to levels specified.

Using the objective of returning sites to conditions near those of surrounding environs eliminates the option of controlling radon at much higher levels, such as 10 to 100 pCi/m^2/sec since background flux rates appear to average about 0.65 pCi/m^2-sec. Random measurements taken in common soils in the Western milling regions indicate that the upper range of flux is about 2.3 pCi/m^2-sec (that is, 99% of the time it is less than this value; see Appendix O). Setting limits which are much less than the proposed level would be unreasonable, since they would be undistinguishable from the radon flux that occurs from normal soils. Moreover, achieving further reductions in flux would require rapidly increasing expenditures (Fig. 12.1).

The staff considers that through its broad evaluation of the radon control issue (as well as the matter of long-term tailings disposal in general), it has effectively addressed the major principles of the International Commission on Radiation Protection (ICRP) concerning the need to keep individual exposures within appropriate limits and keep all exposures as low as reasonably achievable, economic and social factors taken into account.

The level of 2 pCi/m^2-sec was selected over other comparable control levels (such as 1 or 3 to 5 pCi/m^2-sec) because this level appears best to meet the objective of reducing fluxes to levels which are within the range occurring naturally from soils. While slightly higher radon flux limits such as 3 to 5 pCi/m^2-sec would also result in exposures less than the Surgeon General limit, they would be above the upper range of natural background flux rates. Furthermore, Surgeon General limits were developed for a remedial action situation where options are limited, as distinguished from the situation examined here where the same constraints do not present themselves.

In evaluating all aspects of the matter of tailings impoundment long-term cover requirements, the staff has concluded that it is prudent to establish a minimum cover thickness requirement (Sec. 12.3.4.7). This will avoid undue reliance on special materials or maintenance of special conditions, and will provide a reasonable minimum measure of physical isolation of the tailings.

The radon attenuation properties for various soil covers depicted in Figure 12.1 hold true for these soils under optimum conditions. The covers will lose their effectiveness if moisture is lost, cracks form, or the covers are penetrated in any manner. Moisture in a soil is perhaps the most important factor upon which radon attenuation properties depend (App. P and Sec. 9.3.8). With use of some materials, such as clays which have been wetted,

Table 5. Comparison of Continuous Long Term Releases of Radon from Uranium Mill Tailings to Other Continuous Radon Releases[a,b]

	Estimated Annual Release (Ci/yr)	Estimated Annual Population Dose to U.S. (organ-rem to the bronchial epithelium)	Potential Annual Premature Cancer Deaths
Natural soils	1.2×10^8	1.6×10^7	1152
Building interiors	2.8×10^4	2.2×10^7	1594
Evapotranspiration[c]	8.8×10^6	1.2×10^6	86
Soil tillage	3.1×10^6	4.2×10^5	30
Fertilizer used (1900-1977)	4.8×10^4	6.9×10^3	0.50
Reclaimed land from phosphate mining	3.6×10^4	4.9×10^3	0.35
Postoperational releases from tailings[d]			
Base Case	5.5×10^5	4.0×10^4	2.9
Proposed Limit	3.9×10^3	2.8×10^2	0.020

[a]Estimates of all radon releases except those from mill tailings are taken from an investigation of natural and technologically enhanced radon sources performed in support of this generic statement by Oak Ridge National Laboratory (see reference 3, NUREG/CR-0573). Population doses were derived from reference 3 using a dose conversion factor of 0.625 mrem/yr/pCi/m³ (see Appendix G). Exposures to mill tailings in regions around mills are included; see Section 6.4.

[b]Population at risk is taken to be the United States 1978 population, for purposes of comparison. Predicted exposure and health effects for U.S. would be about 88% of the total for North America and about 70% of the global total.

[c]Evapotranspiration is the collective release of water vapor from soil surfaces and vegetation.

[d]For purposes of comparison, risks in this table are only those due to exposures of bronchial epithelium from inhalation, as opposed to total risks from ingestion and inhalation as presented in Table 2.

radon could be attenuated to the prescribed flux limit with relatively thin layers. However, it is imprudent to count on these materials retaining such moisture levels over long periods of time when they are near surface and subjected to climatic influences. The minimum cover thickness precludes reliance on soils retaining moisture contents greater than what is commonly found in similar soils in similar locations.

Also, specifying a minimum cover will minimize the effects of cracking of soils which can occur in several ways. Clays, because they tend to be cohesive materials, will crack upon dessication or when subject to wetting-drying and freeze-thaw cycling. As discussed above, this cycling will certainly occur when they are used as tailings covers. Cracking of soils is also possible, and even probable in many cases, where tailings dry out and consolidate over time and differential settlement of cover occurs. Cracking will lead to dramatic loss in radon attenuation properties. Synthetic cover materials are also not likely to remain intact and maintain initial radon attenuation properties under any reasonable long-term scenario, if applied in relatively thin layers; currently, such synthetic materials must be applied in relatively thin layers to be economically competitive.

Such a minimum thickness requirement will also reduce the likelihood and potentially disruptive effects of root penetration, and provide protection from burrowing animals. Although it is necessary that human land uses be appropriately controlled at disposal sites, the objective is that continued beneficial use of the surface be possible; a minimum thickness requirement will enhance the probability of meeting such an objective. While the overall tailings disposal program must effectively eliminate the potential for disruption by erosion or other natural phenomena, there are undeniable uncertainties about long-term cover performance. The minimum cover thickness provides a desirable margin of safety in the face of these uncertainties. Furthermore, it provides margins of safety which are desirable because of uncertainties about the upward migration of toxic salts from the tailings to the surface which have been raised by recent research.

Deciding what should be a minimum cover thickness is a matter of judgment. The staff considers, however, a minimum cover thickness of 3 m (10 ft) to be a reasonable lower limit. Given moistures and other properties of soil commonly observed under normal conditions in the western milling regions, it is most likely that 3 m or more will be required in most cases to meet the radon flux limit. While materials such as a naturally moist clay might reduce radon flux to prescribed levels in somewhat less than 3 meters (a soil near the upper range of natural moisture contents, under the best of conditions, is needed in a 2.2 meter thickness), it is virtually certain they will not remain free of cracks or other defects over the long-term. So from the point of view of radon attenuation alone, 3 meters appears to be a reasonable lower limit. Considering the other concerns described above, a thickness greater than the minimum needed to meet prescribed radon limits under optimum conditions appears very reasonable.

The staff considers that regulations on uranium mill tailings disposal should generally be cast in the form of performance objectives because of the many site-specific factors involved. However, regulations must explicitly address potential problems where they are known, and this is such a case. The staff considers it prudent to specify the minimum thickness, given the firm knowledge of the problems discussed above. The NRC, as well as other government agencies and industry, will continue to conduct research into tailings cover material technology. It is not beyond the realm of possibility that techniques could be found for economically resolving the concerns that lead to the minimum cover thickness requirement, under certain conditions, which would make it reasonable to relax the requirement. However, the staff is aware of no technology that would do this and cannot ignore the known problems discussed above, simply because of speculation that they might, in the future, be resolved.

The staff considered but determined it would be impracticable and inappropriate to make a fully monetized, incremental cost-benefit optimization the basis for establishing limits on radon flux, given the complex, multi-dimensional and long-term nature of the mill tailings disposal problem. While such an optimization process appears to offer a "rational approach" to decision-making, it can be misleading, because it grossly oversimplifies the problem. Furthermore, it can be quite arbitrary, given the highly subjective nature of some of the major factors and assumptions which must be decided upon to use it. (Sec. 12.3.4.6, Appendix U).

In general, the optimum level of radioactive emission control is that level where costs associated with providing any increased control to avert health effects are balanced against what is considered to be an appropriate monetary value for the health effects averted. To support such a process, the following basic factors must be established and there is either considerable uncertainty or widely varying judgments as to the appropriate value for each:

- The period of time over which health effects should be integrated;
- The economic or monetary value of averting health effects;
- Factors relating health effects to radioactive emission; that is, prediction of resulting health effects per unit of radioactivity release; and,
- The costs of providing emission control and the effectiveness of such control in reducing emissions.

Using what the staff considers to be reasonable ranges of values for these factors, the derived optimum radon flux limit varies over many orders of magnitude (see Table 12.5).

Period of Integration

The period over which health effects should be integrated is highly subjective, and commenters on the draft of this document varied widely in their opinions on the matter. On one hand, 100 years was considered appropriate. On the other hand, a period of time which is commensurate with the long half-lives of the radon progenitors thorium-230 (80,000-year half-life) and uranium-238 (4.5×10^9-year half-life) was urged. Obviously, by selection of this parameter alone, the optimum radon control level can be made to come out either at a level of very little control or at a level of essentially complete control. For example, if one were to select a value of $1 million as the appropriate monetary value of averting a health effect, the optimum flux limit would be nearly 50 $pCi/m^2/sec$ if 100 years of effects were considered, while virtual elimination of radon releases would be called for if effects over a 100,000-year period were considered.

Monetary Value of Health Effects

This factor also involves considerable subjectivity. What is the monetary worth of averting a health effect (premature loss of life by cancer)? Today? 1,000 or 10,000 years from now? Some indication of what society is willing to spend today to avert a health effect can be obtained by examining what society is spending to reduce risk from other life-threatening hazards. This ranges widely, however, depending upon many complex societal factors and perceptions--anywhere from as little as $20,000 to at least $10,000,000 per health effect saved and more has been spent on health protection. This range includes expenditures for such things as medical screening and care, automobile traffic safety, airline safety, radioactive- and nonradioactive-related emissions and activities. Expenditures for radioactivity-related risks are routinely much greater than for other societal risks. Picking the range of $10,000 to $10,000,000 for the value of averting a health effect and selecting a 1000-year integration period, the optimum flux level can vary from greater than 100 pCi/m^2-sec to virtual elimination of residual radon flux.

Health Effect Prediction

There is substantial uncertainty in the calculational models used to estimate the environmental transport of radon and its daughters, and resulting human exposure and potential health effects. When considering the long-term nature of the radon hazard, the very large uncertainties concerning such things as future population size and distribution, impacts of changes in climate (such as heating of the earth's surface and atmosphere, the greenhouse effect), and scientific advances (which could conceivably include a cure for lung cancer) make impracticable definitive health effect prediction. It is estimated that these uncertainties can cause variation in the optimum flux over several orders of magnitude.

Cost and Effectiveness of Control

The factor which will determine what the releases of radon will be over the long-term is not the initial thickness of radon attenuating cover placed over the tailings. It will be a complex function of chiefly climatic and topographic site-specific conditions and of those siting and design features which are built into a disposal program to account for these conditions. The siting and design features include such things as placing tailings below grade, flattening of slopes, minimizing of upstream drainage, providing cover erosion protection, and so on, which are intended to isolate the tailings containment from erosion and other disruptive processes. The cost for these factors will vary widely from site to site (Sec. 12.3.3). Also, there is no practicable way to correlate each of these steps with specific levels of long-term performance. What will be the incremental benefit (increase in containment effectiveness), over hundreds or thousands of years, of providing slopes that are 10h:1v as opposed to 2h:1v?--or of having rock cover over exposed slopes of embankment as opposed to vegetation alone? What will be the difference in erosion over hundreds or thousands of years, if there is an upstream drainage area of a square mile with a 1% grade at a site, as opposed to a few acres with a 5% grade?--or if there is a few more inches of net rainfall per year at one site than at another? These differences are significant in terms of actual future radon releases, but they are impossible to quantify.

This inability to correlate containment performance uniquely with costs is probably the most significant reason why it is not reasonable or realistic to adopt a strict incremental cost-benefit optimization.

The uncertainty associated with containment performance is vastly different from other radioactive environmental control or waste management cases where incremental cost-benefit analysis might, in some cases, be reasonably relied upon. Tailings impoundments constitute large, diffuse, and essentially permanent area sources as opposed to finite-term, point sources which are amenable to mechanical emission control equipment. The hazards in the tailings are very long-lived and the containment will need to be similarly durable. Therefore, there is very large uncertainty as to the long-term isolation performance, unlike what would be the case when controlling a stack emission for a short period of time. As opposed to being disposed of in deep geological formations, tailings are being disposed of near-surface, where conditions affecting performance are much more rapidly variable with time.

Also as discussed previously, there is a strong interrelationship among the various goals of tailings management. In some cases, there is competition among objectives. For example, in attempting to provide greater containment of radon and long-term stability by placing further tailings below grade, with increasingly thicker covers, tailings are being put closer to groundwater formations, making groundwater protection objectives more difficult to achieve. In other cases, working to achieve one objective also contributes toward attainment of another. For example, placing cover over a tailings pile not only reduces radon emissions and the associated impacts, but also provides some isolation from intrusion and reduces potential for tailings misuse. It is not possible to monetize these interrelated factors so as to assure that the cost-benefit optimization is a realistic one.

Conclusion

In view of this discussion, the staff has weighed alternative radon control levels in terms of how they would meet the simple objective of returning disposal sites to conditions which are reasonably near those of surrounding environs. Achievement of this simple objective assures that any resulting incremental impacts from radon, although continuing, will be similar in magnitude and kind to those occurring naturally. In conjunction with the required limit on radon flux, a conservative approach is taken with regard to the general mode of disposal. Below grade burial is identified as the prime disposal mode to assure that the effects of natural weathering and erosion processes which could disrupt the tailings isolation are eliminated or reduced to very low levels. A minimum cover thickness and other protection measures are also required by regulations to provide a measure of conservatism, with regard to long-term stability of tailings cover.

5.2.3 Seepage and Groundwater Protection (Secs. 12.3.5, 9.3.4)

In general, the staff concludes that the most effective way to reduce potential groundwater contamination and associated health effects is to reduce the amount of moisture available to carry toxic contaminants away from the impoundments--that is, to control seepage. Alternatives examined which reduce liquid transport include: recycling of water to the mill, and other process steps which minimize water consumption, use of low-permeability liners on the bottom and sides of the impoundment, and dewatering of tailings.

Recycling of water to the mill process featured in all cases, including the base case, results in reduction in the amount of tailings solution to be disposed of and in a side benefit of reduced consumptive water use in milling areas, which are frequently water-scarce. Highly impermeable clay and synthetic liners drastically reduce the rate at which tailings solutions can seep from the disposal area and, hence, the rate at which toxic materials can escape to groundwater. Dewatering of tailings can simplify the matter of isolating solutions, for example, by reducing the amount of lining needed in cases involving below-grade burial of tailings. Dewatering can also result in more stable impoundments and can reduce problems of impoundment drying, thus simplifying the matter of final tailings covering and reclamation. In situ dewatering of tailings through underdrains is relatively inexpensive but particularly effective.

The determination of which of these methods, or combination, will provide the optimum and most efficient way to avoid groundwater problems must be done on a case-by-case basis. However, costs for employing them are expected to be reasonable in any case. Recycling of process water is standard practice and is assumed to be a part of milling operating costs. Costs of using liners is dependent on disposal location (above or below-grade disposal), method of applying liners (volume of liner materials needed and amount of associated impoundment preparation needed), type of liner used, and whether or not tailings are dewatered. However, in general, groundwater protection of disposal schemes evaluated under the passive monitoring mode would cost between about $5 million and 10 million (about 1 to 2 percent of the price of U_3O_8).

Although the preferred approach towards groundwater protection is isolation of tailings, the staff does not consider complete prohibition of disposal in groundwater appropriate. The conservative approach of providing isolation may be unnecessary where it can be demonstrated that on the basis of site-specific conditions and with tailings treatment, groundwater quality can be preserved.

Since milling is currently conducted in semi-arid regions, where evaporation rates are far in excess of rainfall rates, it is not expected that seepage will be a long-term problem. There is concern about providing good seepage control primarily during the operational period, when hundreds of tons of waste solutions are generated daily at an average mill. After the impoundments dry, there will be virtually no driving force for seepage. There is good reason to expect that there is, in general, little natural recharge of aquifers in interfluvial zones in the semi-arid milling regions, if there is any at all. It is for this reason that the staff considers use of synthetic liners, the likely long-term stability of which is questionable at best, acceptable. Regulations call for neutralization to be considered in developing tailings disposal programs. However, given the expectations about long-term seepage and the extremely high cost of neutralization, it is likely neutralization will not be appropriate for most situations in arid and semi-arid areas. If milling were proposed to be conducted in areas of higher rainfall, neutralization would need to be given strong consideration.

Determining what steps must be taken to control seepage requires complete information and a thorough understanding of site geologic and hydrologic conditions which will control seepage movement; therefore, regulations establish explicitly the collection of such information as a requirement, and identify the general characteristics of the data-collection program that is needed to assure information is complete and representative of actual conditions.

5.2.4 Uncertainty of Future Effects (Secs. 12.6, 9.4)

As stated, the staff considers that conservative design of tailings disposal programs and careful siting of disposal impoundments can provide reasonable assurance that the tailings will remain isolated for very long periods of time. However, the very long-term performance of tailings isolation (that is, several thousands of years into the future and beyond) will be governed by climatic and geologic forces which cannot be predicted precisely. Therefore, there is uncertainty about very long-term effects. However, radioactivity in the tailings, unlike high level nuclear waste, poses a chronic as opposed to an acute hazard. Long and sustained exposure to radioactivity in the tailings pile would be required to produce detectable adverse effects. If degradation or failure of isolation were to occur, it would not lead to catastrophic radiation effects. There would be ample time to take corrective action.

The staff has examined a full range of possible failure modes. It has not done this to predict in absolute or quantitative terms chances for or consequences of failure. Rather, it has done this to provide a guide in siting and design of tailings disposal schemes. The principal question to be addressed is what should be considered or taken account of to provide reasonable assurance of long-term isolation of tailings?

To account for uncertainties and to provide what the staff considers to be a conservative perspective on the matter of potential cumulative health effects from radon release, a "total failure" of ten percent of the tailings isolation areas is arbitrarily assumed. This would result in incremental releases and exposures which are about a factor of 10^{-3} (0.1 percent) of those resulting from natural radon releases (see Table 5). Therefore, consequences of such worst case situations are seen to be a very small fraction of those naturally occurring without milling.

Erosion is expected to occur very slowly (on the order of a foot in tens of thousands of years, Sec. 9.4.1) if it occurs at all, given the siting and design measures being required to reduce erosional potential and avoid other long-term failure mechanisms. Some have suggested, however, that tailings piles will eventually become uncovered and tailings widely dispersed. It has then been suggested that tailings will emit radon undiminished and expose populations for hundreds of thousands of years, until decay of its precursors is complete. Such "worst case" scenarios result in extremely large health impacts. Larger annual death rates than estimated for the uncovered base case (see Table 5) are postulated because tailings are assumed to become totally dispersed and there is no self-shielding or attenuation of radon, as there is when tailings are in a pile form.

The staff considers such scenarios to be completely unrealistic, however. They are not reasonable upper bound scenarios of health impacts associated with tailings disposal. In addition to the fact that measures are taken to avoid such failures, these failure scenarios do not recognize that some erosional processes which must be postulated to uncover and disperse the piles will also work to remove tailings from the earth's surface. Erosion will either cover tailings with other eroded materials or eventually carry them into streams. In fact, it is just as reasonable to assume that the erosion which might uncover tailings piles will eventually uncover natural ore bodies. Viewed in this sense, it can be argued that mining and milling of uranium has no significant net health impacts difference than if mining were not to occur. It only changes the point in time when the uranium and its daughters are brought to the surface and made available to expose people.

The staff considers that tailings disposal alternatives falling into the "passive monitoring mode" include a strong measure of conservatism in design and siting to assure long-term isolation and stability without perpetual active care. However, this analysis shows that the consequences of even an unlikely "total failure" scenario are small in comparison to those occurring from natural releases.

While the primary means of isolating mill tailings must be physical barriers, it would be prudent to have some continued surveillance and control of land uses at tailings sites to confirm that there is no disruption by either natural erosion or by human-related activities, as a supplementary measure. In drawing this conclusion, the staff evaluated various potential future land use scenarios involving both direct and indirect disruption of the tailings by human activity; this is presented in Section 9.4.2. The land ownership arrangement specified in the recent Act of Congress on uranium mill tailings (see reference 4, Public Law 95-604) will assure this kind of control is provided. (Secs. 9.4.2, 10.3, 13.4)

5.3 Decommissioning of Mill Structures and Site (Secs. 12.3.10, 11.3, 9.5)

Cleanup of the mill site, and either dismantlement or decontamination of mill structures to permit complete and unrestricted use of the site (excluding the mill tailings disposal area), can be accomplished utilizing simple and straightforward clean-up and excavation methods. Costs for these operations are estimated to be about $1.3 million at the model mill. In view of these relatively small costs and the nature of the operation, consideration of a less complete decommissioning mode (any type of conditional or restricted use mode) would be unacceptable.

5.4 Conclusions on Nonradiological Environmental Impacts (Chaps. 6 and 9)

The staff has drawn the following conclusion on those nonradiological environmental impacts not discussed previously in Section 5 of this Summary.

- No changes appear warranted in the NRC regulatory program (beyond those identified above for tailings management and disposal) to control nonradiological impacts of milling operations. Mitigating measures can be taken on a case-by-case basis to assure that no unacceptable environmental impacts occur. Thorough environmental assessments, as required in connection with each NRC or Agreement State mill licensing action, will provide an adequate mechanism for dealing with and resolving potential undesirable negative impacts.

- Because impacts tend to be localized, unacceptable accumulations of nonradiological impacts are not expected to occur for cases where there will be a concentration of mining and milling activity. The cumulative effects that will potentially be most significant are socio-economic ones. In some situations, a regional approach towards mitigating impacts may be desirable. In this regard, it is noted that, in response to potential rapid and major development of uranium resources in northwestern New Mexico, the U.S. Department of Interior has undertaken a study with the purpose of developing a regional base of information to aid in mitigating impacts likely to be of concern in the area, such as socioeconomic ones (San Juan Basin Regional Uranium Study, see reference 5). In any case, the staff concludes that nonradiological impacts examined can be mitigated to acceptable levels on a case-by-case basis.

- Impacts which occur will not necessarily result in exceeding any of the existing environmental protection regulations, such as those covering air and water quality of federal or state agencies. For example, with control of airborne emissions during operation, as discussed in Section 5.1, there would be little problem of meeting federal or state air quality limits on suspended particulates at a reference location one km downwind of the model mill, even in the worst case of a multiple mill cluster. Concentrations would be reduced from the 65 $\mu g/m^3$ predicted for the base case to about 45 $\mu g/m^3$ (background is about 35 $\mu g/m^3$).

- Most nonradiological environmental impacts will not be irrevocable or persistent. For example, following mill decommissioning, impacts on soils and biota which occur will disappear, albeit slowly in some cases; vegetation will be reestablished in disturbed areas and wildlife habitats will be restored following site reclamation. (Sec. 9.3.5)

6. SUMMARY OF PROPOSED REGULATIONS (Sec. 12.2)

On the basis of the evaluations in this statement, the staff has concluded that revisions to regulations applicable to uranium milling and mill tailings disposal should be revised to assure public health and safety and protection of the environment. The following summarizes the points which the staff is proposing be incorporated into regulations. Final regulations incorporating these points and certain supporting financial arrangements discussed below in Section 8 of the Summary are currently being promulgated. It is expected that these regulations will become effective within a few months.

6.1 Radioactive Airborne Emissions during Operation

Milling operations shall be conducted so that all airborne effluent releases are reduced to as low as is reasonably achievable. The primary means of accomplishing this shall be by means of emission controls. Institutional controls, such as extending the site boundary and exclusion area, may be employed to ensure that offsite exposure limits are met, but only after all practicable measures have been taken to control emissions at the source. Notwithstanding the existence of individual dose standards, strict control of emissions is necessary to assure that population exposures are reduced to the maximum extent reasonably achievable and to avoid site contamination. The greatest potential sources of offsite radiation exposure (aside from radon exposure) are dusting from dry surfaces of the tailings disposal area not covered by tailings solution, and emissions from yellowcake drying and packaging operations.

Checks shall be made and logged hourly of all parameters (e.g., differential pressures and scrubber water flow rates) which determine the efficiency of yellowcake stack emission control equipment operation. It shall be determined whether or not conditions are within a range prescribed to ensure that the equipment is operating consistently near peak efficiency; corrective action shall be taken when performance is outside of prescribed ranges. Effluent control devices shall be operative at all times during drying and packaging operations, and whenever air is exhausting from the yellowcake stack. Drying and packaging operations shall terminate when controls are inoperative. When checks indicate the equipment is not operating within the range prescribed for peak efficiency, actions shall be taken to restore parameters to the prescribed range. When this cannot be done without shutdown and repairs, drying and packaging operations shall cease as soon as practicable.

To control dusting from tailings, that portion not covered by standing liquids shall be wetted or chemically stabilized to prevent or minimize blowing and dusting to the maximum extent reasonably achievable. This requirement may be relaxed if tailings are effectively sheltered from wind, such as may be the case where they are disposed of below grade and the tailings surface is not exposed to wind. Consideration shall be given in planning tailings disposal programs to methods which would allow phased covering and reclamation of tailings impoundments since this will help in controlling particulate and radon emissions during operation. To control dusting from diffuse sources, such as tailings and ore pads where automatic controls do not apply, operators shall develop written operating procedures specifying the methods of control which will be utilized.

6.2 <u>Mill Tailings Disposal</u> (Sec. 12.2.1)

<u>Siting Criteria and Objectives</u>

In selecting among alternative tailings disposal sites, or judging the adequacy of existing tailings sites, the following site features--which will primarily determine the extent to which a program meets the broad objective of isolating the tailings and associated contaminants from man and the environment during operations, and for thousands of years thereafter, without ongoing active maintenance--shall be considered:

- remoteness from populated areas;
- hydrogeologic and other natural conditions as they contribute to continued immobilization and isolation of contaminants from usable groundwater sources, and
- potential for minimizing erosion, disruption, and dispersion by natural forces over the long term.

The site selection process shall be an optimization, to the maximum extent reasonably achievable in terms of these features.

In the selection of disposal sites, primary emphasis shall be given to isolation of tailings or wastes, a matter having long-term impacts, as opposed to consideration only of short-term convenience or benefits, such as minimization of transportation or land acquisition costs. While isolation of tailings will be a function of both site and engineering design, overriding consideration shall be given to siting features, given the long-term nature of the tailings hazards.

<u>Long-Term Stability of Tailings Isolation</u>

The "prime option" for disposal of tailings is placement below grade, either in mines or specially excavated pits. The evaluation of alternative sites and disposal methods performed by mill operators in support of their proposed tailings disposal program (provided in applicants' environmental reports) shall reflect serious consideration of this. In some instances, below-grade disposal may not be the most environmentally sound approach, such as might be the case if a high quality groundwater formation is relatively close to the surface or not very well isolated by overlying soils and rock. Also, geologic and topographic conditions might make full, below-grade burial impracticable; for example, bedrock may be sufficiently near the surface that blasting would be required to excavate a disposal pit at excessive cost, and more suitable alternate sites are not available. Where full below-grade burial is not practicable (that is, where the need for any specially constructed retention structure is not eliminated), the size of retention structures, and size and steepness of slopes of associated exposed embankments, shall be minimized by excavation to the maximum extent reasonably achievable or appropriate given the geologic and hydrogeologic conditions at a site. In these cases, it must be demonstrated that an above-grade disposal program will provide reasonably equivalent isolation of the tailings from natural erosional forces.

The following site and design criteria shall be adhered to, whether tailings or wastes are disposed of above or below grade:

- Upstream rainfall catchment areas must be minimized to decrease erosion potential and the size of the maximum possible flood which could erode or wash out sections of the tailings disposal area.

- Topographic features should provide good wind protection.

- Embankment and cover slopes shall be relatively flat after final stabilization, to minimize erosion potential and to provide conservative factors of safety assuring long-term stability. The broad objective should be to contour final slopes to grades which are as close as possible to those which would be provided if tailings were disposed of below grade; this could, for example, lead to slopes of about 10 horizontal to 1 vertical (10h:1v) or less steep. In general, slopes should not be steeper than about 5h:1v. Where steeper slopes are proposed, reasons why a slope less steep than 5h:1v would be impracticable should be provided, and compensating factors and conditions which make such slopes acceptable should be identified.

- A full self-sustaining vegetative cover shall be established, or rock cover employed, to reduce wind and water erosion to negligible levels.

  Where a full vegetative cover is not likely to be self-sustaining, due to climatic or other conditions, such as in semiarid and arid regions, rock cover shall be employed on slopes of the impoundment system. The staff will consider relaxing this requirement for extremely gentle slopes, such as those which may exist on the top of the pile.

  The following factors shall be considered in establishing the final rock cover design to avoid displacement of rock particles by human and animal traffic, or by natural processes, and to preclude undercutting and piping:

  - shape, size, composition, and gradation of rock particles (excepting bedding materials, average particle size shall be at least cobble size or greater);

  - rock cover thickness and zoning of particles by size; and

  - steepness of underlying slopes.

  Individual rock fragments shall be dense, sound, and resistant to abrasion, and shall be free from cracks, seams, and other defects that would tend to unduly increase their destruction by water and frost actions. Weak, friable, or laminated aggregate shall not be used. Shale, rock laminated with shale, and cherts shall not be used.

  Rock covering of slopes may not be required where top covers are very thick (on the order of 10m or greater); impoundment slopes are very gentle (on the order of 10h:1v or less); bulk cover materials have inherently favorable erosion resistance characteristics; and there is negligible drainage catchment area upstream of the pile, and good wind protection.

  Furthermore, all impoundment surfaces shall be contoured to avoid areas of concentrated surface runoff, and abrupt or sharp changes in slope gradient. In addition to rock cover on slopes, areas toward which surface runoff might be directed shall be well protected with substantial rock cover (riprap). In addition to providing for stability of the impoundment system itself, overall stability, erosion potential, and geomorphology of surrounding terrain shall be evaluated to assure that there are no ongoing or potential processes, such as gully erosion, which would lead to impoundment instability.

- The impoundment shall not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand. The term "maximum credible earthquake" means that earthquake which would cause the maximum vibratory ground motion based upon an evaluation of earthquake potential, considering the regional and local geology and seismology, and specific characteristics of local subsurface material.

- The impoundment, where feasible, should be designed to incorporate features which will promote deposition. For example, design features which promote deposition of sediment suspended in any runoff which flows into the impoundment area might be utilized; the object of such a design feature would be to enhance the thickness of cover over time.

Final disposal of tailings should be such that ongoing active maintenance is not necessary to preserve isolation.

Tailings Disposal Covering

Sufficient earth cover, but not less than three meters, shall be placed over tailings or wastes at the end of milling operations to result in a calculated reduction in surface exhalation of radon emanating from the tailings or wastes to less than two picocuries per square meter per second. In computing required tailings cover thicknesses, moisture in soils in excess of amounts found normally in similar soils in similar circumstances, shall not be considered. Direct gamma exposure from the tailings or wastes should be reduced to background levels. The effects of any thin plastic or other synthetic caps shall not be taken into account in determining the calculated radon exhalation level. If non-soil materials are proposed to reduce tailings covers to less than three meters, it must be demonstrated that such materials will not crack or degrade by differential settlement, weathering, or other mechanism, over long-term time intervals. Near surface cover materials shall not include mine waste or rock that contain elevated levels of radium; soils used for cover must be essentially the same, as far as radioactivity is concerned, as that of surrounding surface soils. This is to ensure that surface radon exhalation is not significantly above background because of the cover material.

Seepage of Toxic Materials

Steps shall be taken to reduce seepage of toxic materials into groundwater, to the maximum extent reasonably achievable. Any seepage which does occur shall not result in degradation of existing groundwater supplies from their current or potential uses. The following shall be considered in order to accomplish this objective:

- installation of impermeable bottom liners. [Where synthetic liners are used, a leakage detection system shall be installed immediately below the liner to ensure major failures are detected if they occur. Where clay liners are proposed or relatively thin in situ clay soils are to be relied upon for seepage control, tests shall be conducted with representative tailings solutions and clay materials to confirm that no significant deterioration of permeability or stability properties will occur with continuous exposure of clay to tailings solutions. Tests shall be run for a sufficient period of time to reveal any effects if they are going to occur (in some cases, deterioration has been observed to occur rather rapidly after about nine months of exposure).]

- mill process designs which provide the maximum practicable recycle of solutions to reduce the net input of liquid to the tailings impoundment.

- dewatering of tailings. (At new sites, tailings shall be dewatered by a drainage system installed at the bottom of the impoundment to lower the phreatic surface and reduce the driving head for seepage, unless tests show tailings are not amenable to such a system. Where in situ dewatering is to be conducted, the impoundment bottom shall be graded to assure that the drains are at a low point. The drains shall be protected by suitable filter materials to assure that drains remain free running. The drainage system shall also be adequately sized to assure good drainage.)

- neutralization to promote immobilization of toxic substances.

Where groundwater impacts are occurring at an existing site due to seepage, action shall be taken to alleviate conditions that lead to seepage and restore groundwater quality to its potential use before milling operations began, to the maximum extent practicable.

The specific method, or combination of methods, to be used must be worked out on a site-specific basis. Technical specifications shall be prepared to control installation of seepage control systems. A quality assurance, testing, and inspection program, which includes supervision by a qualified engineer or scientist, shall be established to assure the specifications are met.

While the primary method of protecting groundwater shall be isolation of tailings and tailings solutions, disposal involving contact with groundwater will be considered, provided supporting tests and analyses are presented demonstrating that the proposed disposal and treatment methods will not degrade groundwater from current or potential uses.

In support of a tailings disposal system proposal, the applicant/operator shall supply information concerning the following:

- The chemical and radioactive characteristics of the solutions.

- The characteristics of the underlying soil and geologic formations, particularly as they will control transport of contaminants and solutions. This shall include detailed information concerning extent, thickness, uniformity, shape, and orientation of underlying strata. Hydraulic conductivity of the various formations shall be determined.

  This information shall be gathered by borings and field survey methods taken within the proposed impoundment area and in surrounding areas where contaminants might migrate to usable groundwater. The information gathered on boreholes shall include both geologic and geophysical logs in sufficient number and degree of sophistication to allow determining significant discontinuities, fractures, and channeled deposits of high hydraulic conductivity. If field survey methods are used, they should be in addition to and calibrated with borehole logging. Hydrologic parameters such as permeability shall not be determined on the basis of laboratory analysis of samples alone; a sufficient amount of field testing (e.g., pump tests) shall be conducted to assure actual field properties are adequately understood. Testing shall be conducted to allow estimating chemi-sorption attenuation properties of underlying soil and rock.

- Location, extent, quality, capacity and current uses of any groundwater at and near the site.

Furthermore, steps shall be taken during stockpiling of ore to minimize penetration of radionuclides into underlying soils; suitable methods include lining and/or compaction of ore storage areas.

6.3 Decommissioning of Mill Structures and Site

The mill buildings and site (excluding the tailings disposal area) must be decontaminated to levels allowing unrestricted use of the site upon decommissioning. Mill operators should meet requirements issued in the form of regulatory guidance concerning cleanup of contaminated surfaces and land.

6.4 Supplementary Institutional and Procedural Requirements (Sec. 12.2.2)

The staff concludes the following institutional and procedural measures are needed to supplement the proposed physical controls summarized above. Some of these are provided for in recent legislation on uranium mill tailings control, the "Uranium Mill Tailings Radiation Control Act of 1978," reference 4.

Tailings Disposal and Decommissioning Plan, Environmental Review and Public Participation

A plan for decommissioning of the mill buildings and site, and for disposing of the tailings in accordance with requirements delineated above, should be proposed by applicants and approved by appropriate agencies before issuance of a license. Aspects of the decommissioning plan relating to structures and site cleanup should provide sufficient detail to make reasonable cost estimates and to assure that mill design and operations are planned in such a manner that facilitates decommissioning efforts.

Given that each mill tailings pile constitutes a low-level waste burial site containing very long-lived material, a comprehensive environmental review of each mill and tailings waste disposal operation should be conducted. It is also essential that this review be conducted so that there is opportunity for full public participation. The most effective way to achieve this is for the NRC and the Agreement States regulating mills to conduct an independent, documented assessment and make this available for review by the public and interested Government agencies. The NRC has been conducting such assessments in each of its licensing cases and has recently initiated a temporary program to assist Agreement States in conducting reviews of operations in their jurisdictions.

To ensure maximum opportunity for public participation, there should be opportunity for public hearings in connection with each licensing case. For the reasons stated above, no major construction activities should be allowed to begin before the environmental review has taken place and been documented, and there has been opportunity for public review and comment.

Financial Surety

Financial surety arrangements must be established to ensure that sufficient funds will be available for disposal and reclamation of the mill tailings, and decommissioning the site and buildings, in accord with the approved plans.

Preoperational and Operational Monitoring

Applicants should conduct a program of preoperational monitoring in support of their license applications and associated environmental reports, and provide complete baseline data on the site and its environs, before development. Throughout the construction and operation phases of the mill, monitoring programs should continue to demonstrate compliance with applicable standards and regulations, and detect potential long-term effects.

Long-Term Control of Disposal Sites (Sec. 12.3.11)

As a prudent measure of protection, continued control of tailings disposal sites should be exercised, including control of land use and periodic inspection to confirm that the tailings and tailings isolation are not being disrupted by human activities or natural weathering processes. Such control should be provided through ownership and custody of disposal sites by a Government agency following a determination that a licensee has satisfied decommissioning requirements and license is terminated.

6.5 Implementation of Proposed Requirements at Existing Sites (Sec. 12.4, App. K-9)

Because of the site specific nature of the tailings disposal problem, the regulations are being cast primarily in the form of performance objectives and the objectives for tailings disposal were developed primarily in consideration of what can be done in prospective milling operations. Objectives related to siting and groundwater protection may not be met with the same degree of conservatism at existing sites as will be possible at new sites. The staff considers that these objectives, however, should be incorporated to the maximum extent reasonably achievable at existing sites. The regulations are being written to clearly indicate those criteria which are applicable as minimum requirements at all sites. These include, for example, tailings cover surface stabilization and impoundment slope require ments. Numerical requirements such as radon control limits are, in particular, applicable in all cases.

The objectives that will be potentially most difficult to implement at existing sites are those regarding long-term stability, groundwater seepage, and location near populated areas. The existence of current mill tailing disposal operations with associated committed impacts places constraints on mill operation which do not exist before a mill is constructed. However, at each active milling site, evaluations should be conducted of current and planned tailings disposal operations to determine what specific actions reasonably can be required to meet the objectives identified above. The costs and benefits of the following alternatives should be considered:

- Continued use of existing tailings area,
- Discontinued use of the existing area with newly generated tailings disposed of at a new location preferably below grade, and
- Disposal of all tailings at a new location preferably below-grade. This would involve moving existing tailings from current locations above-grade to the new disposal location.

In addition to constraints on alternative tailings disposal methods resulting from existence of very large volumes at existing sites (nearly 30 million tons at one site), there will be a greater problem in paying for tailings disposal at these sites because disposal costs were not incorporated into the price of the product as the tailings were being generated. Therefore, future operations at such sites will have to provide for disposal of both newly generated and existing tailings.

Costs were estimated for stabilizing tailings in place (App. K-9). This might be possible by recontouring the pile to achieve very gentle slopes, and then applying a thick cover stabilized by rock particles. Such costs could vary from 1.2 to 2.5% of product price, if costs were spread over entire mill life at $30/lb. U_3O_8. Moving tailings, for burial at a new site assumed to be 10 km from the existing site because conditions at the existing site are not acceptable, could vary from 3.9 to 4.8% of product price under the same assumptions of U_3O_8 price. If these costs had to be made up by revenues over the last part of mill life, the economic impact could be significantly greater on mill operations than the most expensive of options at new mills. Stabilizing in place would result in costs which, if made up by mill revenues over the last third of mill life, are 3.6 to 7.5% of U_3O_8 price. These compare with an upper bound of new mill costs of about 4% of product price in the case of special pit excavation (costs spread over mill life; see Table 4). While the economic impacts for meeting minimum requirements can be large, they are considered reasonable in view of the very long-lived nature of the hazardous materials requiring isolation.

Many hard decisions will have to be made at existing sites; these should be done publicly through the site-specific evaluations discussed above and documented as described in Section 12.3.10.

6.6 Heap Leaching and Small Processing Sites

Methods for exploiting small or low-grade ore bodies located far from conventional milling facilities have been developed. The small size or low quality of these ore bodies is typically such that costs for transportation to large mill facilities make their processing otherwise economically unviable. Local processing of these ore bodies may involve either heap leaching of raw ore (App. B) or use of semi-portable milling equipment. These activities would present the same kind of environmental problems that occur with conventional milling: releases of radon and radioactive particulates, and seepage of tailings solutions. Therefore, the staff concludes that the same tailings management and disposal criteria for conventional mills should be applied to such activities. This includes the aboveground, solid wastes which result from in situ uranium extraction operations.

While quantities and concentrations of emissions would be lower in the case of these small operations than occur with large mills, they present a unique problem. Exploitation of isolated ore bodies could increase significantly the inventory of sites which must be controlled over the long term. In view of this, the staff considered proposing general rules requiring the consolidation of tailings from such operations with other small operations or with larger mills. It was concluded however, that this would be extremely difficult and, furthermore, unwarranted. By the very nature of these operations (in most cases involving low grade ore and, hence, small concentrations of radioactivity are involved), the relative hazard of tailings produced will be much less than the hazard of tailings from the conventional mill. Disposal at the site of extraction may be entirely adequate in that the additional effort of providing long term control at isolated sites would be only negligibly greater than if there were consolidation at only a few sites. While general rules do not seem appropriate, the staff believes that consideration should be given to consolidation of such tailings on a case-by-case basis, where environmental benefits, costs, and problems of long-term control can be fully examined and balanced.

6.7 Continued Development of Technology

The technical requirements for tailings disposal which are being incorporated into the regulations are not specific as to detailed methods of disposal. The past year or so of mill licensing activity has involved development of new tailings management disposal practices and methods. In fact, many of the specific alternative disposal methods addressed in this study represent those which were developed by industry in working to meet staff interim licensing performance objectives which are very much like the requirements discussed above. It is expected that continued NRC and Agreement State mill licensing experience, the experience of disposing of tailings at inactive tailings sites which will be taking place over the next few years, and general research conducted by various agencies (viz. NRC, EPA, and DOE) and industry will result in development of improved methods of tailings management and disposal. For example, methods of treating tailings so they may be placed below-grade in contact with groundwater, and at the same time preserve groundwater quality, are being examined by various researchers; such a development would facilitate deep below-grade burial of tailings. Also, experience from inactive site remedial work is expected to provide more specific, additional information on surface stabilization of tailings disposal areas. The new regulatory requirements provide flexibility which will allow and, indeed, foster continued improvement in methods and techniques of disposal. The staff plans to reexamine tailings disposal criteria after remedial action has been taken at several sites to determine if any changes to the criteria or more specific guidance is appropriate in view of this experience.

7. SUMMARY OF CUMULATIVE IMPACTS

Table 6 presents a summary of cumulative environmental impacts which will occur as a result of operation of the uranium milling industry through the year 2000. These impacts are those which are expected to occur if the industry operates under conditions proposed by the staff.

Table 6. Summary of Integrated Impacts of Conventional Uranium Milling Industry through the Year 2000[a]

	Estimated Value	Estimated Range
Production (MT U_3O_8 x 1000)	440	410-490
Natural Resource Use		
Land Temporarily Disturbed Milling (ha x 1000)	23	20-29
Tailings Disposal Land Permanently Committed to Restricted Use (ha x 1000)	6.1	3.4-7.6
Land Temporarily Disturbed Mining (ha x 1000)	6.6	5.6-8.2
Water Lost to Evaporation ($m3 \times 10^8$)[b]	5.5	3.1-6.9
Effluents		
Tailings Solids Generated (MT x 10^8)	4.7	4.0-5.9
Radon from Mills (1979-3000) (Ci x 10^6)	9.1	5.1-11.4
Radon from Mines (1979-2000) (Ci x 10^6)	6.2	5.3-7.7
Persistent Radon Releases from Tailings (KCi/yr)	3.9	1.6-4.9
Continental Radiological Impacts[c]		
Milling		
Health effects - 1979 to 3000 (premature deaths)[d]	92	38-120
Life Shortening - 1979 to 3000 (years lost)[d]	1,750	720-2200
Persistent Health Effects - Beyond 3000 (premature deaths/yr)[g]	0.043	0.018-0.054
Milling Occupational		
Health Effects - 1979 to 2000 (premature deaths)	32	30-36
Life Shortening - 1979 to 2000 (years lost)	610	570-680
Mining		
Health Effects - 1979 to 2000 (premature deaths)	56	48-70
Life Shortening - 1979 to 2000 (years lost)	1,060	910-1300

[a]Estimated values and ranges of impacts presented here are those presented in Chapter 15, and are based primarily on information provided in Chapters 3, 5, 6, 9 and 12 and Appendix S. Ranges are based on types and magnitudes of uncertainties as described and assessed in Appendix S.

[b]An additional 20-50% of this amount would be lost due to mining operations. This is counterbalanced by the fact that some evaporation of soil moisture would occur anyway; this evaporative loss would roughly equal precipitation intercepted by tailings areas, which amount to 42% of the evaporation losses shown.

[c]Estimates of radiological impacts reflect only the uncertainty with respect to total radioactivity releases; uncertainties with respect to environmental transport and health effect conversion factors are not included. As indicated in Appendix G-7, health effect conversion factor are uncertain by about a factor of 2 in either direction. Life-shortening per health effect is taken to be 19 years (see App. G-7).

[d]Releases of radon during mill operation are conservatively assumed to be as evaluated for the base case model mill where only 38% control was realized through saturation by tailings liquids. The degree to which radon releases are controlled during mill operation is speculative, depending primarily upon tailings management practices implemented (see Sec. 5.1.1 of this summary).

Estimates of cumulative radon release and land use impacts depend on several key parameters. These include projections of nuclear power growth, uranium fuel enrichment policies, average ore grades processed, surface area and shapes of tailings impoundments and unit radon flux factors (Appendix S). To simplify analysis, the staff selected and used throughout the document single values for each of these key parameters. However, in stating cumulative impacts (Table 6), the staff has presented ranges to characterize the degree of uncertainty that exists.

8. INSTITUTIONAL ISSUES (Chaps. 13 and 14)

Many of the institutional issues surrounding the management of uranium mill tailings have been settled by the recent enactment of the "Uranium Mill Tailings Radiation Control Act of 1978," reference 4. In some areas, the legislation provides the authority to settle these issues; in others, it allows some discretion in terms of implementation. A brief description of both of these kinds of issues follows.

8.1 Issues Settled by Legislation

In addition to authorizing a program for remedial action at inactive mill tailings sites, the legislation amends the arrangement under which NRC regulates active mills. Control over tailings had, in the past, been linked to the source material license for a milling operation and not to the tailings themselves. However, as a result of this recent legislation, NRC is given direct regulatory authority over tailings as a licensable byproduct material. Furthermore, the legislation requires an arrangement where Agreement States are required to regulate tailings in accord with standards that are equivalent, to the extent practicable, or more stringent than standards adopted and enforced by the Commission for the same purpose.

In addition to establishing direct authority over mill tailings and providing for a uniform, national approach to the problem, the recently enacted legislation spells out arrangements for long-term control of tailings disposal sites, including provisions for government ownership of the sites. Specifically, the Act requires that title to the land "shall be transferred to (a) the United States or (b) the state in which such land is located, at the option of such state," unless the Commission determines prior to such termination that transfer of title to such land and such byproduct material is not necessary (Section 202(b), Reference 4).

The Act further specifies authorities and roles of EPA and DOE in the mill tailings area. EPA will establish generally applicable environmental standards, and DOE will assume custody of the disposal sites that are ultimately owned by the Federal Government.

8.2 Issues Evaluated in GEIS

8.2.1 Short-Term Financial Surety (Sec. 14.2)

Short-term financial surety refers to arrangements intended to ensure that the mill operator undertakes the required decommissioning and reclamation activities. These activities would include decontamination of the mill site and structures, as well as tailings reclamation, according to license requirements and regulations. The staff has concluded that specific provisions for short-term financial surety should be incorporated into regulations.

The primary factor that was considered in the evaluation of the various surety mechanisms was the degree to which each method provided protection that the disposal site would not become a public liability. The alternatives were also evaluated from several other points of view, related primarily to administration of the financial surety. Specifically, the staff considers that the regulations: (Secs. 14.2.4, 14.2.5)

- Require that a surety be provided;
- Require that the amount of the surety be determined on the basis of cost estimates in the approved plan for site decommissioning and tailings disposal; costs should be based on contractor costs to perform these activities; therefore, they should include equipment, labor, profit, etc. The amount of the surety should also include the long-term funding charge since this will not be paid to the ultimate custodian until termination of the license.
- Allow flexibility regarding the specific surety mechanism employed, stating that:
  - cash deposits
  - surety bonds
  - certificates of deposit
  - deposits of Government securities, and
  - letters of credit

  have been found to be acceptable mechanisms, and other surety mechanisms (except self insurance) would be evaluated on a case-by-case basis, for acceptability.

Stipulate those factors that must be considered in setting up the surety arrangements including:

- Inflation

- Term of the mechanism (i.e., the term of the surety must be open-ended--it must remain in effect until the regulatory agency releases it, on satisfactory completion of decommissioning and reclamation; or provide an equivalent level of assurance), and

- Adjustment provision that requires a periodic review of surety adequacy. The amount of the surety should be adjusted to recognize any increases or decreases resulting from inflation, changes in engineering plans, activities performed and any other conditions affecting costs. This will yield a surety that is at least sufficient at all times to cover the costs of decommissioning and reclamation of the areas that are expected to be disturbed, before the next license renewal.

8.2.2 <u>Long-Term Funding</u> (Sec. 14.3)

Long-term funding refers to the financing of any monitoring at mill tailings sites after termination of the mill operator's decommissioning responsibilities and license. The staff has concluded that it would be prudent to continue monitoring and exercising land use controls at disposal sites, and the land ownership arrangement specified in the recent enactment assures that this kind of control is provided. The purpose of this surveillance would be to confirm that no unexpected erosion was occurring and that there were no disruptive human activities at a site. Therefore, the primary component of the surveillance would be periodic visual inspection of each site.

The staff concludes the following be done with regard to the issue of long-term funding: (Sec. 14.3.1)

- Funds should be provided by each mill operator to cover the costs of long-term monitoring.

- A charge, adjusted by the change in the Consumer Price Index to be equivalent to $250,000 in 1978 dollars per site, should be levied on mill operators, before termination of a license. The charge would be paid to the Federal Government unless the state in which a mill is located chooses to have this responsibility. In any event, the sum for long-term monitoring should be paid to whichever governmental body is going to be the ultimate custodian of the site.

  If the long-term monitoring charge is paid to the Federal Government, it should be deposited in the general treasury funds of the United States, as opposed to a special earmarked fund that might be established. In the situation where a state opts to have custody of a site, it will also be responsible for fund management. Therefore, if a State wishes to deposit long-term surveillance funds in an earmarked account, rather than seek an annual or biannual appropriation from the State legislature for this purpose, it would be free to do so.

- If monitoring requirements at a particular site are determined, on the basis of a site-specific evaluation, to be significantly greater than those assumed here (e.g., if it is determined that fencing is appropriate) variance in funding requirements should be arranged.

- The amount to be paid by operators for long-term funding should be adjusted prior to actual payment to recognize inflation. The inflation rate to be used is that indicated by the change in the Consumer Price Index, which is published regularly by the U.S. Department of Labor, Bureau of Labor Statistics.

The staff believes that this position is reasonable, because it conforms in general principle with the notion that the waste generator should pay all costs for waste disposal, including any long-term costs incurred. Based on what the staff expects will be needed in terms of the long-term monitoring at most tailings disposal sites, (Section 10.3) the proposed arrangement is a fair, simple, and efficient one. More complicated schemes were felt to be unwarranted, given the level of uncertainty about stability of institutions and long-term interest and inflation rates.

The amount of the charge is based primarily on cost estimates for having inspectors visit each mill tailings site about once a year, to confirm that disposal sites are not being disrupted by human activity or erosion, and possibly conduct limited groundwater monitoring.

A real interest rate of 1% was then assumed to establish what fixed charge would be sufficient to effectively cover this continuing surveillance.

There are several additional monitoring and site control activities, not assumed in the above monitoring scenario, that might, under some conditions, be prudent to perform. The staff considers that these activities are either sufficiently unlikely, or sufficiently low in cost, to make the above estimates of costs reasonably conservative and, therefore, appropriate for establishing long-term funding requirements. In rare cases, it may be decided at a later time that monitoring requirements at a particular site will be significantly greater than those assumed above. In such cases, a variance in funding requirements should be arranged if the level of expected activity is judged to be sufficiently different than that assumed here. The following discusses more fully these potential additional activities and why the staff-proposed funding scheme is appropriate. (For additional discussion of alternate monitoring scenarios and associated cost estimates, refer to Appendix R.)

It may be prudent in some cases for inspectors to sample a few groundwater monitoring wells during their inspection and analyze for an indicator element such as radium-226. The pre-operational, operational and compliance determination monitoring programs will be extensive, both from the point of view of what is done and the period of time covered (15 to 30 years). These programs will be sufficient, therefore, to determine if there are any potential groundwater problems at a site. If problems are identified and remedial action is considered necessary, this will be determined before a license is terminated, and the operator will be available to take action. Therefore, any sampling over the long-term would have the purpose of confirming that there are no problems occurring and, as such, will be very limited.

In some instances, it may be necessary to visit a site more frequently than annually. For example, if there were a period of very severe weather (e.g., heavy rainfall and flooding, a tornado or an earthquake near a site), a special inspection might be required. However, the staff considers that such visits would be very infrequent and that the degree of conservatism in the staff estimate is sufficient to account for them.

In some rare cases, site observation during the operational, reclamation and compliance determination periods might indicate that a site may either require continued fencing or some degree of active care. This is most likely to occur, if at all, at currently active sites where operations began prior to the establishment of the new requirements for tailings disposal. If this occurs, the expected level of care could be estimated on the basis of site-specific conditions and a fee different than that recommended here could be levied on the mill operator to cover the expected additional ongoing effort. This would be worked out in the process of terminating a license and would have to be based on a benefit-cost assessment of the options for taking steps to eliminate the need for such active care, similar to that described in Section 12.4. The regulations on long-term funding, therefore, should provide for such an unlikely contingency, allowing for charges greater than $250,000 to be levied, if extenuating circumstances warrant this.

Despite the fact that such a special case might arise, the staff considers that a funding level should be set now, as opposed to taking a "wait and see" approach at each site. Estimates of what will be required in the future, in the way of site monitoring, will always be speculative. The staff believes the estimates made here to be reasonable, if somewhat on the conservative side. Fixing a fund amount now establishes a basis for planning by mill operators and assures that the full costs of operation, including waste disposal, are understood before the beginning of these operations. Further, establishing a fund amount now will tend to assure that there is uniform and equitable treatment of mill operators; variances from the fund amount will occur only where monitoring activities are significantly different than those assumed here. Finally, this approach will tend to discourage adoption of a view that contribution to a "long-term care" fund might be substituted for development of isolation schemes which will eliminate the need for active care.

Since the question of ultimate site custody may not be decided until termination of the mill operator's license, the staff has concluded that the simplest arrangement for the collection of monies to cover the costs of long-term monitoring is for the charge to be paid, upon termination of the license, to whichever governmental agency will be the ultimate custodian of the site.

Based on the requirement that tailings be disposed of such that no active care be necessary over the long-term, the staff is adopting an arrangement whereby charges for funding of long-term monitoring be a fixed amount, from site to site, as long as this requirement is satisfied. This is appropriate since, without a need for active maintenance, costs will be independent of the size of the tailings pile. Several other options on the long-term funding issue, stemming from different assumptions, were evaluated by the staff. These alternative options include:

No Fund

Because costs associated with the passive monitoring mode are expected to be relatively small, the no-fund option demanded some consideration. Under this alternative, the waste generator would not be paying the full care costs, resulting in an inequitable situation. Thus, the no-fund option was rejected by the staff.

Levy on Product

A fund based on a levy imposed on the amount of product generated per site would yield an amount that would correlate with the size of the pile. This would be an equitable situation in the active care mode. However, in the passive monitoring mode, the size of the tailings pile is not a critical factor. Therefore, the staff rejected this alternative as unnecessary.

Insurance Fund

Establishing a fund to cover the costs of any unexpected extensive monitoring or remedial actions is another alternative. Such an approach might be appropriate where serious uncertainties exist about the necessary level of long-term surveillance. The proposed long-term funding program is designed to cover the costs for a passive monitoring mode, which is all that is expected to be required at most sites meeting the proposed technical requirements for tailings disposal. At the same time, the program recognizes the need for flexibility and variance in setting the funding amount. In view of these factors, an insurance fund does not seem warranted.

Negotiable Fee

Another long-term funding alternative would be to establish a funding requirement, but leave the charge negotiable. The staff chose the generally established fee program over this alternative because it was considered to foster equity and consistency in dealing with various operators. This would be more difficult to achieve if the fee were completely negotiable in each case.

9. MAJOR ISSUES RAISED IN PUBLIC COMMENTS

Appendix A addresses each of the substantive and relevant comments which were made on this document and the associated proposed regulations during the comment period and in public meetings that were held. Nearly 100 comment letters were received. With the transcripts of public meetings, nearly 2000 pages of comments were generated. It was impracticable for all of this material to be reprinted in this document. This material is available for review at the NRC public document room, 1717 H Street N.W., Washington, D.C. The major issues raised in the comments are summarized in this section. The full response to each issue is not repeated in each case; instead, where practicable and appropriate, reference is made to that section of the Summary where the issue is discussed and comments are effectively addressed. Also there is some unavoidable redundancy in the summary of these issues because of the interrelationships between the issues involved.

Timing of Regulations

A number of commenters took the position that there is no great sense of urgency for regulations on uranium mill tailings management and mill operation. However, each year new mills are proposed, and many millions of tons of tailings are generated at existing mills. As new mills are constructed and more tailings are generated, the options for dealing with tailings disposal become fewer. With respect to new facilities it is critically important that the siting and design criteria of the regulations be enacted so that mistakes of the past are not repeated. In addition, and perhaps even more important, radioactive releases from existing mills constitute the largest routine releases from the nuclear fuel cycle. Therefore, it is absolutely essential that regulations, which assure that action is taken to protect the public health and safety, are promulgated promptly.

The staff intends to promulgate the regulations recognizing that research, much of it sponsored by NRC, is still being conducted in many areas covered in the rules. The regulations are established on the basis of knowledge obtained from licensing experience and research conducted to date. Research sponsored by NRC, DOE, the industry, and others will continue and changes can be made to regulations without difficulty, if the research indicates that changes are necessary. It is most likely research will provide a basis for supplementing the broad criteria of the regulations with more specific regulatory guidance, as opposed to necessitating a change in the overall objective of any criterion. In any case, the staff considers it urgent to issue the regulations now, but expects to review them in several years to assess whether any changes are warranted (see Summary Sec. 6.7).

A number of commenters indicated that their interpretation of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) was that EPA was required to develop standards first, followed by NRC's promulgation of rules. Section 275 of the Atomic Energy Act, as amended by the UMTRCA, requires EPA to issue environmental and health standards for uranium mill tailings. However, an analysis of the Mill Tailings Act and its legislative history indicates that the Commission not only has the authority, but also the immediate duty, to insure that the management of uranium mill tailings is carried out in a manner that will protect the public health and safety and the environment.

Although NRC could have delayed developing regulations until EPA issued standards, that would have left unfinished the program to develop rule changes which NRC has been working on for nearly three years. In addition, such a delay would have made it difficult, if not impossible, for the Agreement States to issue equivalent standards as required. It is clear from the UMTRCA, that NRC's minimum Federal Government standards must be promulgated as promptly as possible so that the Agreement States will be able to have equivalent regulations in place by November 8, 1981.

NRC is aware that its regulations must be compatible with the generally applicable standards established by EPA; therefore, the NRC staff has been and will continue to coordinate closely with EPA on this matter. NRC regulations will be revised, if required, when EPA standards are issued.

Application at Existing Sites

Some stated that tailings disposal criteria should not be applied too strictly at existing sites; others were concerned that regulations should be much more specific about how the criteria will apply to such sites.

Regulations were developed recognizing that it may not be practicable to provide the same measures of conservatism at existing sites as can be provided at new sites, where alternatives are not limited. However, certain requirements in the regulations represent minimum levels of protection of public health and safety, and of the environment and can and must be met in all cases; the regulations have been revised from their proposed form to clarify this. For example, the requirement for preservation of groundwater uses, minimum tailings cover requirements, requirements for erosion protection, financial surety provisions, and the broad requirement that no ongoing, active maintenance be needed to preserve the tailings isolation for thousands of years are mandatory in all cases. It would not be possible, on the other hand, to line the bottom of an existing tailings impoundment. Also, objectives concerning remoteness from people and providing below-grade burial may not be met to the same degree at an existing site as at a new site.

At some point, which must be determined by considering how a site measures up against all of the criteria, it may be determined that tailings should be relocated from an existing to a new site, or that while it would be acceptable for existing tailings to be stabilized in place, tailings generated in the future should be deposited at a new location. The conditions which would lead to this determination cannot be spelled out in generic fashion in regulations. In any event, a full evaluation of tailings disposal and alternative sites must be completed at each milling operation, and final plans formulated through a public decisionmaking process, such as is provided for by NEPA and UMTRCA.

See also Summary Section 6.5 and Section 12.4 for discussion of economic impacts of implementing regulations at existing sites. These economic impacts on mill operations may be larger than those at new mills even though the programs may be less comprehensive. This may occur because costs for disposing of all tailings may have to be made up by revenues over a small part of mill life. In any event, the costs for meeting minimum requirements are considered reasonable in view of the long-lived nature of the hazardous materials being isolated.

Form of Regulations

Some stated that the regulations are too specific and inflexible and, thus, restrict operators from finding new and cost effective ways to meet broad goals at any given site. For example, some felt that regulations should only state that groundwater quality must be protected and not be specific about methods of accomplishing this. On the other hand, others considered regulations should be more specific with regard to certain issues; for example, some wanted regulations to specify, in numerical terms, allowable hydrologic, topographic and drainage conditions.

The staff has developed regulations mindful of the need to avoid being overly restrictive. The staff experience of the past several years has been that, working with interim tailings management performance objectives similar in nature to the criteria contained in the regulations, the industry has developed many innovative ways of achieving broad goals. Also the staff recognizes, as stated repeatedly in this document, that the problem of mill tailings management is highly site specific. The precise details of a program can be worked out only when unique conditions of a site are known. For example, the extent of potential groundwater impacts, or the erosion potential of a tailings disposal program depends critically upon topographic, geologic, hydrologic, and meteorologic conditions which can vary significantly from site to site. The regulations have been drafted with flexibility so as to appropriately reflect this fact.

At the same time, however, the staff has tailored the regulations to be appropriately specific where required: (1) for fairness to license applicants and mill operators (it reduces uncertainty about what requirements are and, thus, allows them to plan their operations reasonably); (2) to assure consistency in application of requirements which would not occur if regulations are too broad; (3) to assure that a minimum level of protection is provided where there are known problems or great uncertainties about potential problems. For example, a minimum cover thickness is specified, and criteria for surface stabilization are established, to account for known problems which potentially threaten long-term tailings cover performance.

Scope of the GEIS

There were numerous comments criticizing the "model mill" approach taken by the staff in analyzing potential environmental impacts. More specifically, commenters pointed to various aspects of the mill that were not representative of a certain, real mill, or criticized lack of analysis of certain conditions or impacts which have arisen in specific cases.

However, as repeatedly noted in the document, the factors which determine the extent of impacts from milling operations are extremely site specific. All of the variations which exist with regard to these factors could in no way be explicitly taken into account in this document. The model mill and model site were described, and subsequent analysis of them was carried out, in enough detail to: (1) identify the major issues or impacts of concern with uranium milling and tailings disposal, and (2) characterize their nature and extent. Costs and benefits of alternatives for mitigating these impacts were evaluated. The product of these analyses is a new regulation, cast primarily in the form of performance objectives which recognizes that the precise methods or combination of methods of impact mitigation can only be worked out on a case-by-case basis where all unique, site-specific conditions can be accounted for.

The staff did a comprehensive review of existing conditions in all of the current uranium milling regions in developing the model mill and site, and in performing the analysis of this document in general. (See reference 11, which characterizes all milling regions, and App. K for variability in costs.) This was done to assure that the major differences in conditions from those assumed for the GEIS models were known in performing the analyses. Where these differences are important in terms of specific points in the regulations, such as the radon flux limit, the full range of variability in conditions has been explicitly evaluated, to assure it is reasonable to apply the regulations at all sites.

Because major decisions concerning siting and design remain to be made for each case, once needed site-specific information is available, and because of the significance and longevity of the potential hazards associated with uranium mill tailings, a comprehensive environmental assessment of each mill and tailings waste disposal operation and alternatives must be conducted. It is also essential that this alternatives assessment be conducted so there is opportunity for full public scrutiny of the decision being made. NRC regulations, primarily 10 CFR Part 51, assure that this is done. The UMTRCA establishes a requirement that Agreement States do the same (Chapter 13). The regulations have been designed to assure these decisions are supported by full environmental assessments and investigation of site conditions by applicants and mill operators.

In no way is this GEIS a substitute for site-specific environmental assessments.

Siting of Mills

Many commenters expressed the need to be more specific and stringent concerning siting requirements. For example, some wanted specific definition of what would be accepted as a "remote" site, a term used in the proposed regulations.

However, the matter of tailings disposal is not a one-dimensional problem; that is, several factors must be considered simultaneously. Too much specificty would be imprudent since, for example, establishing a minimum distance to population centers might unduly constrain efforts to deal with other concerns such as protecting groundwater by avoiding aquifers of high quality. The regulations have been revised from their proposed form to clarify that the process of site selection involves optimization, to the maximum extent practicable, in terms of the following general site qualities:

- o remoteness from populated areas;

- o hydrologic and other environmental conditions conducive to continued immobilization and isolation of contaminants from usable groundwater sources; and

- o potential for minimizing erosion, disruption, and dispersion by natural forces.

Tradeoffs will inevitably be required in this process. In any event, siting is of paramount importance in developing optimum tailings disposal programs. The problem of tailings disposal cannot be approached with the attitude that inadequate siting features can be compensated for by design. For this reasons, the regulations state as originally proposed that in the selection of disposal sites, primary emphasis shall be given to isolation of tailings or wastes, a matter having long-term impacts, as opposed to considerations of short-term convenience or benefits, such as minimization of transportation or land acquisition costs.

Radon Control and Tailings Cover Requirements

Many commenters stated that the requirements for radon control should be based upon a fully quantified, incremental cost-benefit evaluation. However, the staff reached a conclusion in the draft GEIS that attempting to establish tailings cover requirements on the basis of a quantified, incremental cost-benefit evaluation is unreasonable and, indeed, may be misleading.

In response to such comments, however, the staff reexamined and expanded its evaluation of the strictly monetized, incremental cost-benefit methodology. Conclusions expressed in the draft statement concerning the impracticability and inappropriateness of attempting to set a radon exhalation limit by this method were fully reconfirmed. This is discussed more fully in Section 5.2.2 of the Summary. Given the long-term nature of the mill tailings hazards, and the complexity and uncertainty associated with predicting actual levels of radon emissions and impacts over the long-term, it is concluded that the problem of determining tailings containment requirements cannot be reduced to the purely mathematical formulations required for the quantitative cost-benefit optimization methodology. This mathematical process grossly oversimplifies the problem and, thus, while this appears to offer a "rational approach" to decision making, it can be misleading and quite arbitrary.

One of the obvious problems with this methodology is that arguments can easily be made for virtually opposite positions (little or no control, versus absolute control of radon releases) merely by choosing short or long time frames over which to integrate potential health impacts. This was, in fact, done by commenters. The monetary worth of averting a health effect ("life loss" or "life shortening" due to cancer) is another highly subjective factor which can vary widely and, thus, make more uncertain the level of control which should be required. While arbitrary decisions might be made concerning these factors, there is no practicable way to correlate containment long-term performance uniquely with containment costs.

The staff established the proposed final tailing radon flux limit based upon an evaluation of a wide range of public health and cost factors, and the variability of site-specific conditions. More specifically, these factors included evaluation of alternative radon release limits in terms of: costs for applying a final tailings cover under a full range of conditions such as will occur with varying ore grades, impoundment sizes and shapes, cover material types and so on; impacts on maximum exposed individuals as they compare with existing radiation protection standards; total population exposures as they compare with population exposures from natural and technologically enhanced radon releases, both short and long term; and, radon fluxes that occur from natural soils.

In consideration of these perspectives and the problem with monetized cost-benefit evaluations, it was determined that the most reasonable residual radon emission limit would be one that would assure that tailings disposal sites are eventually returned to conditions which are reasonably near those of the surrounding environs. The radon flux limit assures that radon exhalation rates will be within the range of flux rates occurring naturally from nearby soils.

Period of Long-Term Concern

Many commenters stated that tailings disposal should be viewed as a problem spanning eventually an infinite period of time, and the total number of potential health effects resulting from radon releases should be viewed in absolute terms. By integrating health effects over such periods of time, the number of calculated health effects is extremely large and, on the basis of this, commenters urged that advanced modes of tailings disposal are warranted to provide complete or improved isolation of tailings. On the other hand, some stated that, because of the vast uncertainties involved, and the potential for development of a cure for cancer, a much shorter period, such as 100 years, is appropriate for evaluating the need and cost-effectiveness of controls. On this basis, much less stringent controls are urged.

The staff has evaluated this problem and developed regulations considering the inescapable fact that the tailings will, in fact, remain hazardous for extremely long periods of time--hundreds of thousands of years. Viewing this matter as one of only short-term significance because of the uncertainties involved with the long-term, or on the speculation that there may be a cure for cancer, is unrealistic and not responsible. On the other hand, attempting to provide absolute assurances that the tailings, which are very large volume, low specific activity wastes, will remain completely isolated for infinite time frames is impracticable and inappropriate, when the potential impacts of other naturally occurring and technologically enhanced persistent radon sources are considered (see Table 5).

The general conclusions about the various tailings disposal modes are summarized in Summary Section 5.2.1 above (Section 12.3.3). The tailings siting and design features specified in regulations, discussed in Sections 5 and 6 above, are intended to provide a degree of isolation which is consistent with the reality that the tailings present long-term hazards. These measures are those identified to be needed to account for potential failure mechanisms which can occur in the very long term (Section 9.4.1). The features which are being incorporated into tailings disposal programs under the regulations are similar to those of landforms which have been known to be stable for extremely long periods of time. For example, elimination of embankment slopes by below grade burial or use of rock covering on very gentle slopes will make sites stable landforms. The latter will duplicate conditions such as those existing in alluvial deposits in Death Valley, which have been stable for 20,000 years because of the "armoring" provided them by course rock and gravel "desert pavements." Minimum requirements on cover thickness have been specified with the knowledge that cover performance can be degraded in numerous ways (Sec. 12.3.4.7).

In general, the condititon of tailings disposal sites will be virtually the same as those in surrounding environs and should remain so without active care and maintenance. Advanced tailings disposal modes such as fixation or nitric acid leaching may offer potentially improved isolation, but the improvement over what are considered adequate programs is uncertain, while the costs are excessively high and other, new problems are encountered with such technologies. (Also, see Summary Section 5.2.4 in connection with this issue.)

<u>Groundwater Protection</u>

A number of separate issues were raised concerning the matter of tailings impoundment seepage and groundwater protection.

Some commenters stated that in addition to requiring control of seepage, the regulations should clearly specify that groundwater uses must be protected, as there will inevitably be some seepage occurring. The staff's intent in the proposed regulations was to protect current and potential groundwater uses; the final regulations have been drafted to explicitly state this. That is, where an aquifer below a site is initially of drinking water quality, it shall remain so during and after operations.

Others questioned whether continued seepage from impoundments would not be a problem over the very long term. Because uranium milling in the U.S. is conducted in semiarid regions, where evaporation rates are far in excess of rainfall rates, it is not expected that seepage will be a long-term problem. There is concern about providing good seepage control primarily during the operational period, when hundreds of tons of waste solutions are generated daily at an average mill. After the impoundments dry, there will be virtually no driving force for seepage. There is good reason to except that there is, in general, little recharge of aquifers in interfluvial zones in the semiarid milling regions, if there is any at all. It is for this reason that the staff has accepted use of synthetic liners, the likely long-term stability of which is questionable at best (12.3.5, 6.2.4, 9.3.4, App. E). Many commenters stated that the matter of groundwater protection should only be presented as a broad performance objective, and that specific methods of control should not be identified in the regulations. The concern is that the regulations will be too restrictive. In general, the staff has identified seepage control as the most effective and positive way of protecting groundwater; methods of seepage control are identified in the regulation, but flexibility is provided to select the most appropriate ones on a case-by-case basis. (See response to the comment on the form of regulations above.)

Some commenters noted that spread of seepage contamination can occur rapidly by fractures, buried channels and other zones of high hydraulic conductivity, and stated that the GEIS and regulations should recognize this. Experience has indeed shown this concern to be valid. This has been a matter which routinely receives scrutiny by the staff in licensing reviews, and uncertainty about the existence of such discontinuous features at a site are, in great measure, the reason for the staff's conclusion that seepage prevention is the most appropriate approach to take in assuring groundwater protection. Furthermore, the regulations have been revised to specify more clearly what site information is needed to provide an adequate understanding of hydrologic and geologic conditions which will control seepage and contaminant transport.

Finally, some stated that any area which overlies an aquifer of potential use must be avoided. As discussed above in discussions of the issue of siting, the staff has revised the regulations to clearly indicate that one of the few most important matters which determine what is an acceptable site is the matter of groundwater protection (see the response to the siting issue above). However, a universal prohibition on siting near aquifers is inappropriate, given constraints imposed in meeting other major objectives, and given the seepage control measures which can be taken to effectively assure groundwater use is preserved.

Cost Estimates

Many considered the estimates of cost of alternatives evaluated were underestimated.

In estimating costs in the draft, the staff considered cost information submitted by the industry in connection with mill licensing cases, obtained quotes from vendors and suppliers, and gathered general information from current literature on earthmoving and construction cost estimation. Alternatives were clearly defined as combinations of separate unit operations, the costs of each unit operation being stated as a range. Single unit costs were selected from within the range, to arrive at total costs. Totals costs were consistent with those reported by the industry in licensing cases. Where costs were particularly sensitive to variable conditions, the effect of the variability on costs was clearly stated.

The staff has reviewed virtually all cost estimates in the draft document, and in doing so has consulted additional sources to those consulted in preparing the draft statement. In general, the staff found that cost estimates increased by an amount which is directly attributable to the inflation which has occurred since the cost estimates were made for the draft document in 1978. Petroleum-based operations and materials increased by large amounts, as much as 100% in some cases.

The staff considers that the bases for cost estimates in the draft, as updated in the final version of this document, are firm.

Environmental Impacts of Obtaining Reclamation Cover Material

Several commenters noted that considerable amounts of cover material would be required to perform final reclamation, that in some cases such material would have to be strip-mined in otherwise undisturbed areas (which would yield significant environmental impacts), and that such impacts were not addressed in the draft statement. It was further stated that this is particularly of concern at existing sites using above-grade disposal and that in some areas the depth of soil available for excavation is very limited. Under such conditions, it would be necessary to excavate cover material from very large areas to obtain sufficient quantities of earth to provide reclamation in accordance with the staff's intended cover requirements.

This final statement includes an assessment of the potential environmental impacts of obtaining cover material (see Section 9.3.8.4). The assessment includes analysis of what is considered by the staff to be a potential worst-case situation wherein: 1) cover material must be obtained by strip-mining otherwise undisturbed terrain; 2) cover material must be hauled to the site from a distance of 10 miles (16 km); and 3) the average depth of soil available for excavation in the borrow area is only about 1 meter (not including about 0.5 m of topsoil which must be stripped, stored, and reapplied to revegetate the borrow area). These conditions are considered to be very conservative assumptions. Overburden or mine waste produced during local mining operations may well be available, and if so, would be suitable material provided only that it did not contain excessive radioactivity. To the extent that overburden or mine waste could be used, requirements for undisturbed soil materials would be reduced. Also, the staff believes that adequate cover materials can be found within distances much less than 10 miles (there are over 300 sq. miles of area within a radius of 10 miles from any point) if not on the millsite itself. Furthermore, the depth of soil which may be excavated and removed will likely be much greater than 1 meter. Even in the rugged and rocky terrain of the Grants, New Mexico area, excavation depths of 15 m (50 ft.) or more are feasible.

With respect to environmental impacts, even under the very conservative assumptions described above, environmental impacts are limited; they are, at worst, comparable to those arising from mill construction with respect to air quality, land use, biota, water resources, and on the community. Given that reclamation of the borrow area will include revegetation to a natural condition, all impacts would be temporary except for the permanent alteration of topography and the irretrievable commitment of fuel burned by the trucks used to haul the cover material to the tailings disposal site. The staff considers such impacts to be small and insignificant in comparison to the benefits obtained by assuring long-term physical isolation of the buried tailings and reduced residual radon emissions.

Financial Surety

Several commenters argued that self-insurance or third-party insurance should be considered as a surety mechanism, and that the required amount of surety coverage should be based on the licensee's costs for decommissioning and reclamation, as opposed to contractor costs which would include increased overhead and profit. The basis for ruling out self-insurance is simply that such an arrangement would provide no additional assurance, other than that which would already exist through license requirements. With regard to the required amount of surety coverage, the purpose of the surety mechanism is to protect the public from the possibility of a licensee's inability to perform decommissioning and reclamation, and thus the only time a surety would be collected would be in the event of default. A licensee's cost estimate would certainly be less than costs which an independent contractor would charge; therefore, inadequate protection would result if cost estimates based on licensee costs were permitted.

Several other commenters questioned the availability of surety bonds under the conditions described as necessary for satisfaction of the surety requirement. Although the staff's investigation of the situation does indicate that there seems to be resistance on the part of some bonding companies to becoming involved in issuing bonds to companies subject to government regulation, the resistance appears to be the result of a misunderstanding of the requirements in the regulation. The surety mechanism covers specific decommissioning and reclamation activities committed to by the operator in the license and is not a guarantee to satisfy an indefinite set of requirements which may be established 15 or 20 years in the future. Furthermore, the evidence indicates that the surety market is competitive, since some bonds have been obtained by uranium recovery operators even recently. In addition, flexibility exists in terms of acceptable types of mechanisms to satisfy the surety requirement.

Another comment which was raised pertaining to the decommissioning and reclamation surety concerned the required term of the surety mechanism. As stated in the draft GEIS and the proposed regulations, the term of the surety mechanism must be open-ended, in order to provide the requisite high level of assurance. The staff considered that unless the surety mechanism remained in force until decommissioning and reclamation activities covered by the arrangement were completed, there would be nothing to prevent the surety company from cancelling the arrangement, if and when the financial stability of the licensee become questionable, or at the end of milling operations when the assurance is most needed. Obviously, this would provide the public with totally inadequate protection. However, through further consideration and investigation, the staff has learned that other types of arrangements may provide the same high level of assurance as an open-ended arrangement does. Therefore, provision has been made in the decommissioning and reclamation surety criterion to allow flexibility concerning the "term" of the arrangement, provided that the same high level of assurance exists.

Long-Term Funding

A number of comments were received concerning the requirment that an amount be paid to cover the costs of long-term site surveillance. Some commenters indicated that the amount, the equivalent of $250,000 in 1978 dollars, was too high; others stated that it was too low; and some indicated that they considered it should correlate with the size of the disposal site. The basis for the long-term fund, as established in Section 14.3 of the draft GEIS, is that something on the order of an annual site inspection to confirm the integrity of the site will be all that is necessary. However, the requirement is designed such that sufficient flexibility exists to increase the required charge if appropriate at certain sites; e.g., if it is determined that the necessary level of surveillance and site control is significantly greater than assumed here. However, the staff considers that as long as some ongoing monitoring is appropriate, the nominal charge established by this requirement could hardly be reduced.

Other commenters indicated that they considered the long-term fund charge should be designed like an insurance fund and should cover any damage which may result from a catastrophic event. As discussed in Section 14.3, the staff considered an insurance fund to cover costs associated with unforeseen events such as catastrophic occurrences, but rejected this option on the basis that the likelihood of such an occurrence would be negligible, and design against it would be impractical beyond that which is already required in terms of siting and design. As mentioned above, where there is significant uncertainty about long-term performance, such as might occur at an existing site where options for tailings disposal are limited (see Summary Section 6.5), more than the minimum fee can be charged.

Government Land Ownership

A number of commenters inquired about how the land ownership requirements would be implemented, particularly with regard to existing facilities where UMTRCA explicitly allows for NRC discretion. The UMTRCA provides that the Commission shall require transfer of title to the tailings and their disposal site, including any interests therein, unless such transfer is determined to be unnecessary to protect the public health and safety. The UMTRCA further states that the Commission may require such transfers for licenses in effect prior to November 8, 1981, but shall take into consideration the status of such interests and the ability of the licensee to transfer title.

Transfer of an unencumbered fee estate may be difficult to achieve since land ownership can be a complex matter, particularly in western states where it is not uncommon for surface rights, mineral rights (including oil and gas), and water rights to be conveyed as separate interests. The staff is concerned that if complete and total transfer is required, land ownership considerations (i.e., the difficulty in assembling title to all interests) may significantly impact the selection of sites. If the ability to obtain title to land became a driving force in the site selection process, this would be wholly inconsistent with the fundamental conclusion of the GEIS; that physical isolation as opposed to institutional arrangements must be the primary means of long-term control.

In addition to concluding that physical site characteristics conducive to long-term stability are of overriding importance, the staff considers that, in most cases, government control of the surface rights is necessary: 1) to control land uses at the disposal site which could lead to disruption of the tailings, and 2) in general, to assure ongoing surveillance is performed. Government control is also considered prudent so that in the unlikely event that remedial action at a disposal site is required, a government agency, because it is probably the only institution which would have sufficient resources, would be available to support proper action. However, transfer of certain subsurface rights may be of less importance in providing the necessary control.

Thus, although Criterion 11 requires applicants/operators to make a serious effort to acquire all interests in the land, sufficient flexibility is maintained to permit the Commission to determine that, by itself, surface ownership of a site with characterisitics conducive to long-term stability (in combination with notification in the public land records that the land is being used for tailings disposal and is, thus, subject to an NRC license prohibiting the disturbance of the tailings) is adequate.

Criterion 11 makes essentially no distinction between land ownership requirements for licenses issued before or after November 8, 1981. As discussed in Sections 12.3.11 and 13.4, the staff has concluded that surface ownership is necessary to assure ongoing surveillance, except possibly in the case of deep mine disposal. Thus, although UMTRCA directs the Commission to specifically consider the status of land ownership at existing facilities, the staff does not consider it reasonable to expect that any licensee or site owner would be willing to accept the onerous obligation associated with a perpetual NRC license, which would be required if land ownership is not transferred. Given these circumstances, the staff does not expect there will be a situation where waivers to surface land ownership transfer requirements will be appropriate or necessary.

Agreement State Regulation

A number of commenters indicated that the GEIS fails to assess the Agreement States's programs. Others inquired as to how the new requirements would be implemented in Agreement States. Staff response refers to the amendments to the Uranium Mill Tailings Radiation Control Act (UMTRCA) which clarify when the new requirements become effective in Agreement States. Generally, the States are required to implement the new requirements immediately, to the extent practicable and to establish standards by November of 1981 which are equivalent to, or more stringent than, the minimum national standards established by the Commission. Also, UMTRCA requires Agreement States to complete independent, documented environmental assessments in connection with each licensing case; the need for such documents and public review is a major conclusion of this statement (see Summary Section 6.4). The UMTRCA also requires the Commission to evaluate the equivalency of the states' programs by November of 1981. A more comprehensive set of criteria to be used in the November 1981 and subsequent reviews of Agreement State programs is being developed by the staff, and will be publicly available. It is considered that a detailed evaluation of the states' programs is not practicable or appropriate in the GEIS; however the general role of Agreement States and their relationship with NRC is discussed.

10. SUPPORTING RESEARCH AND SPECIAL STUDIES

In direct support of this generic statement, several special studies have been performed. Also, an ongoing comprehensive program of research, including both laboratory research and field studies at active uranium mills, continues to yield new information in addition to that already obtained and documented. Much of this supporting work is described in pertinent sections of the main text and appendices where it is directly relevant. In addition, Appendix G-9 summarizes the scope and results of various research and technical investigation efforts sponsored by the NRC in support of its overall regulatory program. Because the NRC research program is ongoing, not all available research results are ever fully documented. Final reports are published as they become available, and are placed in the NRC Public Document Room for inspection and reproduction by the public.

Laboratory and Field Research

Battelle Pacific Northwest Laboratory and Argonne National Laboratory, in conjunction with the U. S. Environmental Protection Agency (Las Vegas, Nevada), have been conducting programs of effluent and environmental measurements at active uranium mills continuously since June of 1977. These field studies have included measurements of radioactive particulates and radon gas in mill effluents and in surrounding air and soils; limited food ingestion studies have also been included. Ford, Bacon and Davis Utah, Inc. has conducted laboratory studies on the matter of radon attenuation by soils. Reports documenting most of the results of these research studies have been completed and issued.[6-9] Results from these and other studies were considered in the preparation of this final statement. Appendix G-9 of this document provides capsule descriptions of the various research and technical investigation efforts sponsored by the NRC in support of this statement and the overall NRC licensing program.

Special Studies

Oak Ridge National Laboratory, using information developed by the National Oceanic and Atmospheric Administration, assessed the radiological impact on the North American continent of radon-222 released from U. S. uranium mills.[3] This work also involved comparing impacts of mills with other natural and technologically enhanced sources of radon-222. Colorado State University conducted a study of long-term stability aspects of various tailings disposal programs evaluated in this statement.[10] Finally, Argonne National Laboratory, in preparing technical sections of this generic statement, has compiled specific information which characterizes the existing environment in western uranium development regions.[11] This information, which was used in defining the model mill and region, includes data on climate, topography, land use, geology and seismicity, mineral resources, surface and groundwater resources, soils, terrestrial and aquatic biota, cultural patterns and historical development, archaeology, and aesthetic and recreational resources. Other studies are described in more detail in Appendix G-9, which summarizes various research and technical efforts sponsored by the NRC in support of its regulatory program for uranium mills.

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1. INTRODUCTION

1.1 PURPOSE OF STATEMENT

This final generic environmental impact statement (GEIS) on uranium milling has been prepared in accordance with a notice of intent published by the Nuclear Regulatory Commission (NRC) in the Federal Register (41 FR 22430) on June 3, 1976, and in response to public comments received on the draft GEIS on uranium milling, published in April 1979, as NUREG-0511. As stated in the notice, the purpose of the statement would be to assess the potential environmental impacts of conventional uranium milling operations, in a programmatic context, including the management of uranium mill tailings, and to provide an opportunity for public participation in decisions concerning any proposed changes in NRC regulations based on this assessment. In support of this purpose, the principal objectives of the statement have been as follow:

(1) To assess the nature and extent of the environmental impacts of conventional uranium milling in the United States from local, regional, and national perspectives on both short- and long-term bases, to determine what regulatory actions are needed;

(2) More specifically, to provide information on which to determine what regulatory requirements for management and disposal of mill tailings and mill decommissioning should be; and

(3) To support any regulation changes that may be determined to be necessary.

Both technical and institutional issues are addressed. The major technical issues break down as follow:

(1) Mill tailings disposal as a long-term waste management problem. Major problems are those of isolating tailings from people for long time periods, control of persistent airborne emissions (particularly radon) and protection of groundwater quality;

(2) Reduction of operational radioactive effluents and impacts;

(3) Decommissioning of mill structures and site (excluding the tailings disposal area); and

(4) Nonradiological environmental impacts and resource use.

The major institutional questions addressed in this document include:

(1) Need for, and use of, land use controls and site monitoring at final tailings disposal sites;

(2) Methods of providing financial surety that tailings disposal and site decommissioning are accomplished by the mill operator; and

(3) Need for and methods of funding any long term surveillance or other requirements at tailings disposal sites which may be necessary.

The analyses of these and other questions are intended to support regulatory requirements for the operation of uranium mills and the management of mill tailings in such a manner as to appropriately assure the public health and safety and the preservation of environmental values.

1.2 SCOPE OF STATEMENT

The scope of this statement is as indicated and announced in the Federal Register (42 FR 13874) on March 14, 1977. Thus, the impacts and effects of anticipated conventional uranium milling operations in the United States through the year 2000 are evaluated in this document. Conventional uranium milling as used herein refers to the milling of ores mined primarily for the recovery of uranium; it involves the processes of crushing, grinding, and leaching of the ore, followed by chemical separation and concentration of uranium. Heap leaching of low-grade uranium ore carried out as a subsidiary process is included within the concept of conventional milling as used here.

Nonconventional recovery processes include in situ leaching from mines or uranium-rich tailings piles and extraction of uranium from mine water and wet-process phosphoric acid. These processes are described to a limited extent for completeness; they are not evaluated in depth since they now produce relatively small quantities of uranium (about 10% of total U.S. production during 1979). Also, operational impacts from in situ mining are almost exclusively related to groundwater and are, therefore, highly site-specific. The localized nature of this potential impact requires close examination on a case-by-case basis. A recent general study of potential in situ mining impacts on groundwater has been conducted by NRC (NUREG/CR-0311, "Groundwater Elements in In Situ Leach Mining of Uranium," Geraghty & Miller, Inc., August 1978).

The limited consideration provided by this study to nonconventional uranium recovery processes is in accordance with the intended scope of work as announced in the Federal Register (42 FR 13874) on March 14, 1977. Similarly, the impacts of uranium ore mining are addressed only briefly, for perspective and completeness. However, the U.S. EPA is currently preparing a report on the potential health, safety, and environmental hazards of uranium mine wastes, as directed by Congress under PL 95-604. This EPA report will contain recommendations for a program to minimize these hazards.

Projections of future uranium requirements by the nuclear power industry indicate the need for substantial growth in the uranium milling industry during the next 20 years. Similarly, information on the availability of uranium resources to be utilized during that period indicates that most of this uranium will be produced in those same western states in which current production is centered. In order to assess the environmental impacts resulting from the growth of the uranium milling industry, this statement has addressed milling activities in these states during the period from 1979 through the year 2000. The location of uranium resources and the technology used to recover uranium for periods beyond the year 2000 are speculative; the resulting large uncertainties preclude usefully extending the time period covered by this statement beyond that point.

In general, the method of assessment involves evaluation of a base case and alternatives chosen to bound the range of health effects and monetary costs for various levels of emission control during mill operation and, in the case of tailings disposal, for differing degrees of isolation. The following brief summary of what is covered in each chapter is provided to help the reader understand the approaches taken in the development of this document:

Chapter 2--A brief history of uranium milling is presented in this chapter for perspective. The major emphasis is on the problems associated with past tailings management at current inactive sites. In effect, Chapter 2 provides an indication of the problems to be evaluated in dealing with tailings generated in the future.

Chapter 3--This chapter includes an evaluation of the need for conventional uranium milling through the year 2000 as a basis for prediction of environmental impacts. Included are estimates of the amounts of uranium that will be required and the relative contributions of current conventional and alternative methods of production.

Chapter 4--A brief description of a general, schematic, model site and region developed to form a basis for analyzing potential environmental impacts and alternative control measures is presented in this chapter. Since environmental impacts of milling are largely site-specific, the site description is given only to the level of detail deemed necessary to illustrate in a general fashion what the effects of the uranium milling industry will be.

Chapter 5--This chapter contains a description of a model mill in a simple fashion to allow consideration of the major issues evaluated in the statement on a common basis. The model mill features a relatively low level of environmental control and as such defines the "base case" to be used as a point of departure for evaluating alternative controls.

Chapter 6--Covered in this chapter are the analyses of environmental impacts to be expected from the base case. Included are estimates of the cumulative effects of a realistic "worst-case" condition that might occur in the year 2000, when the equivalent of twelve model mills might be operating in a single region. So as to evaluate difficulties in meeting applicable radiological safety limits, the primary emphasis in this chapter is on health risks to individuals in the immediate vicinity of the mills. The focus of the health effects evaluation is on the EPA fuel cycle standard (40 CFR 190), which becomes effective as of December 1980, and will limit offsite exposure during milling operations.

Also presented in Chapter 6 are potential continental impacts (only exposure to radon and health effects therefrom are considered) occurring in the base case when the tailings are left exposed following termination of milling operations. The exposures are computed to provide a benchmark for evaluating alternative control measures and to support establishment of regulations dealing with tailings disposal.

Chapter 7--Potential accidents for the base case are evaluated in this chapter.

Chapter 8--Alternatives for mitigating the major environmental impacts identified in Chapter 6 are described in Chapter 8. These alternatives are classified into three groups: (1) those which will reduce operational impacts of milling, (2) those relating to final tailings disposal, and (3) those concerning decommissioning of mill structures and the surrounding site. Alternative tailings disposal programs evaluated were selected to cover a range of isolation levels. They can be categorized in a general way according to the level of long-term care they would necessitate: (a) an active care mode; (b) a passive monitoring mode, and (c) potential reduced care mode.

Chapter 9--This chapter contains evaluations of the environmental impacts of the three categories of alternatives described in Chapter 8. The primary emphasis of the chapter is on evaluation of impacts from tailings disposal alternatives. Special attention is given to this category because the primary purpose of this document is to support decisions (i.e., regulations) concerning controls and institutional changes needed to deal with tailings waste management and disposal problems.

Chapter 10--General principles for establishing a monitoring program during preoperational, operational and post-operational periods are discussed in this chapter.

Chapter 11--The monetary costs for alternatives evaluated in detail in Chapter 9 are presented in Chapter 11.

Chapter 12--This chapter includes a summary of the major technical conclusions of preceding chapters and evaluations and findings as to what steps should be taken to ensure mill operation and disposal of tailings in a manner that appropriately protects the public health and safety and the environment. Specific conclusions as to provisions which should be incorporated into regulations are presented.

Chapter 13--The regulatory authorities of federal and state agencies involved in regulation of uranium mills are described in Chapter 13. The description is related primarily to regulatory authorities in the area of control of tailings waste.

Chapter 14--On the basis of technical analyses and conclusions of previous chapters, evaluations are presented in this chapter on:

(1) Specific methods for providing financial surety that tailings disposal and site decommissioning will be carried out according to requirements; and

(2) Whether there should be a requirement for mill operators to provide funds for any long-term control required at tailings sites.

Chapter 15--This Chapter summarizes the cumulative unavoidable adverse impacts from U.S. milling through the year 2000, the relationship between short-term uses of man's environment and long-term productivity, and the irreversible and irretrievable commitment of resources from the U.S. milling industry.

1.3 RELATIONSHIP OF GENERIC STATEMENT TO SPECIFIC ENVIRONMENTAL IMPACT STATEMENTS

Primary emphasis is given to impacts that are generic in nature. Many of the impacts from uranium milling are highly site-specific and no attempt is made, therefore, to analyze them in great detail; they must be evaluated for each mill as is done through environmental statements prepared in connection with individual mill licensing actions. The evaluation in this document is intended to characterize the nature and extent of the impacts that will result from a typical mill. To do this, a range or upper limit for site-specific impacts is presented.

This generic environmental impact statement is not intended to replace specific environmental impact statements for individual mills. Impact statements will continue to be written for such mills as applications for license or relicense are received. In those statements, site-specific analyses of environmental impacts will be carried out, whereas only the hypothetical impacts of a "model" mill on a "model" site are considered in this generic statement. The primary concern in the generic statement is industry-wide practices and their local, regional, and long range effects over a relatively long period of time. Conclusions reached herein and implemented by way of regulation change will be considered and incorporated into future environmental impact statements written for specific mills. Those site-specific environmental impact statements produced prior to the issuance of this generic environmental impact statement have included the cautionary statement that any licensing actions taken would be subject to the express condition that approved waste-generating processes and mill tailings management practices may be subject to revision in accordance with the conclusions of this final generic environmental impact statement and any related rulemaking.

2. HISTORY OF URANIUM MILLING AND STATUS OF INACTIVE URANIUM MILLING OPERATIONS

2.1 PAST PRODUCTION AND METHODS*

In the past 35 years the uranium industry has undergone a series of transformations, with uranium changing almost overnight from a commodity of only minor commercial interest to one vital for nuclear weapons and, now, to its important peaceful use as a fuel for generation of electrical energy. With each change there has been a surge of interest in ore exploration and development and in new and expanded production facilities.[1]

The military demand for uranium beginning in the early 1940s had to be met from known sources of supply. The rich pitchblende ores of the Shinkolobwe deposit in the Belgian Congo and the Great Bear Lake deposit in Canada supplied uranium during the war years and were supplemented by production from treatment of old tailings dumps and a few small mines in the Colorado Plateau area. These high-grade ores and concentrates were refined by an ether extraction technique adapted from analytical procedures. Crude ore milling processes for low-grade ores used during this period reflected little change from methods used 40 years earlier (at the turn of the last century), with uranium being recovered from the leach solutions by several stages of selective precipitation. Milling costs were high and overall recovery was low, as judged by current standards.

With passage of the Atomic Energy Act of 1946, a strong emphasis was placed on the discovery and development of new worldwide sources of uranium. At the same time, the research efforts begun earlier were expanded in scope and magnitude to advance the process technology. These efforts led to greater use of lower-grade ores than previously had been considered feasible, such as the uranium-bearing gold ores in South Africa, as a source of uranium, and to the discovery and development of large, low-grade deposits in the Beaverlodge, Elliot Lake, and Bancroft regions of Canada.

In the United States, prospecting and mining for uranium were encouraged by the Atomic Energy Commission (AEC) through guaranteed fixed prices for ore, bonuses, haulage allowances, establishment of ore-buying stations and access roads, and other forms of assistance. These incentives led directly to an increase in the known mineable reserves of ore in the western United States from about $.9 \times 10^5$ metric tons (MT) [1×10^6 short tons (ST)] in 1946 to 8.1×10^7 MT (8.9×10^7 ST) in 1959. Programs also were initiated to examine other possible sources of uranium and to develop methods for processing these materials. AEC purchases from 1948 through 1970 totalled approximately 3×10^5 MT (3.3×10^5 ST) of U_3O_8, of which nearly 1.6×10^5 MT (1.8×10^5 ST) with a value of about \$3 billion were supplied from domestic sources.[1]

Mill process development programs in the United States were sponsored by the Manhattan Engineering District, and later by the AEC, through contracts with over 20 organizations from 1944 through 1958. Similar efforts were begun almost simultaneously in other countries, and the cooperative efforts and free exchange of information, particularly with Great Britain, the Union of South Africa, Canada, and Australia, greatly aided the overall effort. Many privately owned companies interested in the mining and milling of uranium also contributed to the knowledge gained during this period. Major developments included progress in chemical flocculents and in techniques for making liquid-solid separations. Studies of variables in the leaching circuit, such as ore particle size, the effect of the state of oxidation of the uranium in the ore on rate of dissolution, the use of oxidants, temperature, time of contact, and other factors, assisted in improving the efficiency of this operation and permitted the treatment of a greater variety of ores with consistently high recovery. Developments in operating techniques and in equipment design contributed to process reliability and to the production of final concentrates of relatively high purity. Dry grinding was used in the early mills but was gradually replaced with more efficient wet grinding, which also reduced dusting. The entire development period was marked by steadily decreasing process costs per unit of production.

*The history of uranium milling operations has been reviewed in a book by Merritt,[1] and material from that source is summarized in this section.

During the peak production years in the United States, from 1960 through 1962, the number of operating mills (excluding plants producing by-product uranium from phosphates) varied from 24 to 26, with total annual production exceeding 1.5×10^4 MT (1.7×10^4 ST) of U_3O_8 from the treatment of about 7×10^6 MT (8×10^6 ST) of ore.

In 1957, it was apparent that very large ore reserves had been developed and that additional contracts, which were the main incentive for exploration by potential producers, would lead to commitments exceeding government requirements through 1966. In 1958, the AEC withdrew its offer to purchase uranium from any ore reserves developed in the future. This led to shutdowns of mills after expiration of contracts and to stretching out of deliveries under long-term contracts in the United States, Canada, and South Africa. As a result of these attempts to balance lowered military demand, and slow development of commercial reactors with an overexpanded supply, the period from 1967 through 1970 saw a considerable reduction in the number and production rates of active uranium mills in the United States and abroad. However, contracts with many U.S. producers were eventually extended through 1970. These contract stretchouts reduced the rate of government purchases and constrained production to values more in line with government requirements. They also served to ease the industry through a period when nuclear power growth had not progressed sufficiently to create a significant commercial demand.

Total production of U_3O_8 through 1979 from U.S. sources is estimated at about 2.75×10^5 MT (3.1×10^5 ST).[2] The amount of ore used in the production of this U_3O_8, and the approximate amount of tailings produced, was expected to reach 1.5×10^8 MT (1.6×10^8 ST) by the end of 1979. Of this total, about 20%, or 2.5×10^7 MT (2.8×10^7 ST), is located at inactive mill sites, and the balance ($\sim$ 80%) is located at currently active mill sites. Some of the problems that have developed with the tailings at the inactive sites are briefly outlined below.

2.2 MILL TAILINGS AT INACTIVE MILL SITES

On 12 March 1974, the Subcommittee on Raw Materials of the Joint Committee on Atomic Energy of the U.S. Congress held hearings on identical bills, S. 2566 and H. R. 11378, providing for a cooperative arrangement between the Atomic Energy Commission and the State of Utah regarding the Vitro tailings site in Salt Lake City for assessment of, and appropriate remedial action to limit, the exposure of individuals to radiation from uranium mill tailings. It was pointed out during the testimony that there are similar problems at other sites, and the Environmental Protection Agency (EPA) and the AEC recommended the issue be approached generically, structured to address the most critical problems first. As a result of this action, 22 inactive uranium mill tailings sites (see Table 2.1) were identified as possible candidates for investigation.

AEC proposed that a comprehensive study be conducted as a cooperative two-phase undertaking by the states concerned and the appropriate federal agencies, such as AEC and EPA. The first phase of the study involved visits to the 22 identified sites to determine the condition of each site, any need for corrective action, ownership, proximity to populated areas, and prospects for future population increases near the site.[3] This phase of the study was carried out during 1974; the 22 identified inactive sites were visited by teams consisting of representatives of AEC (the precursor of the Department of Energy), EPA, and the states. The Phase I study concentrated on visual inspections of the physical conditions at each site. The following criteria were used as a basis for determining the conditions of the sites: conditions of tailings and structures on-site; existence of mill employee housing, fencing, posting, and security; location of property near a stream; evidence of wind or water erosion; and whether any tailings have been removed for private use. Although some of the tailings at the inactive sites have had some degree of stabilization, the sites that have been partly stabilized, such as by vegetative cover, required continual maintenance. All of the sites at the time of the study showed signs of deterioration such as erosion due to wind or water and loss of cover. Thus, the stabilization work done to date represents a holding action, sufficient for the present, but not a satisfactory answer for the long term. In several cases, where no steps were taken to stabilize the tailings, they have been blown off site into unrestricted areas. About half of the sites were situated near a stream, and therefore could provide a source of river contamination in case of flooding. Perhaps the most significant problem with the tailings, however, was the potential of removal for private use, such as for fill material on construction projects. It is believed that tailings removal for private use has occurred at six sites. The most widespread use of tailings in building construction occurred in Grand Junction, Colorado. An estimated 270,000 MT of uranium tailings have been moved from the Grand Junction site and used as fill material on various construction projects. The contaminated locations, however, have been identified, and corrective action is being carried out by DOE, in conjunction with the State of Colorado.

A preliminary report, which served as a basis for determining whether a detailed engineering assessment (Phase II)4 was necessary, was prepared for each mill site. The second phase of the study included more specific environmental measurements that determined the extent of contamination from the tailings piles. These more detailed studies were conducted to form a basis for

Table 2.1. Inactive Processing Sites, Priorities for Remedial Action, and Quantity of Tailings

Location and Processing Site	Remedial Priority	Amount of Tailings,[a] 10^6 MT	Last Year of Operation
Arizona			
Monument City[b]	Low	1.0	1968
Tuba City[b]	Medium	0.7	1966
Colorado			
Durango	High	1.8	1963
Grand Junction	High	2.5[a]	1970
Gunnison	High	0.6	1962
Maybell	Low	2.4	1964
Naturita	Medium	0.6	1963
Rifle (New Rifle)	High	2.4[a]	1972
Rifle (Old Rifle)	High	0.3	1958
Slick Rock (NC)	Low	0.02	1957
Slick Rock (UC)	Low		1961
Idaho			
Lowman	Low	0.08	1960
New Mexico			
Ambrosia Lake	Medium	2.3	1963
Shiprock[b]	High	1.9	1968
North Dakota[e]			
Belfield	Low	0.6	1968
Bowman	Low	0.5	1967
Oregon			
Lakeview	Medium	0.1	1960
Pennsylvania			
Canonsburg[c]	High	0.2	1966
Texas			
Falls City	Medium	2.2[a]	1973
Utah			
Green River	Low	0.1	1961
Mexican Hat[b]	Medium	2.0	1965
Salt Lake City	High	2.0	1968
Wyoming			
Baggs[e]	Low	0.01	--
Converse County	Low	0.17	1965
Riverton[d]	High	0.8	1963

[a]At three sites, tailings from commercial sales were comingled with those from government defense operations. At Grand Junction, CO, the ratio is 80% government, 20% commercial; at New Rifle, CO, 99% government, 1% commercial; and at Falls City, TX, 34% government, 66% commercial. All other piles contain tailings from government operations only. (Based on personal communication from J. S. Themelis, Director, Engineering and Safety Division, Grand Junction Office, DOE, 14 March 1980.)

[b]Processing site on tribal lands owned by the Navajo Nation.

[c]The Canonsburg, PA, site was started in 1911 and was used as a custom mill to extract radium and uranium from ores. (Based on "First Annual Status Report on Inactive Mill Tailings Sites; Remedial Action Program, December 1979," U.S. Dept. of Energy, 1979.)

[d]Processing site located on private property within the boundaries of the Wind River Indian Reservation.

[e]The sites in North Dakota and the Baggs site in Wyoming were identified and designated subsequent to the enactment of the Act. All other sites were identified prior to the Act and designated by the Act.

engineering assessments and cost studies for alternative remedial actions. The studies included gamma surveys, radon concentration measurements, and measurements to determine the extent of windblown soil, groundwater, and surface water contamination.

Descriptions of the conditions at the 22 sites have been issued in a series of reports[4] prepared by Ford, Bacon and Davis, Utah documenting the Phase II assessments. In addition, Oak Ridge National Laboratory (ORNL) has been preparing another series of 20 reports[5] summarizing the radiological surveys performed at these sites as a part of the assessments. Detailed summaries of the conditions at these sites are beyond the scope of this chapter.

In April 1978, the Department of Energy (DOE) submitted proposed legislation to Congress which would establish a program to stabilize and control the mill tailings in a safe and environmentally sound manner. Hearings on the proposed legislation began in June 1978 in conjunction with similar bills introduced in the Senate and House of Representatives.

As a result of these hearings, Public Law 95-604 was enacted on 8 November 1978.[6] The Act (see Appendix Q) authorizes DOE, along with the affected states, Indian tribes, and persons who owned or controlled inactive uranium mill tailings, to establish assessment and remedial action programs at inactive uranium mill tailings sites. Title I of the Act further stipulates that DOE will meet all radiation standards promulgated by EPA. Additionally, DOE will finance 90% of the remedial action costs, and the affected states will be required to pay remaining costs from non-federal funds. Exceptions to this requirement are those sites on Indian tribal lands, where 100% of the costs for remedial action will be borne by the federal government.

As discussed in Reference 7, major program requirements to be accomplished over the seven years following enactment of P.L. 95-604 to implement the Remedial Action Program are as follows:

- Designation of processing sites
- Establish site priorities for remedial action
- Establish cooperative agreements with affected states and applicable Indian tribes
- Acquisition and disposition of lands and materials
- Reprocessing of residual radioactive materials
- Compliance with the National Environmental Policy Act (NEPA)
- Remedial action
- Public participation
- Annual status reports to Congress.

2.3 SUMMARY OF DOE REMEDIAL ACTION PROGRAM

As a result of the enactment of P.L. 95-604 (the Act), the 22 sites already identified were designated by Congress for inclusion in the Remedial Action Program. In addition to the first 22 sites, three more inactive sites were later (November 1979) designated by DOE, in cooperative efforts with the states and NRC, for processing under the Remedial Action Program. These are the Belfield and Bowman sites in North Dakota and the Baggs site in Wyoming. Conditions at these sites are still under investigation.

The current (July 1980) designation of inactive uranium (and other) mill processing sites has been published as shown in Table 2.1. This table includes the quantity of tailings at each site and the priorities for remedial action established by DOE.

As specified in Section 102(b) of the Act, DOE has assessed the potential health effects to the public from the residual radioactive material on or near the 22 site locations referenced in Section 102(a)(1) of the Act. Utilizing the advice from the EPA (Appendix I of Ref. 7), DOE has established the priorities listed in Table 2.1 for performing remedial actions. These priorities were established using estimates of the near-term local rates of induction of health effects associated with radon. The ranking of high, medium, and low categories was considered more meaningful than a numerical ranking because of uncertainties in the estimates of radon-associated health effects. The site summaries for these 25 processing sites are listed in Appendix K of Reference 7.

DOE currently is preparing remedial action plans for the first several high-priority sites. NRC has the responsibility for concurring in the DOE Remedial Action Program at each site. In addition, NRC has the responsibility to license DOE for the maintenance and monitoring of the processing sites once the remedial actions have been completed. The NRC is therefore working closely with DOE to ensure that the requirements of the Act are adequately carried out. The staff considers that the regulations being promulgated for active mills (see Sec. 12.2) are appropriate also to inactive site remedial actions. It is expected, therefore, that the criteria in these regulations will be applied to DOE remedial actions in the same manner as will be done at existing active mill sites (see Sec. 12.4).

References

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2. J. F. Facer, Jr., "Production Statistics" Supply Analysis Div., U.S. Energy Research and Development Administration, presented at Grand Junction Office Uranium Industry Seminar, October 1979.

3. "Summary Report - Phase I, Study of Inactive Mill Sites and Tailings Piles," Ford, Bacon, & Davis Utah, October 1974.

4. "Engineering Assessment of Inactive Uranium Mill Tailings - Phase II," Ford, Bacon, and Davis Utah, Inc., ERDA Contract E(05-1)-1658, 1977.

5. "Radiological Surveys at Inactive Uranium-Mill Sites," Oak Ridge National Laboratory, ORNL/TM-5251 and ORNL-5447 through ORNL-5465 (DOE Contract W-7405-eng-26), 1980.

6. Uranium Mill Tailings Radiation Control Act of 1978, PL95-604.

7. "First Annual Status Report on the Inactive Mill Tailings Sites; Remedial Action Program, December 1979," Environmental Control Technology Division, Office of Environmental Compliance and Answers, Assistant Secretary for Environment, U.S. Dept. of Energy, 1979.

3. PRODUCTION OF URANIUM

The quantities of uranium projected to be needed and the amount likely to be produced in the United States through the year 2000 are considered in this chapter. In the first part, the quantity of uranium needed for the generation of nuclear power is predicted. The current uranium milling industry is then described in terms of mill capacity, geographic location, and the significance of "unconventional" production sources. This is followed by a more detailed account of the "unconventional" sources, including projections of their contributions to the total uranium supply. An overview of the milling industry to the year 2000 is then given. Descriptions of the more important uranium mining and milling processes are presented in Appendix B.

3.1 THE NEED FOR URANIUM WITHIN THE CONTEXT OF THIS GENERIC STATEMENT

The need for uranium in commercial reactors in the United States is primarily a function of two factors: (1) the installed commercial nuclear reactor capacity, and (2) U.S. uranium enrichment policies. Evaluations of these factors were based on information available from the U.S. Department of Energy (DOE). The sensitivity of cumulative environmental impacts to nuclear power projections, enrichment tails assays, ore grades and other key parameters is discussed in Appendix S. The installed nuclear reactor capacity and uranium enrichment policies are discussed below.

The installation schedule assumed for this document (chosen from many that have been projected) is the DOE Mid-Range projection shown in Table 3.1. This projected growth rate is substantially below prior expectations and results, at least in part, from recent drops in the demand for electricity and increased costs for constructing new nuclear power plants. Approximately 9% of U.S. electricity now is generated by nuclear power. The DOE Mid-Range capacity schedule shown in Table 3.1 is expressed in terms of metric tons of U_3O_8 in yellowcake required annually and cumulatively in Table 3.2. The quantities of U_3O_8 required are based on a "once-through" (throwaway) uranium fuel cycle which does not include recycle of either uranium or plutonium, and a 3-year lead time for yellowcake production (prior to fuel utilization).

A comparison between estimated total requirements for electrical generating capacity and the projected nuclear capacity through the year 2000 is given in Table 3.1. It is shown that nuclear generating plants are expected to furnish from 9% to 20% of the electrical energy supplied during this period. The projections are affected by national policy relative to nuclear power. For example, decisions concerning nuclear reprocessing, the breeder reactor program, spent fuel storage, and nuclear waste disposal are all important factors in determining the economic viability and political acceptability of nuclear power. The availability and economic competitiveness of alternative energy sources such as coal, natural gas, petroleum, and solar energy also influence these projections.

For use in commercial LWRs, the atomic percentage of the fissile nuclide U-235 must be enriched from its natural abundance of 0.71%. The amount of natural uranium required to produce a desired amount of product material of a given enrichment is related to the percentage of U-235 remaining in the enrichment tails, the residual uranium from which some of the U-235 has been removed. The enrichment factors used in converting nuclear fuel requirements into U_3O_8 requirements were based on an enrichment tails assay of 0.20%. The average reload enrichment was taken as 3.0% for the reactor system projected. Enrichment policy changes, such as changing the tails assay or the required delivery time of U_3O_8 to the enrichment plant, will change U_3O_8 requirements. (For example, if the enrichment tails assay were increased to 0.25%, although it would be less costly in terms both of energy and money to do so, the increase in annual U_3O_8 requirements could be 12%.) Perturbations in uranium demand caused by changes in Department of Energy uranium fuel enrichment policies were not factored into the U_3O_8 requirements assumed herein.

Uranium requirements can be filled by other than conventional mining and milling techniques. In addition, uranium can also be imported. The effects of "unconventional" sources are discussed in Section 3.3. The uranium requirements projected in this study are based on the premise that all needs are filled from domestic resources.

An important consideration in this generic study is the comparison of the amounts of raw material (U_3O_8) required for the projected reactor schedule (see Table 3.2) to the estimated domestic uranium resources available (Table 3.3). It is shown in Table 3.3 that currently known reserves and probable resources are adequate to support the presumed 180-GWe schedule through the year 2000.

Table 3.1 Comparison of Total and Nuclear Generating Capacity, 1979-2000

Year	Total Generating Capacity, GWe[a]	Nuclear Generating Capacity, GWe[b] Low Range	Mid-Range	High Range	% Nuclear (Mid-Range)
1979	549	49.0	49.0	49.0	8.9
1980	550	53.1	55.3	55.3	10.1
1985	638	86.5	98.3	108.7	15.4
1990	740	121.4	127.7	139.4	17.3
1995	817	137.1	150.9	159.8	18.5
2000	902	160.0	180.0	200.0	20.0

[a]Data shown are from Reference 2. Growth rates used were 3% per year through 1990 and 2% per year thereafter.

[b]Data shown are from Reference 1. Mid-range estimates essentially amount to fulfillment of currently planned nuclear reactor development and have been selected as the basis for estimating uranium demand.

Table 3.2 Requirements for U_3O_8, 1979-2000[a]

Year	Generating Capacity, GWe	Required U_3O_8 Content in Yellowcake Production, 10^3 MT Annual	Cumulative
1979	49.0	13.4	13.4
1980	55.3	14.6	28.0
1981	61.5	16.0	44.0
1982	72.3	18.2	62.2
1983	79.1	20.6	82.8
1984	86.4	22.1	104.9
1985	98.3	22.9	127.8
1986	111.2	23.2	151.0
1987	119.5	23.6	174.6
1988	123.7	24.7	199.3
1989	125.5	25.3	224.6
1990	127.7	26.2	250.8
1991	133.4	27.5	278.3
1992	136.8	27.9	306.2
1993	141.6	29.0	335.2
1994	148.4	30.1	365.3
1995	150.9	31.2	396.5
1996	156.7	32.2	428.7
1997	162.5	33.3	462.0
1998	168.4	34.4	496.4
1999	174.2	35.5	531.9
2000	180.0	36.5	568.4

[a]DOE Mid-Range nuclear generating capacity estimates are used, from Table 3.1. Conversion from GWe to uranium requirements is based on an average of 185 MT U_3O_8 in yellowcake required per GWe-year. This is the factor for 3.0% reload enrichment, 0.20% enrichment tails, and an effective average plant capacity factor of 75%. A three-year delay between yellowcake production and fuel utilization is assumed.

Table 3.3 Comparison of U.S. Reactor Requirements and Domestic Resource Availability (in MT U_3O_8 as of January 1978)[a]

Time Period	Reactor Demand	Resource Availability @ \$50/lb[b,c]
1979 to 2000	568,400	
Reserves[d]		890,000
Probable resources		1,395,000
Sum of reserves & probable resources		2,285,000

[a]Based on information presented by D. L. Hetland and W. D. Grundy, at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1978, and in "ERDA Makes Preliminary Estimate of Higher Cost Uranium Resources," U.S. Energy Research and Development Administration, Notice 77-105, 22 June 1977, and updated July 1978.

[b]Costs include all those incurred in property exploitation and production except profits and costs of money. Costs are the current ones, and are not intended to project future uranium prices.

[c]\$50/lb is equivalent to \$110/kg.

[d]Does not include U_3O_8 which could be produced as a byproduct of phosphate fertilizer and copper production.

3.2 THE CURRENT URANIUM MILLING INDUSTRY

The current conventional uranium extraction and processing industry involves a combination of mining and milling methods that have been developed through experience gained since about 1940. A brief history of this evolution is given in Section 2.1. The mining and milling methods currently used, while capable of general characterization as open pit or underground for mining, and acid or alkaline leach for milling, have evolved into systems usable anywhere in the western United States for sandstone-deposited ores. These ores constitute practically all of the reserves and probable resources identified to date in the United States. In conventional practice, the location of the mill with respect to the mine, the specific process used by the mill, the size of the mill, and the tailings management schemes used are all directly influenced by mining procedures and the chemical and physical characteristics of the ore. Mining and milling operations are discussed in more detail in Chapter 5 and Appendix B.

In this section the current U.S. conventional mill capacity is discussed, the locations of proven and potential uranium reserves are given, and the contribution of "unconventional" processes is considered.

3.2.1 Conventional Mill Capacity in the United States[3,4]

Mill capacities in 1978 ranged from 360 to 6300 MT (400 to 7000 ST) of ore per day, averaging about 1800 MT (2000 ST) per day. On the basis of an average ore grade of 0.10% U_3O_8, a model mill of 1800 MT/day capacity, as described in Chapter 5, would produce about 580 MT (640 ST) of yellowcake per year at 85% capacity, containing about 520 MT (570 ST) of U_3O_8. About 80% of the current milling capacity involves the use of the sulfuric acid leach process; the rest involves the use of the basic (carbonate) solution leach process.

At a few mills an additional process--heap leaching--is either being used on a small scale or is being planned. Heap leaching is a technique usually designed to remove unrecovered uranium from low-grade ores or tailings containing less than 0.05% U_3O_8 and is not expected to contribute any major amount towards annual U_3O_8 production. One major heap leach operation, undertaken in 1976, was at Union Carbide's Maybell, Colorado, site, which is remote from any conventional mill.

Heap leaching does not necessarily increase environmental impacts, whether used on existing uranium tailings piles or on low-grade ore transported to the mill for heap leaching. The process might result in slight modification of tailings management procedures because tailings and leached ore could be mixed, rather than separated as in conventional mining and milling; however, operations would still be above the ground and impacts would be essentially unaltered. Heap leaching operations are considered to be part of the conventional milling industry.

The total capacity of conventional mills operating in 1979 was about 43,900 MT (48,200 ST) of ore per day (see Table 3.4). Production of U_3O_8 in 1977 from conventional mills was about 13,000 MT (14,500 ST); 1979 conventional mill U_3O_8 production is estimated to have been about 16,000 MT (17,600 ST) and account for about 90% of total production by all methods.[4] About 14.4 million MT (15.8 million ST) of ore was processed by 21 conventional mills operating in 1979, indicating an average ore grade of about 0.12% and an overall capacity factor of almost 90%.

Average ore grades were about 0.16% in 1977, 0.13% in 1978, and 0.12% in 1979. The average grade of ore processed by conventional milling facilities has been projected to gradually decline to a level of about 0.08% in the 2000.[3] The average ore grade between now and the year 2000 is estimated to be about 0.10% and that figure is used as the basis for subsequent calculations of environmental impacts.

Average mill uranium recovery was about 92% in 1977 and 91% in 1978. The estimated uranium recovery rate for 1979 is between 91% and 92%, despite the decline in average ore grade. Further improvements in extraction efficiency are anticipated as the basic technology evolves, as operators gain experience processing lower ore grades, and as gradual price increases begin to justify the costs of additional equipment or process modifications necessary to enhance recovery.

3.2.2 Geographic Locations of Uranium Reserves in the United States

Most of the nation's known uranium resources are located in the West, as shown in Figure 3.1, and all of the 21 conventional uranium mills now operating (Table 3.4) or currently planned for operation are (or will be) west of the Mississippi River. Information is presented in Table 3.4 showing the relative amounts of operating conventional milling capacity in each of the six uranium-producing states and by NURE (National Uranium Resource Evaluation) region.[4-6] The NURE regions were selected principally to allow categorization of uranium reserves on a regional basis. The estimated quantities of the nation's uranium resources are listed by category in Table 3.5. The meanings of the categories are as follows:

1. Reserves - Uranium which occurs in known ore deposits of such grade, quality, and configuration that it can be economically recovered with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposit and on knowledge of the ore body.

2. Potential Resources (three subgroups):

    a. Probable (potential) resources are located in extensions of established ore trends or in areas demonstrated to contain uranium.

    b. Possible (potential) resources are located (by estimation) in new deposits in formations or geologic settings similar to production areas elsewhere.

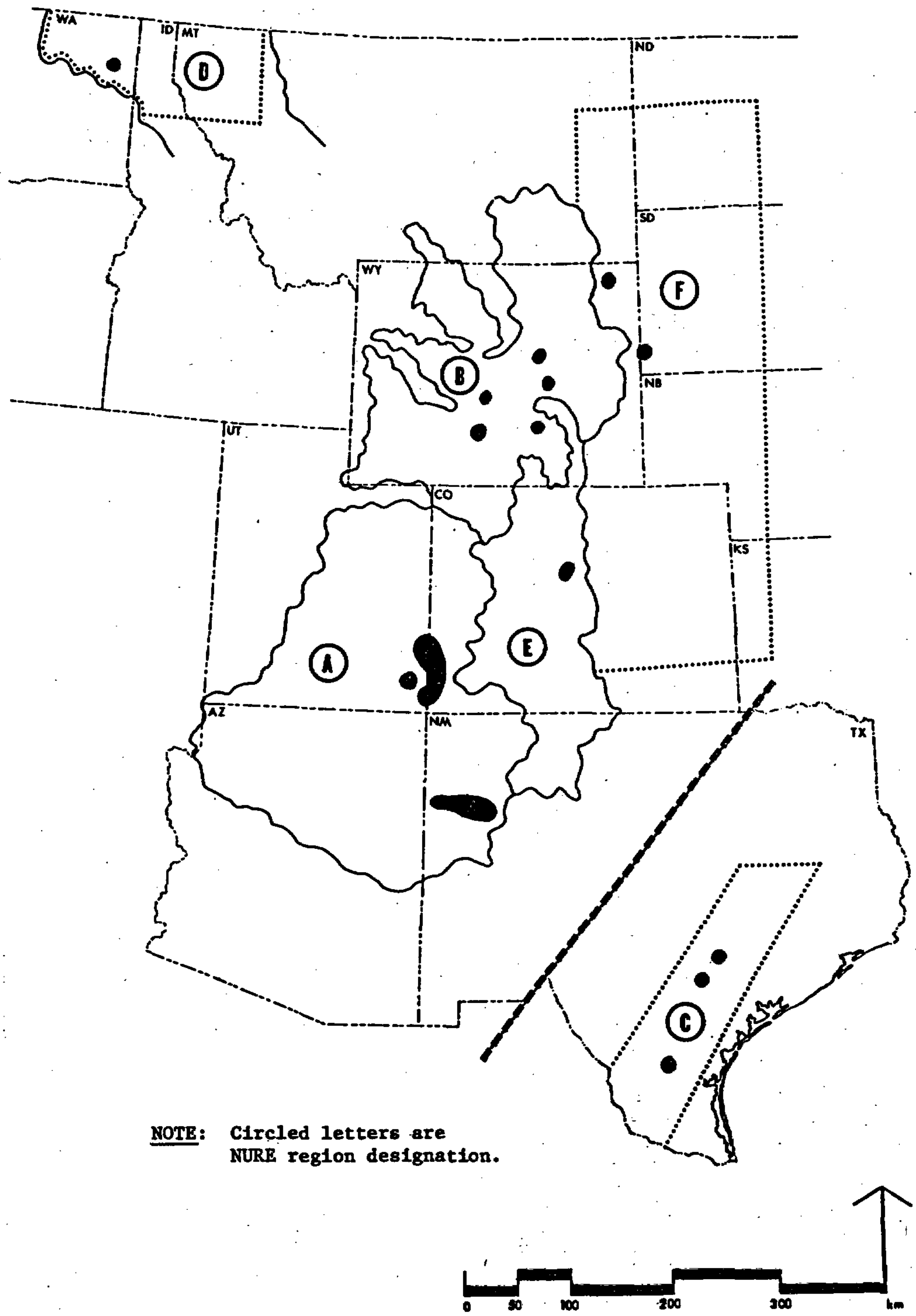
    c. Speculative (potential) resources are located (by estimation) in new deposits in formations or geologic settings not previously productive.

The above classes are divided in Table 3.6 on the basis of the indicated forward costs, i.e., all costs yet to be incurred by the mining company at the time the estimate is made, except profit and cost of money, and are in the dollars of the year of estimation. The six principal NURE regions had produced 281,000 MT (312,300 ST) of U_3O_8 (as of 1 January 1978) and contain 2.2×10^6 MT (2.4×10^6 ST) of U_3O_8 as reserves and probable resources recoverable at \$110/kg (\$50/lb) or less. Uranium requirements are expected to reach 568,000 MT (625,000 ST) of U_3O_8 (70% of the 1978 reserves in the six principal NURE regions) by the year 2000, and production to meet these needs will likely be centered in these six NURE regions. Production and resources are shown by region in Table 3.5.

3.2.3 Contribution of Unconventional Processes

Although most uranium production is by the conventional acid or alkaline leaching processes, "unconventional" methods are used for some production. Such methods include solution mining (also known as in situ mining), uranium recovery from mine water, copper dump leach liquor, or wet process phosphoric acid effluents. In each case, the uranium is recovered from solution by ion-exchange or solvent extraction. Production of U_3O_8 by these methods totaled 450 MT (500 ST) in 1976. Production was about 760 MT (850 ST) of U_3O_8 in 1977 and was expected to reach about 1900 MT (2200 ST) in 1978.[7]

Production from solution mining was relatively constant at less than 1% of total uranium production for more than 15 years. This percentage increased to about 3% in 1977 and was expected to be about 7% in 1979. Production by solution mining was expected to be about 1300 MT (1430 ST) in 1979.[4]



NOTE: Circled letters are NURE region designation.

Fig. 3.1 Uranium Reserves and Resources in Western United States.

Table 3.4 Conventional U.S. Uranium Mills Operating in 1979[a]

State & Company	Location	Max. Cap., MT ore/day	NURE Region[b]	Process Used
New Mexico				
Anaconda Company	Grants	5,400	A	Acid leach, CCD, solvent extraction
Kerr-McGee Nuclear Corporation	Grants	6,300	A	Acid leach, CCD, solvent extraction
Sohio-Reserve	Cebolleta	1,500	A	Acid leach, CCD, solvent extraction
United Nuclear Corporation	Church Rock	2,700	A	Acid leach, CCD, solvent extraction
United Nuclear-Homestake Partners	Grants	2,700	A	Carbonate leach, caustic precipitation
	TOTAL	18,600		
Wyoming				
Exxon, U.S.A.	Powder River Basin	2,700	B	Acid leach, CCD, solvent extraction
Federal-American Partners	Gas Hills	860	B	Acid leach, eluex
Pathfinder Mines Corporation	Gas Hills	3,500	B	Acid leach, eluex
Pathfinder Mines Corporation	Shirley Basin	1,600	B	Acid leach, CCD, column ion exchange
Petrotomics	Shirley Basin	1,300	B	Acid leach, CCD, solvent extraction
Rocky Mtn. Energy & Mono Power	Powder River Basin	1,800	B	Acid leach, CCD, solvent extraction
Union Carbide Corporation	Natrona County	1,100	B	Acid leach, eluex
Western Nuclear, Inc.	Jeffrey City	1,500	B	Acid leach, eluex
TOTAL		13,500		
Utah				
Atlas Corporation	Moab	1,350	A	Carbonate leach, resin in pulp & acid leach, solvent extraction
Rio Algom Corporation	La Sal	640	A	Carbonate leach, caustic precipitation
TOTAL		2,000		
Colorado				
Cotter Corporation	Canon City	1,300	E	Carbonate leach, caustic precipitation
Union Carbide Corporation	Uravan	1,200	A	Acid leach, CCD, column ion exchange
TOTAL		2,500		
Texas				
Chevron	Panna Maria	2,200	C	Acid leach, CCD, solvent extraction
Conoco & Pioneer Nuclear, Inc.	Falls City	2,900	C	Acid leach, CCD, solvent extraction
TOTAL		5,100		
Washington				
Dawn Mining Company	Ford	400	D	Acid leach, CCD, column ion exchange
Western Nuclear	Wellpinit	1,800	D	Acid leach, CCD, solvent extraction
TOTAL		2,200		
GRAND TOTAL		43,900		

[a]Modified from Reference 4.

[b]Region as defined by Figure 3.1 and Table 3.5.

Table 3.5 Summary of Uranium Production, Reserves, and Potential Resources by NURE Regions ($50 forward costs as of 1 January 1978)[a]

Region	Past Production ST U_3O_8	ST U_3O_8[b]			
		Reserves	Potential Resources		
			Probable	Possible	Speculative
(A) Colorado Plateau	216,300	485,200	665,000	815,000	40,000
(B) Wyoming Basins	68,900	264,000	375,000	115,000	30,000
(C) Coastal Plain	10,000	53,900	180,000	95,000	35,000
(D) Northern Rockies		25,400	27,000	63,000	50,000
(E) Colorado and Southern Rockies		25,800	56,000	56,000	41,000
(F) Great Plains	17,100	8,000	27,000	70,000	48,000
Subtotal A,B,C,D,E,F	312,300	862,400	1,330,000	1,214,000	244,000
(G) Basin & Range		25,500	59,000	292,000	76,000
(H) Pacific Coast and Sierra Nevada	<1,000	2,100	4,000	9,000	9,000
(I) Central Lowlands	<1,000	0	c/	c/	110,000
(J) Appalachian Highlands	<1,000	0	c/	c/	95,000
(K) Columbia Plateaus	<1,000	0	c/	c/	31,000
(L) Southern Canadian Shield	0	0	c/	c/	c/
(M) Alaska	<1,000	0	2,000	c/	c/
TOTAL	313,100	890,000	1,395,000	1,515,000	565,000

[a]Based on the information derived from:

(1) D. L. Hetland, "Discussion of the Preliminary NURE Report and Potential Resources," presented at the Grand Junction Office Uranium Industry Seminar, U. S. Dept. of Energy, October 1978.

(2) D. L. Everhart, "Status of NURE Program," presented at the Grand Junction Office Uranium Industry Seminar, U. S. Dept. of Energy, October 1978.

(3) "Reserves and Resources of Uranium in the U. S.," supplement to Mineral Resources and the Environment, National Academy of Science, 1975.

[b]Conversion factor: one short ton (ST) = 0.91 metric ton (MT); \$50/lb = \$110/kg.

[c]Resources not estimated because of inadequate knowledge.

Table 3.6 U. S. Uranium Resources[a] (ST U_3O_8 as of 1 January 1978)

Cost Category, $/lb U_3O_8	Reserves	Potential Resources[b] Probable	Possible	Speculative
Less than $15	370,000	540,000	490,000	165,000
$15 - $30	320,000	475,000	645,000	250,000
$30 - $50	200,000	380,000	380,000	150,000
Total	890,000	1,395,000	1,515,000	565,000

[a]Based on information derived from:

(1) R. J. Meehan, "Uranium Ore Reserves," presented at the Grand Junction Office Uranium Industry Seminar, U. S. Dept. of Energy, October 1977.

(2) D. L. Everhart, "Status of NURE Program," presented at the Grand Junction Office Uranium Industry Seminar, U. S. Dept. of Energy, October 1977.

(3) "Reserves and Resources of Uranium in the U. S.," supplement to Mineral Resources and the Environment, National Academy of Science, 1975.

(4) D. L. Hetland and W. D. Grundy, "Potential Uranium Resources," Resource Division, U. S. Dept. of Energy, Grand Junction, Colorado, October 1978.

[b]The reliabilities of the potential resource estimates decrease from the probable to the speculative class.

Production of uranium from mine water amounts to about 100 tons U_3O_8 per year. This will increase as more underground wet mines come into production, but the method still is unlikely to account for more than 1% or 2% of domestic uranium production.

During 1979, three companies were producing U_3O_8 from wet process phosphoric acid, and two other operations should begin production during 1980. Production by this method was about 400 MT (440 ST) in 1979.

Much effort has been expended to determine the amounts of uranium that might be recovered from coal and lignite. Some uranium was recovered from lignite ash in the early 1960s, but that lignite was not a suitable fuel, supplementary fuel being necessary for the conversion to ash, which is necessary before uranium can be extracted. No uranium has been recovered as a byproduct from the ash of coal- or lignite-fired power plants. Ash samples continue to be analyzed for uranium, but to date no ash containing more than 20 ppm U_3O_8 has been found, and most ash samples contain 1 to 10 ppm U_3O_8.

3.3 PROSPECTS FOR UNCONVENTIONAL METHODS OF URANIUM PRODUCTION

Principal production methods that could reduce the total conventional milling capacity needed in the future are:

- In situ mining (in-place leaching of ore deposits);
- Production by extraction from "other than uranium" process streams (also called byproduct production);
- Imports and exports.

The potential of these techniques to reduce the number of conventional mills needed and thus reduce mill-associated impacts is summarized in Table 3.7 and examined in more detail below.

3.3.1 In Situ Mining

In situ leaching (solution mining) of uranium is a viable uranium production method that will likely reduce the total conventional milling capacity needed in the future by a significant amount. The method involves (1) the injection of a leach solution (lixiviant) into a subterranean uranium-

Table 3.7 Estimated $50/lb Uranium Production Capability by Nonconventional Techniques

Year	Production Capability, 10^3 ST U_3O_8 per year[a] Solution Mining	Byproduct Recovery	Total Nonconventional
1980	2.5	0.95	3.4
1981	3.3	1.3	4.6
1982	3.9	2.1	6.0
1983	4.6	3.0	7.6
1984	5.4	3.2	8.6
1985	6.1	3.5	9.6
1986	6.6	3.8	10.4
1987	7.4	4.0	11.4
1988	8.6	4.3	12.9
1989	9.7	4.5	14.2
1990	10.3	4.7	15.0
1991	10.6	4.9	15.5
1992	10.7	5.1	15.8
1993	10.6	5.2	15.8
1994	10.5	5.3	15.8
1995	10.4	5.4	15.8
1996	10.4	5.5	15.9
1997	10.4	5.6	16.0
1998	10.2	5.9	16.1
1999	10.1	5.9	16.0
2000	9.9	5.9	15.8
Total	172.2	90.0	262.2

[a]Adapted from data presented in Reference 3.

bearing ore body to dissolve and complex the contained uranium, (2) the mobilization of the uranium complex formed, and (3) the surface recovery of the uranium from the uranium-complex-bearing solution by conventional milling unit operations.

Whereas conventional extraction of minerals may produce significant environmental impacts, the use of solution mining offers the potential advantage of reducing surface disturbance and associated impacts. In situ leaching may also permit economical recovery of currently unrecoverable low-grade uranium deposits, thereby enhancing the nation's uranium reserves.

In this method, an acidic or basic oxidizing leach solution is injected into and withdrawn from the naturally situated ore body via sets of wells. The chemical technology is similar for both acidic and basic leaching. No conventional ore mining, transporting, or grinding operations are needed prior to chemical processing to recover the uranium. Although some solid wastes (primarily calcium salts comobilized with the uranium complex) are generated, large quantities of mill tailings are not produced. For a given production of yellowcake, solid wastes from solution mining are much smaller in volume than tailings from conventional mills. Wastes produced in conventional uranium mining contain essentially all of the associated radium-226 (and its daughter products); on the other hand, less than 5% of the radium (along with the mobilized calcium) from a given ore body is commonly brought to the surface by solution mining techniques. A potential disadvantage of this method of uranium extraction is possible significant deterioration of the groundwater quality; however, groundwater contamination can often be limited by process controls.

Since the technology for in situ solution mining of uranium is still being developed, there are many variations in the process. Further plant and process modifications are likely to be implemented before in situ solution mining can be classified as a conventional mining method. A more detailed description of in situ solution mining is provided in Appendix B.*

*The U.S. NRC has been actively following developments in the area of solution mining, and has issued environmental impact statements for two solution mining projects.[9,10] In addition, the NRC has funded a study by Geraghty and Miller, Inc., of possible groundwater contamination.[11]

Direct measurement of the uranium content of the ore body is much more difficult in in situ mining than in conventional mining. For this reason, the efficiency of recovery is more difficult to estimate, but is expected to be less than in conventional mining. Because of these uncertainties, the actual contribution of in situ mining to future uranium production is difficult to predict. The U.S. Department of Energy has projected that in situ production capability could reach 9700 MT (10,700 ST) of U_3O_8 per year by 1991 and hold at about that level through the year 2000 (see Table 3.7).[3]

3.3.2 Recovery of Uranium as a Byproduct

Two major sources from which byproduct uranium is being recovered are copper mining leach liquors and wet process phosphoric acid. Of the two, phosphoric acid manufacture (for fertilizer) is receiving the most emphasis. The status of the process development at phosphoric acid plants in Florida is discussed in some detail in Reference 4; a brief summary is presented in the following paragraphs.

The recovery process is based on solvent extraction of uranium from a phosphoric acid stream normally produced at or near the phosphate rock mine. After extraction of the uranium, this phosphoric acid is normally sent to other plants for manufacture of fertilizer. The solvent extraction process is similar to that used in conventional uranium mills, and the U_3O_8 produced is of acceptable quality. Since the uranium is extracted from the phosphoric acid product stream, the amounts of uranium will depend on production rates of the acid, as well as the uranium concentration, and will fluctuate as the market for phosphate-based fertilizer fluctuates. Demand for fertilizer in the world market should increase with demands for increased food production, and this increased demand in turn should result in increased phosphate mining in the United States.

As of 1978 seven companies were in various stages of construction of plants with a total annual production capacity of about 1800 MT (2000 ST). The recovery of uranium from wet-process phosphoric acid is not developing as rapidly as expected, but this process is expected to account for about 2.8% of domestic uranium production in 1979. The best phosphate rock deposits in the United States occur in Florida, and most of the acid from which the uranium will be extracted is manufactured in that state. Wet-process phosphoric acid derived from Florida phosphates contains U_3O_8 in the range of 50 to 200 ppm.

Prediction of the amounts of U_3O_8 which will be recovered from phosphate production is risky, primarily because of the process difficulties involved and dependence of acid availability on the fertilizer markets. Currently, U_3O_8 production is about 400 MT (440 ST) per year but could reach 2700 MT (3000 ST) per year by 1985 and about 4700 MT (5200 ST) by the year 2000 (see Table 3.7).[3]

During the last 15 years, the U.S. Bureau of Mines (Salt Lake City), Kennecott Copper Corporation, and Wyoming Mineral Corporation, a subsidiary of Westinghouse, have extensively tested recovery of uranium from copper dumps, which frequently contain 1 to 12 parts of U_3O_8 per million parts of solution. As a result, Wyoming Mineral Corporation and Kennecott are now operating a 65 MT/yr commercial uranium recovery operation at Bingham Canyon near Salt Lake City. Anaconda and Amax are presently completing a similar size facility to recover uranium at Twin Buttes, south of Tucson, Arizona. In addition, Brush-Wellman has built a uranium recovery circuit into its beryllium mill in Utah to recover 9 to 18 MT of uranium per year as a byproduct.[4]

From the above information it appears feasible to extract uranium as a byproduct in copper milling as well as in other metals industries. However, these extraction techniques are not now as mature as those being applied to recover uranium from phosphoric acid. Together with uranium extraction from mine water, these techniques accounted for about 2% of all U.S. uranium production in 1979.

3.3.3 Imports and Exports

Of all of the effects of unconventional sources for U_3O_8 on mill requirements, those of imports and exports are most difficult to assess. The relationship between world and United States prices will affect the United States import/export balance. As shown in Table 3.8, the percent of world production supplied by the United States is estimated to decline slightly by 1985. U.S. government policies regarding enrichment capacity increases, and the nuclear option generally, could dramatically increase or decrease the amounts of U_3O_8 which could or would be exported. For these and other reasons, among which is the complexity of the world markets for uranium, the staff has not attempted to incorporate the effects of net import-export balances into its uranium demand projections. The import-export trade market is extremely volatile and cannot be predicted with any certainty through the year 2000. Therefore, the staff has assumed no net import or export of uranium through the year 2000.

3.3.4 Summary of Effects on Mill Requirements Caused by Unconventional Production Sources

As indicated by Table 3.7, potential cumulative nonconventional uranium production through the year 2000 is about 239,000 MT (262,000 ST) of U_3O_8. This is an upper limit estimate, based on full exploitation of all nonconventional production methods and resources, and represents about 21% of potential cumulative uranium production by all methods.[3] Potential production by all methods through the year 2000 amounts to about 1.14 million MT (1.25 million ST) of U_3O_8,[3] almost exactly double the reactor uranium requirements estimated in Table 3.2. Therefore, the staff estimates that actual uranium production by all methods through the year 2000 will be about 50% of potential production. Actual nonconventional uranium production, on an annual basis, is estimated to be 55% of the potential production figures shown in Table 3.7, in order to conservatively account for present trends toward greater proportional utilization of nonconventional methods.

On this basis, Table 3.9 indicates that conventional uranium production requirements through the year 2000 could be satisfied by the equivalent of about 833 years of operation of the model mill described in Chapter 5. On an annual basis, from 23 to 55 model-mill-equivalents would be required to be operating from 1979 to the year 2000. Ore processing capacity available in 1979 totaled 43,900 MT/day, or about 24 model mills of 1800 MT/day capacity. Thus, about 31 new model-mill-equivalents will be needed by the year 2000, not including replacement capacity to make up for potential retirements. In later evaluations, the staff has assumed the retirement of one model-mill-equivalent per year over the period 1980 through the year 2000 (21 model mills retired at the end of the year 2000); this corresponds with an assumed average lifetime of about 20 years for currently operating mills.

3.4 PROJECTED URANIUM MILLING INDUSTRY

Information presented in this section is based on the projections for installation of nuclear power plants shown in Section 3.1 and on the assumption that conventional uranium mills, as described in Section 3.2 and 3.3, will be used to furnish most of the fuel for those power plants. The data presented are intended only to illustrate the need for milling capacity and the concomitant milling impacts resulting from the assumed power projections.

A major determinant of both the ore-processing capacity needed to provide the necessary fuel and of the environmental impacts of milling operations is the quality of the ore (e.g., U_3O_8 content and chemical composition). This quality establishes the amount of ore that must be processed and the quantity and radioactivity content of the tailings produced. Presently mined ore resources contain from about 0.05% to 0.25% U_3O_8, and the staff assumes that the range will be similarly broad for the foreseeable future.

The milling techniques currently used, with such minor modifications as increasing the concentration of acid used in leaching or improving resins for concentration of uranium, will likely continue through the year 2000. None of the foreseeable changes in mill processes will drastically affect the number of conventional mills required.

The potential effect of increasing the capacity of individual conventional mills, as from 1800 MT (2000 ST) to 7200 MT (8000 ST) per day, is to lower the relative plant costs. It is common for more than one mine to be developed in an area containing economically recoverable ores. This favors construction of a centrally located mill of sufficiently large capacity to serve several mines within economical transport distance. (See Appendix I for discussion of effect of larger mills on tailings management.)

3.4.1 Current Plans for Increasing U.S. Milling Capacity

In addition to the mills and capacities listed in Table 3.4, other plants are scheduled for probable start-up between 1980 and 1982. These are listed in Table 3.10. There are plans for development of other mills at later dates, but these are considered less definite.

3.4.2 Meeting Projected U_3O_8 Requirements

The projected uranium fuel requirements and the translation of these requirements into the number of model mill equivalents are discussed in this section. These mill and ore requirements are based on the reactor installation schedule given in Table 3.2. These requirements and the effect of unconventional processes are shown in Table 3.9.

The staff has assumed that the U_3O_8 content of the ore will remain constant at about 0.10% through the year 2000 and that all mills will operate at 85% of capacity. The average online operating capacities as percentages of stated capacity in 1975, 1976, 1977, and 1978 were, respectively, 83%, 87%, 75%, and 91%. The 1977 value of 75% was lower than the previous years because of poor performance from new mills and older mills which were being expanded to handle more ore. The annual output of U_3O_8 for the conventional standard mill [1800 MT (2000 ST) of ore per day] is 520 MT (570 ST) of U_3O_8 per year, assuming operation at 85% of capacity.

Table 3.8 World Uranium Production Capability (thousands of short tons U_3O_8)[a]

Year	U.S.[b]	U.S. % of World	Canada[c]	South & SW Africa[d]	France[e]	Niger[e]	Gabon[e]	Australia[f]	Other Western Nations	Total
1977	15.7	44	7.9	5.0	2.3	1.9	1.0	1.0	1.0	35.8
1978	21.0	42	8.4	11.0	2.9	2.9	1.6	1.0	1.0	49.7
1979	26.1	43	9.1	12.0	3.9	5.2	1.6	1.0	1.5	60.4
1980	29.1	43	10.4	13.2	3.9	5.2	1.6	1.0	2.8	67.2
1981	34.0	43	12.7	14.0	4.0	5.2	1.6	2.5	4.3	78.3
1982	40.3	43	13.3	15.0	4.0	7.8	1.6	6.8	4.3	93.1
1983	41.8	40	14.5	16.5	4.5	7.8	1.6	8.8	7.0	102.5
1984	44.6	40	16.3	16.5	4.5	7.8	1.6	12.4	7.0	110.7
1985	46.8	41	16.3	16.5	4.5	7.8	1.6	14.0	7.0	114.5

[a]Conversion factor: One short ton (ST) = 0.91 metric ton (MT).

[b]ERDA, 1977.

[c]Energy Mines and Resources, Canada, 1977.

[d]Uranium Institute, 1976.

[e]Organization for Economic and Commercial Development (OECD), 1975.

[f]Adapted from Ranger Environmental Inquiry, Second Report, 1977, and Company plans.

Table adapted from R. J. Wright, "Foreign Uranium Developments," presented at the Grand Junction Office Uranium Industry Seminar, U. S. Dept. of Energy, October 1977.

Table 3.9 Conventional Uranium Production Requirements, 1979-2000

Year	Estimated Reactor Requirements,[a] 10^3 MT U_3O_8	Estimated Nonconventional Production,[b] 10^3 MT U_3O_8	Required Conventional Production, 10^3 MT U_3O_8	Model Mill Equivalents Required[c]
1979	13.4	1.5	11.9	22.8
1980	14.6	1.7	12.9	24.7
1981	16.0	2.3	13.7	26.2
1982	18.2	3.0	15.2	29.1
1983	20.6	3.8	16.8	32.1
1984	22.1	4.3	17.8	34.0
1985	22.9	4.8	18.1	34.6
1986	23.2	5.2	18.0	34.6
1987	23.6	5.7	17.9	34.6
1988	24.7	6.5	18.2	34.6
1989	25.3	7.1	18.2	34.6
1990	26.2	7.5	18.7	35.6
1991	27.5	7.8	19.7	37.7
1992	27.9	7.9	20.0	38.2
1993	29.0	7.9	21.1	40.3
1994	30.1	7.9	22.2	42.4
1995	31.2	7.9	23.3	44.6
1996	32.2	8.0	24.2	46.3
1997	33.3	8.0	25.3	48.4
1998	34.4	8.0	26.4	50.5
1999	35.5	8.0	27.5	52.6
2000	36.5	7.9	28.6	54.7
Totals	568.4	132.7	435.7	833.2[d]

[a]Based on DOE Mid-Range reactor installation schedule in Table 3.2

[b]Assumes 55% of production capability as shown in Table 3.7.

[c]Based on a model mill processing 1800 MT/day of 0.10% ore, with an 85% capacity factor and a 93% extraction efficiency.

[d]A total of 833 model-mill-years are estimated to be necessary to fulfill conventional uranium production requirements through the year 2000.

Table 3.10 Additional Uranium Mills Scheduled for Startup 1980-1982

Company	Mill Location	Year of Startup[a]	Capacity, MT/day
Minerals Exploration Co.	Red Desert, WY	1980	2700
Homestake Mining Co.	Marshall Pass, CO	1980	540
Bokum Resources	Marquez, NM	1980	1800
Energy Fuels Nuclear	Blanding, UT	1980	1800
Plateau Resources, Ltd.	Shootering Canyon, UT	1981	680
Pioneer-Uravan, Inc.	Slick Rock, CO	1981	900
Gulf Minerals Resources	McKinley County, NM	1982	3800

[a]The year of startup for each plant is tentative.

The requirements presented in Table 3.9 do not take into account inventories of U_3O_8 or UF_6 held by the U.S. Department of Energy at enrichment plants nor inventories held by users. The DOE inventories are estimated to be about 26,000 MT (29,000 ST) and the user inventories to be 33,000 MT (36,000 ST). The DOE plans to reduce its inventory to a working level of 4100 MT (4500 ST). The user inventory is expected to increase through 1980 and to decrease steadily thereafter to about 9100 MT (10,000 ST) by 1984. The staff estimates that full use of the inventories through 1985 would have little effect on overall mill requirements through the year 2000.

The Department of Energy has recently changed its policies regarding early delivery of material for enrichment and enrichment tails assay. The NRC staff estimates that without these changes, increased needs for U_3O_8 would have required the equivalent of an additional six to eight standard (1800 MT/day) mills between 1983 and 1990. These additional U_3O_8 requirements that would have been necessitated by continuation of past DOE policies have not been included in the NRC staff's calculation of the number of mills required through the year 2000. For the purpose of these calculations, it has been assumed that the enrichment tails assay would remain at 0.20% U-235 (in the depleted uranium produced) to produce all of the enriched uranium produced through the year 2000.

The estimates shown in Table 3.9 as to the number of equivalent model mills required to be operating do not include provisions for replacement of mills operating in 1979. The average age of the 11 U.S. mills operating in 1979 which had been in operation prior to 1970 was 23 years; the minimum age was 18 years. If the same average age holds through the year 2000, then mills starting up in 1979 or later would not require replacement until past the year 2000. For calculational purposes, the staff has allowed for the retirement of older mills by assuming the retirement of one model mill equivalent per year, from 1980 through the year 2000.

Heap leaching is expected to make some minor contribution to U_3O_8 production at conventional mills. The economic viability of heap leaching will depend on the price of uranium. As the price increases, lower percentages of U_3O_8 in ore will be economically recoverable by conventional means. Exceptions could occur where the cost of transporting the low-grade ore to a conventional mill proves to be prohibitive. Heap leaching will then be practical at existing mills, but new mills will attempt to recover more U_3O_8 by conventional processes. For these reasons, heap leaching will be done only by a small segment of the uranium industry and is not expected to contribute more than 1% to 2% (a maximum of 300 MT) of the U.S. requirements of U_3O_8 per year by the year 2000.

In summary, based upon a reactor schedule of 180 GWe by the year 2000, there will be a need for milling capacity equivalent to about 55 model mills [1800 MT/day (2000 ST/day)] by the year 2000.

3.4.3 Geographic Location of Future Conventional Industry

The location of probable resources is shown in Figure 3.1. The potential for expansion of milling activity is greatest in such states as New Mexico, Wyoming, Utah, Colorado, Texas, and Washington, which already are the most active locations of uranium milling and exploration. In Table 3.11, ten states are ranked on the basis of the probable uranium resources contained. The distribution of uranium reserves and probable resources by region and state also is shown in Table 3.12. The number of new mills required between now and the year 2000 within each region and state is estimated on the basis of this distribution and the assumption that mill location will coincide with combined reserve and resource locations. The expected distribution of new model mill equivalents among the states is depicted in Table 3.12.

3.5 SUMMARY

Nuclear energy growth projections resulting in a nuclear generating capacity of 180 GWe in the year 2000 were used in estimating U.S. uranium production necessary to meet estimated nuclear fuel needs through the year 2000. Current nuclear energy production requires about 13,400 MT of U_3O_8 per year; these annual U_3O_8 requirements are expected to increase by 170% by the year 2000. Cumulative U_3O_8 requirements over the time period 1979 to 2000 are projected to be about 568,000 MT. It is estimated that conventional milling will produce about 77% of U_3O_8 requirements (about 436,000 MT) out of the total over the time period 1979 to 2000. Based on the assumption that a model mill, operating at 85% capacity, would produce 520 MT of U_3O_8 per year, it would take about 833 model mill years to produce 436,000 MT of U_3O_8.

Although there is some uncertainty about the growth of the unconventional milling industry, other methods of production, such as in situ mining, byproduct recovery, and imports, are expected to supply over 20% of cumulative U_3O_8 requirements through the end of this century. These projected nuclear fuel needs will necessitate construction and operation of about 53 additional conventional model mills over this time period. These mills would be in addition to the 23 model-mill-equivalents now required, 21 of which are projected to be retired as of the year 2000. Nearly all of the new mills are expected to be located in the western United States, with over 60% in Wyoming and New Mexico. Projected nuclear generating capacity, annual U_3O_8 requirements, and annual U_3O_8 production from conventional mills are shown in Tables 3.2 and 3.9.

Fulfilling these future energy requirements according to the adopted scenario will generate about 4.7×10^8 MT of tailings through the year 2000 by conventional milling; these tailings would be in addition to the 2.5×10^7 MT (2.8×10^7 ST) of tailings now at inactive sites, and the 1.2×10^8 MT (1.4×10^8 ST) of tailings at currently active mill sites at the end of 1978.

Cumulative impacts due to milling over the time period 1979 to 2000 are addressed in several sections of this document, including: radiological health risks to workers (Sections 6.2.8.2 and 9.2.8.2); radiological health risks to populations (Sections 6.4, 9.3.8 and 12.3); and environmental impacts and resource commitments for the case in which proposed regulatory actions (delineated in Chapter 12) are implemented (Chapter 15). Cumulative impacts are dependent, in part, on the nuclear power projections, enrichment tails assay policies and ore grade assumptions given in this Chapter. The effect of different nuclear power projections, enrichment tails assays, ore grades, and other factors on cumulative impacts is discussed in Appendix S.

Table 3.11 Share of Potential Resources of Uranium in Individual States[a]

State	Share of Probable Resources,[b] %
New Mexico	30
Wyoming	15
Colorado	11
Utah	14
Texas	10
California	2
Arizona	4
South Dakota	1
Nevada	2
Washington	2

[a]From D. L. Hetland, "Potential Resources of Uranium," presented at the Grand Junction Office Uranium Industry Seminar, U. S. Dept. of Energy, October 1978.

[b]Conventional sources only.

Table 3.12 Probable Need for and Distribution of New Conventional Uranium Mills, 1979-2000[a,b]

NURE Region	Reserves & Probable Resources, 10^3 MT U_3O_8	Percentage of U. S. Total in Region	Number of New Model Mill Equivalents 1980-2000	States with Mills in 1978[c]
A	1150	52	28	New Mexico, Colorado, Utah (Arizona)
B	634	29	15	Wyoming (Montana)
C	234	11	6	Texas (14 other states)
D	52	2	1	Washington (Idaho, Montana)
E	82	4	2	Colorado, New Mexico
F	35	2	1	Wyoming, South Dakota (8 other states)
Total	2192	100	53	

[a]From D. L. Hetland, "Discussion of the Preliminary NURE Report and Potential Resources;" and R. J. Meehan, "Uranium Ore Resources," both presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1978.

[b]Assumed capacity of 1800 MT/day each.

[c]States in parentheses are in the given NURE region, but had no mills operating in 1978.

References

1. "Annual Report to Congress-1979." U.S. Dept. of Energy, Energy Information Administration, July 1980.

2. "Fossil and Nuclear Fuel for Electric Utility Generation," National Electric Reliability Council Report, 1977.

3. J. Klemenic, "Uranium Production Capability in the United States," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1979.

4. J. F. Facer, Jr., "Uranium Production," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1979.

5. D. L. Hetland, "Discussion of the Preliminary NURE Report and Potential Resources," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1978.

6. R. J. Meehan, "Uranium Ore Resources," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1978.

7. J. F. Facer, Jr., "Production Statistics," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Dept. of Energy, October 1978.

8. J. N. Frank, "Cost Model for Solution Mining of Uranium," presented at the Grand Junction Office Uranium Industry Seminar, U.S. Energy Research and Development Administration, October 1976.

9. "Irigaray Uranium Solution Mining Project - Wyoming Mineral Corporation," U.S. Nuclear Regulatory Commission, NUREG-0481, September 1978.

10. "Highland Uranium Solution Mining Project - Exxon Minerals Corporation," U.S. Nuclear Regulatory Commission, NUREG-0489, November 1978.

11. "Ground-Water Elements of In-Situ Leach Mining," Geraghty and Miller, Inc., for U.S. Nuclear Regulatory Commission, NUREG/CR-0311, August 1978.

4. ENVIRONMENT OF THE MODEL REGION

A brief description for a general, schematic, model site and region developed to form a basis for analyzing potential environmental impacts (Ch. 6) and alternative control measures (Ch. 9) is presented in this chapter. Since environmental impacts of milling are largely site-specific, the site description is given only to the level of detail deemed necessary to illustrate in a general fashion what the effects of the uranium milling industry will be and to support broad decision-making functions of this document (Ch. 1). Since many of the impacts are site-specific, they must be evaluated for each mill as is done through environmental statements prepared in connection with individual mill licensing actions. Analogous descriptions of the six regions are given in a Supplement to this document.[1]

The model mill (described in Ch. 5) is postulated to be situated at the center of a hypothetical model site with a radius of 40 km (25 miles) (Fig. 4.1). Surrounding the model site is a doughnut-shaped model region with an inner radius of 40 km (25 miles) and an outer radius of 80 km (50 miles). The area of the site is thus about 5000 km^2 (2000 mi^2) and that of the region about 15,000 km^2 (6000 mi^2). For some purposes, the site and region are considered together and termed the "aggregated area."

This chapter includes descriptions of the aspects of a region which are commonly considered in the evaluation of the environmental impacts of a uranium milling operation. When possible, all of the descriptions are based on weighted averages of the pertinent characteristics of the six physiographic regions of the United States within which uranium is milled. In those cases not amenable to such treatment, a central estimate was made based on the attributes of the six physiographic regions. Thus the presentation of descriptive material in this chapter is designed to reflect, to the extent possible, a composite of the characteristics of areas where actual uranium milling is taking place. Where regional variations are important in arriving at decisions, such as in the determination of the effectiveness of various soils in attenuating radon exhalation from tailings, they are incorporated into the appropriate analyses.

4.1 CLIMATE

4.1.1 General Influences

As is typical of much of the western U.S., the weather of the model region is dominated by the influences of elevation and of the high- and low-pressure systems that pass through the area during the year. The climate is semiarid, and the seasons are distinct, with mild summers and harsh winters.

4.1.2 Winds

A wind rose for West City is given in Figure 4.2; strong winds are frequent. Joint frequency of annual average wind speed and direction at the model site are presented in Table 4.1.

4.1.3 Precipitation

The average annual precipitation at the mill site is 31 cm (12 inches), but relatively large variations in the monthly and seasonal totals occur from year to year. Precipitation in late spring and summer is normally derived from scattered thunderstorms. Data on precipitation and snowfall at West City and at the model site are given in Table 4.2. Snowfall accumulations of greater than 50 cm (20 inches) are rare. Potential evaporation exceeds precipitation, averaging 150 cm (60 inches) per year.

4.1.4 Storms

Winter storms, with attendant snowfall, low temperatures, and high winds, are common. Thunderstorms, frequent in spring and summer, occasionally spawn tornadoes that tend to be less

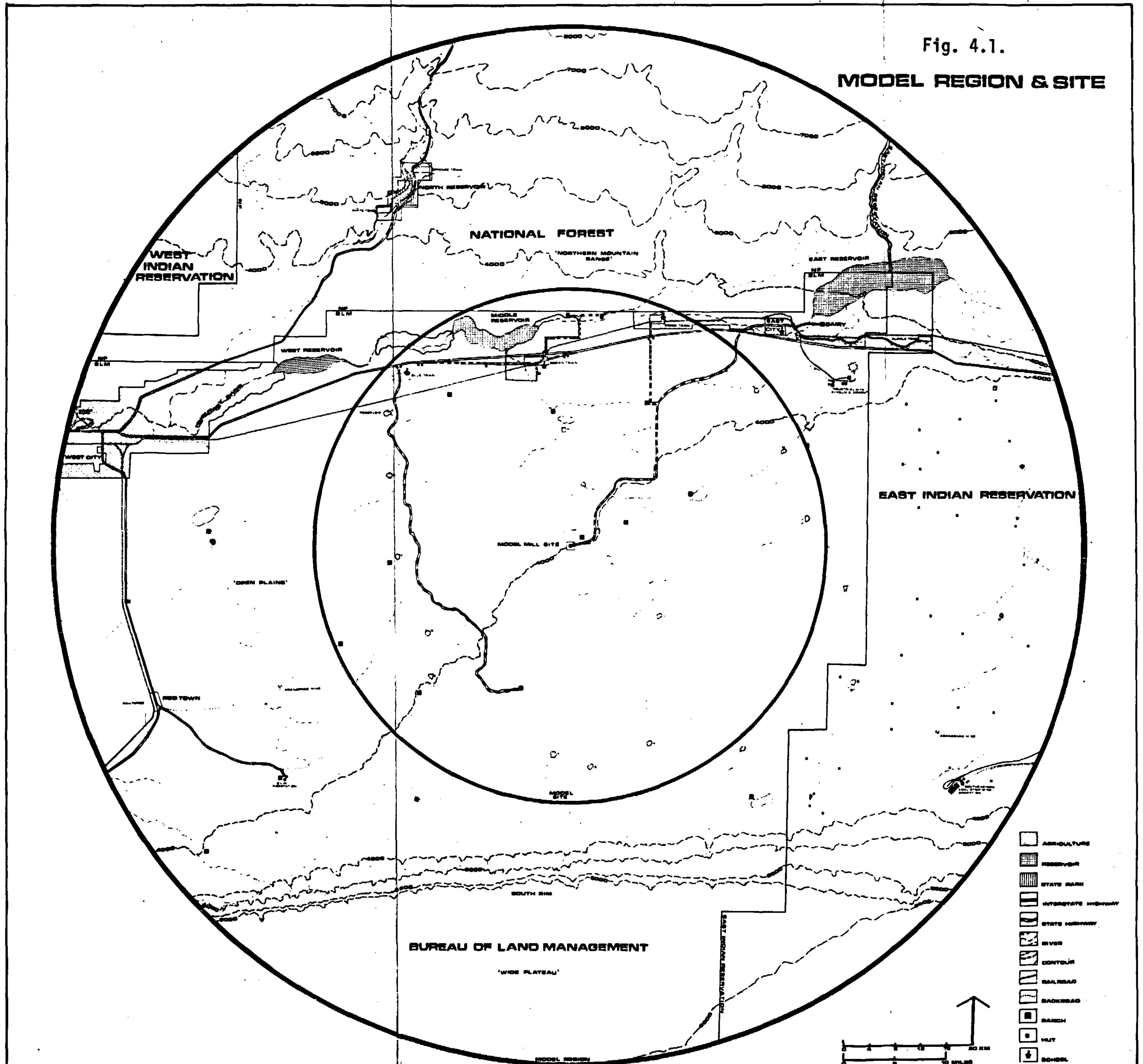


Fig. 4.1.
MODEL REGION & SITE

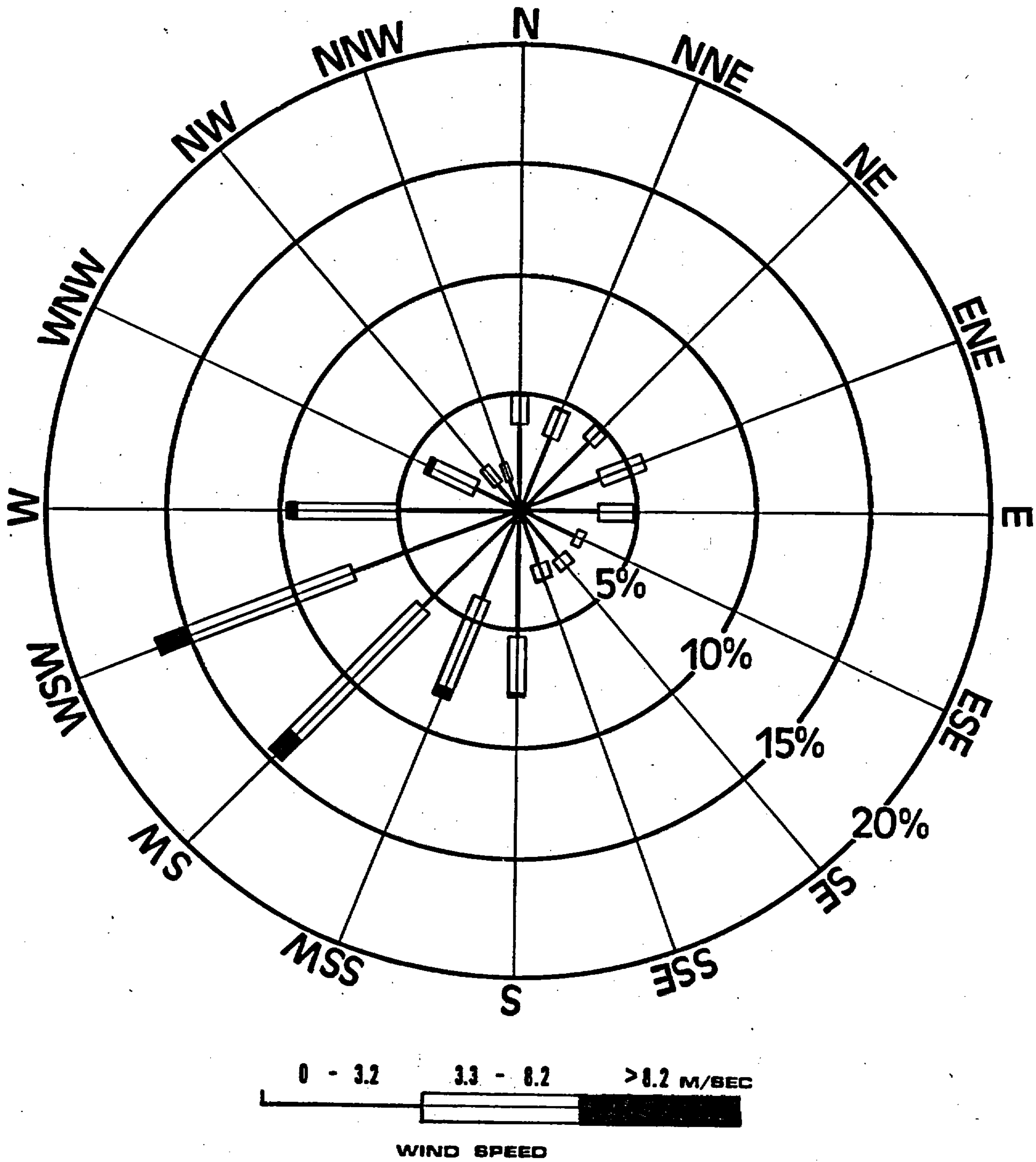


Fig. 4.2. Annual Wind Rose for West City. (Direction from which wind blows.)

Table 4.1. Joint Frequency of Annual Average Wind Speed and Direction at Model Mill

Direction	Speed, m/s 0-1.5	1.6-3.2	3.3-5.1	5.2=8.2	8.3-10.8	>10.8	Total
N	2.3%	1.4%	1.0%	0.3%	0.0%	0.0%	5.0%
NNE	2.1	1.3	0.8	0.3	0.1	0.0	4.6
NE	2.7	1.4	0.7	0.2	0.0	0.0	5.0
ENE	2.4	1.2	1.5	0.4	0.0	0.0	5.5
E	2.4	1.0	1.1	0.4	0.0	0.0	4.9
ESE	1.9	0.6	0.2	0.1	0.0	0.0	2.8
SE	1.7	0.8	0.3	0.2	0.0	0.0	3.0
SSE	1.5	0.8	0.6	0.1	0.1	0.0	3.1
S	3.5	1.8	1.8	0.7	0.1	0.0	7.9
SSW	2.5	1.5	2.9	1.3	0.4	0.0	8.6
SW	3.7	2.1	3.9	3.8	1.1	0.2	14.8
WSW	4.7	2.8	4.1	3.4	1.2	0.2	16.4
W	2.9	2.1	2.5	1.8	0.5	0.0	9.8
WNW	1.2	0.9	1.1	0.9	0.1	0.1	4.3
NW	0.8	0.6	0.5	0.4	0.0	0.0	2.3
NNW	0.8	0.5	0.6	0.1	0.0	0.0	2.0
Total	37.1	20.8	23.6	14.4	3.6	0.5	100

Table 4.2. Precipitation Records for West City and Model Mill Site

	West City				Model Site
	Precipitation, cm[a]		Snowfall, cm		Precipitation, cm
Month	Mean	Maximum	Mean	Maximum	Mean
January	1.4	4.8	23.4	99.8	1.3
February	1.5	4.9	25.0	50.4	1.7
March	2.5	10.4	40.7	81.2	2.5
April	3.4	12.3	38.9	55.0	3.8
May	5.1	10.4	6.3	78.0	5.0
June	3.3	9.9	1.0	7.8	3.4
July	1.8	4.4	0.0	0.0	2.0
August	2.5	9.7	Trace	Trace	2.4
September	2.7	6.8	2.5	10.8	2.8
October	1.8	5.1	12.7	84.7	2.1
November	2.2	4.7	23.3	51.3	2.1
December	1.8	4.8	22.8	43.4	1.9
Annual	30.0		196.6		31.0

[a]Precipitation includes snowfall; a factor of 0.1 was used to convert snowfall to precipitation.

destructive than ones occurring further east. Dust devils are frequent and occasionally cause slight damage to structures in their path.

4.2 AIR QUALITY

Present air quality is considered to be good. Data on current concentrations and applicable standards for airborne pollutants are presented in Table 4.3. The entire basin is classified as

Table 4.3. Ambient Concentrations of Airborne Pollutants at the Model Site and Applicable Air Quality Standards

Pollutant	Concentration μg/m^3	Applicable Standard, μg/m^3
Suspended particulates		
24-hour average	4-90	150
Annual average	31	60
SO_2 (annual average)	6	60
NO_x (annual average)	15	100
Hydrocarbons		
3-hr average	45	160
Annual average	<5	

an "air quality maintenance area," meaning that it is viewed by the EPA as having the potential for significant decline in air quality because of the projected increases in mining and industrial activity. The high wind speeds and the sparsity of vegetation often result in wind erosion and thus in high concentrations of suspended particulates. The low population density, lack of industrial pollution sources (other than fossil-fired electrical generating plants at West City and East City), and the dispersive characteristics of the region account for the current good air quality in the basin.

4.3. TOPOGRAPHY

The model site is located on plains of moderate relief, ranging in elevation from 1200 m (4000 ft) to 1300 m (4300 ft). The plains are dissected by the Tributary River and its associated streams. The base of the Northern Mountain Range, with elevations up to 1200 m (4000 ft), lies at the northern tip of the model site. The southern boundary of the site reaches the rim of the Wide Plateau, which rises almost vertically from an elevation of 1300 m (4300 ft) to 2000 m (6000 ft).

The northern section of the region is in the National Forest, with elevations rising to 2400 m (8000 ft). Elevations in the floodplain of the Tributary River range from slightly over 1000 m (3600 ft) at West Reservoir to 1200 m (4000 ft) at East Reservoir. South of the Tributary River, the Open Plains stretch across 70 to 80 km (40 to 50 miles) of prairie.

4.4 LAND RESOURCES AND USE

Most of the land within the model site is in the public domain and administered by the Bureau of Land Management (BLM). This land and that of the few scattered private ranch holdings are primarily in the following land use categories (as given in the "National Atlas of the United States"): desert shrubland, subhumid grassland, and semiarid grazing land. The primary uses of the land in the model region are shown in Table 4.4. Ownership patterns are shown in Table 4.5.

Rangelands managed by the BLM and the Forest Service, as well as those in private holdings, are extensively grazed. Overgrazing and poor management have led to a lowered carrying capacity on much of the land. National Forest covers 18 km^2 (7 mi^2) of the northern tip of the model site. This land is primarily used for timber production and grazing. Along the Tributary River a small amount of privately owned land (10% of the total land of the region) is used as irrigated and nonirrigated pasture, cropland, and orchards. Also, small urban centers (occupying less than 1% of the region) are dotted along the floodplain. A small regional forestry industry uses the northern forests and woodland to grow and harvest timber. BLM and National Forest lands are also used for recreational activities.

Scattered areas throughout the region are used for mineral extractive industries. Minerals mined in the region include uranium, gypsum and coal. Major transportation routes are a railroad and an interstate highway, both paralleling the Tributary River; several roads branch off the interstate to ranches and uranium mines and mills, and others connect with the few urban areas. There is a small airport southwest of West City.

Table 4.4. Land Use in the Model Region

Land Use	Percent of Region
Subhumid grassland and semiarid grazing land	30
Desert shrubland grazed	25
Forest and woodland grazed	15
Open woodland grazed	20
Irrigated land, cropland, and cropland mixed with grazing land	10

Table 4.5. Land Ownership in the Model Region

Ownership	Percent of Region
Public domain managed by Bureau of Land Management	30
Public domain managed by National Forest Service	25
Indian Reservation	15
Private	25
State	6

4.5 GEOLOGY* AND SEISMICITY

A cross-sectional view showing the geology of the model site is presented in Figure 4.3. The bedrock underlying the model site consists of sedimentary strata ranging from Precambrian to Cretaceous in age; these are typical of those found in areas in which uranium is mined. The sedimentary rock dips to the south at about 5 degrees. The uranium mines are located in Jurassic sandstone and the mill and tailings pond area on Triassic siltstone. A thin [$\sim$100 m (330 ft)] surficial deposit of terrace and pediment alluvium caps the Triassic siltstone.

The geology of the model region surrounding the model site is basically the same. No change in the regional geology occurs parallel to the strike of the sedimentary rocks (i.e., in a east-west direction) except for sedimentary facies changes. Perpendicular to the strike (i.e., in a north-south direction) Cenozoic and additional Cretaceous sediments are included to the south.

The model region, although stable in the tectonic sense, has had scattered earthquakes of intensity greater than Modified Mercali VI during historic time. According to the current Uniform Building Code, the region would be in Zone 2 on the Seismic Risk Map,[5] i.e., well-built structures should experience negligible damage. In general, the model region is not in a zone of great seismicity, but in light of the seismic history of the region, structures should be built to withstand an earthquake of intensity MM VI.

4.6 MINERAL RESOURCES AND USE

The most extensively mined mineral resource of the model site is uranium, which occurs as roll-front deposits within the Jurassic sandstone formation. It is mined by open pit methods where

*Topographic, hydrologic and other features are adjusted to conform to the geology of the site.

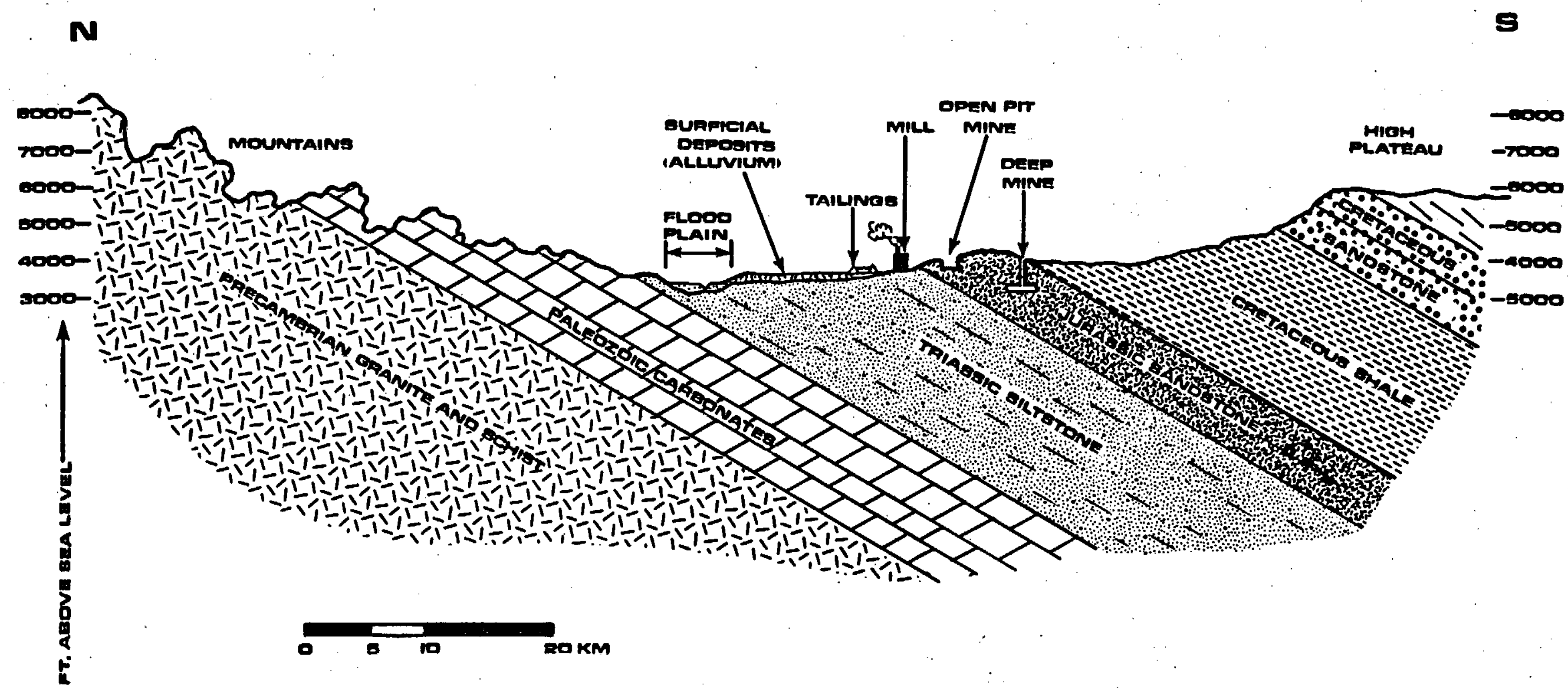


Fig. 4.3. Geologic Cross Section of the Model Site.

the Jurassic sandstone crops out to the north and by underground methods where the sandstone dips under younger sediments to the south. About 660,000 MT (730,000 ST)of ore are produced per year.

Coal is mined from Cretaceous sandstone in a large open pit coal mine 60 km (40 miles) east of the model mill. Production is about 3.6×10^6 MT (4×10^6 ST) per year. Production at the gypsum mine 50 km (30 miles) west of the uranium mill is small, with about 9000 MT (10,000 ST) taken annually from Triassic siltstone. Sand and gravel are found in surficial deposits; production totals 27,000 MT (30,000 ST) annually.

4.7 WATER RESOURCES AND USE

4.7.1 Surface Water

The surface water resources in the region include ephemeral streams, small ranch impoundments used for livestock watering, four major reservoirs, and a river (Tributary River).

Three of the reservoirs are on the Tributary River (East, Middle, and West reservoirs), and one (North Reservoir) is in a canyon between White Town and Orange Town. North Reservoir has a volume of 8.0×10^6 m^3 (6.5×10^3 acre-feet); East, Middle and West reservoirs have volumes of 60×10^7, 1.8×10^7, and 1.0×10^7 m^3 (0.5×10^6, 15×10^3, and 8×10^3 acre-feet), respectively.

Tributary River flows from east to west and drops 150 m in 160 km (500 ft/100 miles). The average width is 45 m (150 ft) and the depth is 1 m (3 ft). The average flow of Tributary River is 20 m^3/s (0.3×10^6 gpm). Maximum flow [80 m^3/s (1.3×10^6 gpm)] occurs in early June; minumum flows of 5 m^3/s (80×10^3 gpm) occur from September to February. The 100-year return period flood conditions reach 100 m^3/s (1.6×10^6 gpm), and 7-day, 10-year low flows are 4 m^3/s (63×10^3 gpm). Ephemeral streams have maximum flows in June and July and are dry from September to February.

The average and annual maximum concentrations of chemical constituents in Tributary River are given in Table 4.6.

Table 4.6. Concentrations of Chemical Constituents of the Water in the Tributary River (all concentrations in μg/L except as noted)

Constituent	Annual Average Concentration	Annual Maximum Concentration
Hg	2	2
As	15	95
Cd	3.5	8
Cr	11	34
Cu	20	44
Fe	300	1,500
Pb	37	65
Mn	135	300
Zn	65	85
Se	3	7
Mg (mg/L)	30	50
SO_4 (mg/L)	115	430
B	380	950
F	380	500
Mo	3	7
NO_3 (mg/L)	20	40
Al	100	100
Ba	30	30
PO_4 (mg/L)	20	40
Ni	25	25
V	6000	65,000
$CaCO_3$	350	1,200

4.7.2 Groundwater

The principal use of the groundwater resources in the model region is for domestic or stock water. These wells are generally spaced about 1.5 km (1 mile) apart, and withdrawal is about 0.06 L/s (1 gpm) from wells about 100 m (300 ft) deep. A total of six municipal and industrial wells within the region withdraw about 6 L/s (100 gpm).

The best aquifer is the Paleozoic carbonates, followed by the Cretaceous and Jurassic sandstones and the Triassic siltstones (see Fig. 4.3). The Cretaceous shales and Precambrian rocks have low permeability. The surficial deposits are very permeable and, if saturated, yield large amounts of water.

The quality of water found in these deposits is variable and generally decreases with increasing depth. Permeable strata have better quality water than strata of low permeability.

4.8 SOILS

The soils of the model region can be divided into five general groups. Soils at elevations above 2000 m (6500 ft) in the National Forest are mainly Alfisols formed in material weathered from sandstone, shale, and siltstone under forest vegetation. The soils on the mountain slopes are mainly Entisols formed from clay shale and sandstone. Contiguous to the river are nearly level to gently sloping soils (mainly Entisols) on floodplains and alluvial fans. These soils form in alluvium of mixed origin. On the high plateau in the southern portion of the region, the soils are mainly Entisols associated with sandstone rockland. These soils are well drained, shallow to very shallow, on nearly level to moderately sloping loamy sand formed in residuum from sandstone. Sandstone outcrops comprise about 50% of the association.

In the central portion of the region (which includes the model mill site), the soils are mainly fine sandy loams of the Entisol order. They are underlain by sandy alluvium or fine sandy loam containing threads of segregated lime, occasionally with a prominent lime zone below about 100 cm (40 inches). Sandstone fragments are common in soil layers. Slopes range from 0 to 10%, with soils depths of 10 to 50 cm (4 to 20 inches). Topsoil suitability is poor, mainly because of the presence of sandstone fragments. A number of physical and chemical properties of the soils characteristic of the model site are listed in Table 4.7.

4.9 BIOTA

4.9.1 Terrestrial

4.9.1.1 Regional Characteristics

Flora

Four principal and one minor vegetative community types occur within the model region. The northern montane portions of the region are characterized by ponderosa pine and Douglas fir forests at elevations of 1800 to 2300 m (6000 to 7000 ft). The pinyon-juniper community occurs in the foothills in northern portions of the region, along the rim of the Wide Plateau in the southern portion of the region, and along the washes leading down from the rim. The Wide Plateau supports a desert shrub community comprised mostly of shrubs, such as sagebrush and rabbitbrush, and a variety of bunch grasses (western wheatgrass, green needlegrass, Indian ricegrass, threeawn grass).

The central portion of the region, in which the model mill is located, has the characteristics of a shortgrass prairie that has been subjected to heavy grazing pressure. Grasses consist mainly of blue grama and buffalo grass. Sagebrush and rabbitbrush also occur.

The minor community type consists of riparian communities along the reservoir and river in the central portion of the region. These are dominated by cottonwoods and willows. Some areas contiguous to the river are planted with vegetable crops.

Fauna

Common mammals of the region include ground squirrels, jackrabbits, least chipmunks, deer mice, kangaroo rats, badgers, and coyotes. Important game species in the region include pronghorn antelope, mule deer, desert cottontail, and blue grouse. Six to eight herds of antelope, with 6 to 20 individuals in each herd, inhabit the central and southern portions of the region. Mule deer inhabit the ponderosa pine and Douglas fir forests in summer and move to the foothills during the winter. In addition to native mammals, about 20,000 head of cattle graze in the region. About 50 hectares (ha) (125 acres) of range are required to support one cow with calf, or five sheep.

Table 4.7. Soil Properties at the Model Mill Site

Property	Value
Slope range	10%
Soil depth	10 - 50 cm
Dominant surface texture	Fine sandy loam
Subsurface texture	Fine sandy loam
Permeability	1.4×10^{-3} - 4.2×10^{-3} cm/s
Wind erodibility group	3[a]
Bulk density	1.36 g/cm^3
Total porosity	49%
Available water holding capacity	0.3 - 0.36 cm water/cm soil
pH	7.8 - 8.2
Salinity	0.86 mmoh/cm at 25°C
Cation exchange capacity	10 - 15 m.e./100 g
Chemical constituents	
Available K	200 ppm
Bicarbonate-soluble P	1 ppm
Organic matter	0.8%
Exchangeable sodium, percentage	2%
Water-soluble B	0.6 ppm
Available Se	0.03 ppm
Nitrate	1.0 ppm
DTPA[b]-extractable: Cu	1.4 ppm
Fe	85 ppm
Mn	65 ppm
Zn	7 ppm
Extractable Mo	0.2 ppm
Trace elements (total, ppm)	
Arsenic	0.5
Beryllium	2
Boron	2
Cadmium	2
Chromium	50
Fluorine	100
Mercury	0.02
Manganese	150
Molybdenum	2
Nickel	35
Lead	24
Selenium	2
Vanadium	30
Uranium	6

[a]Requires at least two measures to control wind erosion. Erodibility is about 86 tons/acre/year from an isolated, level, unsheltered, wide, and bare field with a noncrusted surface (D. G. Craig and J. W. Turelle, "Guide for Wind Erosion Control on Cropland in the Great Plains States," U. S. Dept. of Agriculture Soil Conservation Service, July 1964.

[b]Diethylenetriaminepentaacetic acid.

A diverse bird population exists in the region, with the greatest diversity in riparian and montane communities north of the model site. The American peregrine falcon (*Falco peregrinus anatum*), on the Federal list of endangered species, nests in the region; one falcon eyrie is on the rim of the High Plateau in the southern portion of the region, and another is on a rock face cliff in the foothills north of the reservoir. No other threatened or endangered vertebrate species occur in the region.

4.9.1.2 Site Characteristics

For purposes of impact evaluation, it is convenient to describe the site at the ecosystem level. This allows data obtained under the U.S. International Biological Program (IBP) to be utilized, thus providing "baseline" information over a three-year period.* Relevant ecological characteristics of the model site are listed in Table 4.8. Vegetation is dominated by blue grama and buffalo grass. Small mammal biomass, dominated by the thirteen-line ground squirrel, can vary from 35 to 960 grams live weight per hectare (35 to 960 g/ha, or 0.5 to 14 oz/acre) over a three-year period (perhaps as a function of drought).[2] The diet of the small mammal populations on the model site consists of herbage (25-33%), seeds (6-13%), and invertebrates (61-65%). Less than 10% of primary food production on the site, but essentially all of the invertebrate food source, is utilized. Food reserves are concluded to be marginal and severely limiting to small mammals at certain times, and the site (as well as the region) is at maximum carrying capacity.

Table 4.8. Site Ecosystem Characteristics[a]

Characteristic	Value[b]
Primary production[c]	5.4×10^9 J/ha
Primary consumption	2.5×10^7 J/ha
Seed production	1.6×10^9 J/ha
Seed consumption	4.2×10^6 J/ha
Secondary production	5.9×10^7 J/ha
Secondary consumption	5.0×10^7 J/ha
Small mammal biomass[d]	35-960 live wt. g/ha
Avifaunal biomass	
Passerine species[e]	160-170 g/ha (270-390 individuals/km^2)
Raptor species[f]	0.6-3.6 g/ha (0.05-0.2 individuals/km^2)

[a]Data derived from J. A. Wiens, "Pattern and Process in Grassland Bird Communities," Ecol. Monog. 43:237-270, 1973; and N. R. French, W. E. Grant, W. Grodzinski, and D. M. Swift, "Small Mammal Energetics in Grassland Ecosystems," Ecol. Monog. 46:201-220, 1976.

[b]Data for production and consumption of biomass are usually expressed as grams dry weight. For use in studies on energetics, biomass values were converted to energy units using the following equivalents: herbage = 4.1 kcal/g dry weight; invertebrates = 5.8 kcal/g dry weight; seeds = 4.4 kcal/g dry weight. Data in the above references (footnote a) were expressed as kcal/ha; the values in this table have been converted to joules as follows: kcal $\times$ 4.184 $\times$ 10^3 = J.

[c]Dominant vegetation is blue grama and buffalo grass.

[d]Consisting primarily of four species: northern grasshopper mouse, deer mouse, Ord kangaroo rat, and 13-lined ground squirrel.

[e]Consisting primarily of horned lark, western meadowlark, lark bunting, McCown's longspur, and Brewer's sparrow.

[f]Consisting primarily of golden eagles and marsh hawks.

*Methods for data collection and a system analysis approach to the study of grassland ecosystems are described in French et al.[2] Some liberties were taken in applying the IBP data for a shortgrass prairie biome to the model mill site described here; however, since the model site is described for illustrative purposes only, exact replication of the IBP data was not considered essential.

Bird species on the site are upland plover, common nighthawk, mourning dove, horned lark, western meadowlark, lark bunting, grasshopper sparrow, Brewer's sparrow, McCown's longspur, and chestnut-collared longspur.[3] Horned larks, the dominant bird species on the model site, feed chiefly upon seeds, beetles, and ants. Of the raptors known to frequent the site, the most abundant are golden eagles and marsh hawks; these large birds prey on small mammals. In general, composition of bird populations at the site is stable from year to year, although annual and seasonal variations occur in the densities of most species. Densities of avifauna are shown in Table 4.8. It was concluded from the IBP study that the total energy flow through bird populations in grasslands, and thus on the model site, is very small.

4.9.2 Aquatic

As shown in Table 4.9, the major contributors to primary production in Tributary River are periphytic algae in the upper third of the river and filamentous green and blue-green algae and periphytic algae in the middle and lower thirds. In the lower third this production is supplemented by some macrophytes (pondweeds). Primary production in the impoundments and reservoirs results from the growth of planktonic and periphytic algae and some macrophytes (cattails and plume grass) along the margins.

Table 4.9. Aquatic Plants and Invertebrates of the Model Region[a]

Species	Tributary River			Reservoirs
	Upper Third	Middle Third	Lower Third	
Primary Producers				
Planktonic green algae				x
Filamentous green algae		x	x	
Filamentous blue-green algae			x	
Blue-green algae		x		x
Diatoms	x[a]	x	x	x
Pondweed			x	
Cattails				x
Plume grass				x
Invertebrates (present in all areas)				
Mayflies				
Stoneflies				
Caddisflies				
Dragonflies				
Midges				
Damselflies				
Craneflies				
Beetles				
Waterstriders				
Backswimmers				

[a]"x" indicates group present.

First order secondary production (macroinvertebrates) in Tributary River is dominated by populations of mayflies, stoneflies, beetles, waterstriders, backswimmers, damselflies, dragonflies, craneflies, midges, blackflies, and other dipterans (Table 4.9). Higher order secondary production (fish) varies with aquatic habitat. Fish species found in the region are listed in Table 4.10.

4.10 SOCIOECONOMIC PROFILES

4.10.1 Demography

In general, the aggregated area of the model site and model region is sparsely populated. The current population is 57,300, with a density of 2.85 persons per km^2 (7.38/mi^2), as shown in Table 4.11. There is no major metropolitan center within 80 km (50 miles) of the mill site, but about 69% of the population of the aggregated area are town dwellers. The largest city, West, has a population of 22,000. It is about 80 km (50 miles) west of the mill (Fig. 4.1). East City, about 50 km (30 miles) east of the mill, has a population of 13,000. There are four towns

Table 4.10. Fish Species in the Model Region[a]

Species	Tributary River Upper Half	Tributary River Lower Half	Impoundments & Reservoirs	Ephemeral Streams
Fathead minnow	x[a]	x	x	x
Creek chub	x			x
Speckled dace	x	x		x
Red dace	x			
Longfin dace				x
Longnose dace	x			x
Red shiner	x	x	x	x
White sucker	x	x	x	
Flannelmouth sucker		x	x	
Longnose sucker	x		x	
Rainbow trout	x	x	x	
Brown trout	x	x	x	
Cutthroat trout				x
Carp		x	x	
Channel catfish		x	x	
Yellow bullhead		x	x	
Black bullhead	x		x	
Walleye		x	x	
Bluegill sunfish		x	x	
Green sunfish		x	x	
Warmouth		x	x	
Largemouth bass			x	
Mottled sculpin	x			
Colorado squawfish	x			

[a]"x" indicates species present.

Table 4.11. Population Change in Urban and Rural Areas in the Model Region, 1960-1976

Distance from Mill,[a] km	1960 Urban	1960 Rural	1960 Total	1976 Urban	1976 Rural	1976 Total	1976 Area, km^2	1976 Density, persons/km^2	Percent Increase, 1960-1976
0-40	1,250	670	1,920	1,500	700	2,200	5,020	0.44	15
40-80	31,460	16,100	47,560	38,000	17,100	55,100	15,080	3.65	16
0-80	32,710	16,770	49,480	39,500	17,800	57,300	20,100	2.85	16

[a]The distance from 0-40 km from the mill represents the model site; from 40-80 km represents the model region excluding the site; and from 0-80 km represents the aggregated area.

in the model region with populations ranging from 500 to 1500. The three towns in the model site all have populations of approximately 500. The only permanent residences within 20 km (12 miles) of the mill are two ranches--one 2 km (1.2 miles) to the NE and the other about 10 km (6 miles) to the ENE.

Population growth during the period 1960 through 1976 is shown in Table 4.11. The urban population increased 20%, compared with an increase of 5% in rural areas.

4.10.2 Economy

The region is primarily agricultural, principally ranching and hay production, with an industrial center located in West City. Employment levels within the labor force range from 36% for mixed

Northern European Americans to 26% for Native Americans (American Indians). Poverty is the most common among Native Americans (about 40%), and the least common among the mixed Northern European Americans (14%). During the period 1960 to 1976, per capita income in the aggregated area increased 90%, from $2260 to $4860. This increase was 1.45 times greater than the national rate. As shown in Table 4.12, approximately 62% of the families earned less than $10,000 in 1970; whereas only 30% currently have an income of less than $10,000 (1976 dollars).

The current labor force in the aggregated area is 20,800. The average unemployment rate in 1976 was 5.9%, appreciably lower than the national average of 7.7%. About 60% of the employment is associated with government, services, wholesale, and retail trade sectors. About 13% of the employees in nonagricultural pursuits work in the mining sector (Table 4.13). The national average is 0.9%. West City is the regional retail and wholesale trade center; there are 45 wholesale and 280 retail establishments with annual sales volumes of $26 million and $70 million, and employing 230 and 1600 people, respectively.

Table 4.12. Family Income Distribution in the Model Region

Family Income	Percent of Families, 1970	Percent of Families, 1976
Less Than $2000	7.6	3.2
$ 2000 - $ 2999	5.9	2.5
$ 3000 - $ 4999	12.9	6.1
$ 5000 - $ 6999	13.8	6.9
$ 7000 - $ 7999	7.6	3.6
$ 8000 - $ 9999	14.6	7.4
$10000 - $11999	12.1	7.8
$12000 - $14999	11.6	12.7
$15000 - $19999	8.2	19.4
$20000 - $24999	2.8	13.0
$25000 - $49999	2.4	15.1
$50000 or more	0.4	2.3

Table 4.13. Employees in Nonagricultural Employment, 1975

Sector	Percent
Manufacturing	5.6
Wholesale and retail trade	21.0
Government	24.5
Services	14.7
Transportation, public utilities	8.4
Finance, insurance, real estate	3.4
Contract construction	9.8
Mining	12.6

4.10.3 Sociocultural Characteristics

In the 16th century, the region was inhabited by two major Indian tribes. The Alpha tribe, composed of tribally organized agricultural villages, was indigenous to the area. The Beta tribe moved into the area somewhat later. The Betas were nomadic, having a specialized economy based on bison hunting. The Spanish began exploring, and then settling, the area in the 17th Century. By the late 18th and early 19th Centuries settlers primarily of Northern European descent moved into the region. The new settlers eventually displaced the Spanish populations and took control of the region.

The earliest settlers in the region experienced some initial conflicts with local Indian groups, particularly with members of the nomadic Beta tribe. By the mid-19th century, both the Beta and Alpha were assigned large reservation tracts, and the economic base of both groups shifted towards cattle and sheep production.

The current population of the model region reflects the three principal cultural traditions: Native Americans (Indian), constituting 4% of the population, Hispanic Americans 14% of the population, and mixed Northern European Americans. Approximately 98% of the people reside in single-family households. The average household size is 3.3 persons; however, family size varies both within and among the populations of the three traditions.

A majority, but not all, of the Native Americans live on two Indian reservations in the region. The Alpha Indians live at the Western Reservation. Traditionally, these people exhibit a strong desire to maintain a sense of "community." The Beta Indians live at the Eastern Reservation. They are highly family oriented, identifying strongly with other families to which they are linked through marriage.

Hispanic Americans include people of Spanish-Indian and Mexican descent. The majority of the Hispanic people speak Spanish as their mother tongue and live within a close extended family unit.

The mixed Northern European Americans that are numerically predominant in the area are descendants of the 19th century European and eastern United States settlers. Within contemporary communities, aspects of the predominant culture or lifestyle (e.g., German, Scandinavian, Pennsylvanian) may still persist. The ranchers of the region represent a separate subgroup and tend to be younger men who are upholding a family tradition of ranching.

4.10.4 Political Organization

The county is governed by a three-member Board of Commissioners elected by popular vote to work with the state in enforcing the laws and sharing responsibilities of highway construction and repair, social services, and various other services and to serve as the government for the rural, unincorporated areas within the region. Pursuant to state law, municipalities select the structure of their government according to the population size of the community.

Political structures of the Alpha and Beta Indian reservations are distinct. The governmental structure of the Alpha tribe incorporates a governor, lieutenant governor, and a council of 12 members who are popularly elected. The council strictly controls the civil affairs of the reservation. The Beta tribe is governed by a general council that consists of all males 21 years and over who reside on the reservation. They select a six-member business council that conducts the necessary administrative and law enforcement activities.

4.10.5 Services

- Medical Care. There are four hospitals in the region. The largest is a 200-bed county hospital in West City; a hospital/clinic with 35 beds is located in East City; and there is one clinic/hospital on each Indian reservation. All of these facilities have an 80% occupancy rate and could accommodate a small increase in use.

- Education. The region contains two public school systems. The West City system includes all towns north of Tributary River and transports children to a central junior-senior high school in West City. The East City system includes all towns south of the river and transports children to a junior-senior high school in East City. These systems can each accommodate another 50 students, provided that the elementary-aged students are well distributed among the available classrooms. There is a branch of the state university in West City and a junior college in East City. The average educational level varies from 9 to 12 years.

- Municipal Services. The municipal sewage and water systems in East City could provide services to an additional 25 families; West City has capabilities for servicing another 50 families. All other families living in the model region have septic tanks and private wells.

Both East and West Cities provide municipal police and fire services that are adequate for present populations. Volunteer fire departments handle county and community needs in the other areas of the region. Police protection (full or part-time) is available in other communities. In addition, there is some protection through the sheriff's department.

4.11 ARCHEOLOGICAL, HISTORICAL, ESTHETIC, AND RECREATIONAL RESOURCES

4.11.1 Archeological and Historical

The sequence of cultural traditions reflected in the archeological finds in this region is presented in Figure 4.4. Evidence of the earliest occupants in this area is very scanty. A pre-projectile-point horizon (ca. 40,000 B.C.) is present. A few cultural remains dating from the following period associated with the hunting of big game have been uncovered along the rim of the Wide Plateau in the southern portion of the region. By 7000-8000 B.C. small band-level societies began to exploit a much wider range of plant and animals located in varying ecosystems. Archeological sites are typically found in caves located in the southern bluff area and along the river/creek floodplains.

Between 100 B.C. and A.D. 400 the subsistence base shifted to cultivation of crops as maize, beans, and squash, although some hunting and plant collecting continued to be of importance. Sedentary villages that included individual pit-houses, jacals (stone or adobe houses), and multistoried buildings of stone or adobe masonry were common, and several sites of this type have been found along the Tributary River and in the southern parts of the region. Between A.D. 400 and 1000, a well-defined regional subtradition more heavily based on agriculture developed. This culture can be traced through archeological remains to the Alpha tribes still inhabiting the same area. The remains of one large town developed between A.D. 1000 and 1300 has been identified in the western part of the region.

Several centuries prior to Spanish exploration of the region, members of the Beta tribe moved into the northeastern portion of the region. Settlements were temporary; small villages composed of related nuclear families and sites were located near to rich hunting areas and pasture. Sites are most often located on ridge tops and along drainage areas.

Locations of the few significant archeological finds reported within the model site are shown in Figure 4.5.

4.11.2 Esthetics and Recreation

The esthetics of scenery play an integral role in determining how viewers perceive the environment. Because the model region exhibits such diverse landscape, its esthetic attributes are numerous. The Northern Mountain Range dominates the northern part of the area, with rugged terrain, coniferous forests and secluded valleys. Farther south the mountains taper off into acres of nonforested land that eventually leads to the Open Plains in the central part of the region. Shifting sands on the plains form dunes, and within depressions between the dunes there are many ephemeral lakes and ponds. The Open Plains end at the base of Wide Plateau. The Plateau's rim is a deeply eroded rock formation which stretches across the southern end of the region.

The potential for recreational use and development in the model region is high. Present recreational activities include varied use of wilderness and primitive areas enclosing the summits of the northern mountain range and National Park backcountry and fishing in Tributary River and Lake and in all of the region's northern lakes, streams, and beaver ponds. Lakes and reservoirs along Tributary River also provide beaches and facilities for boating, swimming and water skiing. There is some hiking and camping along winding trails up the rim of the Wide Plateau, and wilderness rides on jeep trails and rock hounding are popular activities across the Wide Plateau. Hunting is a major recreational activity throughout the region.

The model site lies almost entirely in the Open Plains and only the northern and southern tips give way to more diverse landforms. Thus the scenery is less diverse than in other parts of the region, but the model site still has high potential for recreational development. The Tributary River is probably the most heavily used tourist attraction.

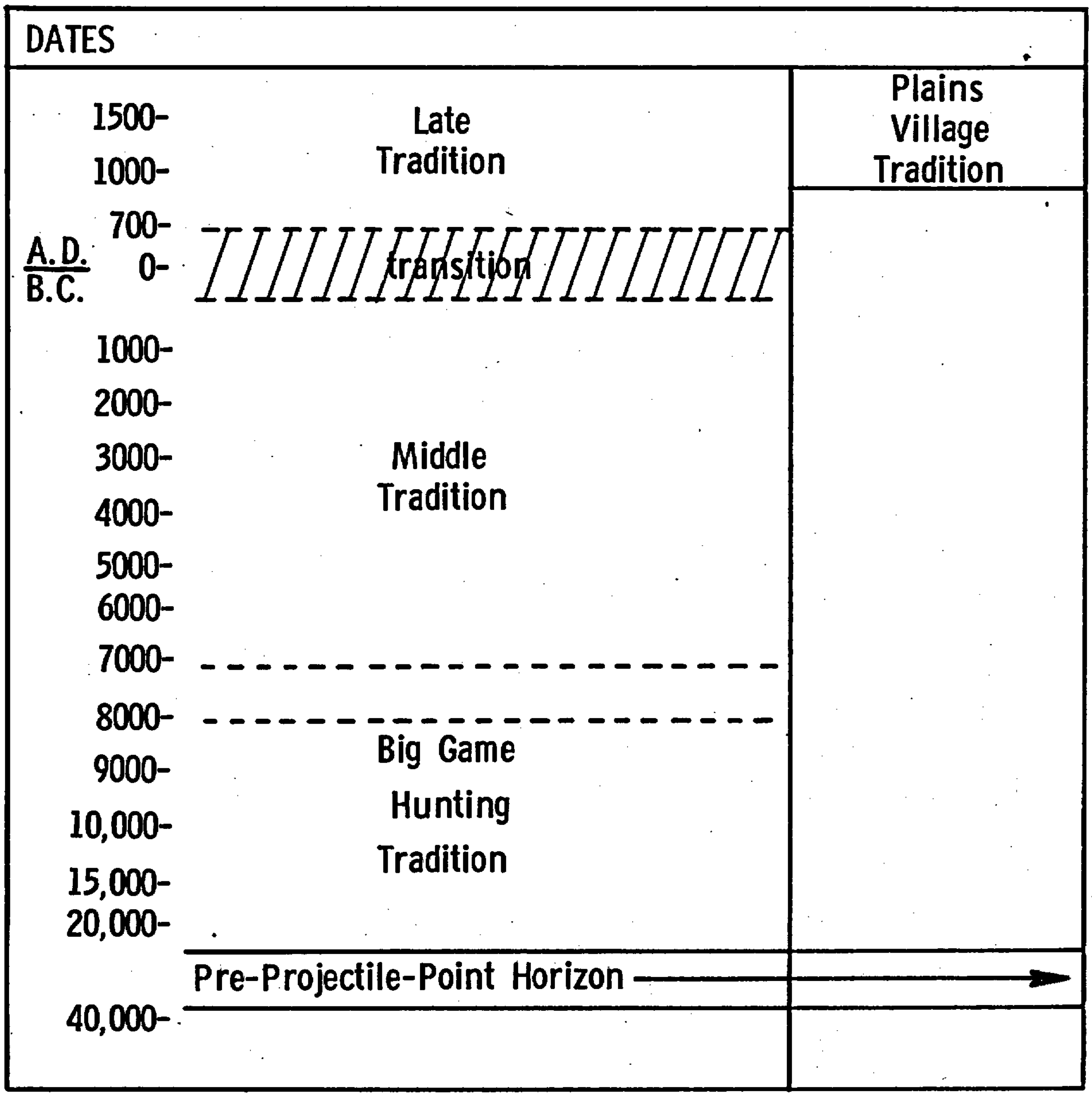


Fig. 4.4. Archeological Sequence for the Model Region. (Modified from G. R. Willey, "An Introduction to American Archaeology. Vol. 1, North and Middle America," 1966; J. D. Jennings, "The Desert West," and W. W. Wedel, "The Great Plains." The last two sources appear in <u>Prehistoric Man in the New World</u>, University of Chicago Press, 1964.)

(1) Sites associated with the Desert Tradition (early sites)

(2) Villages of The South-western Tradition (400 A.D.-1000 A.D.)

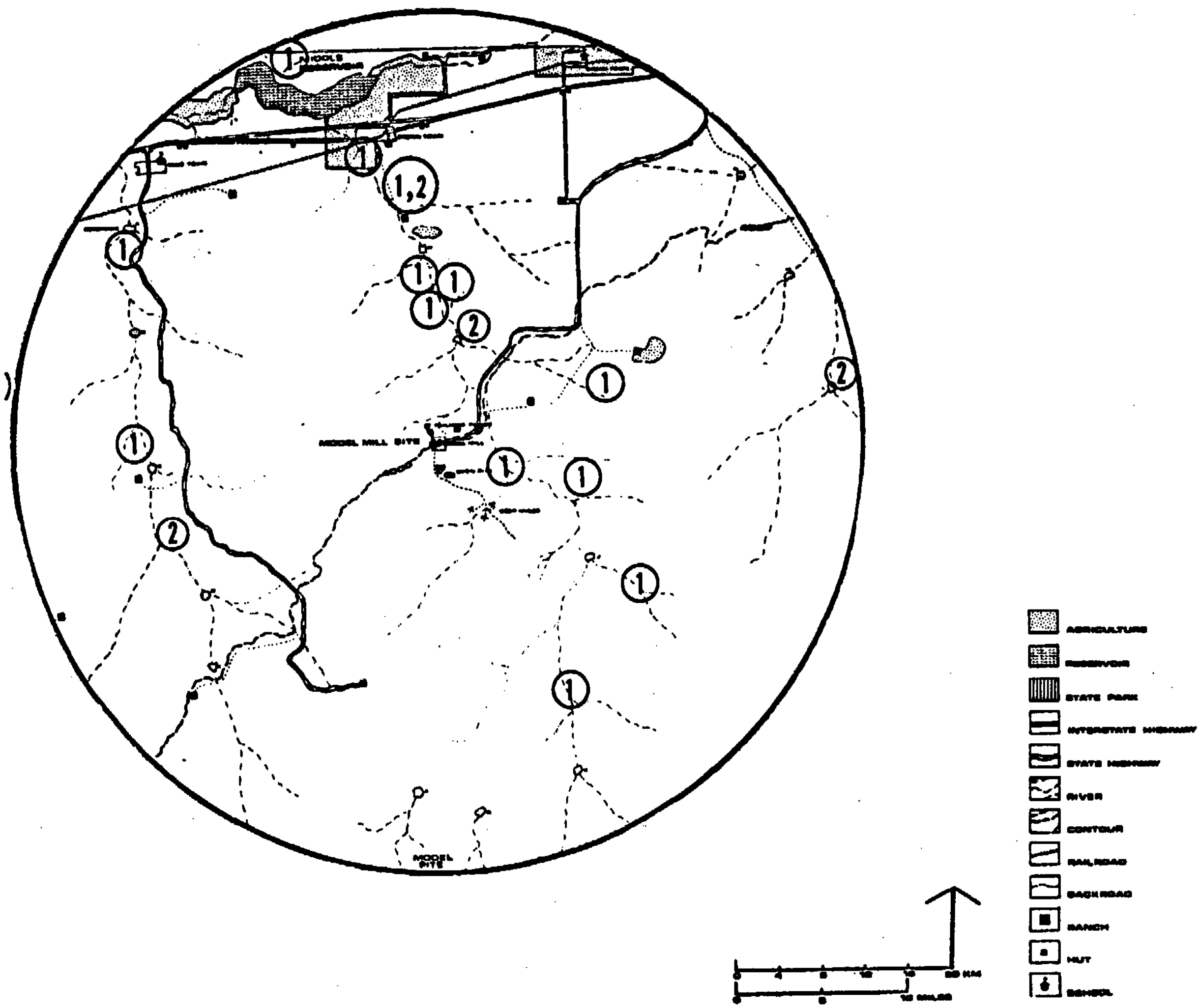


Fig. 4.5. Locations of Archeologically Significant Sites in Vicinity of the Model Mill.

4.12 EXISTING RADIATION ENVIRONMENT--NATURAL AND MAN-MADE*

The preoperational radiation environment, or background radiation, originates from natural and technologically enhanced sources. Natural background includes cosmic, cosmogenic, and terrestrial radiation, as well as radiation from inhaled radon. Technologically enhanced radiation in the model region is chiefly a result of fallout from weapons tests. A gypsum mine and a coal mine in the area are expected to be negligible sources of radiation. Medical irradiation is not commonly classified as background radiation, but it does represent a significant source to which the public is regularly exposed. For example, the mean active bone marrow dose to adults from diagnostic X rays is about 100 mrem/yr.[4] A summary of the background radiation doses to the population of the model region from various natural and man-made sources, exclusive of diagnostic X rays, is given in Table 4.14. In Sections 2 through 4 of Appendix C these sources are discussed in more detail and the large variability of those that occur naturally is noted.

Table 4.14. Annual Dose Equivalent from Background Radiation

	Tissue Dose Equivalent, mrem			
Radiation Source	Whole Body	Bone	Lung	Bronchial Epithelium
Cosmic	54	54	54	
Cosmogenic	1	1	1	
Terrestrial (external)	62	50	62	
Terrestrial (internal)	21	52[a]	21	
Inhalation			<1.0	
Radon daughters				
Ranch house				560
Mud-lined huts				1100
Trailer home				150
Fallout	4.5	30		
TOTAL	143	187	144	560[b]

[a]This is the estimate for bone surfaces. The dose equivalent to compact bone from internal emitters is approximately 115 mrem.

[b]Based on residency in a ranch house. The basis for these dose estimates is described in Appendix C, Section 3.

References

1. "Descriptions of United States Uranium Resource Areas: A Supplement to the Generic Environmental Impact Statement on Uranium Milling," U.S. Nuclear Regulatory Commission, NUREG/CR-0597, June 1979.

2. N. R. French, W. E. Grant, W. Grodzinski, and D. M. Swift, "Small Mammal Energetics in Grassland Ecosystems," Ecol. Monog. 46:201-220, 1976.

3. J. A. Wiens, "Pattern and Process in Grassland Bird Communities," Ecol. Monog. 43:237-270, 1973.

4. B. Shleien, T. T. Tucker, and D. W. Johnson, "The Mean Active Bone Marrow Dose to the Adult Population of the U.S. from Diagnostic Radiology," Bureau of Radiological Health, Public Health Service, Dept. of Health, Education and Welfare Publication (FDA) 77-8013, January 1977.

5. S. T. Algermissen, "Seismic Risk Studies in the United States," Proc. 4th World Conf. on Earthquake Engineering, Santiago, Chile, January 1969.

*The basic assumptions used in establishing values for the existing radiation environment in the model region, as well as a discussion of the basic concepts of radiological terminology used in this and subsequent sections, are given in Appendix C.

5. MODEL MILL

A "model mill" based on features typical of uranium mills in operation in the early 1970s is described in this chapter. The characteristics, operating procedures, processes, and effluents of the model mill were derived from data for existing mills as described in technical literature and various environmental reports and statements.[1-12] The basis for source term estimates is given in Appendix G-1. (A plot plan of the model mill is shown in Figure 5.1.) The model mill concept serves two basic functions: (1) it provides a means of assessing the environmental impact of the model region and the model site (described in Chapter 4); and (2) it serves as a base case for evaluating the environmental impacts of alternative methods of effluent control and tailings management. The model mill features a relatively low level of environmental control, which in some respects represents a lower level of control than that currently used at U.S. mills. The environmental impacts of the model mill are described in Chapter 6. Alternatives are described in Chapter 8 and their impacts in Chapter 9.

Depending on the chemical characteristics of the ore, conventional uranium mills employ either the acid-leach process coupled with solvent extraction or the alkaline-leach process coupled with caustic precipitation for the concentration and purification of leached uranium. These processes are most common in the industry at present, and this situation is expected to continue for the period of interest. As of 1976, mills employing the acid leach process represented 82% of the total U_3O_8 production capacity of the conventional milling industry; mills with alkaline leach circuits accounted for the remaining 18%. In view of the preponderance of acid-leach mills, the model mill will employ the acid-leach process (Fig. 5.2). The alkaline-leach process is described in Appendix B. The major impacts from the alkaline-leach process are not expected to be significantly different from those of the acid-leach process.

5.1 PRINCIPAL MILL OPERATING CHARACTERISTICS

The model mill is to have an ore-processing capacity of 1800 MT (2000 ST) per day, the average milling rate of the 16 conventional mills in operation in 1976.[1] The grade of the ore to be processed by the model mill during the period from the present to the year 2000 is expected to average 0.10%. Source term estimates in Section 5.3, as well as the radiological impact assessment, are based on this value. The ore is to be transported from the mine to the mill by trucks with an average load of 23 MT (25 ST) over an average hauling distance of 50 km (30 miles). The ore is stored on ore pads, usually occupying an area of about 0.5 ha (1.3 acres), and providing sufficient feed material for 10 days of operation. The model mill is assumed to be operated 310 days a year and have a total work force of about 160. With a uranium recovery efficiency of 93%, the average annual production is about 520 MT (570 ST) of U_3O_8. If the product is 90% U_3O_8, the yellowcake production rate is 580 MT (635 ST) per year. The yellowcake is shipped by truck in 55-gallon drums; each contains a maximum of 430 kg (950 lb) of yellowcake, and up to 40 drums are carried on each truck. The principal operating characteristics of the model mill are summarized in Table 5.1.

Sufficient supplies of the chemicals used in the milling process (see Table 5.2) are maintained at the site to ensure continuous mill operation. Typically, 20- to 30-day supplies of sulfuric acid and anhydrous ammonia are kept on hand. Sulfuric acid usually is shipped by rail and then transferred by tank trucks to the mill; anhydrous ammonia is delivered by truck.

5.2 MILL WASTES

A number of radioactive and nonradioactive wastes are generated by the processing of ore in the model mill. The tailings represent the bulk of both radioactive and nonradioactive wastes. With the exception of the recovered uranium and some process losses, tailings account for practically all of the ore solids and the process additives, including water. Each day the model mill generates 1800 MT (2000 ST) of dry tailings slurried in water to about 50% solids by weight (density about 1.6 g/cm^3) and sent to a tailings retention system. On the average, 30% of the tailings liquid is recycled for use in the milling process, so that the net consumption of water is 1260 MT per day (1400 ST/day). Tailings are usually classified as: (1) sand, consisting of

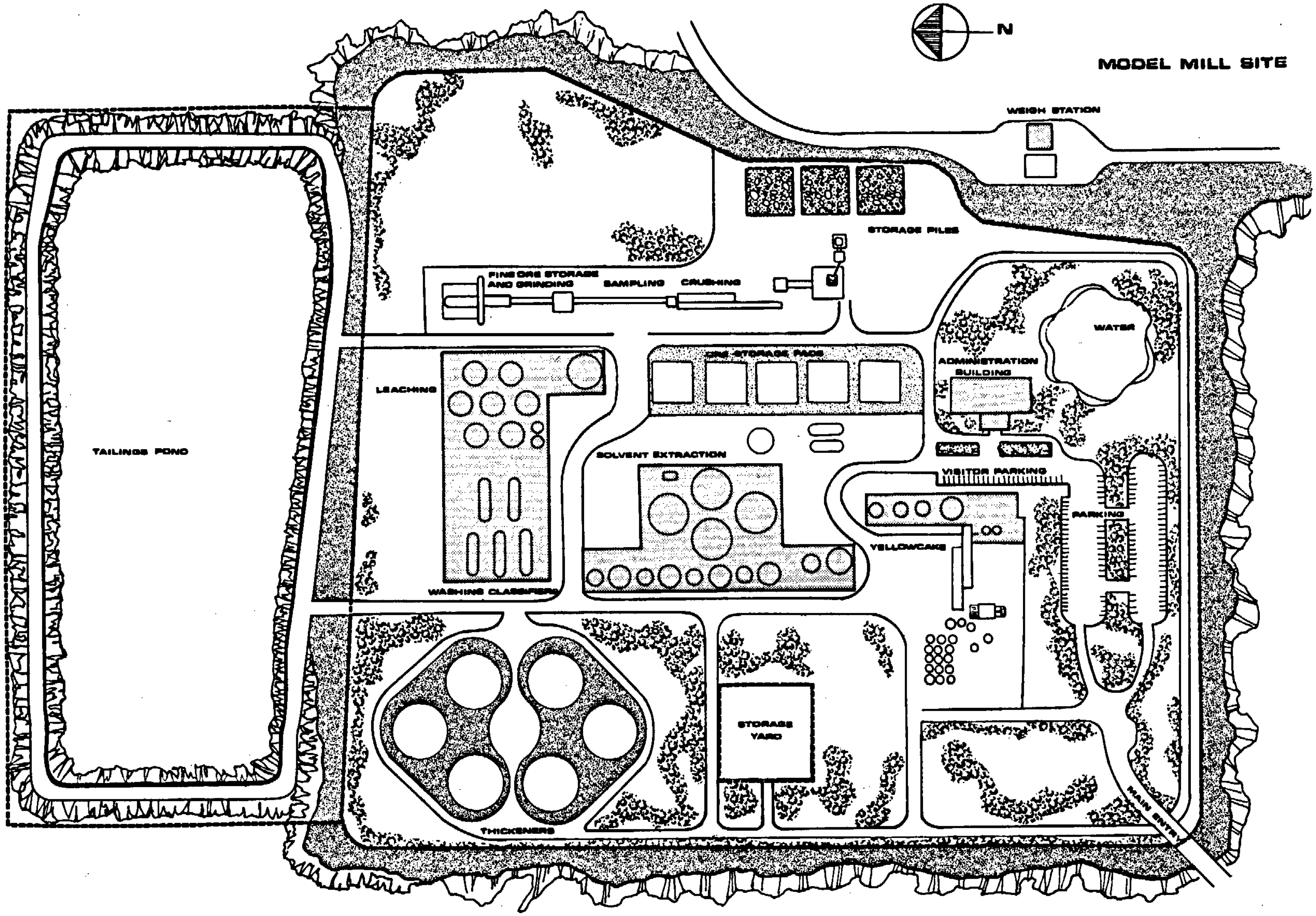


Fig. 5.1. Plot Plan of the Model Mill.

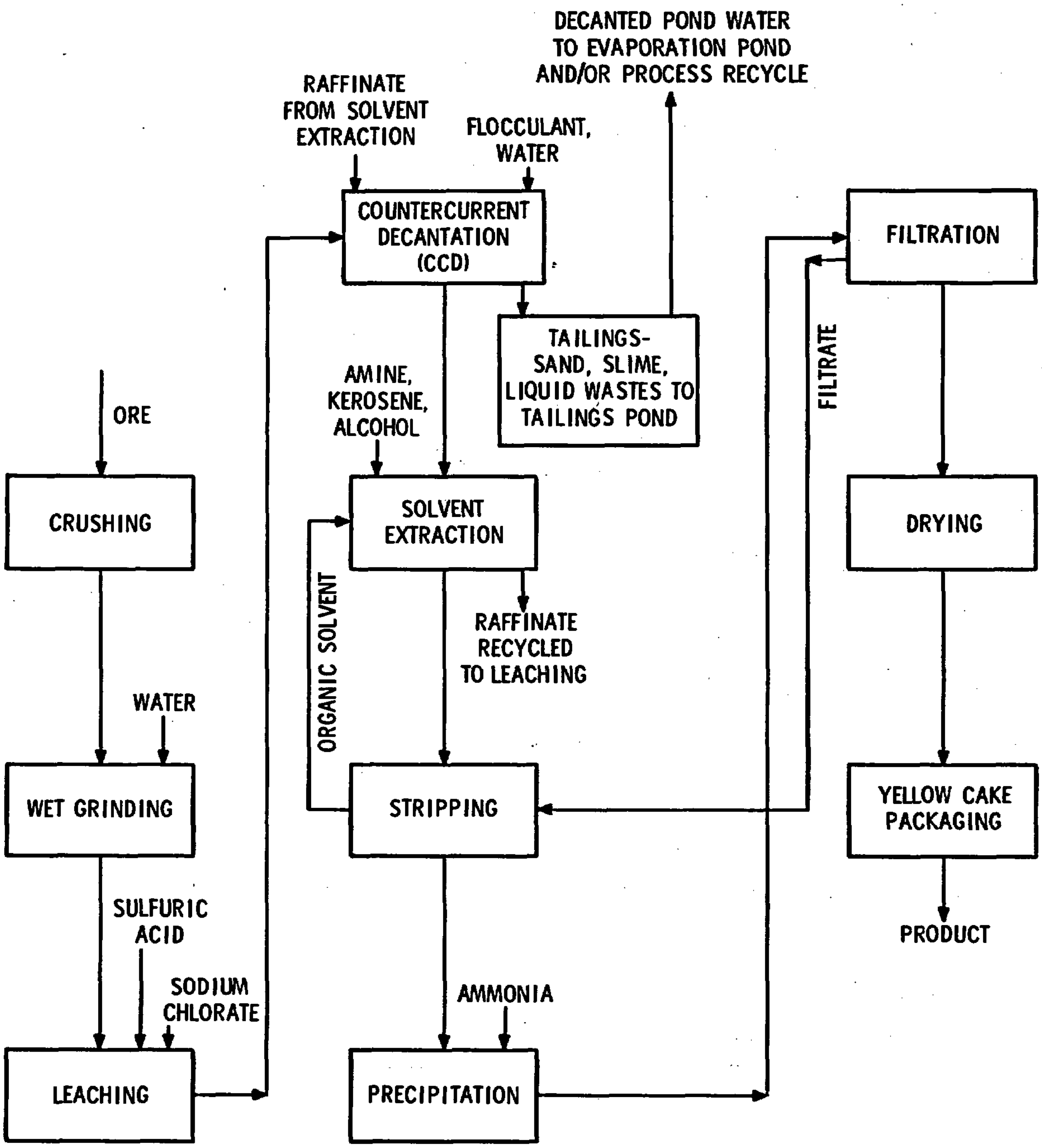


Fig. 5.2. Flow Diagram for the Acid-Leach Process. (Modified from "A Study of Waste Generation, Treatment and Disposal in the Metals Mining Industry," Midwest Research Institute for U.S. Environmental Protection Agency, EPA No. 68-01-2665, October 1976.)

Table 5.1 Summary of Principal Operating Characteristics of the Model Mill

Parameter	Value
Ore process rate	1800 MT per day
Average ore grade (% U_3O_8) 1980-2000	0.10%
Ore activity, U-238 and each daughter in secular equilibrium (0.10% U_3O_8)	280 pCi/g
Ore transport	Haulage from mine to mill by truck (23 MT average load per truck)
Ore hauling distance	15 to 80 km (50-km average)
Ore pad area normally in use	0.5 ha
Ore storage time (10-day supply on hand)	∿ 12 days
Operating days per year	310
Manpower requirements	∿ 160 employees and others onsite
Uranium recovery (extraction efficiency)	93%
Product purity	90% U_3O_8
Average annual production (0.10% U_3O_8)	520 MT U_3O_8 or 580 MT yellowcake
Yellowcake transport	Shipment in 55-gallon drums by truck; each drum containing a maximum of 430 kg of yellowcake; 40 drums carried per truck
Dry solid waste generated (tailings)	1800 MT/day
Tailings density (slurry)	1.6 g/cm^3
Gross water flow to tailings pond	1800 MT/day
Tailings pond water recycled	30%
Net water consumption for tailings slurry	1260 MT/day
Area of milling facility (excluding tailings pile)	50 ha
Area of tailings impoundment	100 ha
Extra unused land	150 ha
Total area owned by milling operation	300 ha

solids greater than 200 mesh (+75 microns), (2) slimes, consisting of solids less than 200 mesh (-75 microns), and (3) liquids, which are solutions of chemicals from the ore and process reagents. For the model mill, slimes are taken to constitute 35% of the tailings, by weight, and to contain 85% of the radioactivity. The chemical and radiological properties of the dry tailings solids and of the tailings liquid waste generated by the model mill are listed in Table 5.3.

Table 5.2. Additives for Acid-Leach Process

Additives	Quantities, kg/MT ore
Sulfuric acid	45.0
Sodium chlorate	1.4
Ammonia	1.1
Flocculant	0.06
Amine (long chain)	0.015
Alcohol	0.04
Kerosene	0.45
Iron (rods for grinding)	0.25

When discharged from the mill, the slurried tailings material is pumped through steel or plastic pipes to an impoundment (tailings pond). The tailings pond initially is a square basin formed by building low earthen embankments. The tailings slurry from the model mill is discharged into the tailings impoundment via a peripheral discharge system. Because the location of the slurry discharge pipe is moved on occasion to keep the tailings area fairly level, areas of the tailings dry out intermittently. As the basin is filled, the coarse fraction of the tailings (sands) is used to raise and broaden the embankments. The embankments are compacted on the outer side to provide strength.

The initial earthen embankment is assumed to be 3 m (10 ft) high, 3 m (10 ft) broad at the top, and 15 m (50 ft) broad at the base with each side 947 m (3100 ft) long at the centerline. The final embankments would be 10 m (33 ft) high, 13 m (43 ft) broad at the crest, and 53 m (174 ft) at the base; the initial centerline length would be unchanged. The volumes of the initial and final embankments would be 102,000 m^3 (133,000 yd^3) and 1,250,000 m^3 (1,630,000 yd^3), respectively. The total tailings disposal area is around 100 ha (250 acres), of which 80 ha (200 acres) contain tailings; 20 ha (50 acres) are covered by water, 10 ha (25 acres) are maintained "wet" during operation; hence, 50 ha (125 acres) are dry during operations. After milling operations cease, the tailings are allowed to dry sufficiently to accommodate heavy equipment. The ultimate depth of the tailings pile is calculated to be about 8 m (26 ft). The tailings will dry out over a period of some years and will be subject to dusting until natural revegetation occurs. Under these circumstances, the exclusion fence is considered to be maintained by the mill operator for an indefinite period of time. A description of the construction and operation of typical tailings ponds is presented in Appendix B.

The model mill is not designed to process low-grade ores ($\leq$0.04% U_3O_8). Uranium from such low-grade ores can, however, be extracted by heap leaching (see detailed description of the operation in the Supplement) near the mine site or at low-grade ore dumps.[13] The resulting enriched solution (0.06 to 0.1 g U_3O_8/L) is collected and processed at the leaching site by solvent extraction and precipitation with ammonia. The crude precipitate is then shipped by truck to the model mill for further processing. In cases where the dumps can be located reasonably near the mill, the acid solution from the mill circuit is used for heap leaching, with the enriched solution being returned to the mill circuit for processing. The uranium recovery from heap leaching is expected to range from 50% to 80%, resulting in a final tailings material of around 0.01% U_3O_8 content.

Shipment of enriched solutions or precipitated slurries from heap leach operations to the model mill is basically an intermittent operation and, at such times, the regular ore throughput in the model mill will have to be decreased accordingly so as not to overload the processing circuits. Consequently, the model mill is considered to maintain its fixed yellowcake production rate of 580 MT (635 ST) per year. Contributions from heap leach operation to overall yellowcake production in the model mill is expected to be modest.

For the purpose of this generic assessment, the heap leaching operation conducted in conjunction with the model mill may be assumed to involve low-grade ore piles occupying an aggregate land area (near the mine mouth) of approximately 14 ha (35 acres) at any given time.

More complete discussion of uranium milling is presented in Appendix B.

X

Table 5.3. Chemical and Radiological Properties of Tailings Wastes Generated by the Model Mill

Parameter	Value[a]	EPA Reported Value[b]
Dry Solids		
U_3O_8, wt %	0.007	
U nat, pCi/g[c]	39	
Ra-226, pCi/g	280	
Th-230, pCi/g	280	
Tailings Liquid		
pH	2	
Aluminum, mg/L	2,000	700 - 1,600
Ammonia, mg/L	500	
Arsenic, mg/L	0.2	0.1 - 3.4
Calcium, mg/L	500	
Carbonate, mg/L		
Cadmium, mg/L	0.2	0.08 - 5
Chloride, mg/L	300	
Chromium, mg/L		0.02 - 2.9
Copper, mg/L	50	0.7 - 8.6
Fluoride, mg/L	5	1.4 - 2.1
Iron, mg/L	1,000	300 - 3,000
Lead, mg/L	7	0.8 - 2
Magnesium, mg/L		400 - 700
Manganese, mg/L	500	100 - 210
Mercury, mg/L	0.07	
Molybdenum, mg/L	100	0.3 - 16
Nickel, mg/L		0.13 - 1.4
Selenium, mg/L	20	
Sodium, mg/L	200	
Sulfate, mg/L	30,000	
Vanadium, mg/L	0.10	0.1 - 120
Zinc, mg/L	80	
Total dissolved solids, mg/L	35,000	
U nat, pCi/L	3,300	
Ra-226, pCi/L	250	
Th-230, pCi/L	90,000	
Pb-210, pCi/L	250	
Po-210, pCi/L	250	
Bi-210, pCi/L	250	

[a]Based on:

- M.B. Sears et al., "Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing as Low as Practicable Guides--Milling of Uranium Ores," ORNL-TM-4903, 1975.
- "WIN Reports on Uranium Ore Analysis," U.S. AEC Contract 49-6-924, various reports 7 January 1957 through 10 July 1958.
- "United States Mineral Resources," Geological Survey Professional Paper 820, 1973.
- "Mineral Facts and Problems," U.S. Bureau of Mines Bulletin 667, 1975.

[b]"Environmental Study on Uranium Mills," by Jackson, Coleman, Murray and Scints, TRW, Inc., for U.S. Environmental Protection Agency, Contract #68-03-2560, EPA Effluents Guidelines Division.

[c]A picocurie of natural uranium (U nat) weighs 1.5 μg and contains 0.49 pCi each of U-238 and U-234, and 0.023 pCi of U-235.

5.3 EMISSION SOURCE TERMS

5.3.1 Nonradioactive

Major sources of nonradioactive contaminants are the ore storage pads and the tailings disposal area, as well as roads and other areas disturbed by heavy equipment. In addition, effluents originate from various processing areas in the mill; the sources and rates of these emissions are given in Table 5.4.

5.3.2 Radioactive

The sources of radioactive airborne effluents from the model mill are described briefly below and summarized in Table 5.5. More details of their calculation are given in Appendix G-1. These releases represent what the staff considers to be an upper bound or "worst case" situation. Available technology and management procedures described in Chapter 8 would be expected to reduce substantially the quantities of radioactive material released from modern mills. The radiation dose commitments which result from releases from the model mill are described in Section 6.2.8.

Two types of radiological effluents are considered in this analysis--particulates and radon gas. The sources of particulates of sufficient magnitude to warrant consideration are: (1) the initial stages of milling, including ore storage, feed, crushing and grinding; (2) the final production stage of yellowcake drying and packaging; and (3) the mill tailings or waste residue from the previous operations. Radon gas is released from the ore as processing begins and from the stored tailings, but not to any significant extent from the yellowcake operations. Effluents from mining and from transportation of the ore to the site are not included.

Table 5.4. Emissions Generated Daily by the Model Mill[a]

Emission	Emission Source	Daily Rate
Ore dust	Ore storage & crushing/grinding	6.3 kg
U_3O_8	Product drying and packaging	1.4 kg
Tailings dust	Tailings pile	1080 kg
Organic solvent (92% kerosene)	Solvent extraction ventilation system	70 kg
Sulfur dioxide and sulfuric acid fumes	Acid leach tank vent system	1 kg
SO_2	Burning of fuel oil	22 kg
NO_2	Burning of fuel oil	5 kg
Domestic sewage[b]	Washrooms, showers, etc.	30,000 L

[a]Assumes use of acid-leach process. Values have been normalized for a 1800 MT/day mill on the basis of average emissions reported in environmental reports and environmental impact statements for various existing mills.

[b]Domestic sewage will undergo treatment prior to discharge.

5.4 VIEWS OF TYPICAL URANIUM MILLS

To provide general background for reading this document, Figures 5.3 through 5.10 provide views of actual mills, mill operations, tailings piles as well as several open pit uranium mines.

Table 5.5. Radioactive Emissions Generated by the Model Mill[a]

Emission Source	Particulates, mCi/yr: U-238, U-234	Particulates, mCi/yr: Th-230	Particulates, mCi/yr: Ra-226, Pb-210, Po-210	Radon-222, Ci/yr[b]
Ore hauling and storage pad[c]	0.67	0.67	0.67	68 (combined with ore crushing and grinding)
Ore crushing and grinding[c]	0.90	0.90	0.90	
Yellowcake drying & packaging[d]	150	0.73	0.15	Negligible
Tailings pile	8.7	120	120	4400
Dispersed ore & tailings[e]				48

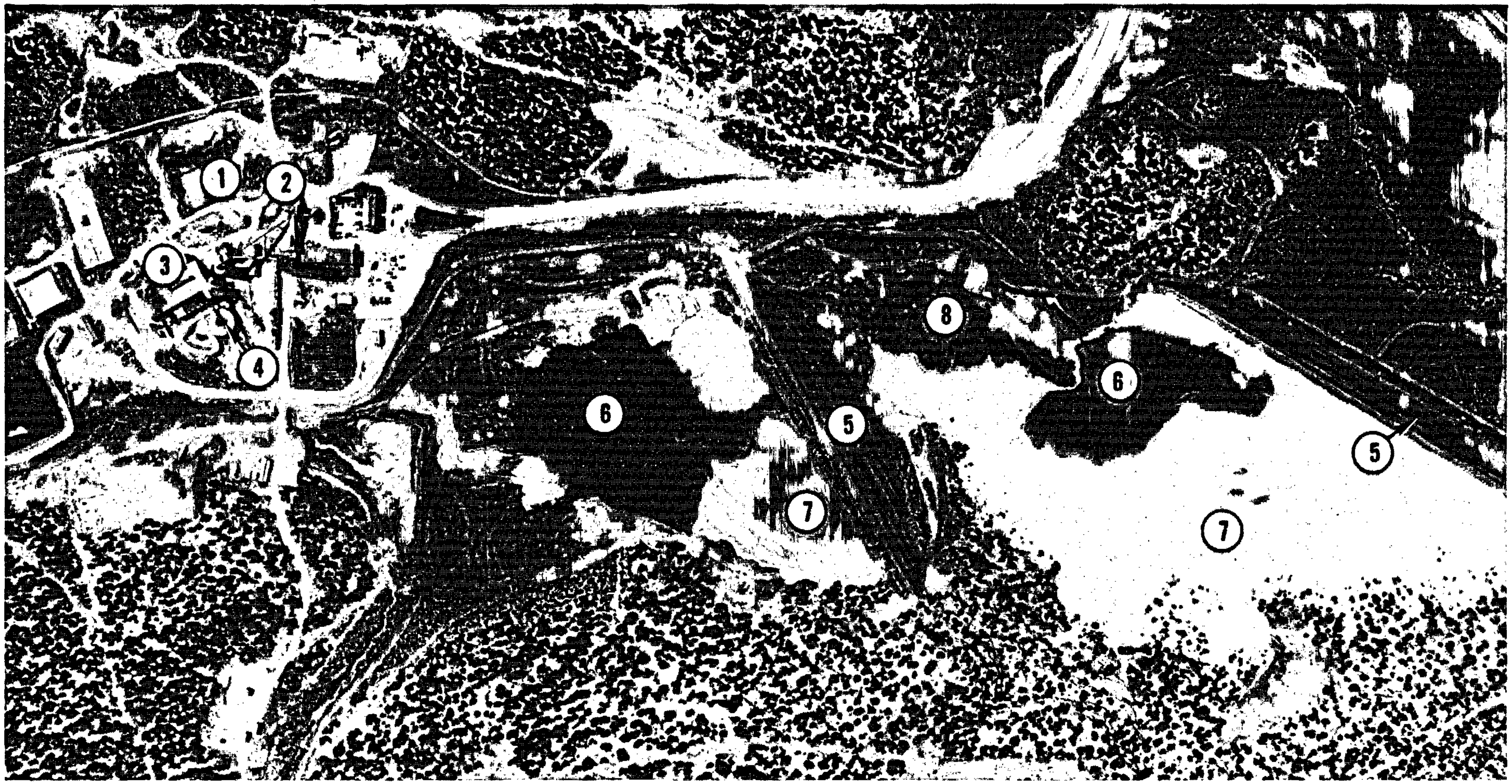
[a]The bases for source term estimates are given in Appendix G-1. All numbers are rounded to two significant digits.

[b]Note that because of the short half-life (3.82 days) of radon-222, very little of the 4500 Ci of that radionuclide released during a year will be present in the environment at the end of that year. Equilibrium between the rate of radon release (roughly 0.5 Ci/hr) and its rate of radioactive decay is established relatively quickly. Thereafter, releases at a constant rate equivalent to 4500 Ci/yr will result in only 70 Ci of Rn-222 existing outside the source at any time.

[c]Total mass released from all ore operations is estimated to be 6.3 kg/day, with a specific activity 2.4 times the average specific activity of the ore.

[d]Total mass released from yellowcake operations is estimated to be 1.4 kg U_3O_8/day, if averaged over 365 day/year.

[e]Ore and tailings dusts dispersed during operations give rise to a secondary source of Rn-222 emission. The figure given for this source, 48 Ci/yr, is that calculated in Appendix G-1 to result after 15 years operation.



(1) Ore Stockpile
(2) Crushing Facility
(3) Leaching and Concentrating Facility
(4) Thickener
(5) Tailings Embankment
(6) Tailings Pond
(7) Tailings-Dried Beaches
(8) Tailings-Partial Cover

Figure 5.3 AERIAL VIEW OF TYPICAL URANIUM MILL AND MILL TAILINGS

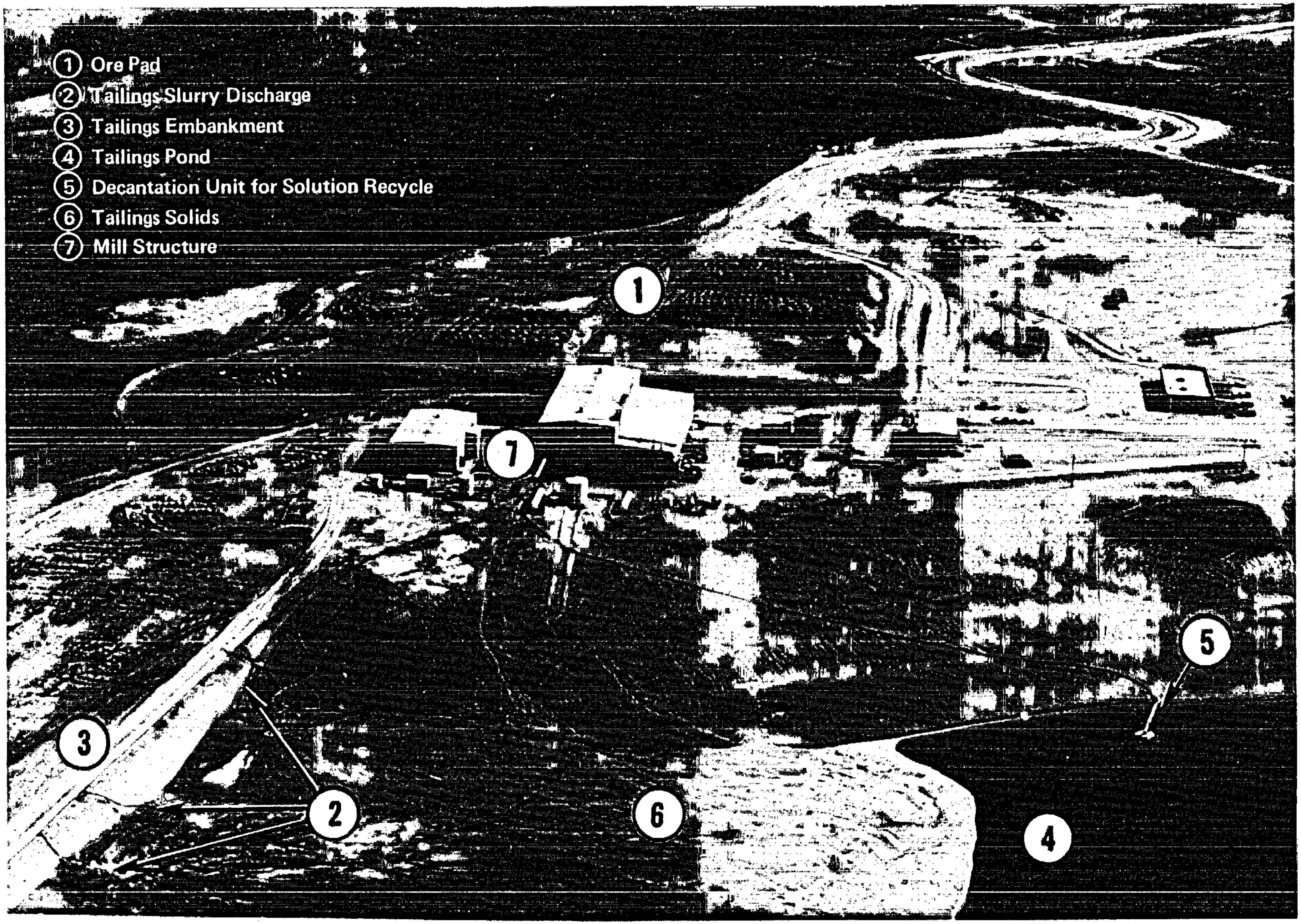


Figure 5.4 TYPICAL NEW MILL IN WYOMING

Figure 5.5 Ore Truck Arriving at a Mill.
Structures in Background House Ore Crushing Operations.

Figure 5.6 An Ore Storage Area.

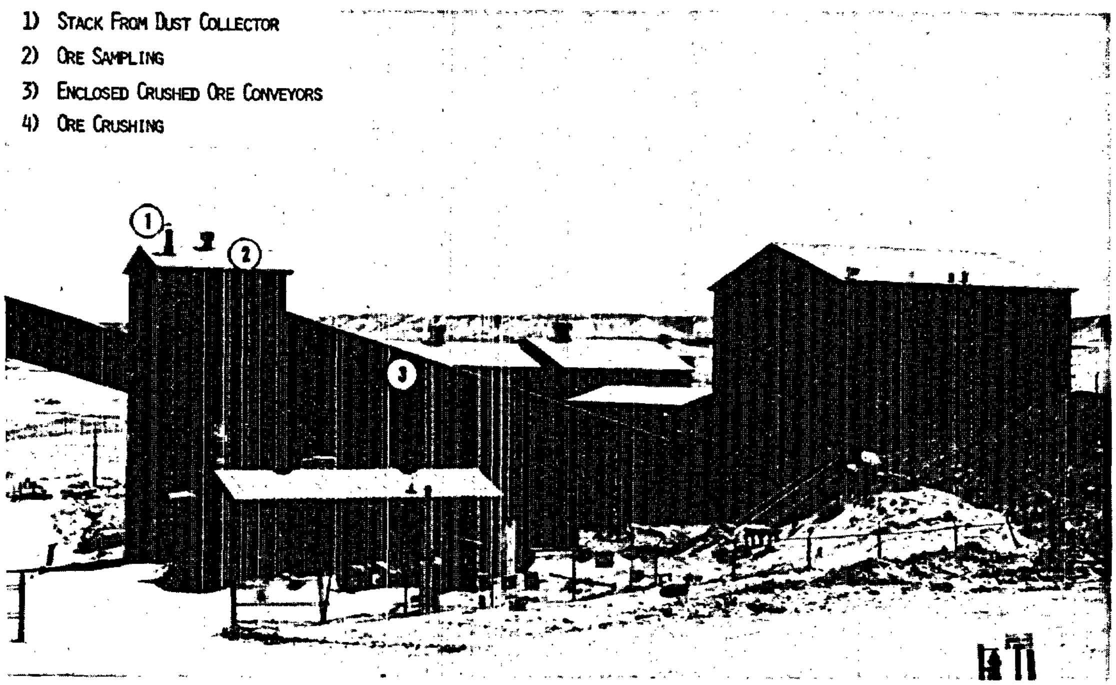


Figure 5.7 Structures Housing Ore Crushing Operations
(Note absence of these structures in a new mill shown in Figure 5.4 which utilizes wet-semiautogenous grinding (SAG) of ore. The SAG process eliminates dry crushing of ore; see Figure 8.1.)

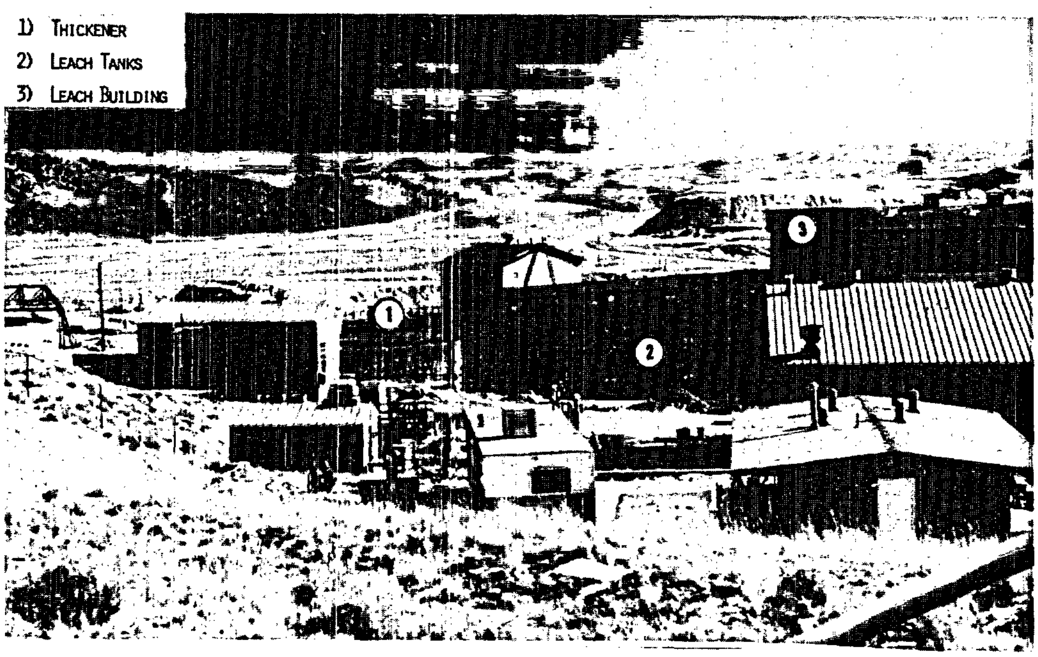


Figure 5.8 View of Buildings at Typical Mill Located in Sparsely Populated Arid Region

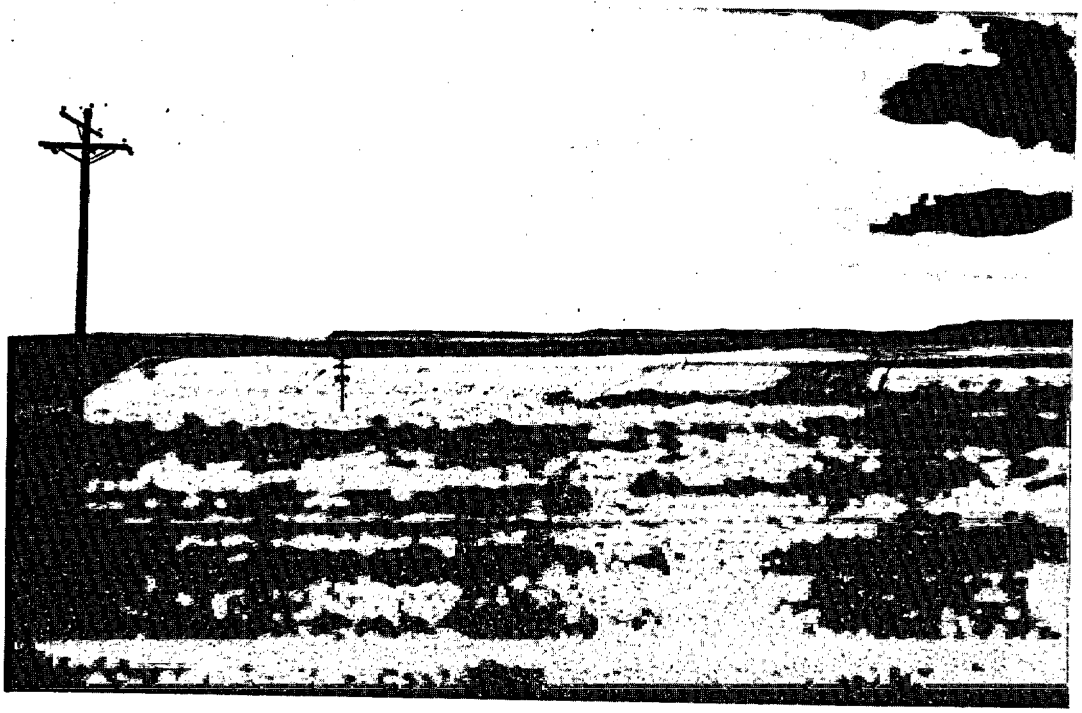
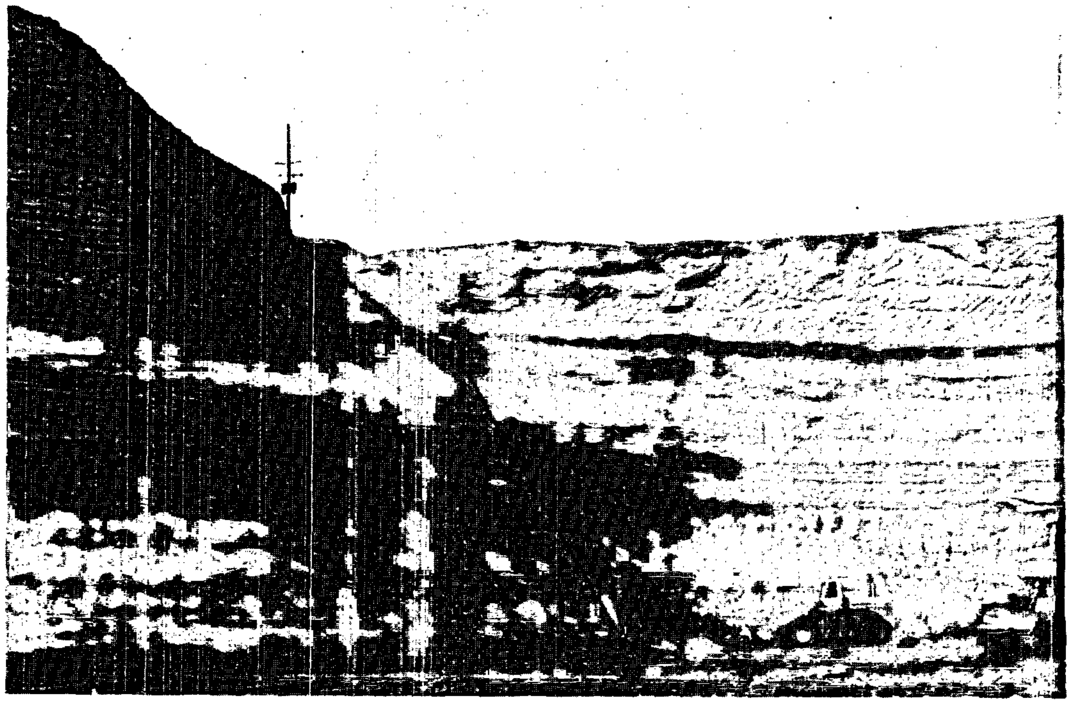


Figure 5.9 Side Views of Several Existing Uranium Mill Tailings Piles



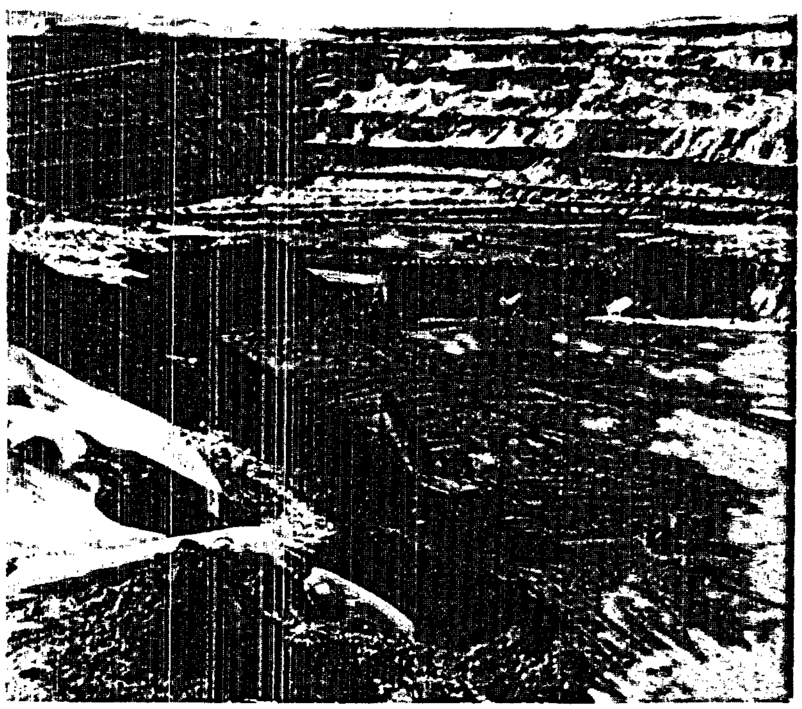


Figure 5.10 Several Views of Open Uranium Mine Pits

References

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13. R. C. Merritt, "The Extractive Metallurgy of Uranium," Section 5-5.2, Colorado School of Mines Research Institute, Golden, Colorado, 1971.

6. ENVIRONMENTAL IMPACTS

6.1 INTRODUCTION

This chapter contains the analysis of the environmental impacts that would occur up to the year 2000 from uranium milling operations in the model region if few mitigative measures were employed. This constitutes analysis of the "base case" of environmental control represented by the model mill described in Chapter 5. The model mill features a relatively low level of environmental control, which in some respects represents a lower level of control than at current mills.

Primary emphasis is given to impacts that are generic in nature. Many of the impacts from uranium milling are highly site-specific and no attempt is made, therefore, to analyze them in great detail; they must be evaluated for each mill as is done through environmental statements prepared in connection with individual mill licensing actions. The evaluation in this document is intended to characterize the nature and extent of the impacts that will result from the model mill as defined in Chapter 5. To do this, a range or upper limit for site-specific impacts is presented. To illustrate the significance of these predicted values, they are compared with applicable regulations and standards such as (1) limits on radioactive exposures expressed in standards of the EPA covering the nuclear fuel cycle (40 CFR 190) and in NRC radiation protection standards (10 CFR 20), (2) EPA air quality standards, and (3) EPA water quality standards.

Environmental impacts are described for two cases: (1) a single mill, and (2) a cluster of mills. In the latter case, the intent is to evaluate the cumulative impacts that may result in a realistic worst case situation which might occur in a region of intensive milling activity in the year 2000. Specifically, a cluster of 12 mills, each equivalent in capacity to a 1800 metric ton (MT), or 2000 short ton (ST), per day mill, is considered.

The analysis in Section 6.2 of the environmental impacts of a single mill is based on the model mill (Ch. 5) situated in the center of the model site (Ch. 4), as illustrated in Figure 6.1. The impacts are evaluated for three periods: (1) during construction of the mill, (2) during operation of the mill, and (3) after operations cease. The impacts considered are divided into eight categories: (a) on air quality, (b) on topography and land use, (c) on mineral resources, (d) on water resources, (e) on soil resources, (f) on biota, (g) on the community, and (h) radiological impacts. As mentioned above, the model mill does not employ mitigative measures (such as tailings burial, site revegetation, etc.) which are in use or planned at some existing mills; however, the base case is developed to provide a method for illustrating the reduction of impacts that can be achieved by various means as described in the evaluation of alternatives of Chapter 9. The evaluation of the impacts identifies the source and magnitude of the major impacts, assesses the relative significance of the impacts, and indicates critical areas of uncertainty.

The analysis of a cluster of mills presented in Section 6.3 is based on 12 model mills sited near the center of the model region; the locations are chosen to be consistent with the descriptive geology of the site (Sec. 4.3), that is, the mills are located near the uranium mines (Fig. 6.2). It is assumed that the mills are constructed in phase so that at most two will be under construction simultaneously; however, for a brief period all 12 will be operating simultaneously. This situation is analyzed in a manner analogous to the single mill case; the same areas of potential impacts are evaluated, with emphasis on instances where the multiple mill impacts are different from the single mill case.

For both the single and multiple mill assessments, impacts on (1) individuals living near a mill and (2) general populations in a milling region are explored. However, these assessments indicate that only radiological and socioeconomic impacts extend beyond the model region. Continental radiological effects from the inhalation of radon are presented in Section 6.4. The staff can make only qualitative remarks that the socioeconomic effects of uranium milling beyond the regional boundary are very small (even in the 12-mill case) and largely untraceable in view of the fact that uranium milling is a very small segment of the national economy.

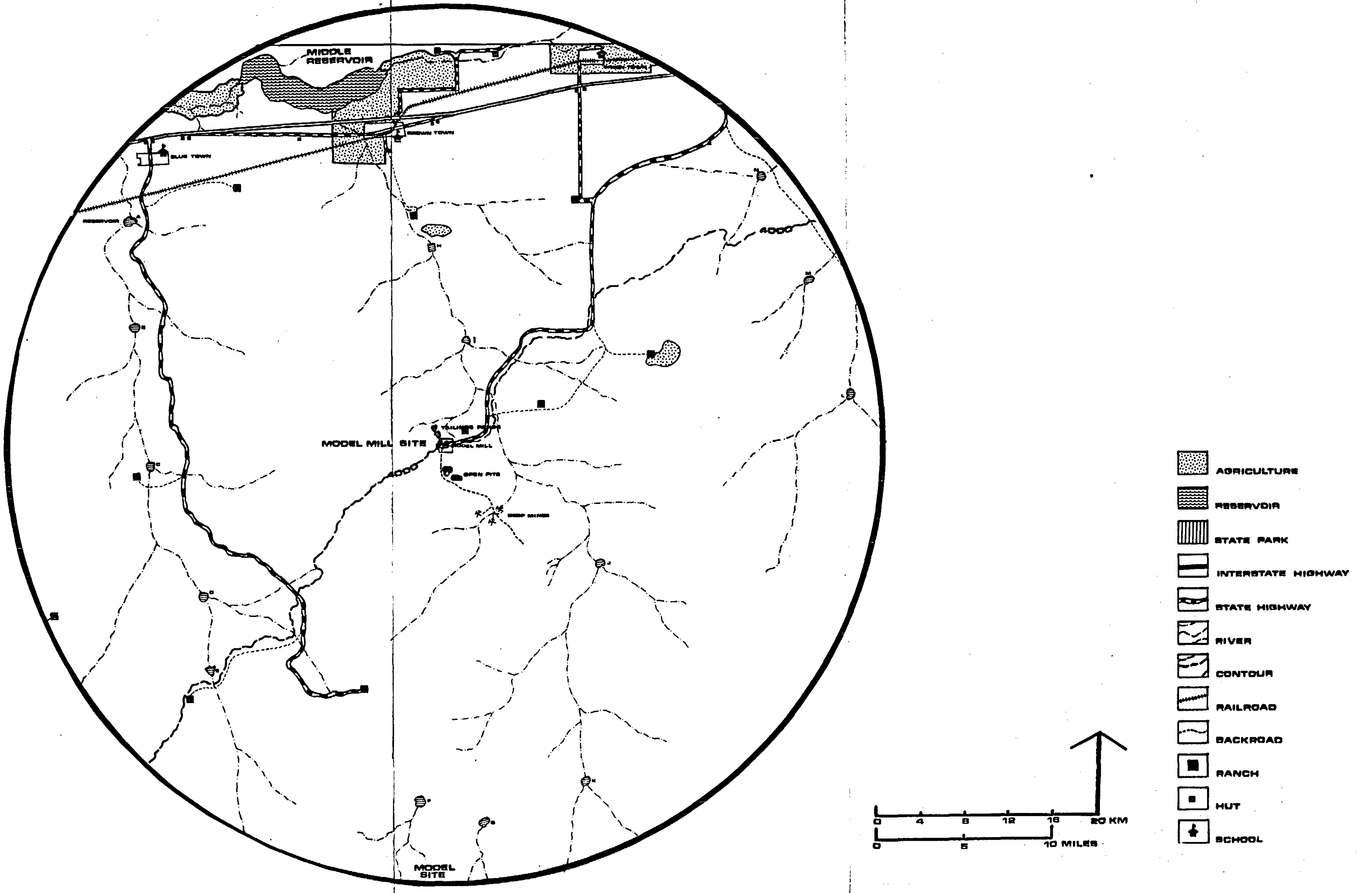

Fig. 6.1. Map of Model Region Showing Layout for One-Mill Scenario.

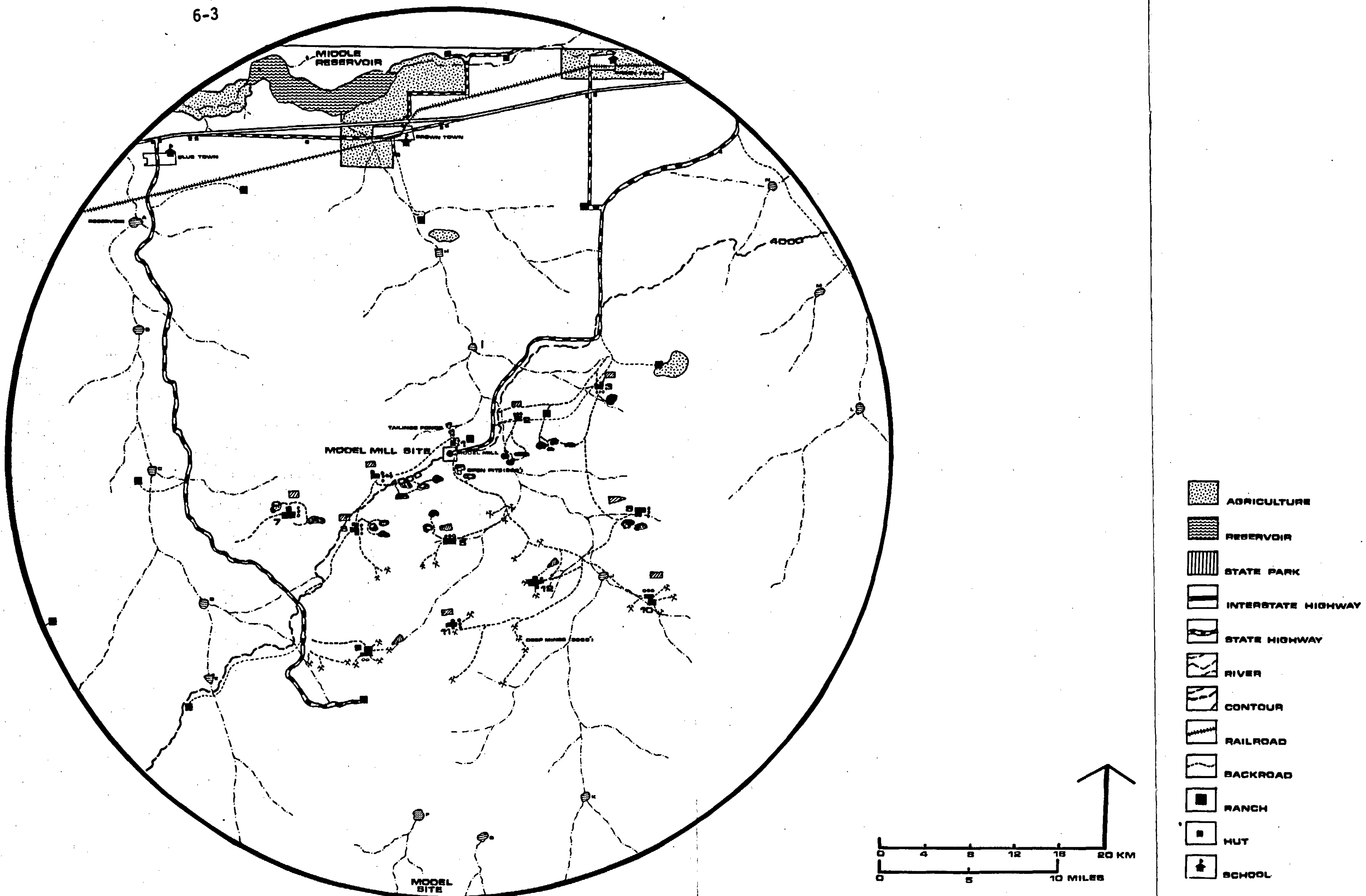

Fig. 6.2. Map of Model Region Showing Layout for 12-Mill Scenario.

6.2 SINGLE-MILL IMPACTS

6.2.1 On Air Quality

6.2.1.1 Construction

The principal impact on the air quality of the model site during mill construction would be an increase in suspended particulates as a result of heavy equipment operation. During dry periods and when wind speeds are high, fugitive dust concentrations would approach or exceed short-term federal limits in the immediate vicinity. However, no measurable impacts would be expected outside of the model site.

In order to illustrate the magnitude of impacts on air quality, it is estimated that at a distance of 1000 m (3300 ft) from the construction area the maximum average annual concentration of suspended particulates caused by the project would be less than 15 $\mu g/m^3$. This would be a less than 50% increase in dust above background levels. This estimate is based on application of the methods of Turner[1] to the assumptions that approximately 32 ha (80 acres) would be disturbed by heavy equipment at any given time and that during heavy equipment operation, dust releases would be 4.5 kg/ha-hr (4 lb/acre-hr).[2] The dust release thus would total 6.7×10^4 kg/month (74 ST/month). Drilling, blasting, and related activities would also contribute to fugitive dust releases on a sporadic basis but would not change substantially the annual average concentrations.

6.2.1.2 Operation

The major operational impact upon the air quality of the model site would be an increase in suspended particulates as a result of releases from the tailings piles, the ore pads, and a small amount from the yellowcake dryer, as well as dust raised by vehicles moving on unpaved haul roads. Since dusting from the haul roads is dependent upon road conditions, vehicle traffic, and wind conditions, only an estimate of increased dust loadings can be made.

The increase in suspended particulates that would result from the tailings pile, the ore pads, and the yellowcake dryer is estimated to be less than 10 $\mu g/m^3$ at 1000 m (3300 ft) from the center of the tailings pile, in addition to the present 35 $\mu g/m^3$ background concentration. Increased dust loadings that would result from traffic on the haul roads are conservatively estimated by assuming steady traffic on 25 km (15 miles) of haul roads with dry surfaces. The average dust release[1] would therefore be 5×10^4 kg/month (60 tons/month), resulting in an average annual increase of approximately 12 $\mu g/m^3$ at 1000 m (3300 ft) from the roads. The total suspended particulate concentration (57 $\mu g/m^3$) at the 1000-m (3300-ft) reference location would be near the 60-$\mu g/m^3$ limit of some states, such as Wyoming. The particulate concentration increase attributable to operations at the mill itself would be less than 1 $\mu g/m^3$ at the boundary of the model site.

Additional impacts upon the air quality would result from the gaseous emissions of kerosene, NO_x, SO_2, and sulfuric acid mist from the mill processes. In order to illustrate the magnitude of these impacts, concentrations of these emissions at 1000 m (3300 ft) and 25 km (15 miles) from the mill center are given in Table 6.1. These concentrations would be well below background levels, and the concentrations off the model site would be too low to be measurable.

Table 6.1. Calculated Maximum Annual Average Concentrations of Airborne Effluents from the Model Mill

Effluent	Concentration at 1000 m, $\mu g/m^3$	Concentration at 25 km, $\mu g/m^3$	U. S. Standard,[a] $\mu g/m^3$
SO_2	1	7×10^{-4}	60
NO_2	0.2	3×10^{-4}	100
Kerosene	3	4×10^{-3}	

[a]National Primary and Secondary Ambient Air Quality Standards, Federal Register, Vol. 36, No. 84, 20 April 1971.

6.2.1.3 Postoperational Impacts

The principal impact on air quality after cessation of milling activities would be the blowing of sand from the tailings area. Because the entire tailings surface would be dried, and thus subject to dusting, impacts would be greater during the postoperational period than during the operational period. It is estimated that until the area revegetated, the maximum average annual increased particulates downwind of the abandoned tailings pile would be 35 $\mu g/m^3$.

6.2.2 On Topography and Land Use

6.2.2.1 Construction

Construction of the model mill would result in land being removed from its previous use as rangeland and instead being committed to industrial use. Land occupied by the mill and tailings retention system and by power lines, access roads, parking lots, ore storage piles and septic leach fields would amount to about 150 ha (375 acres). At least an equal amount of land adjacent to buildings, roads, etc., would be disturbed by construction vehicles or would be used for construction-related activity. The total area directly impacted during construction would thus be approximately 300 ha (750 acres). In many cases, construction activities would entail changes in the topography of the land, e.g., digging of ponds and pits and erection of embankments.

6.2.2.2 Operation

During operation of the mill, there would be increased wear on the surrounding landscape by man and machinery. As milling progressed, more acreage would be taken up for tailings disposal, storage piles, and access roads and right-of-ways. During operation, about 50 ha (125 acres) of land would be devoted exclusively to milling and allied activities, and about 100 ha (250 acres) eventually would be devoted to tailings storage.

Offsite land could be impacted by blowing tailings, reducing to a small extent the grazing potential of such land. More specifically, light contamination of the upper surfaces of soil at average levels greater than 5 pCi/gm of radium is estimated to extend about 200 meters (660 ft) past the tailings pile in the downwind direction (see Appendix G-4; inferred from Figure G.4-9.). It is likely that this contamination would become concentrated above 5 pCi/gm in certain areas, such as in low spots in the surrounding terrain, where runoff collects or windblown particulates might be deposited. Concentrations above background could extend for as far as 1 km (0.6 mile) past the pile's edge. The areal extent of windblown soil surface contamination above 5 pCi/gm of radium might involve as much as about 10 ha (25 acres) of land. These estimates of contamination are consistent with some recent field research data gathered at an active mill and measurements taken at inactive mill sites. The extent to which land uses would be precluded would depend upon concentration levels and depths of mixing. It is estimated that, except for localized areas which would concentrate contamination, gamma levels would reduce to a level of 5 μR/hr a short distance from the pile's edge.

6.2.2.3 Postoperation

During the postoperation period, impacts on the topography of the site would continue unless careful consideration of topography had been incorporated into plans for reclamation of the mill site. Most of the 50 ha (125 acres) dedicated to milling activities could be returned to other uses after operations cease, but the 100 ha (250 acres) devoted to the tailings impoundment would remain unavailable. Indeed, since the tailings would not be covered, the unavailable area would probably be extended by the deposition of windblown contaminants, unless natural revegetation were to successfully stabilize the pile.

6.2.2.4 Summary

For an uncovered tailings pile at a model mill the major land use impact would be the permanent commitment of about 100 ha (250 acres) of rangeland to tailings disposal. Most aspects of land use for uranium milling are similar to those of other milling industries, but the radioactive character of uranium mill tailings poses special problems of long-term land use control. These concerns are discussed in Chapter 10.

6.2.3 On Mineral Resources

6.2.3.1 Construction and Operation

The construction of the model mill would not affect the quality or eventual exploitation of any mineral resource.

In addition to uranium (the most valuable mineral resource in the area), other mineral resources likely to be found in the region are coal, oil, and gas.

6.2.3.2 Postoperation

If the mill and tailings impoundment had been situated in the area of the model site with the lowest potential for mining, extraction of ore elsewhere in the area would not be hindered. On the other hand, the potential for further dispersion of tailings would limit postoperational mining activities in the areas occupied by the mill facilities and tailings impoundment. Metals of commercial interest could include uranium, thorium, radium, scandium,[3] molybdenum, vanadium, copper, and selenium. The model tailings pile, above grade with no cap, would allow for easier recovery of these metals.

6.2.4 On Water Resources

There are two basic types of water resources considered in impact assessments: (1) surface water (that water on the surface of the earth, such as in lakes and rivers) and (2) groundwater (that water occurring below the surface of the earth in the zone of saturation). The impacts on these two types of water resources in the model region are discussed in the following subsections for the base case. The base case includes an unlined tailings disposal area. A sensitivity analysis is carried out for groundwater impacts by varying the important parameters over an appropriate range.

6.2.4.1 Surface Water

6.2.4.1.1 Construction

Construction of mill facilities on the model site would alter the surface drainage of a small portion of the area drained by ephemeral streams. During construction the total drainage from the site would flow into these streams, resulting in minimal damage to adjacent areas.

Impact to surface water quality from construction would be primarily due to erosion of surface materials. Construction activities would expose soils (fine sandy loam) to wind and surface water runoff, which would erode and redistribute soil particles, many of which would ultimately be deposited in low-lying areas. During periods of rainfall and following snowmelt, resuspension of this material would increase the concentration of suspended sediments in the surface waters to levels slightly higher than normal. Some of the particulates probably would settle onto the stream bed; the rest of the material would remain suspended and be carried into the small stockwatering impoundments downstream from the site (Fig. D.1 in App. D). These impoundments would act as settling basins for most of the particulates; however, some material originating from the site might reach Middle Reservoir on Tributary River. The increase of suspended solids in the streams directly draining the site would be slight, and increases in Middle Reservoir and Tributary River would probably be undetectable.

6.2.4.1.2 Operation

During operation of the mill, seepage from tailings ponds could add heavy metals, suspended solids, radioactive contaminants, and soluble salts to surface waters. Three routes of contamination might occur as a result of this seepage:

1. Seepage water from the tailings pond could intercept the aquifer and contaminate the groundwater (Sec. 6.2.4.2). This contamination would eventually reach Tributary River and degrade surface water quality during periods of base river flow. Irrigation wells or water supply wells could also penetrate aquifers that have been contaminated by seepage from tailings ponds. Water pumped from such wells would normally discharge into a surface water irrigation ditch or canal and ultimately into a stream. Contaminated water extracted via such wells would remain contaminated when it entered the surface water streams.

2. Seepage water could form pools downgradient from the tailings ponds. Consideration of the transport time and concentration data for the seepage pools (Sec. 6.2.4.2) indicates that the trace materials in the pools would have the same initial composition as the tailings pond. This surface water would be subject to a high rate of evaporation, which would result in a concentration of the soluble ions as the volume of seepage water decreases. During periods of local precipitation and spring runoff this contaminated water might reach ephemeral streams and eventually Tributary River.

3. During dry periods seepage water might reach the ground surface and be subject to a high evaporation rate, which would result in salt deposits. These areas would be exposed to surface runoff during periods of precipitation (March to September) or during periods of snowmelt, during which time the precipitates again would be subject to dissolution and transport, resulting in a pulse of contaminated water reaching the

river. Depending on the amount of materials in the runoff and the dilution capacity of the existing streamflow, the water quality of the stream on rare occasions could reach toxic levels.

Rainstorms in the model region which produce 28 m^3/s (1×10^3 cfs) peak streamflows (return period of 5 to 10 years) and 2.3×10^2 m^3/s (8×10^3 cfs) (return period of 50 years) would cause runoff to reach Tributary River.[4] These peak flows would result from runoff or lateral movement of water through the soil and into the stream bed. This water movement on the surface of the soil or through the soil interstices would transport dissolved salts (contaminants) from seepage areas and areas where these contaminants accumulate through wind dispersal. The elements most likely to be transported are zinc, selenium, and arsenic (Table 5.3, Ch. 5). A small risk would exist for producing poor water quality in the river.

6.2.4.1.3 Postoperation

Seepage from contaminated groundwater would not be likely to reach the spring at stock watering impoundment I until 80 years after mill operations have ceased (Appendix E), after which time the spring water entering impoundment I would contain materials from the tailings pond. Seepage from the tailings pond would cease after the tailings dried out by evaporation. During this period, the water quality of the impoundment would depend on the amount of dilution water available (which is a function of time of year), precipitation, and runoff. Water quality will range from acceptable levels when the amount of dilution water available from runoff and streamflow is high, to conditions in which water quality standards might be violated when the stream is dry and no dilution water is available, at which time concentrations could approach 95% of that found in the tailings pond. (The Environmental Protection Agency criteria for water quality for livestock and wildlife are given in Table 6.2.)

Approximately 300 years after mill operations have ceased, contaminated groundwater would reach Middle Reservoir (Appendix E). For the 100 years following this, contaminated groundwater would continue to enter the reservoir. Because of the long time span, the frontal length of the diffused groundwater/reservoir surface water interface, and volume of dilution water, no detectable changes in surface water quality would be expected in the reservoir.

The possibility that runoff from the tailings might contaminate surface waters was considered, but the effect was found to be even more inconsequential than those considered above.

6.2.4.1.4 Water Use

Surface water use in the model mill region is principally for stock watering and irrigation. Process water for the mill would be obtained from deep production, and small volume wells in the alluvial aquifer would be used for domestic supply. No surface waters would be used in mill operations, and therefore there would be no impacts on use of surface water. These conclusions are based on the assumption that the impact of withdrawn groundwater on base flow is negligible.

6.2.4.2 Groundwater

The impacts of uranium milling operations on groundwater are generally site-specific (because of regional and local variations in geology and hydrology) and thus are difficult to discuss on a generic basis. For illustrative purposes, however, a set of geological and hydrological characteristics has been assumed for the model region (Ch. 4), and in this section, impacts to groundwater are assessed on the basis of those characteristics.

The effects of mining on groundwater can be fairly extensive and in many cases logically cannot be separated from the effects of nearby milling operations. (For instance, water containing contaminants from leakage at several Wyoming uranium tailing ponds collects in deep open-pit mines only a few hundred meters away.) For the model mill, however, it is assumed that the mines will be sufficiently far from the tailings pond to have no effect on tailings pond seepage.

Current methods of predicting movement and dispersion of contaminants do not permit accurate determination of impacts on groundwater. All of the many mathematical models in use include many simplifying assumptions that limit the degree of accuracy of the results. Laboratory data on rates of movement of contaminants are meager and generally related to specific subsoil types. Among the relevant contaminants, results to date show a wide range in ion movement rates--from dissolved sulfate, which moves at about the same velocity as water, to thorium, which essentially becomes "fixed" on soil particles and does not move. If these limitations are kept in mind, however, the methods used to determine groundwater impacts in the model region (App. E) can be used to assess impacts at actual sites.

Table 6.2. EPA Criteria for Water Quality[a,b]

Constituent	Livestock Consumption	Wildlife Consumption
pH	---	6.0 - 9.0
Alkalinity	---	30 - 130
As	0.2	---
Be	No Limit	---
B	5.0	---
Cd (μg/L)	50	---
Cr	1.0	---
Cu	0.5	---
Fe	No Limit	---
Pb	0.1	---
Mn	No Limit	---
Hg - Inorganic (μg/L)	1.0	0.5 μg/g in fish
NO^3	100 combined NO_3 and NO_2	---
NO^2	10	---
Se	0.05	---
Zn	25	---
Microorganisms	5000 coliforms/100 mL average of a minimum of two samples per month; 20,000/100 mL individual sample	2000/100 mL
Fecal coliforms	1000/100 mL average of a minimum of two samples per month; 4000/100 mL individual sample	2000/100 mL
Radioactivity	Same as Federal Drinking Water Standards	---

[a]Source: "Quality Criteria for Water," EPA 440/a-76-0.23, July 1976.

[b]Criteria are given in mg/L unless otherwise indicated.

6.2.4.2.1 Construction

Aquifers would not be disturbed and the tailings pond would not be operative during construction, thus groundwater would not be affected.

6.2.4.2.2 Operation

By far the greatest impact to groundwater resulting from operation of the model mill would be from seepage from the tailings pond. Tailings pond is used in the general sense in this context. The term is intended to include evaporation ponds or any other type of unlined facility which receives mill waste water. The model mill would contain an unlined tailings disposal area. Calculations of the seepage rate and resulting groundwater contamination are given in Appendix E. It is indicated from the calculations in Appendix E-1 that the seepage rate from the unlined tailings pond would be 2.2 x 10^5 m^3/yr (110 gpm), or equivalent to 0.365 m/yr over the area of the pond. With more permeable subsoil conditions, seepage would not be much greater because the net inflow to the tailings pond from the mill would be 4.6 x 10^5 m^3/yr (230 gpm).

The rate of movement of liquid seeping from the tailings pond, as determined in Appendix E-2, would be 3.7 m/yr (12 ft/yr) downward from the tailings pond; the first seepage would thus reach the water table at 25 m (82 ft) depth in about seven years. After spreading downward and outward from the center of the tailings pond to a parabolic bulb of 1000-m (3300-ft) radius (22 years after mill operations start), the seeping liquid would move downgradient (towards the north, Fig. E-2.1, App. E) at an average velocity of about 80 m/yr (260 ft/yr).

The principal contaminants in the acidic tailings pond liquid would be radium, thorium, sulfate, iron, manganese, and selenium. (The concentrations of dissolved contaminants in the seeping liquid are calculated in Appendix E-3.) In spite of the initial presence of radioactive materials in the seepage, no radioactive contamination of groundwater would be expected during or after mill operation. After 15 years of mill operation, radium, the most common and mobile radionuclide, would have advanced only about 0.3 m (1 ft) below the bottom of the tailings pond. Thorium, a common radionuclide in the tailings water, would have penetrated less than 0.1 m (0.3 ft).

Under the buffering conditions assumed for the porous medium in the model, the acidic seepage water would be completely neutralized as it advanced through the subsoil. Many ions held in solution in the acidic tailings pond water would tend to precipitate out, and other ions would undergo ion exchange in the subsoil and be removed from solution. The only contaminant ions expected to remain in the seeping water are sulfate, iron, manganese, selenium, and possibly calcium, sodium, and some trace elements, such as lead and arsenic. Conservative estimates of the concentrations of major contaminants which would reach a ranch house well 2 km (1.2 miles) downgradient are listed in Table 6.3. The concentrations of iron, manganese, sulfate, and selenium could exceed the U.S. EPA maximum permissible drinking water concentration.

In addition to seepage directly under the pond, it is postulated that a small amount [< 1 L/s (≤ 15 gpm)] of tailings liquid would seep under the tailings impoundment and leak out at the north side of the dam (Fig. E-2.1, Appendix E). The concentrations of contaminants are also given in Table 6.3. The seep is postulated to begin about one year after mill operations commence and last until the operations cease. The impacts of this seepage on water resources are described in Section 6.2.4.1.

6.2.4.2.3 Postoperational

It was indicated above that no radioactive contaminants would have reached the water table at a depth of 25 m (80 ft) after 15 years. After mill operations ceased, no more water would be added to the tailings pond by the mill, and the idle tailings would drain to a moisture content in equilibrium with gravity and atmospheric conditions. During the postoperational period an advancing front of seepage water containing nonradioactive contaminants (including 2000 mg/L sulfate, 10 mg/L iron, 5 mg/L manganese, 32 mg/L selenium, and possibly other metals in dilute concentration) would extend about 2000 m (6600 ft) in width and be moving downgradient (toward the north) at an average velocity of 80 m/yr (260 ft/yr). In this analysis, contaminant concentrations have been calculated on the assumption that there would be no lateral dispersion; this is a conservative assumption in that it results in overestimation of downgradient concentrations of contaminants. As these contaminants disperse downgradient, their concentrations would be reduced. After about 360 years seepage water would ultimately discharge into Middle Reservoir, reaching a maximum concentration of less than 6.5 mg/L iron after 400 years, and gradually diminishing to background concentration during the following 40 years. Sulfate, manganese, selenium, and trace metals would be reduced in concentration as shown in Appendix E and Table 6.3. Perhaps the greatest impact would occur at Reservoir I, 8 km (5 miles) downgradient from the tailings pond. Because of sporadic rising of the water table as a result of locally heavy precipitation, groundwater might seep into surface waters, causing perennial reaches in a normally ephemeral stream. Tailings pond seepage water would reach this surface outlet after 100 years, with iron reaching a maximum concentration of 9.5 mg/L after 125 years and dropping to background concentration after 150 years. Other contaminant concentrations at Reservoir I are shown in Table 6.3.

After mill operations cease, seepage from the tailings would be substantially reduced because of the cessation of discharge of water from the mill. It is shown in Appendix E that the permanent seepage rate caused by precipitation (consisting of relatively pure water) falling on the uncovered, abandoned tailings would be about 1.12×10^4 m^3/yr (4×10^5 ft^3/yr), about 5% of the rate during the 15-year operational period. A small degree of radioactive contamination of groundwater would occur after about 1500 years; a small degree of nonradioactive contamination would occur continuously, but the concentrations of contaminants would decrease with time. It should be emphasized that this analysis assumes that no new wells are permitted which would withdraw contaminated groundwater from the aquifer affected by the seepage.

6.2.4.2.4 Variation of Parameters for Groundwater Seepage

It should be emphasized again that the predictions given above are based on a set of hypothetical geological and hydrological characteristics postulated for a model mill site. The values given in the predictions were derived from the use of mathematical models described in Appendix E. Because a wide range of geological characteristics occur at actual sites, this analysis is intended for illustrative purposes only. To illustrate the range of effects expected, a sensitivity analysis for parameters used in assessing groundwater impacts is presented in Table 6.4. The effects on dependent variables caused by changes in independent variables are shown in the table. The maximum and minimum values of the independent variables are believed to represent a reasonable range expected for the environs of uranium mill sites in the six U.S. regions in which uranium mining occurs.

Table 6.3. Concentration of Major Groundwater Contaminants

Contaminant	U.S. MPC[a]	EPA[e]	Mill Effluent to Tailings Pond	Seep at Base of Tailings Pond	Ranch Well, 2 km Downgradient[b]	Reservoir I, 8 km Downgradient[c]	Middle Reservoir, 30 km Downgradient[d]
pH (units)	6-9	6.5-8.5	2	(neutralized) →			
Iron (mg/L)	0.3	0.3	1,000	10	10	9.5	< 6.5
Manganese (mg/L)	0.05	0.05	500	5	5	4.75	< 3.25
Sulfate (mg/L)	250	250	30,000	2000	2000	1950	< 1300
Selenium (mg/L)	0.01	0.01[f]	20	32	32	30	< 21
Radium (pCi/L)	3	5	250	(reduced to background) →			
Thorium (pCi/L)	2000[g]	--	90,000	(reduced to background) →			
Other trace metals	--	--	(up to 100 x background)	(appreciably reduced) →			

[a]U.S. Public Health Service maximum permissible concentration.

[b]Reaches maximum concentration at 45 to 55 years.

[c]Reaches maximum concentration at 125 years.

[d]Reaches maximum concentration at 400 years.

[e]EPA secondary maximum drinking-water level.

[f]EPA interim primary maximum drinking-water level.

[g]10 CFR 40.

Table 6.4. Sensitivity Analysis for Variables Used in Groundwater Impacts (maximum and minimum values show range reasonably expected within the six physiographic regions)

	Independent Variable (cause)								Dependent Variable (effect)			
	Subsoil											
	Hydrogeology				Hydrogeochemistry		Meteorology		Seepage Effects		Downgradient Effects (Reservoir I)	
	Saturated Hydraulic Conductivity (cm/sec) K_h	K_v	Water Table Slope	Dispersivity[b] (a_i) (M)	Distribution Coefficient[a] (K_d) (mL/g)	Percent $CaCO_3$	Mean Annual Ppt. (cm)	Mean Annual Evap. (m)	Seepage Rate ($\times 10^5$ m^3/yr)	Ra Movement 15 years (m below tail. pond)	Time for Maximum Conc. to Res. I (yrs.)	Maximum Concentration Se at Res. I (mg/L)
Base Case	10^{-2}								2.20	0.26	125	30
Maximum	10								c	c	~10	10[d]
Minimum	10^{-4}								c	c	~12,500	32
Base Case		10^{-5}							2.20	0.26	125	30
Maximum		10^{-3}							6.57	26	c	12[e]
Minimum		10^{-7}							0.03	0.0026	c	90
Base Case			0.0025						2.20	0.26	125	30
Maximum			0.025						c	c	~30	20[f]
Minimum			0.001						c	c	~500	31
Base Case				5					2.20	0.26	125	30
Maximum				500					c	c	30	20[g]
Minimum				0.05					c	c	c	32
Base Case					10				2.20	0.26	125	30
Maximum					1,000				c	0.0026	c	c
Minimum					1				c	2.6[h]	c	c
Base Case						1			2.20	0.26	125	30
Maximum						10			c	c	c	c
Minimum						0.1			c	c	c	c,i
Base Case							31		2.20	0.26	125	30
Maximum							90		1.73	c	c	37[j]
Minimum							15		3.94	c	c	30
Base Case								1.5	2.20	0.26	125	30
Maximum								1.8	1.97	c	c	57[k]
Minimum								1	2.85	c	c	25[m]

[a]The usefulness of this parameter in adequating assessing groundwater seepage rates is questionable, particularly in cavernous limestone or lava flows.

[b]Dispersivity is extremely hard to determine and few field data are available.

[c]Variation of independent variable does not change dependent variable.

[d]Increase in K_h increases downgradient velocity, which increases dispersion, which causes decrease in concentration.

[e]Increase in K_v decreases Q_{evap} which changes residual concentration.

[f]Increase in slope increases downgradient velocity, which increases dispersion, which causes decrease in concentration.

[g]Increased dispersion decreases downgradient concentration, but spreads the contamination over a longer time.

[h]Groundwater contamination by radium does not occur because water table is at 25-m depth.

[i]Subsoil still has adequate neutralizing capacity to completely neutralize advancing seepage.

[j]Decrease in precipitation results in larger concentration in the residual tailings pond liquid.

[k]Increase in evaporation increases the concentration in the residual tailings pond liquid.

[m]Selenium concentration changes because residual concentration changes in pond because of changing evaporation and precipitation.

The analysis given here is a simplification of a complex hydrogeologic situation. Many variables are interdependent and cannot be assigned as being either dependent or independent. An example is the seepage rate, which is affected by changes in evaporation and yet also causes changes in evaporation. In addition, only changes in the effects of a given variable on one other variable are treated in this analysis. In nature these parameters are interrelated in complex ways. For instance, an increase in the vertical hydraulic conductivity (which brings about an increase in the seepage rate) is often associated with deep water tables (which lessen the likelihood of radioactive contamination).

Only the independent variables believed to be most important in terms of groundwater impacts are listed in Table 6.4. Some variables, such as depth to water table and porosity and thickness of subsoil, were not evaluated. The effects of variation of the chemistry of the tailings pond liquid are discussed under four surface water impacts (Ch. 9). The dependent variables were chosen as being indicative of groundwater contamination. In spite of the limitations of this study, a cursory inspection of the table shows that some independent variables have a profound effect on the dependent variables chosen to illustrate groundwater contamination. An increase in the vertical hydraulic conductivity brings about a moderately large increase in the seepage rate and a large increase in the distance radium moves into the subsoil. However, the concentration of selenium is lowered downgradient. Changes in the horizontal conductivity cause profound changes in the time of arrival of contaminants downgradient. The wide range in the distribution coefficient of radium brings about a directly related change in the distance that radium moves. The variations of water table slope, dispersion coefficient, percent $CaCO_3$, and meteorological parameters do not cause very large changes in the dependent variables.

6.2.4.2.5 Water Use

Operation of the model mill will result in the use (loss to evaporation, seepage and entrainment in the tailings pile) of about 4.6×10^5 m^3 (1.2×10^8 gallons) of water annually. However, because process water for milling operations will be obtained from the Jurassic sandstone aquifer, no additional impact to groundwater will result from process water withdrawals. Most of this water [about 60% or 2.8×10^5 m^3/yr (7.4×10^7 gallons/yr)] will be consumptively lost into the atmosphere via evaporation from the tailings pond. Because dewatering of the aquifer for mining will lower water levels in the aquifer only locally, the groundwater supplies of the nearby towns, 32 km (20 miles) and more distant from the milling and mining locality, will not be impacted. This is due to the large volumes of groundwater in storage in the alluvial aquifer and the relatively low withdrawal rates. Even if process water were pumped from the shallow aquifer the water use patterns at a distance of 32 km (20 miles) would not be adversely affected.

6.2.4.2.6 Summary

The principal impact of the unlined pond of the model mill on groundwater would be contamination by selenium, sulfate, manganese, and iron that would limit the use of groundwater as a drinking supply in a belt 2000 m (6600 ft) wide. The concentrations of these elements in this groundwater zone would exceed the U.S. MPC. The parameter variability study indicates that the hydraulic conductivity and distribution coefficients are the variables causing the widest range in variation of the dependent variables chosen to represent groundwater contamination impacts. A similar sensitivity analysis for the Jeffrey City, Wyoming, tailings pond showed that varying the distribution coefficient was most effective in changing groundwater contamination predictions.[5] Several variables which could be significant but which are conservatively not considered here are lateral and vertical dispersion. Including these would decrease concentrations in the predicted seepage plume. Alternatives for reducing this impact are discussed in Chapter 8. The model mill will consume about 4.6×10^5 m^3 (1.2×10^8 gallons) of water annually; most of this water will be lost through evaporation.

The limitations of the assessment of the groundwater impacts for the base case are a result of the site-specific nature of hydrogeologic processes. The basic type of subsoil encountered is the dominant parameter upon which all predictions of groundwater contamination rest, because its geologic character determines the hydraulic conductivity and the distribution coefficients.

6.2.5 On Soils

Impacts to soil, although of concern in any region, are of particular importance in arid and semiarid regions, where the rate of soil formation is very slow and where the potential for wind erosion is high. The major impacts of the model mill on the soils of the site and region are described in this section, based on the soil characteristics given in Chapter 4, on actual data from operating mills, and on model mill effluent characteristics described in Chapter 5.

6.2.5.1 Construction

Construction of the mill would permanently remove about 150 ha (375 acres) of the model site's soils from rangeland productivity. It is assumed that the topsoil removed during construction would be stored; however, topsoil storage does not automatically ensure that productivity of the stored material is retained. It is also likely that much of this material would be lost because of wind and water erosion during the 20 or more years of storage. Productivity would be lost on an additional 70 ha (200 acres) during the construction (and operation) period. Construction of the mill would cause no major impacts to soils outside the model site. (Increased grazing by animals displaced from the construction site probably would cause some small additional soil compaction and erosion in the areas to which the animals move.)

6.2.5.2 Operation

During operation of the mill, impacts to soils of the site would result from chronic seepage of solution from the tailings impoundment, and from deposition of windblown tailings. Seepage and other releases of tailings solution would result in loss of organic matter from the soil, leaching of nutritive ions from the soil exchange complex, and eventual salinization of the soils. A soil is said to be salinized when a saturation extract exceeds a conductivity measurement of 4 mmhos/cm at 25°C. Salinized soil cannot support other than salt-tolerant plant species. Most rangeland species can tolerate salinities up to 8 mmhos/cm;[5] beyond about 12 mmhos/cm, the vegetation becomes largely unpalatable to cattle. Soil structure is destroyed under saline conditions, which increases the erosion hazard. Copious amounts of fresh water would be required to flush the salts from the soil, and since rainfall in the area is low, reclamation of salinized areas would be difficult.

In the analysis of seepage from the unlined tailings pond on the model site (App. E) it is assumed that there would be no upward movement of seepage from the tailings pond; in that case, no adverse effects to soils would occur except as a result of the small surface seepage of less than 1 L/s (15 gpm) at the north end of the pond. This seep would contain 2000 mg/L sulfate (Table 6.3), and would affect an area of 1.3 ha (3.2 acres). After 20 years, the sulfate concentration in the soil, assuming a 50-cm (20-inch) soil depth, could reach as high as 14%. At this high concentration, salt crusts would accumulate on the soil surface, no vegetation would be likely to grow, and the soil would be susceptible to erosion.

Deposition of windblown tailings can change the physical and chemical characteristics of soils. At an operating mill near Jeffrey City, Wyoming, samples of surface soils downwind of an active tailings pond were lower in pH, higher in total salt content, and had higher concentrations of sulfate, nitrate-nitrogen, sodium, and arsenic than soil samples taken farther away from the pile along the same transect.[5] In a few cases, these changes can be beneficial, e.g., higher nitrogen and sulfur content of the soil would lead to better vegetative growth, particularly in soil low in organic matter. The majority of the changes, however, are likely to be adverse, e.g., soil salinization (high total salts), alkalinization (high sodium), and decrease in pH.

The acid-leach milling process results in the release of sulfur dioxide to the atmosphere. In the atmosphere it normally undergoes chemical transformation to the sulfate ion, which eventually is brought down to the soil surface by rainfall. The average sulfate ion concentration in the troposphere is 2 $\mu g/m^3$;[6] the calculated maximum annual average concentration of sulfate ion from mill operation at a distance of 1000 m (3000 ft) downwind from the building would be 1 $\mu g/m^3$ (Sec. 6.2.1.2), assuming that all the SO_2 emitted would be converted to the sulfate ion. These emissions would thus add about 50% more sulfate ion to the soil than would be brought down normally by rain. These additions to the soil would tend to increase soil fertility.

Soils of the region outside the model site would not be affected by mill operation.

6.2.5.3 Postoperation

Much of the soil removed from 150 ha (375 acres) during construction of the mill buildings and the tailings impoundment and subsequently stored during mill operation would be lost through erosion during the 20-year storage period. That material remaining could be placed as earth cover to aid revegetation during reclamation procedures. The additional 70 ha (200 acres) of soil disturbed during construction and operation probably could return to productivity within five years if proper revegetation procedures were followed. No additional soil losses or impacts would occur after operation ceases, unless previously undisturbed soils were removed for reclamation of the mine or mill sites.

6.2.5.4 Summary

The major impacts to soils of the model site would be loss of soils on about 150 ha (375 acres) and salinization of about 1.3 ha (3.2 acres). These impacts can be considered either as an acceptable trade-off for electric power or as an irretrievable loss of long-term rangeland productivity.

6.2.6 On Biota

The major nonradiological impacts to biota that may arise during construction and operation of the model mill and during the postoperation period are described in this section. The analysis was based on the characteristics of the model site as described in Chapter 4 and on actual data from operating mills.

6.2.6.1 Terrestrial

6.2.6.1.1 Construction

Impacts to the terrestrial ecosystem of the model site during construction are summarized in Table 6.5. Construction of the mill would result in a 0.05% reduction in the total rangeland production on the model site. The loss of small-mammal biomass on the 220 ha (550 acres) altered by construction would include 200 to 1200 ground squirrels, deer mice, grasshopper mice, and kangaroo rats. These animals would be destroyed or die rather than simply move to nearby undisturbed areas--their home ranges are relatively small,[7] and according to the U.S. IBP data,[8] invertebrate food reserves in a shortgrass community are marginal; thus the terrestrial communities surrounding the construction area would already be at their maximum carrying capacity. The significance of these losses to the regional ecosystem is beyond present assessment capabilities; however, these losses would be similar to those from construction of other industrial or commercial installations in the same area and involving the same amount of land.

Bird populations would be impacted by the loss of rodents serving as food sources for raptors, by loss of seed sources, which comprise about 30% of food sources for nongamebirds of the site, and by loss of invertebrates, which comprise 70% of the diets of dominant bird species. In addition, loss of vegetation would reduce the available nesting habitat. The larger mammals (cattle, sheep, and pronghorn antelope) which no longer had access to the site would graze offsite, thus increasing to a small extent the grazing pressure in the region. Since the number of these animals would be relatively small, about five cows or 25 sheep, the effect on regional grazing or rangeland would be small. The staff also estimates that 3 to 15 pronghorn antelope would be similarly displaced. However, No competition between displaced antelope and livestock is anticipated because antelope do not compete intensively with cattle, preferring browse and forbs rather than grasses.[9] Adverse impacts to the antelope would result from increased highway or road accidents and increased hunting pressure from construction workers.

Windblown dust from construction operations would be deposited on vegetation, leading to a decrease in photosynthetic activity, a decrease in primary productivity, and an increase in toothwear of grazing animals. These effects, although not quantified, would be minor relative to the total loss of rangeland productivity from the 220 ha (550 acres) disturbed.

6.2.6.1.2 Operation

Biota could be affected as a result of seepage of potentially toxic elements from the tailings impoundment, or from purposeful or accidental releases of tailings solution outside the impoundment. These substances, which originate in the uranium ore, include radionuclides (discussed in Sec. 6.2.8), selenium, molybdenum, manganese, vanadium, and nitrate. If these potentially toxic elements are released, or seep, from the tailings pond, they could reach animal drinking water sources. The drinking water concentrations above which these elements and ions are toxic to livestock, and presumably also to wildlife, are listed in Table 6.6. In some cases concentrations exceeding the recommended limits for some of these elements have been found in the ground and surface waters in the vicinities of actual mines.[10,11] The surface seep from the northern end of the model mill tailings impoundment would contain potentially hazardous concentrations of such chemicals as lead, arsenic, and selenium (see App. E-3). Domestic animals and wildlife drinking exclusively from this seep might suffer acute or chronic selenium poisoning.[12] However, access by domestic animals to such a seep could be easily restricted. This impact will be minor.

Table 6.5 Site Biotic Losses Due to Construction of a Single Mill[a]

Biotic Element	Quantity Lost
Primary production	1.3×10^3 GJ
Seed production	2.8×10^3 GJ
Secondary production	5.9 GJ
Small mammal biomass[b]	7.9×10^3 grams to 2.2×10^5 grams
Livestock	5 cows or 25 sheep displaced
Large mammals	3 to 15 pronghorn antelope displaced
Avifaunal biomass[c]	3.9×10^4 grams

[a]Values based on data from the U.S. IBP shortgrass prairie community (see Section 4.9.1.2). Based on a total of 230 hectares of land disturbed.

[b]Consisting primarily of four species: northern grasshopper mouse, deer mouse, Ord kangaroo rat, and 13-lined ground squirrel.

[c]Consisting primarily of horned lark, western meadowlark, lark bunting, and McCown's longspur.

Table 6.6 Recommended Limits for Concentrations of Elements and Ions in Livestock Drinking-Water Sources Above Which Toxic Effects May Occur[a]

Element or Ion	Recommended Limit, mg/L
Aluminum	5
Arsenic	0.2
Boron	5.0
Cadmium	0.05
Chromium	1.0
Copper	0.5
Fluorine	2.0
Lead	0.1
Mercury	0.01
Molybdenum	uncertain[b]
Nitrate	100
Nitrite	10
Selenium	0.05
Vanadium	0.1
Zinc	25
Total soluble salts	5000

[a]Compiled from "Water Quality Criteria, 1972," National Academy of Sciences for U. S. Environmental Protection Agency, EPA-R3-73-033, March 1973.

[b]Toxicity is influenced by many factors. Natural surface waters rarely contain over 1 mg/L (see "Water Quality Criteria, 1972").

These toxic elements could also be ingested through the food chain. The soils of the site are mainly sandy loams with relatively low cation-exchange capacity (Sec. 6.2.4.2) and thus would have little retention capacity for some toxic cations. In addition, although absorption of an element by the soil exchange complex would temporarily exclude it from entering the groundwater, it would not exclude it from entering the food chain via uptake by vegetation. The accumulation in forage vegetation could be toxic to herbivores. The availability of these ions for plant uptake is mainly dependent on the ionic form of the element, which in turn is partly a function of the pH of the soil solution. In the normally alkaline milieu of the site soils, elements such as iron and manganese would be relatively unavailable to plants; however, introduction of the acid tailings solution could make these elements sufficiently available to cause toxic effects to vegetation. On the other hand, the availability of selenium to plants generally decreases with increasing soil acidity.[12] Iron and managnese are not absorbed by plants in amounts toxic to grazers.[13] Molybdenum and selenium, however, can be tolerated in certain plant species and accumulated in amounts toxic to grazers. Values for the normal range and maximum concentration of trace metals in plants are listed in Table 6.7. Windblown tailings deposited on the soil could also add potentially toxic elements to the plant growth medium, and thence into the plant and herbivore; such tailings deposited on foliage would be consumed directly by herbivores.

Additional impacts to terrestrial biota from mill operation would be the radiation effects discussed in Section 6.2.8 and the hazards due to increased road traffic, increased hunting pressure, and physical obstructions, such as electrical transmission towers and lines that can pose hazards to raptors. The presence of transmission towers in an area essentially devoid of observation perches may encourage raptor foraging on the mill site, thus increasing the chance of exposure of raptors to radionuclide-contaminated food sources and to site hunters. However, all of these impacts are believed to be minor.

Table 6.7 Normal Range and Suggested Maximum[a] Concentrations of Metals and Ions in Plant Leaves[b]

Element	Concentration, ppm, dry wt Range	Maximum
Arsenic	0.1-1.0	2
Barium	10-100	200
Boron	7-75	150
Cadmium	0.05-0.20	3
Cobalt	0.01-0.30	5
Copper	3-40	150
Chromium	0.1-0.5	2
Fluorine	1-5	10
Iodine	0.1-0.5	1
Iron	20-300	750
Manganese	15-150	300
Molybdenum	0.2-1	3
Nickel	0.1-1.0	3
Lead	0.1-5.0	10
Mercury	0.001-0.01	0.04
Selenium	0.05-2.0	3
Vanadium	0.1-1.0	2
Zinc	15-150	300

[a]Concentrations that exceed the listed "maximum" values may or may not result in toxic effects upon the vegetation or herbivores, depending on the species tolerance, the amount of herbage consumed, and the concentration in excess of that listed.

[b]Data of S. W. Melsted, "Proc. Joint Conf. Recycling Municipal Sludges Effluents Land," pp. 121-128, 1973, as cited by D. E. Baker and L. Chesnin, "Chemical Monitoring of Soils for Environmental Quality and Animal and Human Health," in: Adv. in Agron. 27:305-374, 1975.

6.2.6.1.3 Postoperation

Nonradiological impacts to biota following cessation of operations would result from remnants of seepage, reduction of food resources on salinized areas, and continued deposition of windblown tailings. The latter factor in particular would cause build-up of potentially toxic elements in the surface soils, continued accumulation by perennial vegetation, and subsequent toxic effects to vegetation and/or animals. Deposition of windblown tailings on surfaces of vegetation would allow direct consumption of radionuclides and potentially toxic elements by herbivores. Members of higher trophic levels (i.e., carnivores) would be affected to a lesser degree since their foraging habits generally encompass a larger area, thus reducing the likelihood of their consuming high concentrations of toxic elements.

6.2.6.1.4 Summary

For the base case model mill, the major impacts to terrestrial biota would arise from removal of habitat and from contamination of forage with potentially toxic elements originating in seepage and fugitive dust from the tailings impoundment. The importance of these impacts is difficult to assess, but long-term effects to herbivores such as cattle could be appreciable. In Chapter 9, alternatives are examined that would reduce some of these impacts.

6.2.6.2 Aquatic

No impact to aquatic biota would result during the construction or postoperational phases. During the operational phase, however, it is possible that the initial flow to Tributary River following heavy precipitation could contain concentrations of contaminants exceeding water quality criteria (Sec. 6.2.4.1.2). Even if this happened, little effect on aquatic biota would be expected because of subsequent dilution of contaminants (see discussion in App. D).

6.2.7 On the Community

The communities of a specific region may experience a wide variety of impact responses to uranium development. Prediction of site-specific impacts depends upon recognizing the major variables producing the impacts and the way in which these variables interact at the community, regional, and/or national level. The approach used in developing the impacts outlined in the following sections is more thoroughly described in Appendix F-1.

6.2.7.1 Construction

Demography and Settlement Patterns

The construction of the model mill would require 120 workers,* and the staff for the operational phase would eventually total 160 workers* (all of the demographic estimates used herein are discussed in Appendix F-2).

About 40% of the mill work force would consist of residents from the impact region,[14] most would remain at their existing residences. Some construction workers would be expected to commute over distances of 80 km (50 miles) one-way.[15] The urban areas of East and West Cities would have the largest and most diversified work forces in the region; consequently a large number of workers would commute from those towns to the mill site. At least half of the in-migrating workers would be expected to prefer to live in a small town/rural setting. The demographic effects of construction (and operation) of the model mill are summarized in Table 6.8 and more fully explored in Appendices F-2 and F-3.

Social, Economic, and Political Systems

Construction of the model mill would result in minimal effects on the sociocultural organization of the region as a whole. However, impacts of different magnitudes would be experienced at the family, neighborhood, and community levels.

Workers, in-migrant service personnel, and families moving into the area would occupy the few vacant homes available. The lack of zoning would allow fringe developments for mobile homes and uncontrolled use of available lots for trailer homes and campers in and around the towns. Competition for housing and increased costs would result in problems for retirees and other people living on fixed incomes.[16,17] For the most part, construction of the model mill would have little impact on the public services of the counties and communities of the region; the most notable impact would be the additional pupils enrolling in the school system of County S_1. The approximate increases in demands and costs throughout the area are shown in Tables F-4.1 and F-4.2 of Appendix F-4.

The regional economy would be stimulated both by the local purchases of goods, materials, and services directly related to the construction activities and by the local spending of wages by construction and service workers and their families.

*These are the actual estimates. The higher totals of Table 6.8 result from the partitioning of these workers among the various cities and the avoidance of fractional workers.

Table 6.8. Summary of Demographic Effects of Construction and Operation of a Single Model Mill[a]

City	Distance from Mill, kilometers	Population	Five-Year Projected Population without Development[b]	Construction Phase: Workers and Families Non-Local	Construction Phase: Workers and Families Local	Construction Phase: Workers x 2.3 Family Members	Construction Phase: Secondary Workers and Families (0.6 multiplier)	Operational Phase: Workers and Families Non-Local	Operational Phase: Workers and Families Local	Operational Phase: Workers x 2.3 Family Members	Operational Phase: Secondary Workers and Families (1.2 multiplier)
Green	38	500	510	25	10	80	50	35	10	100	120
Brown	29	500	510	5	10	35	20	5	10	35	40
East	48	13,000	13,330	40	20	140	85	55	25	185	225
Purple	64	500	510	5	5	25	15	5	5	25	30
Blue	38	500	510	5	5	25	15	5	5	25	30
West	80	22,000	22,550	0	5	10	5	0	5	10	10
Red	70	1,500	1,540	0	0	0	0	0	0	0	0
White	60	500	510	0	0	0	0	0	0	0	0
Orange	63	500	510	0	0	0	0	0	0	0	0
TOTAL		39,500	40,480	80	55	315	190	105	60	380	455

[a]The values in this table have been rounded to the nearest 5 from estimates more fully explained in Appendix F-4.

[b]Based on growth of 2.5% over five years.

Probably no notable political impacts to the political structure would be perceived.

Archeological and Historic Resources

Five prehistoric archeological sites have been identified in the model site. A careful study would have to be made to determine if any are eligible for inclusion in the National Register and to determine if construction plans posed any threat to the known sites.

Esthetics and Recreational Resources*

The location of the model mill site is remote from centers of population and traffic routes, so the plant would not be visible to the general public. Even so, the mill buildings, tailings pond and equipment areas are designed and constructed so as to be as unobtrusive as possible on the surrounding landscape. The mill site is not located in an area of extensive recreation resources, and those that do exist in the area would not be significantly impacted.

6.2.7.2 Operation

Demography and Settlement Patterns

The general in-migrant settlement and local commuting patterns identified for the construction period would continue during the operational phase (see Table 6.8 and Appendices F-2 and F-3).

Social, Economic, and Political Systems

The economic benefits identified for the construction phase would continue to accrue to the local communities and to the region. Sociocultural costs would be largely confined to the effects from the in-migrating members of the operational work force and their families on members of local communities. Because of the high turnover rates of mill workers (50 to 100% per year, see Appendix F-2), many families would not remain long enough to adjust to the new setting and become integrated into the local sociocultural setting. Stress would likely be experienced by local families as well as by the operational work force. Many workers and families would move into temporary housing in fringe developments established during the construction period. Highly changing neighborhoods of this type are associated with numerous family, social, and economic stresses.[15-19]

Demands for county and community services would be generally similar to those experienced during construction, but the magnitude and duration of impact would be different. An increased demand could develop for public or private social and health services beyond those traditionally considered necessary (see App. F-4).

Over the life of the mill, the company would purchase some local materials and supplies, possibly providing an opportunity for development of new businesses and/or the expansion of older establishments. The workers and service personnel would also contribute economic benefits to the area by spending a portion of their wages locally for rent, food, recreation, and other goods and services.

Notable impacts on the political structure are not expected.

Archeological and Historic Resources

During operation of the mill, the remaining archeological sites would be preserved and protected.

Esthetics and Recreational Resources

The principal esthetic impact of the model mill would depend mainly on the maintenance of the tailings ponds and of the mill buildings.

Dispersed recreation, outdoor recreation in which participants are usually spread out over relatively large areas, would increase in the model region with the influx of workers and their families and construction of additional roads for mineral exploration and mine access. However, if certain sections of the mill are fenced (e.g., tailings pond), this recreation can exist compatibly with livestock, wildlife, timber harvesting, or mining.

*See Appendix F-5 for further discussion.

6.2.7.3 Postoperation

Demography and Settlement Patterns

Portions of the operational force would be absorbed into the regional job market; however, it might be necessary for these workers to commute to the towns of West or East, where more job opportunities would exist. Another portion of the operational force probably would move out of the region.

Social, Economic, and Political

There would be only minor impacts on the region once the mill workers left. Since the population of the region would have increased by only approximately 2% as a result of the mill, few social or economic dislocations would be experienced when a portion left. In fact, the absence of the operational work force with its high turnover, might increase the stability of some neighborhoods.

Archeological and Historic Resources

When the operational force leaves the mill facility, archeological sites would no longer receive physical protection unless special arrangements were made.

Esthetics and Recreational Resources

On the basis of the assumed conditions, the postoperational impacts on the esthetic resources of the site could be severe. The tailings ponds would be vulnerable to both wind and water erosion, and some dispersion of tailings over the surrounding area is to be expected. Appropriate decommissioning, including screening the site using physical manipulation of landforms and the removal of obtrusive mill structures (stacks, utility lines, etc.), would reduce visual impact; however, the tailings ponds would constitute an unnatural and permanent fixture on the landscape.

The presence of the tailings disposal areas would contribute to the devaluation of the land in the immediate vicinity as a potential recreation resource.

6.2.8 Radiological Impact

In this section, the methodology used to predict individual and population dose commitments from a single model mill is described, and these doses and the related health effects are summarized. The radiological impact of multiple mills within the same model region is described in Section 6.3.8. In both of these sections only the impact on the area within an 80-km (50-mile) radius of the hypothetical milling operation is considered. The potential impact of the uranium milling industry on the entire North American continent is addressed in Section 6.4.

This document includes detailed consideration of radiological risks to the general public, either as individuals or members of a population group, and also addresses, in Section 6.2.8.4, radiation dose commitments to workers who are occupationally exposed in the uranium milling industry. There would also be radiological impacts on species other than humans within the model region; however, the dose rates and doses to animals living in the region of the mill are expected to be low enough that any deleterious effects would be manifest only after a long latent period. Since the life span of most animals is rather short, and populations in the wild are subjected to high attrition rates, the effects of radiation from the mill would not be distinguishable from other naturally occurring forces. Although guidelines have not been established for acceptable limits for radiation exposure to species other than man, it is generally agreed that the limits established for human beings are also conservative for other species. The BEIR Report concluded that the evidence to date indicates that no other living organisms are very much more radiosensitive than man.[21] Therefore, only radiation doses to man have been analyzed in detail.

It is possible that animals living onsite, in or close to an ore or tailings pile, might be subjected to doses that are high compared to those that could result offiste. However a relatively small proportion of the individuals within the region would likely be affected, and the total impact on the local biota therefore is expected to be small.

The radiological impact on man of the single model mill is considered at three stages--construction, operation, and after the mill has closed. Although the total impact of mill construction may be appreciable, the radiological effects are negligible. In contrast, the radiological impacts both during and after operation may be significant for persons in the immediate vicinity of the mill site, assuming the mill were operated as described in Chapter 5. Alternatives are presently available to reduce radiological impacts during and after mill operation. These are described in Chapter 8 and the expected reductions in radiation doses and health effects are outlined in Chapter 9.

6.2.8.1 Construction

Inasmuch as no radioactive materials would be used in the construction of the mill, there would be no nontransient radiological impacts resulting from such construction. A possible transient effect might result from disturbance of the land and ground cover, such as in excavation and road-building. These activities would add incrementally to releases of fugitive dust (Section 6.2.1.1) and possibly slightly increase radiation exposure from this source; however, the dust raised would be of the same composition as the background dust, so any effect would be small, and probably undetectable. In comparison to the radiological impact during and after mill operation the radiological effects of construction are negligible.

6.2.8.2 Operation

6.2.8.2.1 Introduction

People living in the vicinity of uranium mills may be exposed to ionizing radiation originating from radioactive materials dispersed by various mill operations. Even after a mill is decommissioned, exposure may continue from residual sources. This section includes estimates of the radiation dose commitments* that would be received by two groups: (1) individuals at locations near the model mill, and (2) the general population within the hypothetical region surrounding the model mill. These estimates are based on detailed analyses of the sources and rates of radioactive releases and the pathways by which dispersed radioactive materials may reach man and irradiate his tissues.[22] The methods used for dose calculations are described qualitatively in this section and in detail in Appendix G. Potential health effects resulting from the calculated dose commitments are also estimated. Both predicted radiation dose commitments and potential health effects are described in terms of their relative magnitudes as compared to appropriate indices.

6.2.8.2.2 Sources of Radioactivity and Exposure Pathways

All significant sources of radioactive mill effluents and exposure pathways to man are illustrated in Figure 6.3. The sources of radioactivity include: (1) ore pad storage, feed, crushing and grinding; (2) yellowcake drying and packaging; and (3) stored mill tailings.

These sources are described and the magnitude of the annual releases from each are given in Section 5.3. Because of their physical properties and physiological behavior, the radionuclides of primary concern are uranium-238 and 234 (U-238 and 234), thorium-230 (Th-320), radium-226 (Ra-226), lead-210 (Pb-210), and the chemically unreactive gas radon-222 (Rn-222).

These six radionuclides are associated with the U-238 decay series, which is described in Appendix C. U-235 and its daughter products also are present in natural uranium. As it is found in nature, uranium generally consists of 99.3% U-238 and only 0.7% U-235. A high-quality ore with 1% U_3O_8 would contain 2800 pCi of U-238 and 130 pCi of U-235 per gram. Under conditions of secular equilibrum there would also be 2800 pCi/g of each U-238 daughter product and 130 pCi/g of each U-235 daughter. Because the activity of U-238 and its daughters is much greater, and the half-lives generally longer, only this series is considered in evaluating the radiological impacts of the model mill.

Uranium ores may also contain small amounts of long-lived thorium-232 and its daughter products. The radiological parameters associated with the Th-232 series are such that the impact of these isotopes is relatively inconsequential, even when they are present in amounts comparable to the natural uranium concentration in ore. The ore processed in the model mill is assumed to contain a negligible concentration of Th-232 (as in most actual mills), so this radionuclide is not included in the analysis of the radiological impacts.

*Readers for whom this and other radiological terms are not familiar may wish to consult Appendix C for an introduction to some of the vocabulary.

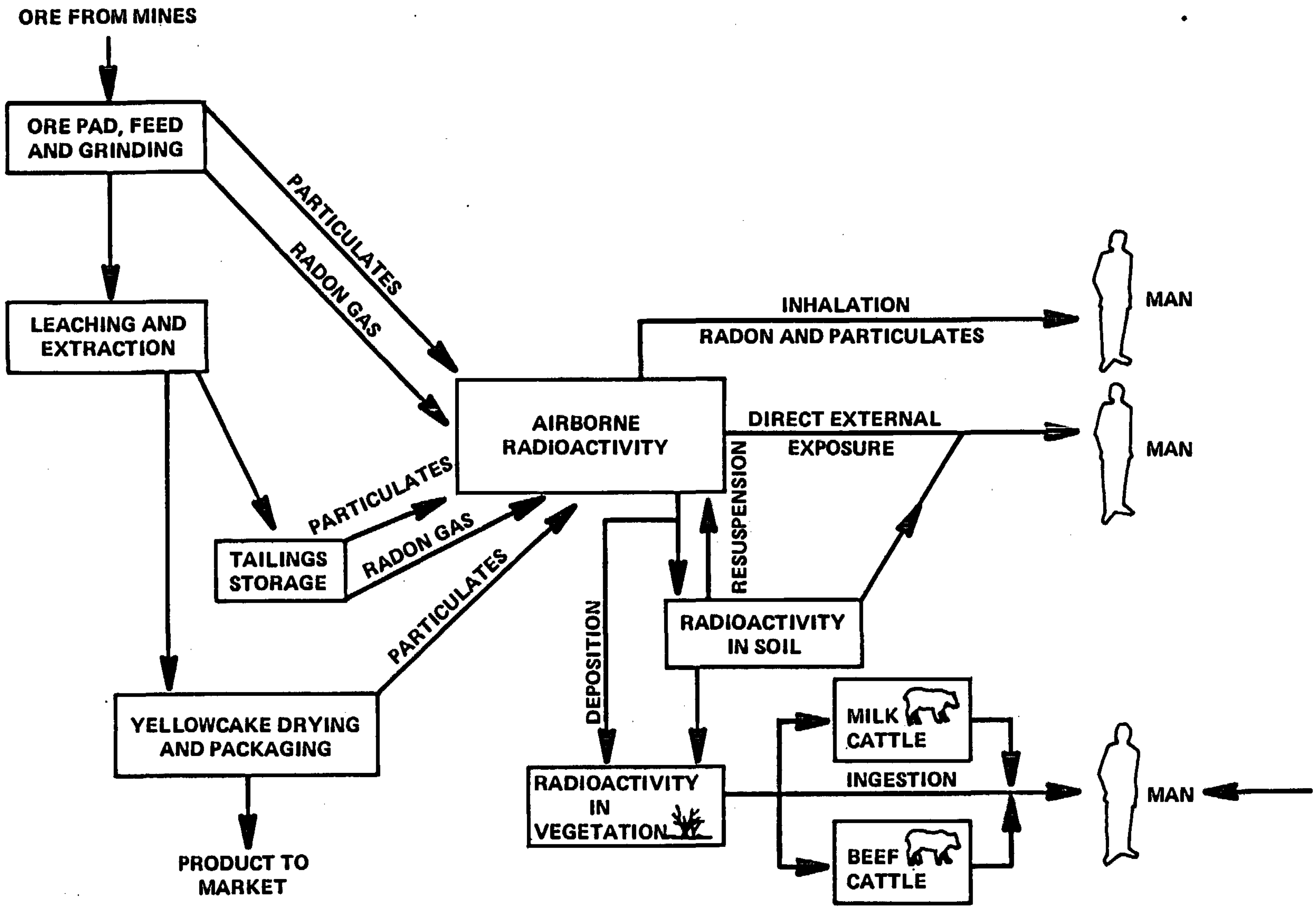

Figure 6.3. **Sources of Radioactive Effluents from the Model Mill and Exposure Pathways to Man.**

Ores may not be in radioactive equilibrium because of differential leaching of radionuclides under natural hydrological conditions. Selective removal of uranium will leave a relative excess of daughter thorium and radium isotopes in the ore. In general, this and other mechanisms leading to disequilibrium are not constant throughout geologic time and also may not be constant within a given ore body. In this analysis, secular equilibrium for the U-238 series is assumed.

All of the radioactive isotopes which are present in uranium ore are released to some extent from exposed ore storage areas and the initial dusty crushing and grinding operations. At the end of the milling operation, the drying and packaging of uranium concentrate, or yellowcake, provides another source, mostly of the uranium isotopes. Finally, the bulk of the other nuclides is discharged with the mill tailings, which thereafter may be a source of particulates and radon gas. The relative contribution of each of these three major sources to the total air concentration of the important radionuclides, at distances of 1.0, 2.0 and 80 km (0.6, 1, and 50 miles), is given in Table 6.9. It is apparent that the tailings pond contributes the major portion of the airborne activity (except for uranium) at all distances. Most of the uranium that becomes airborne is released in the yellowcake operations.

The principal pathways by which radioactivity from these sources may reach human beings and irradiate their tissues include: (1) direct, external exposure from radionuclides in the air or on the ground; (2) inhalation of radioactivity into the lungs, possibly followed by redistribution to other organs of the body; and (3) ingestion of radioactivity in foodstuffs. The inhalation and ingestion pathways result in the radioactive material being deposited inside the body and irradiating it from within. Accordingly, doses received via these pathways are referred to as internal doses so as to distinguish them from radiation received from sources external to the body. In general, members of the public outside the mill boundary would receive no significant direct, external exposure from radioactive materials which remain onsite in process systems or storage.

6.2.8.2.3 Location of Dose Receptors

All of the exposure pathways of significance begin with dispersion of radionuclides by atmospheric transport. Radioactivity released from the mill is moved through the air and diluted in such a way that air concentrations decrease as the distance from the mill increases. Thus, the dose estimates are strongly dependent on distance (and direction relative to the prevailing winds) of the receptor point from the mill. The locations at which specific calculations of individual doses are required are highly variable among actual sites of uranium mills. Therefore, individual dose calculations have been performed for a range of distances along the east-northeast direction, which is the downwind direction of the prevailing winds for the model site. Calculations for a range of distances allow the presentation of results graphically, as well as for specific reference locations. For the model mill, certain hypothetical individual dose receptor locations have been conservatively established as reference points for calculations of maximum risk and evaluations of compliance with applicable radiation exposure limits. These hypothetical locations are defined and characterized as follows:

(a) The point of maximum air concentrations which is accessible to the public, i.e., the fence location in the downwind direction. For the model mill, this is assumed to be 100 m from the edge of the tailings area, 0.64 km (0.4 mile) east-northeast of both the mill and the center of the tailings pond (colocation of these two sources is conservatively assumed but would be impossible at any real mill). Maximum occupancy of this location is assumed to be 10% of the year.

(b) The closest downwind location where a temporary residence might be established. This is assumed to be 0.4 km (0.25 mile) from the tailings area [0.94 km (0.58 mile) from the mill] and is considered to be a potential site for a mobile home or trailer. Only vegetables are grown here and occupancy is assumed for only six months per year.

(c) The closest permanent residence downwind of the site. This is assumed to be a ranch 2.0 km (1.2 miles) from the mill [about 1.5 km (0.9 mile) from the fence], occupied year-round, where vegetables and beef cattle are grown.

In addition to individual dose calculations, total cumulative doses to the entire population due to contamination within a radius of 80 km (50 miles) of the mill have also been estimated based on the assumed population distribution, annual average meteorological conditions, and regional food production rates.

Table 6.9. Relative Contributions of Major Release Sources to Total Air Concentrations at 1, 2, and 80 km

Location[b]	Percent of Total Air Concentration Due to Indicated Source[a] U-238	Th-230	Ra-226	Rn-222	Pb-210
I. 1.0 km ENE					
A. Ore pad, grind. & crush.	0.9	4.2	4.3	1.6	4.3
B. Yellowcake dry. & pack.	97.6	2.2	0.4	0.0	0.4
C. Tailings	1.5	93.6	95.3	98.4	95.3
II. 2.0 km ENE					
A. Ore pad, grind. & crush.	0.8	3.1	3.5	1.6	3.3
B. Yellowcake dry. & pack.	97.7	2.1	0.4	0.0	0.4
C. Tailings	1.5	94.8	96.1	98.4	96.3
III. 80 km ENE					
A. Ore pad, grind. & crush.	1.0	2.3	2.2	1.5	1.7
B. Yellowcake dry. & pack.	95.8	1.0	0.2	0.0	0.0
C. Tailings	3.2	96.7	97.6	98.5	98.3

[a]Total air concentrations plots are presented in Appendix G-4.

[b]Locations used are in the ENE direction, which is the downwind direction of the prevailing winds.

6.2.8.2.4 Individual Dose Commitments

Determining the radiological impact of a uranium mill involves estimating the radiation dose commitments that may be received by individual members of the general public. In the following sections the methodology used to calculate these doses is outlined and the results are presented. These results are compared to applicable Federal guidelines in order to identify potential problems.

The major components of the total dose commitments received by individuals are the direct, external radiation doses from radioactive material in the air and deposited on the ground, the internal dose commitments from inhalation of airborne radioactivity, and the internal dose commitments from ingestion of contaminated foods. A discussion of each of these components follows.

6.2.8.2.4.1 Individual External Exposure

Individuals may be exposed to radiation originating outside their bodies from radioactive particulates or gas (radon) in the surrounding air or from radioactive materials which have been deposited on the ground. As a starting point in estimating the dose received at a given distance and direction, the airborne concentrations produced directly by each source must be calculated. Also, the amounts of radioactivity deposited on ground surfaces must be estimated as a function of time since mill operation first began. Finally, a portion of the materials on the ground will be resuspended and add to the air concentrations attributable directly to transport from the original sources. From these the external dose from the airborne material can easily be estimated.

The radioactive emissions from the model mill were described earlier, in Chapter 5, and are based on estimates made in accordance with the models, data, and assumptions detailed in Appendix G-1. These airborne radioactivity releases have been analyzed using the assumed site meteorological data and the methodology that has been described in Appendix G-2 to determine the resulting annual average air concentrations at offsite locations, arising directly from atmospheric transport. These original air concentration values are referred to as "direct" air concentrations and do not include incremental additions due to resuspension of radioactive materials previously deposited on ground surfaces. They do, however, include the effects of depletion due to deposition (for particulate materials other than ingrown daughters of released radon) or ingrowth and decay during transport (for radon and ingrown daughters). The basic dispersion model utilized consists of a straight-line Gaussian plume model, modified to account for area rather than point sources. It is used here to obtain sector average, annual average, direct air concentrations.

Released particulate materials are depleted in transit due to loss from the plume due to deposition on ground surfaces. In the calculation of direct air concentrations, depletion losses are accounted for by the application of an effective source strength equal to the fraction of the original source still airborne at any given distance. The effective source strength, as a function of distance, is determined by numerical integration of the total deposition occurring within that distance, and subtraction of that fraction of the source from its original value.

For radon gas releases, ingrowth and decay of daughter radionuclides during atmospheric transport is accounted for explicitly using the standard Bateman formulation. Decay of radon itself during transit is also accounted for. However, deposition losses of ingrown particulate radon daughters are not treated.

Computed direct air concentrations are utilized to determine "direct" deposition rates onto ground surfaces, and resuspended air concentrations, using the equations described in Appendix G-3. Ground concentrations resulting from constant deposition over the model mill's operational lifetime are calculated from the deposition rates resulting only from direct air concentrations. Resuspension is not assumed to constitute a mechanism of either loss or gain for ground-deposited radioactive materials. The resulting ground concentrations are then utilized to determine external dose rates to individuals from radiation emitted by deposited radioactivity. External dose rates from airborne radioactive materials are determined from total air concentrations, which are evaluated as the sum of direct and resuspended air concentration values.

For this study, particulate resuspension is estimated using a model based on actual experimental data. The calculation of resuspension of previously deposited particles utilizes a factor to relate surface concentration to volume concentration in the overlying air mass. The resuspension factor utilized depends on the size of the particle, being inversely proportional to its deposition velocity, and changes as a function of time to account for the decreasing availability for resuspension of material as it ages. A description of the methodology employed and the equations used in this analysis are given in Appendix G-3.[22]

Once the ground concentrations and total air concentrations have been established as a function of time, distance, and direction from the model mill, the external radiation exposure rates and doses to a person at a given location may be estimated by relatively straight-forward calculations. The equations, assumptions, and dose conversion factors used to calculate external doses are presented in Appendix G-5. At a given receptor point, the average annual external exposure from airborne material transported directly from sources at the mill will be constant from one year to the next so long as the release rates and meteorological conditions remain unchanged. The portions of the total external exposure originating from ground contamination and from resuspended material in the air will increase over the operating lifetime of the mill and reach a maximum in its final year of operation. For this reason, annual doses from external exposure during mill operation are calculated for the 15th year of operation, which is the final operating year assumed for the model mill.

External doses to the whole body in the prevailing downwind direction are presented graphically in Figure 6.4. From this figure it is clear that exposure from radionuclides deposited on the ground is the major source of external doses within about 10 km (6.2 miles) of the model mill. The external dose rate from airborne activity actually increases out to about 1 km (0.6 mile) from the mill because of the in-growth of radon-222 daughters as the gas moves away from its sources. Beyond this, the dose rate from the cloud decreases as the radioactivity is dispersed.

Appendix G-4 contains graphs of the concentrations of U-238, Th-230, Ra-226, Pb-210, and Rn-222 in air, as well as for radon daughters in working-level units, as a function of distance from the model mill. Curves also are given for ground concentrations of the particulates. In all the graphs, the curve for $\theta = 67.5$ degrees represents the downwind (ENE) direction. Appendix G-4 also contains isopleths (lines of equal air concentration) for U-238, Ra-226, and Rn-222 within the model region.

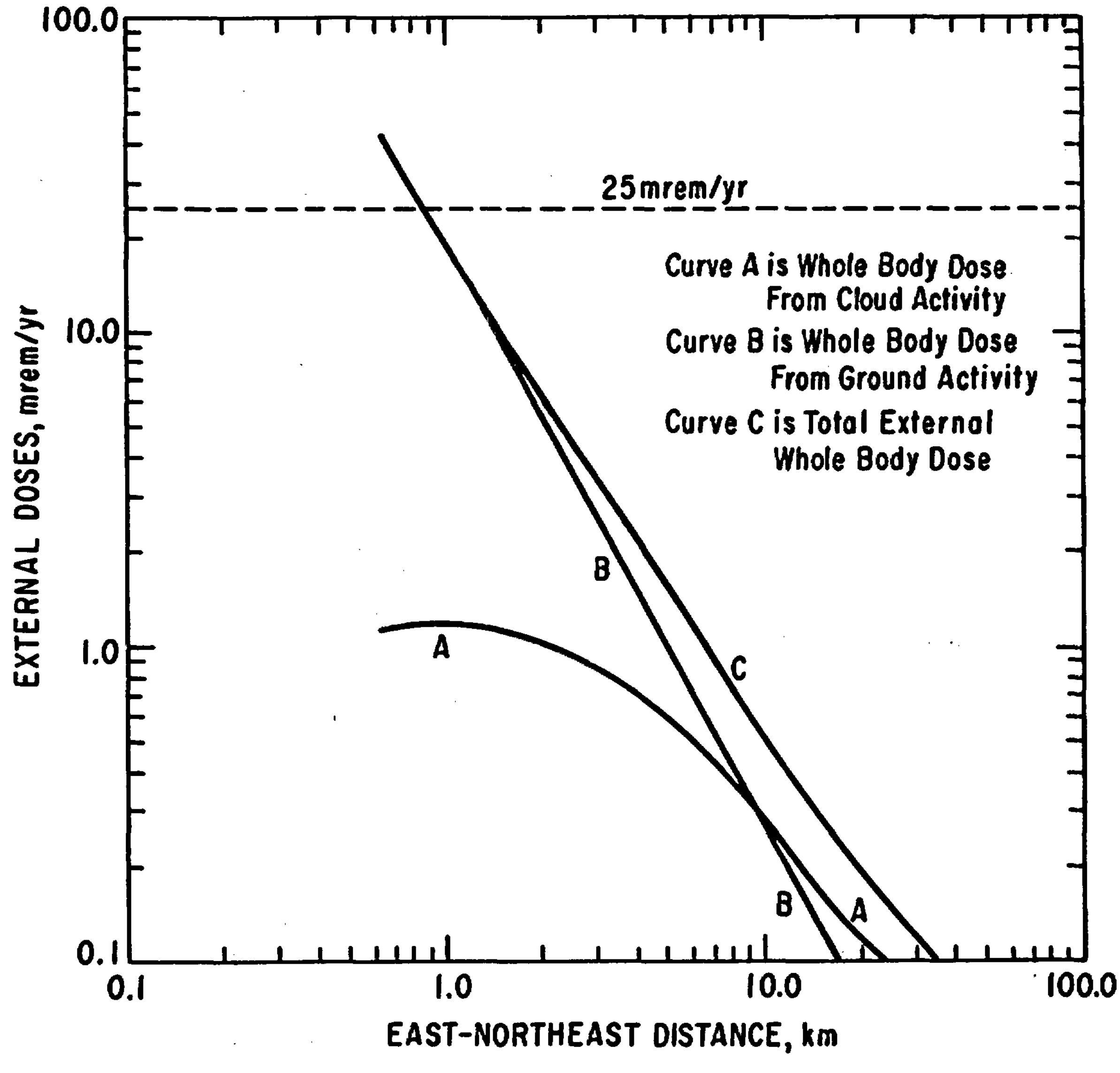

Figure 6.4. External Doses During the Final Year of Mill Operation.

6.2.8.2.4.2 Individual Internal Exposure via Inhalation

The alpha-emitting isotopes of the U-238 decay series are generally weak gamma emitters and can contribute relatively little to external exposure. However, when they enter the body and come directly into contact with living tissue, their alpha radiation will deliver substantial dose equivalents compared to that imparted by equal concentrations of beta/gamma emitters. Because these radionuclides are present in mill effluents, it is important to analyze the pathways by which they might become deposited in human beings living in the mill environs. The two major pathways to be considered are inhalation of airborne material and ingestion of food contaminated with radionuclides.

The uptake of radioactive material into the lungs via inhalation, and subsequent translocation to other body organs is estimated from the airborne concentration of each radioisotope, using the model developed by the Task Group on Lung Dynamics of Committee II of the International Commission on Radiological Protection.[23] The fraction of inhaled activity that is deposited and the region of the lung where deposition occurs are determined by the aerodynamic properties of the particles. The rate of removal of deposited material (or rate of clearance) and the site of its subsequent deposition, if it is not eliminated from the body, are determined by many factors. These factors include the physical and chemical form, solubility characteristics of the material, and the point of initial deposition. The radioactive material irradiates lung tissues until cleared from the lungs and then, if not removed from the body, continues to irradiate tissue at the new site of deposition.

Because the radionuclides of concern in this study generally have relatively long residence times once they have been deposited in body organs, the total dose from a given intake will be delivered over an extended time period. In this analysis, internal 50-year dose commitments have been calculated for a one-year intake period, for inhalation and ingestion exposures. Since the elements of major concern (U, Th, Ra, Pb) have long residence times in most tissues and organs, the actual dose rate from a specified intake must be integrated over the following 50 years to yield the 50-year dose commitment. For all calculations of internal dose, this analysis has used dose conversion factors which yield the 50-year dose commitment, i.e., the entire radiation insult received over a period of 50 years following either inhalation or ingestion.

Because the radioactivity in the mill surroundings builds up during operation, the intake in the final (15th) year of operation will be greater than in other years of operation. The annual dose commitments, therefore, have been calculated from environmental media concentrations calculated for the 15th year. Inhalation dose commitments calculated for the whole body, bone, and lung in the downwind direction of the prevailing winds are presented in Figure 6.5. Although presented as a lung dose, the inhalation doses from radon-222 are, more specifically, doses to the bronchial epithelium. The equations and dose conversion factors used to calculate inhalation doses are presented in Appendix G-5.

6.2.8.2.4.3 Individual Internal Exposure via Ingestion

The second major pathway resulting in the intake of radioactive materials into the body, and thus internal radiation exposure, is ingestion. Upon ingestion of radioactivity in food, some fraction of each radionuclide is absorbed into the bloodstream and may be transported to various internal body organs. The general ingestion pathway is made up of the three more specific pathways considered for the model mill. These include vegetable, meat, and milk ingestion.* For purposes of analysis, the vegetable ingestion pathway is further subdivided by vegetable type and includes all edible above ground vegetables, potatoes, and all other vegetables grown below ground level. In order to estimate radioactivity concentrations in the meat and milk from local cattle, vegetation concentrations are also estimated for grass used for grazing and hay or other stored feed.

The models, equations, data, and assumptions used to calculate radioactivity concentrations in vegetables, meat, and milk are described in Appendix G-3. Concentrations for the various types of vegetables and vegetation are determined by accounting for the transfer of soil or ground activity to the edible portions via root uptake, and foliar retention of airborne activity depositing directly on plant structures. Direct foliar retention sources are treated by taking into account the fraction of total deposition initially retained on plant surfaces, losses due to weathering processes such as wind turbulence and wash-off, and, for below ground vegetables, the fraction of retained activity reaching the edible portions. For vegetables, preparation

*Since the milk ingestion pathway is only very infrequently present at nearby receptor locations, it has not been included in the actual calculations of maximum individual doses resulting from operation of the model mill. It is included in the explanatory discussion here for purposes of completeness, as the milk pathway is considered in detail with respect to population doses.

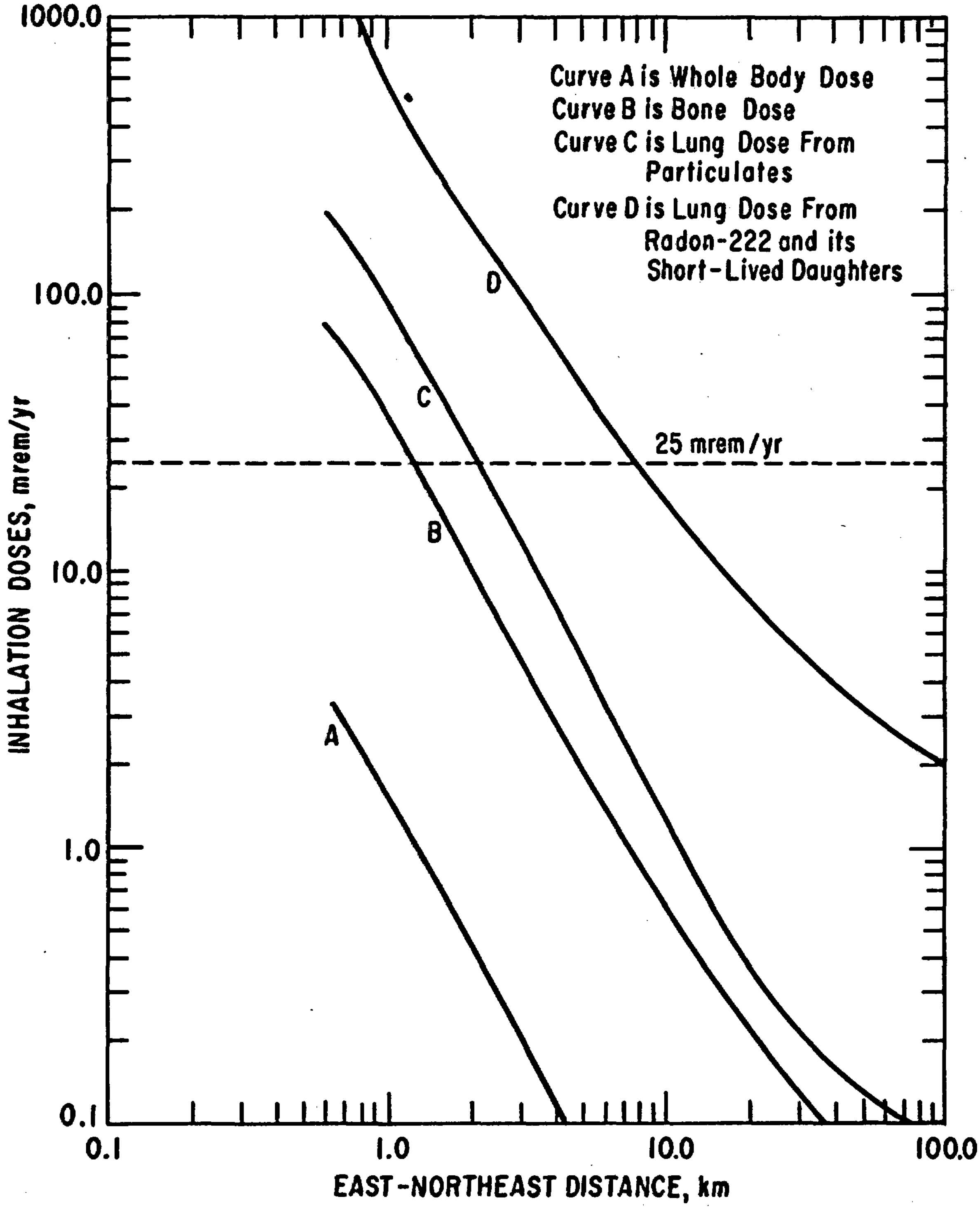

Figure 6.5. Inhalation Doses During the Final Year of Mill Operation.

for the table can result in sizable losses of the initial activity content. Vegetable preparation most often involves washing, peeling, boiling, etc. Therefore, 50 percent of the in-the-garden concentrations are assumed to be lost prior to ingestion. No preparation losses are assumed for milk or meat.

For the model mill it has been assumed that meat and milk animals will obtain 50 percent of their annual feed requirement by grazing on open range or pasture, and the remaining 50 percent will be supplied in the form of locally grown stored feed. Thus, the radioactivity content of available grasses, hay, or other feed is transferred to the meat and milk of cattle, which are subsequently ingested by man. Only the radioactivity in feed vegetation is considered in estimating meat and milk concentrations. Meat and milk concentrations resulting from inhalation by cattle of airborne activity are insignificant by comparison.

Ingestion rates of vegetables, meat, and milk routinely assumed for individuals, and the dose conversion factors used to estimate resulting doses, are provided in Appendix G-5. These ingestion rates are average values typical of a rural farm household, and represent entire annual requirements of all fresh vegetables, beef, fresh pork, and lamb, and fresh milk. Food items not included, largely due to the rarity with which they are home-grown in typical milling and mining areas, include fruits, grains, processed vegetables, other milk products, processed pork, poultry, eggs, and miscellaneous non-staples.

Since the milk pathway is also not routinely present at nearby receptor locations, it has not been included in maximum individual doses presented herein. For the foods that are assumed to be produced and consumed by individuals about the model mill, no credit or reduction factor is applied to account for portions of the year when such foods may not be available.

For the ingestion pathways, doses to individuals and populations have been assessed by taking age-dependency into account. The population has been assumed to consist of individuals belonging to one of four age groups, infants, children, teenagers, and adults. The ingestion rates assumed for individuals vary significantly by age group and have a significant effect in determining the critical age group in terms of maximum radiation dose commitment received. Also, the various metabolic and physiologic parameters entering into the determination of dose conversion factors (dose commitment per unit activity intake) vary according to age. Therefore, age dependent dose conversion factors have been used in the determination of individual ingestion doses. This is not necessary in the case of estimating external doses, and in the case of estimating inhalation doses has not been feasible (the use of the Task Group Lung Model of the International Commission on Radiological Protection requires values of basic parameters for which age-dependent data are as yet unavailable).

In general, the radiation dose commitment received per unit activity intake is greater for infants or children than for teenagers or adults. This is primarily due to the smaller organ and body sizes available to receive essentially identical amounts of radiation energy. Radiation dose is proportional to the amount of radiation energy absorbed per unit mass. Hence, a smaller organ receiving the same energy deposition as a larger organ, will receive a greater dose. For the vegetable and meat pathways, infants are assumed to have no intake and a child's ingestion rate is taken to be less than that of those for an adult. Thus, for these food pathways, although children receive greater doses per unit intake, adults receive greater doses overall. For the milk pathway children and infants are assumed to ingest about 1.6 times as much milk as an adult and infants are the critical receptors, receiving milk ingestion doses marginally (less than 10 percent) above those for children. However, infants have no assumed vegetable or meat intake due to their age.

The net effect of all of these perturbations is that if the milk pathway is in existence, along with the vegetable and meat pathways, total ingestion doses to an adult are slightly higher than children's doses. If the milk pathway is not present, as assumed herein, the adult is still the critical receptor. For the analyses performed for the model mill, total ingestion doses are, therefore, always higher for adults.

Staff experience in actual uranium mill licensing analyses has indicated that the meat pathway will exist at nearby locations almost without exception. The vegetable pathway may or may not actually exist at any given time and place but is usually assumed, unless there is specific evidence to the contrary, in view of the immediacy and ease with which it is established. The milk pathway also may or may not exist at any specific site. Staff contacts with state agricultural agents in primary milling states have indicated that on the order of 20 percent of local farms and ranches can be expected to have one or more dairy cattle. Thus, the milk pathway is considered to be somewhat more hypothetical than the beef and vegetable pathways, and is therefore not included. Maximum total whole body and bone ingestion doses, as a function of distance in the prevailing downwind direction, are displayed graphically in Figure 6.6 for the case where there is no milk pathway (adult doses given). If the milk pathway were present, maximum doses would still be to an adult.

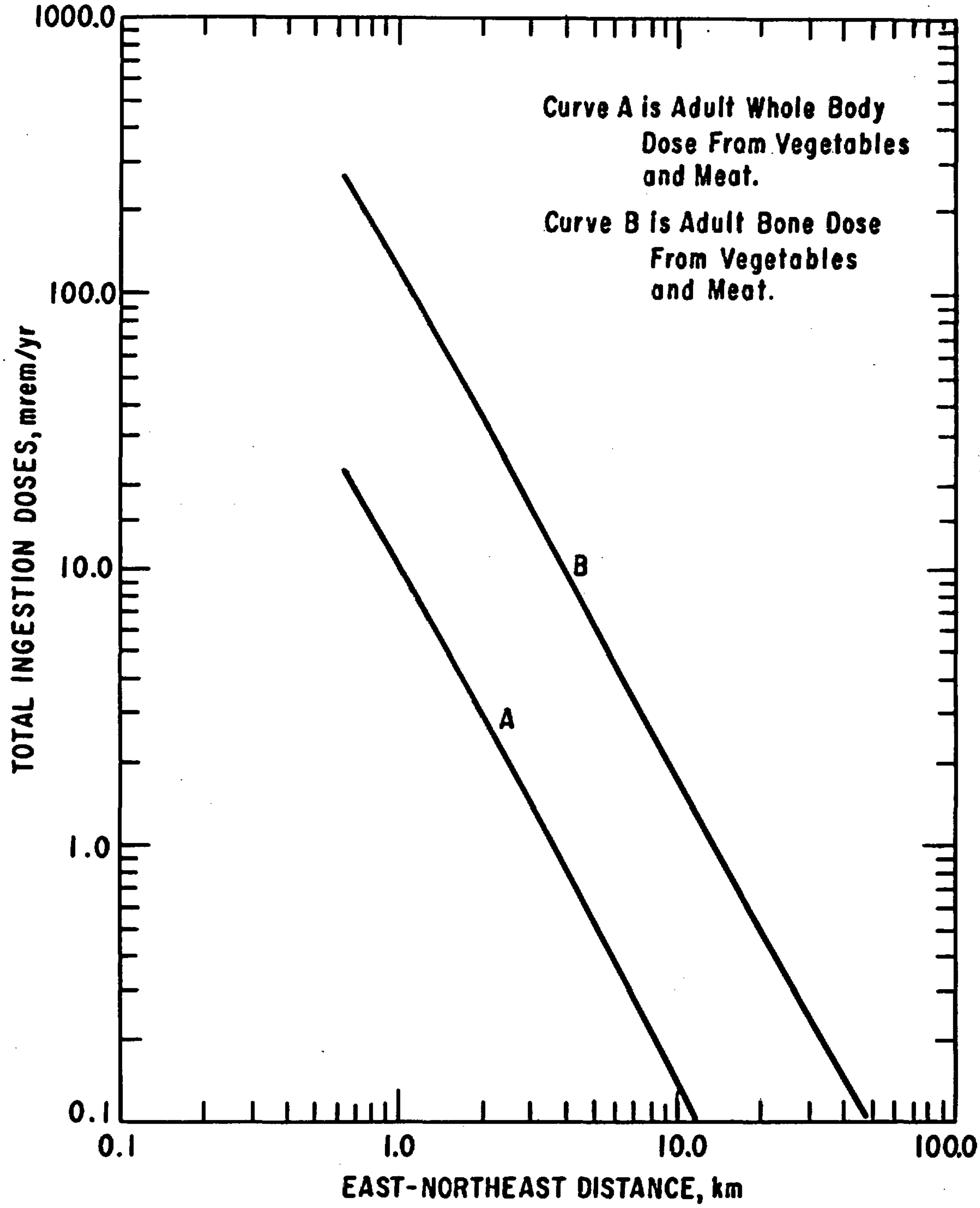

Figure 6.6. Total Ingestion Doses During the Final Year of Mill Operation.

Ingestion doses for all age groups and assumed pathways have been calculated for a range of distances to the east-northeast of the model mill, the downwind direction of the prevailing winds. Results of these calculations, for whole body, bone, and lung doses, are presented in Table 6.10, along with estimated doses for external and inhalation pathways.

6.2.8.2.4.4 Total Individual Dose Commitments

In preceding sections individual calculations of doses resulting from external exposure (to air and ground radioactivity concentrations) and internal exposure (inhalation and ingestion) were described. Calculated individual doses resulting from exposure pathways were presented as a function of distance in the downwind direction of the prevailing winds.

Table 6.10 presents numerical results for each of the assumed individual exposure pathways and dose totals from all pathways combined. The dose totals in this table represent maximum individual doses resulting if the milk pathway is not present. Most often, the milk pathway will not exist at the nearest residence. For this reason Table 6.10 includes doses calculated for an adult on the assumption that vegetables and meat are the only existing ingestion pathways. From the results presented in this table, total doses to individuals at the three hypothetical reference receptor locations can be estimated.

Because the selection of specific receptor locations for calculating maximum individual doses resulting from the model mill is, by necessity, somewhat arbitrary, individual doses have been calculated and presented for a range of distances. However, this allows only general qualitative judgments to be made concerning the need for, and effectiveness required of, various procedures and mechanisms for controlling radioactive effluents. The three specific hypothetical receptor locations have been especially pre-selected as locations at which to make detailed evaluations of both maximum individual health risk and compliance with applicable radiation exposure limits. Such determinations allow the later assessments of required emission controls, based on the degree to which the base-case model mill is unacceptable. In this regard, the reference fence, trailer, and ranch locations serve as benchmarks for the evaluation of available control technology. This section presents an evaluation of compliance with applicable radiation exposure limits imposed by the regulations of the U.S. Nuclear Regulatory Commission under 10 CFR Part 20 and the U.S. Environmental Protection Agency under 40 CFR Part 190.

Limits for radiation exposure in unrestricted areas are numerically expressed in 10 CFR Part 20 as maximum annual average air concentrations by isotope. These concentration limits are presented in Table 6.11 along with the annual average concentrations from the model mill predicted for the three reference receptor locations. Concentrations of U-238, Ra-226, and Pb-210 at the fence location are at least a factor of about 50 beneath the 10 CFR Part 20 limits for those isotopes; the Th-230 concentration is about 20 percent of its 10 CFR Part 20 limit. The Rn-222 fence concentration is about two-thirds of the 10 CFR Part 20 limit given specifically for Rn-222. However, the working-level concentration of short-lived radon daughters at the fence location is well within the more applicable working-level limit, even for a strictly hypothetical indoors situation. As the critical dose resulting from Rn-222 releases results not from Rn-222 itself, but rather from its short-lived daughters, and since the working level concentration of the short-lived daughters is well within its applicable limit, both Rn-222 and its daughters would be at concentrations well under 10 CFR Part 20 limits, even at the fence location.* Since all other isotopic concentrations are within their individual limits, and since, for the total concentration mixture, the sum of the fractions of the limits reached by each isotope is less than one, all off-site annual average air concentrations would be allowable under 10 CFR Part 20 regulations.

Compliance with EPA's 40 CFR Part 190 regulation is measured on an entirely different basis. This regulation, which becomes effective for uranium milling operations as of December 1, 1980, states that operations covered by the regulation

> "...shall be conducted in such a manner as to provide reasonable assurance that: the annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of planned discharges of radioactive materials, radon and its daughters excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations."

*10 CFR Part 20 expresses limits for Rn-222 and working level concentrations, but allows the optional alternative use of either.

Table 6.10. Maximum Individual Doses During the Final Year of Mill Operation

Calculated Adult Whole Body Dose Commitments, mrem/yr

Distance ENE, km	External Doses Ground	Cloud	Inhalation Dose	Ingestion Doses Vegetable	Meat	Milk[a]	Total Dose
0.64	40.9	1.13	3.16	19.1	2.92	0.0	67.2
0.94	20.9	1.20	1.72	9.80	1.49	0.0	35.1
2.0	5.29	1.05	0.451	2.48	0.377	0.0	9.67
5.0	0.987	0.572	0.085	0.462	0.071	0.0	2.17
10.0	0.266	0.271	0.025	0.125	0.019	0.0	0.707
20.0	0.069	0.124	0.009	0.033	0.005	0.0	0.240

Calculated Adult Bone Dose Commitments, mrem/yr

Distance ENE, km	External Doses Ground	Cloud	Inhalation Dose	Ingestion Doses Vegetable	Meat	Milk[a]	Total Dose
0.64	40.9	1.13	72.7	230.	36.1	0.0	381.
0.94	20.9	1.20	39.2	118.	18.5	0.0	198.
2.00	5.29	1.05	10.3	29.8	4.67	0.0	51.1
5.0	0.987	0.572	2.01	5.57	0.876	0.0	10.1
10.0	0.266	0.271	0.623	1.53	0.243	0.0	2.94
20.0	0.069	0.124	0.225	0.425	0.069	0.0	0.911

Calculated Adult Lung Dose Commitments, mrem/yr

Distance ENE, km	External Dose	Inhalation Doses Particulates	Radon	Ingestion Doses Vegetable	Meat	Milk[a]	Total Dose
0.64	42.0	184.	1270.	19.1	2.92	0.0	1518.
0.94	22.1	104.	659.	9.80	1.49	0.0	796.
2.00	6.34	27.1	184.	2.48	0.377	0.0	220.
5.00	1.56	4.64	45.5	0.462	0.071	0.0	52.3
10.0	0.537	1.25	17.7	0.125	0.019	0.0	19.7
20.0	0.193	0.359	7.44	0.033	0.005	0.0	8.03

[a]The milk pathway is not assumed to exist for nearby receptor locations, due to the rarity with which that is not the case. Milk pathway doses, if present, would be less than those shown for the meat ingestion pathway which are themselves only small fractions of the total exposure from all pathways combined.

Table 6.11 Comparison of Air Concentrations During the Final Year of Mill Operations with Background and 10 CFR Part 20 Limits

	Total Air Concentrations, pCi/m^3					WL Concentrations[a]	
	U-238	Th-230	Ra-226	Pb-210	Rn-222	Outdoors	Indoors
I. Range of Typical Natural Background Values[b]: From........	7.0×10^{-5}	2.0×10^{-5}	4.0×10^{-5}	1.0×10^{-3}	1.0×10^{1}	6×10^{-5}	1.5×10^{-3}
To..........	1.7×10^{-4}	7.0×10^{-5}	7.0×10^{-5}	3.0×10^{-2}	1.0×10^{3}	8×10^{-3}	1.5×10^{-2}
II. Predicted Values							
A. Fence (0.64 km ENE)..............	6.16×10^{-2}	1.53×10^{-2}	1.51×10^{-2}	1.50×10^{-2}	$2.04 \times 10^{+3}$	3.72×10^{-3}	1.02×10^{-2}
B. Trailer (0.94 km ENE)............	3.55×10^{-2}	7.98×10^{-3}	7.84×10^{-3}	7.85×10^{-3}	$1.05 \times 10^{+3}$	2.77×10^{-3}	5.25×10^{-3}
C. Ranch (2.0 km ENE)...............	9.14×10^{-3}	2.10×10^{-3}	2.07×10^{-3}	2.16×10^{-3}	$2.94 \times 10^{+2}$	1.43×10^{-3}	1.47×10^{-3}
III. 10 CFR Part 20 Limits[c]...............	3.0	8.0×10^{-2}	2.0	4.0	3.0×10^{3}	3.3×10^{-2}	3.3×10^{-2}

[a]WL denotes "working level". A one-WL concentration is defined to be any combination of air concentrations of the short-lived Rn-222 daughters Po-218, Pb-214, Bi-214, and Po-214 that, in one liter of air, will yield a total of 1.3×10^{5} MeV of alpha particle energy in their complete decay to Pb-210. Predicted values given for outdoor air are those calculated on the basis of actual ingrowth from released Rn-222. Predicted indoor WL concentrations are estimated from the Rn-222 air concentration by assuming 5.0×10^{-6} WL indoors per pCi/m^3 of Rn-222 outdoors (see Appendix G-5 for further explanation of this factor).

[b]Total air concentration values are taken from Tables 20 and 26 of NCRP Report No. 45, National Council on Radiation Protection and Measurements, 1975. Outdoor WL concentrations are obtained using equilibrium relationships from References 38 and 39. Indoor WL concentrations are taken from Reference 39.

[c]Values given are from 10 CFR Part 20, Appendix B, Table II, Col. 1. For particulates, the lower of the two values given (for soluble and insoluble) is presented. For Rn-222, the air concentration limit and the WL limit are interchangeable.

Whereas air concentration limits are imposed under 10 CFR Part 20, 40 CFR Part 190 imposes limits on total dose, including contributions from all covered nuclear fuel cycle operations (regardless of location), dose components from all environmental exposure pathways, and direct radiation from any on-site radioactive materials. Specifically excluded are any doses and dose commitments arising from releases of radon and daughters.

Table 6.10 presented dose totals from all exposure pathways combined for the whole body, bone, and lung. Under 40 CFR Part 190 doses from released radon and daughters are not regulated and are not included in evaluations of 40 CFR Part 190 compliance. On this basis bone doses are critical rather than lung doses, particulate inhalation doses and ingestion doses are essentially unaffected within a distance of 5 km (3.1 miles), and external doses are drastically reduced since the primary gamma emitters are short-lived radon daughters. The specific details of the methodology utilized to determine total doses for 40 CFR Part 190 compliance evaluations are delineated in Appendix G-5. Appropriate total doses for evaluation of 40 CFR Part 190 compliance are presented in Figure 6.7 as a function of distance. As the figure indicates, the base-case model mill could not comply with 40 CFR Part 190 within about 2.7 km (1.7 miles).

Table 6.12 presents an evaluation of 40 CFR Part 190 compliance for the three hypothetical reference receptor locations. Total doses are also presented to illustrate the impact of disregarding the unregulated radon and daughter releases. From the data in this table it follows that 40 CFR 190's 25 mrem/yr dose limit would be exceeded for occupancy factors of more than 14% at the fence location and about 16% (with vegetable ingestion) at the trailer location. If vegetables are not grown and consumed by trailer residents, compliance could be established for a maximum occupancy factor of about 24%, or three months per year. At the ranch location, compliance could not be established unless occupancy was less than 100% and the vegetable pathway was not present.

6.2.8.2.5 Regional Population Exposure

The preceding section was entirely directed at an assessment of maximum individual radiological impacts to persons at locations in the immediate vicinity of the model mill. Various results demonstrated that with increasing distance, individual doses can become very small. Although the concentrations and doses resulting from uranium milling operations assume smaller and smaller magnitudes with increasing distance, they do not entirely vanish. And as distance increases, greater numbers of individuals can be affected.

In order to determine total regional radiation doses, population dose commitments have been calculated by summing doses to all individuals out to a distance of 80 km (50 miles). At this distance more than 99% of all tailings dust leaving the site has already been deposited, and yellowcake dust and fugitive ore dusts are more than 96% depleted. However, radon is an inert gas and therefore does not become depleted due to deposition losses. Whereas almost all radiological impacts resulting from radioactive particulate releases are assumed to occur within 80 km (50 miles), impacts from radon are estimated for the whole of North America (see Section 6.4) as well as the lesser site region.

Regional population doses have been estimated for all basic exposure pathways. However, the ingestion pathways have been broadened to take into account many of the various food commodities that are not routinely, or typically, produced by individuals for their own use in the climates and terrains commonly existing in areas of uranium milling. For population dose calculations, the vegetable pathway includes all vegetables, berries and tree fruits, and grains; the meat pathway includes all beef, lamb, pork, and poultry; and, the milk pathway is evaluated and includes all dairy products. Within the 80-km region, total population doses due to the model mill from inhalation and external doses depend on the regional population distribution. For the ingestion pathways, total population doses resulting from contamination of the regional food production depend on the gross radioactivity content of the food produced, without regard for the locations of consumers. Thus total population ingestion doses are based on the total amounts of mill-released radioactive isotopes in the region's annual food production. For the model mill more food is assumed to be produced in the region than is consumed by the regional population, resulting in net food exports. Ingestion doses to the population of the model mill region are estimated by assuming they utilize as much of the regionally produced food as is necessary to satisfy their consumption requirements (see Appendix G-6).

Population doses from inhalation and external exposure pathways are calculated by dividing the region into segments, establishing average individual doses within each segment, computing segment population doses, and summing. Total population doses from food ingestion are estimated by first calculating the gross radioactivity content of regionally produced food. For each food type, this is done by estimating average radioactivity concentrations within each segment, multiplying by the assumed segment production rate to obtain gross radioactivity content by

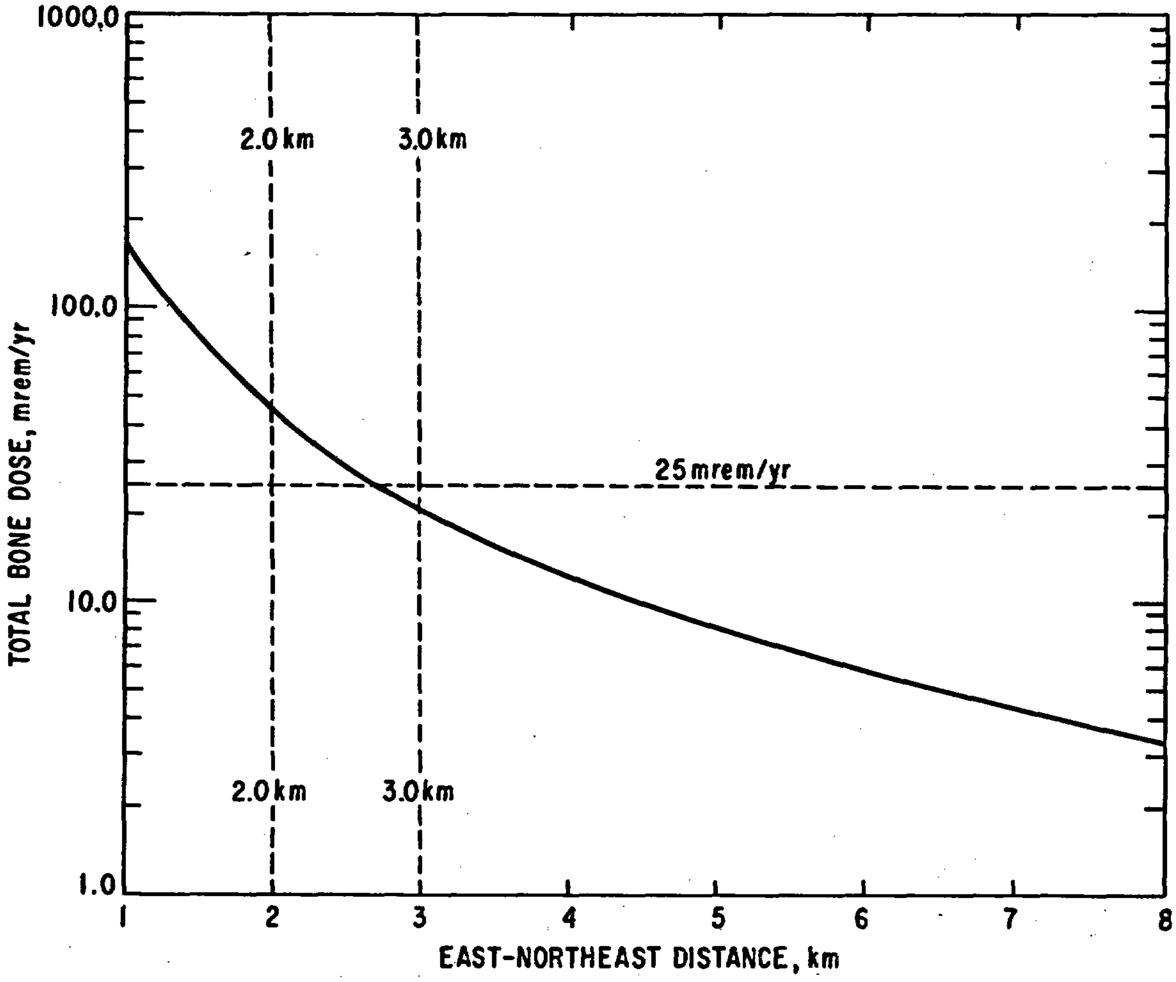

Figure 6.7. 40 CFR Part 190 Maximum Individual Doses during the Final Year of Mill Operation.

Table 6.12 40 CFR Part 190 and Total Maximum Individual Doses at Hypothetical Locations During the Final Year of Mill Operation

Location	Exposure Pathway	Bone Doses, mrem/yr 40 CFR 190 Doses	Bone Doses, mrem/yr Total Doses	Lung Doses, mrem/yr 40 CFR 190 Doses	Lung Doses, mrem/yr Total Doses
I. Fence (site boundary)	External (ground)	0.12	4.09	0.12	4.09
Occupancy: 10%	External (cloud)	neg.	0.11	neg.	0.11
Age: Adult	Inhalation (part.)	7.27	7.27	18.4	18.4
0.64 km ENE	Inhalation (radon)	-	-	-	127.
	TOTALS:	7.39	11.5	18.5	150.
II. Trailer	External (ground)	0.33	10.5	0.33	10.5
Occupancy: 50%	External (cloud)	neg.	0.60	neg.	0.60
Age: Adult	Inhalation (part.)	19.6	19.6	52.0	52.0
0.94 km ENE	Inhalation (radon)	-	-	-	330.
	Ingestion (veg.)	59.0	59.0	4.9	4.9
	TOTALS:	78.9	89.7	57.2	398.
III. Ranch	External (ground)	0.17	5.29	0.17	5.29
Occupancy: 100%	External (cloud)	neg.	1.05	neg.	1.05
Age: Adult	Inhalation (part.)	10.3	10.3	27.1	27.1
2.0 km ENE	Inhalation (radon)	-	-	-	184.
	Ingestion (veg.)	29.8	29.8	2.47	2.48
	Ingestion (meat)	4.66	4.67	0.38	0.38
	TOTALS:	44.9	51.1	30.1	220.

segment, and summing. Age dependency is taken into account by apportioning consumption among the various age groups in accordance with their average consumption rates and their proportions of the entire population.

For the region of the model mill uniform agricultural productivity rates, in units of kg/yr-km^2, were selected and assumed to apply without variation over the entire area from one to 80 km (0.6 to 50 miles). The production rates selected were averages of the data presented in Table 6.13, which was assembled from innumerable documents reporting inventories of animals, production, acres in use etc., by county and/or state. The available raw data were of varied content, quality and age and, therefore, these estimates are considered to be rough approximations at best. Average values were determined for most major uranium-producing states. These were then weighted by expected uranium development activity in each state to obtain values for use in calculating total population ingestion doses. However, these values are still likely to be conservative on the basis that typical areas of concentrated uranium milling activity are possessed of climates and topography of below average quality with regard to agricultural use. For example, South Dakota is shown to have an above average milk production rate but no account has been made of the fact that uranium milling is localized in the southwest corner of the state while most of the milk is produced to the east, near Minnesota.

In addition to the above considerations, regional population doses have been computed using the models, equations, and other assumptions and data presented in all of Appendix G. Appendix G-6 discusses the reasons and mechanisms for computing two varieties of population doses. The first variety is the conventional population dose commitment resulting from a one-year period of exposure. The results of this type of analysis are referred to here as "annual population dose commitments" and are based on a one-year period of exposure to concentrations in environmental media calculated to exist during the 15th year of continuous operation of the model mill. This is the year when environmental concentrations resulting from releases during mill operation will be at their highest values. Annual population dose commitments resulting from exposure to these concentrations therefore represent the highest levels of such doses resulting from any single one-year exposure period. However, population dose commitments resulting from both previous and future exposure years are smaller and would remain uncalculated.

In order to assess the total regional population doses resulting from releases during all of the model mill's 15 years of operation the concept of environmental dose commitment (EDC) is employed. Results of this type of analysis are referred to here as "annual environmental dose commitments." This analytical method essentially entails the calculation of all population

Table 6.13 Staff Estimate of Agricultural Productivity in Uranium Milling States

State	Estimated Agricultural Productivity, kg/yr-km^2 [a] Vegetables	Meat	Milk
Colorado	2800.	3200.	1400.
New Mexico	280.	1150.	460.
South Dakota	2400.	6400.	3600.
Texas	1200.	5300.	2100.
Utah	370.	790.	1800.
Washington	10700.	1600.	6000.
Wyoming	320.	1400.	230.
Weighted Averages:[b]	1020	1980	1140

[a]Vegetables include fruits and grains, as well as all vegetables. Meat includes beef, lamb, pork, and poultry.

[b]The food growth statistics are weighted by the percentage of milling activity that is predicted in each of the major producing States. See Chapter 3.

doses resulting from a one-year release of radioactive materials, over the entire period that such materials may persist in the environment. Rigorous EDC calculations require specific models and data allowing the accurate forecast of the long-term time dependency of population distributions and agricultural productivity, as well as resulting radioactivity concentrations in environmental media. And, should these time dependent behaviors not be amenable to expression by the simplest of mathematical functions, calculational burdens rapidly become restrictive due to the time integrations involved.

The precise technique for calculating EDC's reported here has incorporated the simplifying but non-conservative assumption that the population and agricultural characteristics of the model region will remain constant with time. Also, the time interval utilized for calculating population doses following release is 100 years, rather than some longer time. This is also non-conservative in view of the fact that any population doses arising from residual activity persisting in an environmentally available state for more than 100 years is not included. The net effect of each of these dual informalities, as discussed in Appendix G-6, is an underestimate by about 10 percent of total EDC's from all pathways combined. This lack of precision is considered relatively insignificant in view of the initial hypothetical nature of the site-specific parameters and the levels of uncertainty inherent in the atmospheric dispersion and other intermediate calculations, and has therefore, been accepted.

The calculated annual population dose commitments (for the 15th year of mill operation) and annual 100-year environmental dose commitments are presented in Table 6.14. The short-lived daughters of Rn-222 are responsible for essentially all of the external doses, and all of the inhalation dose to the bronchial epithelium. Short-lived Rn-222 daughters continue to yield significant external doses from ground surface concentrations even beyond mill shutdown because they grow in from deposited Ra-226 (the radon produced from deposited Ra-226 is assumed to remain trapped in ground surface particulates).

Of the doses presented in Table 6.14, most of the whole body and bone doses arise from the ingestion pathways. Since total ingestion doses are based on regional food production, which exceeds regional food consumption, actual ingestion doses received by the regional population are less than the totals presented in Table 6.14. Of the total ingestion doses presented the regional population could actually receive only about 77% of the vegetable ingestion doses, 15% of the meat ingestion doses, and 52% of the milk ingestion doses, based on food requirements for that group. These fractions have been used to determine the annual dose commitments actually received by the regional population, which are also provided in Table 6.14. Other calculational results indicate that most of the non-radon population doses resulting from mill operation arise from intake of Ra-226 and Pb-210 via ingestion pathways. From Table 6.9, it is apparent that over 95% of environmental concentrations of these two radionuclides, at all distances, arise from dispersed tailings dusts, and ingrowth of Pb-210 from released Rn-222.

Table 6.14 Annual Population and Environmental Dose Commitments Resulting from Operation of the Model Mill

Exposure Pathway	Total Dose Commitments: Whole Body	Total Dose Commitments: Bone	Total Dose Commitments: Lung	Total Dose Commitments: Bronchial Epithelium[c]	Doses Received by the Regional Population[b]: Whole Body	Doses Received by the Regional Population[b]: Bone	Doses Received by the Regional Population[b]: Lung	Doses Received by the Regional Population[b]: Bronchial Epithelium[c]
Annual Population Dose Commitments, person-rem/yr[a]								
External from ground	0.306	0.306	0.306	-	0.306	0.306	0.306	-
External from cloud	1.46	1.46	1.46	-	1.46	1.46	1.46	-
Inhalation	0.102	2.94	2.46	84.9	0.102	2.94	2.46	84.9
Vegetable Ingestion	1.89	27.9	1.89	-	1.46	21.6	1.46	-
Meat Ingestion	0.415	6.59	0.415	-	0.062	0.977	0.062	-
Milk Ingestion	0.204	2.29	0.204	-	0.107	1.20	0.107	-
TOTALS	4.38	41.5	6.74	84.9	3.50	28.5	5.86	84.9
Annual Environmental Dose Commitments, person-rem/yr								
External from ground	1.12	1.12	1.12	-	1.12	1.12	1.12	-
External from cloud	1.46	1.46	1.46	-	1.46	1.46	1.46	-
Inhalation	0.102	2.95	2.48	84.9	0.102	2.95	2.48	84.9
Vegetable Ingestion	2.24	31.8	2.24	-	1.73	24.7	1.73	-
Meat Ingestion	0.569	8.60	0.569	-	0.084	1.28	0.084	-
Milk Ingestion	0.298	3.25	0.298	-	0.156	1.70	0.156	-
TOTALS[d]	5.79	49.2	8.17	84.9	4.65	33.2	7.03	84.9

[a] Based on exposure during the final year of mill operation.

[b] Doses received by the regional population are less than total doses for ingestion pathways because the regional population consumes only about 77%, 15%, and 52% of regionally produced vegetables, meat, and milk, respectively.

[c] Doses presented for the bronchial epithelium are those resulting from inhalation of short-lived Rn-222 daughters.

[d] The following percentages of annual dose commitments received by the region are due to annual radon releases (4.5 kCi): whole body, 43%; bone, 41%; lung, 35%; and bronchial epithelium, 100%.

Total regional radiological impacts from operation of the model mill for 15 years are estimated by multiplying the annual environmental dose commitments by 15. Based on the annual EDC's presented in Table 6.14, total population doses resulting from 15 years of model mill operation are calculated to be 87 whole body person-rem, 738 bone person-rem, 123 person-rem to the lung from particulates, and 1270 person-rem to the bronchial epithelium from inhalation of short-lived radon daughters. Total EDC's from 15 years of model mill operation received by the population of the model region are 70, 498, 105, and 1270 person-rem to the whole body, bone, lung, and bronchial epithelium, respectively.

6.2.8.2.6 Health Effects on Man

A perspective concerning the significance of the radiation dose commitments to individuals and to the population of the region which are predicted to result from operation of the model mill may be gained by comparisons with background radiation and with published protection standards. Another perspective may be obtained by estimating the impact of radiation on man in terms of affecting man's health. This section makes estimates of health effects to a maximally exposed individual living near a mill and to a population living in the model region. The basis for health effects estimates is given in Appendix G-7.

The maximally exposed individual is characterized as a person living at a ranch house 2.0 km downwind of the mill. The doses that could be accumulated per year of continuous residence at the ranch by this individual during mill operation are given in Table 6.10. Using the risk estimators given in Appendix G-7, the total risks to this hypothetical individual, from 15 years of mill operation, of dying from radiation-induced cancer is estimated to be one chance in approximately 3800. The risk to the maximally exposed individual of premature* death from cancer due to 15 years of mill operation represents about a 0.13% increase in the natural risk from cancer. About 75% of the risk of a premature death from exposure at the ranch is associated with lung cancer induced by radon and its daughters. Efforts to reduce radon emissions are discussed in Chapter 8 and 9.

The potential number of cancer deaths that might occur among the population of the region as a result of 15 years of model mill operation has been calculated using the environmental dose commitments listed in Table 6.14 and the risk estimators given in Appendix G-7. In Table 6.15, the number of premature deaths expected in the region from several types of cancer resulting from exposure to mill effluents is compared to the number which might result from background exposure and the natural incidence of cancer assuming that no milling took place. Even one death is improbable as a result of the dose commitment to the entire population from effluents released throughout the operating lifetime of the mill. Since this statistically unlikely death, should it occur, would be but one of thousands of other natural cancer deaths, its etiology would be entirely unrecognizable.

For the average individual living in the model region, the probability of a premature cancer death as a result of 15 years of mill operation is about 2.0×10^{-6} with a range from 8.4×10^{-7} to 4.1×10^{-6}. The risk to the average individual of premature death from cancer due to 15 years of mill operation represents about a 0.001% increase in the natural risk from cancer.

In Section 6.2.8.2.5, total population exposures to whole body, bone and lung were estimated to be greater than those occurring in the model region alone, because of the assumptions made regarding quantities of food grown in the model region. A net export from the region was assumed. However, the exposures to bronchial epithelium are not affected by this export of food. (Note: exposures and health risks due to radon and daughters which are transported out of the 80 km radius model region are considered in Section 6.4.) For this reason, and because of the relative size of the bronchial epithelium dose and radiosensitivity of this organ, health risks associated with the exported food component are not a large fraction above that estimated for the region alone. An increased total cancer risk of about 4.7% is estimated for this exposure increment.

Genetic effects transmitted to the offspring of parents living in the model region have also been estimated using the risk estimators of Appendix G-7. Among the entire population of the region, the probability of a single genetic defect attributable to the environmental dose commitments from the entire 15-year operating lifetime of the mill is one chance in 55. Should one defect occur, it would be obscured among abnormalities of the types listed in Table 6.15 which would occur in about 5% of the live births in the region, or at a rate of approximately 40 per year.

*The term "premature death" is used instead of death because all persons, regardless of radiation exposure, will eventually die.

Table 6.15 Estimated Health Effects Among Population of Model Region[a]

Somatic Effects

Organ at Risk	Premature Deaths Attributable to 15 Years of Mill Operation: Range	Central Value	Deaths Attributable to Natural Background Radiation[b]	Natural Incidence of Cancer[c]
Lung	0.041-0.21	0.10	44	-
Bone	0.0025-0.004	0.003	1	-
Whole body	0.0045-0.024	0.011	19	-
Totals	0.048-0.24	0.11	69	11,500

Genetic Effects

	Excess Effects Attributable to 15 Years of Mill Operation: Range	Central Value	Spontaneous Incidence[d]
Specific genetic defects	0.0035-0.035	0.011	120
Defects with complex etiology	0.0007-0.07	0.007	490
Totals	0.0042-0.11	0.018	610

[a]Based on environmental dose commitments from Table 6.14 multiplied by 15 years of operation.

[b]For population of 57,300 over 15 years exposed to the radiation environment described in Section 4.12.

[c]Approximately 20% of all deaths in the United States are due to cancer ("Cancer Facts and Figures," American Cancer Society, 1979). Assuming that 20% of the population in the model region would eventually die from cancer, approximately 11,500 deaths from cancer would be expected.

[d]The spontaneous incidence is estimated for a 15-year period. The spontaneous incidence rate is derived from Table 4 of the 1972 BEIR Report (Ref. 21) and assumes 14,000 live births per year per million population.

6.2.8.2.7 Occupational Exposures and Health Effects

The estimates of occupational exposures to radiation are based principally on worker exposures measured at seven operating uranium mills in Wyoming and New Mexico. The seven mills were visited from fall 1975 to spring 1977 by the NRC staff. Results were obtained from individual mill monitoring programs, and the average exposure levels are published here for the first time.

6.2.8.2.7.1 Average Individual Occupational Exposure

External Dose to Individuals

The average annual dose equivalent from external penetrating whole-body radiation was 685 mrem based on data from four mills. This average was increased greatly by the 2000 mrem/year average from one mill that had an unusually high buildup of radium in the circuit. The average from the remaining three mills was 250 mrem/year. By comparison, 7 of 17 licensed uranium mills reported an average whole-body dose of 380 mrem in voluntarily reported data for 1975 (NUREG-0419). The more accurate estimate of whole-body dose from external radiation is probably the 380-mrem/year value, and this is used subsequently.

Individual Internal Exposures

Inhalation is the only pathway leading to significant internal exposure to radionuclides by uranium mill workers.

Exposure to Uranium Ore Dust. Uranium ore dust in crushing and grinding areas of mills contains natural uranium (U-238, U-235, and U-234), thorium-230, radium-226, lead-210, and polonium-210 as the important radionuclides. The average uranium concentration present in the crushing and grinding areas of the seven mills was 2.6 pCi/m^3 of U-238 and each of its daughters. These concentrations were measured in dustier areas while machinery was actively producing new dust. The particles therefore tend to have large activity median aerodynamic diameters (AMADs). Unpublished measurements by the U.S. DOE's Environmental Measurements Laboratory place the AMADs at 10 to 15 μm.

The inhalation dose conversion factors from Table G-5.3 in Appendix G-5 were used to calculate doses to workers exposed to uranium ore dust. For convenience of calculation, a particle size of 5 μm was chosen (AMAD = 7.75 at a density of 2.4). This particle size results in a slightly larger estimate of the fractional deposition of dust in the pulmonary tissue than would be the case if an AMAD of 10-15 μm were used. Average occupational doses calculated to result from exposure to an ore dust concentration of 5.2 pCi/m^3 of natural uranium are given in Table 6.16. These doses are based on the assumption that a mill employee spends one-third of his working time in areas containing ore dust.

Table 6.16. Average Occupational Internal Dose due to Inhalation of Ore Dust[a]

	Dose from Isotopes in Ore, mrem/yr						
Organ	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Total
Avg. Lung	2.11×10^{1}	2.40×10^{1}	3.99×10^{2}	8.21×10^{2}	9.53×10^{1}	5.43×10^{1}	1.41×10^{3}
Whole body	1.42	1.62	2.92×10^{1}	1.15×10^{1}	1.40	2.05×10^{-1}	4.53×10^{1}
Bone	2.40×10^{1}	2.62×10^{1}	1.04×10^{3}	1.15×10^{2}	4.33×10^{1}	8.35×10^{-1}	1.25×10^{3}

[a]Doses are calculated based on the assumption that an occupational worker spends one-third of his workweek (40 hours) in the crushing and grinding areas of the mill. Dose conversion factors for occupational exposure are listed in Appendix G-5. Each isotope is assumed to be present in a concentration of 2.6 pCi/m^3.

Exposure to Yellowcake Dust. The average uranium concentration present in the yellowcake-handling areas of five uranium mills was 18.3 pCi of U-nat/m^3 (i.e., 9.15 pCi of U-238/m^3 and 9.15 pCi of U-234/m^3). Average occupational doses due to exposure to yellowcake dust at this concentration are given in Table 6.17. These doses are based on the assumption that a worker spends one-third of his time in yellowcake-handling areas.

Exposure to Rn-222 and Daughters. Prior to 1976, mill operators were not required to monitor radon levels. Consequently, only a few measurements are available on annual average radon daughter concentrations. These measurements indicate that the average working level (WL) exposure is about 0.05 WL. Thus, a worker in a mill would be exposed to 0.6 WL-months of radon daughters per year. It is assumed that one WL-month exposure to radon daughters will deliver a dose of 5 rem to the bronchial epithelium, and thus the average worker would be exposed to a dose of 3 rem/year.

Total Dose to an Average Individual Worker. It is assumed that an average worker is exposed annually to external radiation that delivers 380 mrem to the whole body and to radon daughters that produce a dose of 3 rem to the bronchial epithelium. It also is assumed that of the 40 hours per week that a worker spends in the mill, one-third of the time is spent in ore dust areas, one-third is spent in yellowcake areas, and one-third in areas of little airborne particulate radioactivity. The doses that an average worker would receive as a result of these

Table 6.17 Average Occupational Internal Dose Due to Inhalation of Yellowcake Dust[a]

Organ	Dose From Isotopes in Dust, mrem/yr U-238	U-234	Total
Avg. Lung	1090.	1230.	2320.
Whole Body	10.0	11.4	21.4
Bone	169.	184.	353.

[a]Doses are calculated based on the assumption that an occupational worker spends one third of his workweek (40 hours) in the yellowcake handling areas. Dose conversion factors for occupational exposure are listed in Appendix G-5. Doses are based on 9.15 pCi/m^3 each of U-238 and U-234.

conditions are given in Table 6.18. The risk of premature death due to cancer associated with these annual doses is 5.9×10^{-4}. Over a career (i.e., 47 years), an average mill worker would be exposed as follows: whole body, 21 rem; bone, 93 rem, and lung, 334 rem. The lifetime risk of premature death due to cancer is estimated to be about 2.8%. The lifetime risk is equivalent to about a 14% increase in the natural risk from cancer.

6.2.8.2.7.2 Cumulative Occupational Exposures and Health Effects

Cumulative occupational exposures are calculated on the basis of the estimated average number of radiation workers at a mill (about 80) and the number of conventional-model-mill-years that will be needed to produce the required U_3O_8. It has been projected in Chapter 3 that 436,000 MT (479,000 ST) of conventionally produced U_3O_8 will be needed over the time period 1979-2000. Based on the assumption that each mill will produce 523 MT (575 ST) of U_3O_8 per year (operating at 85% capacity), a total of approximately 833 mill-years will be needed to produce the required amount of U_3O_8.

Table 6.18. Average Occupational Dose Commitment to Uranium Mill Workers

	Annual Dose Commitment to Organs at Risk, mrem/yr			
			Lung	
Source	Whole Body	Bone	Average Lung	Bronchial Epithelium[a]
External	3.80×10^2	3.80×10^2	3.80×10^2	-
Ore dust	4.53×10^1	1.25×10^3	1.41×10^3	-
Yellowcake dust	2.14×10^1	3.53×10^2	2.32×10^3	-
Radon	-	-	-	3.00×10^3
TOTAL	4.47×10^2	1.98×10^3	4.11×10^3	3.00×10^3

[a]The dose to the bronchial epithelium is distinguished from the lung dose because the major dose delivered by radon daughter is to the bronchial epithelium.

Cumulative occupational exposures, somatic health effects, and genetic health effects estimated on the basis of these assumptions are given in Tables 6.19 through 6.21. Since the human body may be able to repair the effects of irradiation received at very low dose rates, it is possible that the risks may be much less than those presented.

Table 6.19 Cumulative Occupational Dose Commitment to Workers in U.S. Uranium Mills, 1979-2000[a]

	Dose Commitment (organ-rem)			
			Lung	
Source	Whole Body	Bone	Average Lung	Bronchial Epithelium
External	2.53×10^4	2.53×10^4	2.53×10^4	-
Ore Dust	3.02×10^3	8.33×10^4	9.40×10^4	-
Yellowcake dust	1.43×10^3	2.35×10^4	1.55×10^5	-
Radon	-	-	-	2.00×10^5
TOTAL	2.98×10^4	1.32×10^5	2.74×10^5	2.00×10^5

[a]Dose commitments are based on a total of 66,700 mill-worker-years over the period 1979-2000.

Table 6.20 Cumulative Somatic Health Effects Related to Occupational Radiation Exposure of Workers in U.S. Uranium Mills, 1979-2000

	Organ at Risk			
Category	Whole Body	Bone	Lung	Total
Premature deaths	4.5×10^0	0.8×10^0	3.4×10^1	3.9×10^1

Table 6.21 Cumulative Genetic Health Effects Related to Occuptional Radiation Exposure of Workers in U.S. Uranium Mills, 1979-2000

Category	Specific Defects	Defects with Complex Etiology	Total
Effects from occupational dose commitment[a]	4.7×10^0	3.0×10^0	7.7×10^0
Spontaneous incidence for 66,700 person-years[b]	9.0×10^0	3.8×10^1	4.7×10^1
Fractional increase in incidence of genetic defects among workers due to milling	5.2×10^{-1}	7.9×10^{-2}	1.6×10^{-1}

[a]It is assumed that 100% of this population is of childbearing age.

[b]The spontaneous incidence is estimated for a 15-year period. The spontaneous incidence rate is derived from Table 4 of the 1972 BEIR Report (reference 21) and assumes 14,000 live births per million population.

The estimated fatality incidence rate of uranium mill workers due to occupational radiation exposure is compared with the risk to other occupational groups in Table 6.22. The fatality incidence rates are based on deaths in 1975 due to a job-related injury or illness. In terms of job-related fatalities, the occupational risk associated with the average radiation dose (42 premature deaths/10^5 person-years) is higher than the average private sector risk (10 premature deaths/10^5 person-years). However, the risk to uranium mill workers is lower than the risk for a number of other groups.

Table 6.22 Incidence of Nonviolent Job Related Fatalities

Occupational Group	Fatality Incidence Rates[a] (premature deaths/10^5 person-year)
Underground Metal Miners[a]	1244
Asbestos Insulation Workers[b]	365
Uranium Miners[a]	232
Smelter Workers[a]	193
Mining[c]	61
Uranium Mill Workers[d]	60
Transportation and Public Utilities[c]	24
Services[c]	3
Total Private Sector[c]	10

[a]"The President's Report on Occupational Safety and Health," May 1972.

[b]Irving J. Selikoff and William J. Nicholson, "Deaths Among 17,800 Abestos Insulation Workers in the United States and Canada, January 1, 1967, through January 1, 1977," National Institutes of Health, 1978.

[c]"Occupational Injuries and Illnesses in the United States by Industry, 1975," Bureau of Labor Statistics, Bulletin 1981, 1978.

[d]The fatality incidence rate for uranium mill workers includes estimates of only radiation-related fatalities.

6.2.8.2.8 Summary

In this section the conclusions of the preceding analysis of the radiological impacts of the operational model uranium mill are summarized. Comparisons are made among predicted values, applicable standards, and background data. The assumptions that have been made for purposes of this analysis are considered to be representative of recent past practice in the industry. The references to a "model" mill are not meant to imply that the assumed parameters represent the best currently available control technology. Possible alternatives which would reduce the radiological impact from operation of the model mill are discussed in Chapter 8.

<u>Dose Commitments</u>

1. Average concentrations of airborne radionuclides, including the resuspended portion, at the fence, trailer, and ranch in the 15th year are given in Table 6.11. Background concentrations typical for the U.S. are also given. It is apparent that estimates for the mill effluents are many times larger than the average background values. On the other hand, the calculated concentrations are within the applicable limits of Title 10 of the U.S. Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation," for releases to unrestricted areas.

2. Table 6.12 presents doses calculated for the three hypothetical reference receptor locations for the purpose of evaluating compliance with the 25 mrem/yr limit to be imposed under 40 CFR Part 190. At the fence post location a maximum occupancy of about 14% (51 days/yr) would be allowable, provided that the individual of concern ingested no locally grown food during that occupancy and accrued no significant exposure from the base case model mill or any other regulated sources during the remainder of the year. For the hypothetical trailer location, where vegetables are assumed to be grown, 25 mrem/yr would result from an occupancy of about 16% (58 days/yr). If no vegetables were grown at this location, occupancy for 87 days per year (24%) would be required to accrue 25 mrem/yr. At the ranch location, which is assumed to be a permanent residence, 100% occupancy is presumed. Compliance with 40 CFR 190 at the ranch location could not be demonstrated under this condition, due to inhalation exposure.

3. The maximum annual population dose commitments to the population of the model region are those occurring during the 15th year of mill operation. As given in Table 6.14 these dose commitments are about 3.5, 29, 5.9, and 85 person-rem/yr to the whole body, bone, lung, and bronchial epithelium, respectively. Annual doses to the same population from natural background, based on dose rates presented in Table 4.14, amount to 7910, 9000, 7910, and 32100 person-rem to the whole body, bone, lung, and bronchial epithelium, respectively. The increase in regional population doses due to the base case model mill is, therefore, estimated to be no more than about 0.3%.

4. Total radiological impacts from operation of the model mill for 15 years are estimated as 15 times the annual environmental dose commitments from mill operation. Based on results given in Table 6.14, these total dose commitments are about 87, 740, 120, and 1270 person-rem to the whole body, bone, lung, and bronchial epithelium, respectively. Radon releases from the tailings pile alone have been calculated to account for over 80% of the annual incremental cancer risk due to mill operation. Since closing the mill will remove only the ore and yellowcake sources, it is clear that the end of mill operation will not by itself bring about an appreciable reduction in annual radiological impacts.

Radiological Risks

1. Health effects were estimated for two types of individuals (Sec. 6.2.8.2.6) living within 80 km of a mill. The first individual was characterized as the maximally exposed individual living for 15 years 2.0 km downwind from a mill. The probability of this hypothetical individual suffering a premature death due to radiation-induced cancer was calculated to be about 2.6×10^{-4} over the individual's lifetime. The risk to this maximally exposed individual represents about a 0.13% increase in the natural risk from cancer. The second individual was characterized as the average individual living for 15 years within 80 km of a mill. The risk to the average individual (2.0×10^{-6}) is about two orders of magnitude below the risk to the maximally exposed individual. For both individuals over 75% of the total radiation cancer risk is attributed to the lung dose from radon and its daughters.

2. For occupational workers the average lifetime risk of premature death due to cancer associated with career exposures (i.e, 47 years of exposure) is estimated to be about 2.8%. This lifetime risk is equivalent to about a 14% increase in the natural incidence of cancer.

6.2.8.3 Postoperational

Residents of the model region may continue to be exposed to radioactive effluents from the mill site even after the mill itself has ceased to operate. The purpose of this section is to describe the postoperational radiological impacts to individuals and the population which are predicted assuming that no efforts are made to reduce emissions from the tailings pile for a period of 5 years after mill shutdown. Alternatives to this so-called base case (no controls) are explored in Chapter 8, and the reduced radiobiological impacts which would result from implementation of these alternatives are described in Chapter 9. Also in this section the postoperational impacts expected in the base case are compared to those which in Section 6.2.8.2 were predicted to occur as a result of mill operations. It is important to note that while the operating phase is finite (assumed to be 15 years), emissions from exposed tailings could continue almost indefinitely.

The project-related radiation exposure within the region in each year following shutdown of the mill will primarily depend on management of the tailings pile. This is because the air concentrations of all radionuclides except U-238 and U-234 originate principally from the tailings (see Table 6.9). Mill shutdown, including cessation of yellowcake drying and packaging, will effectively eliminate about 94% of the uranium particulate sources, but less than 2% of the thorium and even less of other nuclides. This would reduce the total dose commitments to the organs of nearby residents, especially lung and bone doses from particulate inhalation, but would have an insignificant effect on overall population doses and associated health risks.

The comments above all refer to the base operating case where it is assumed there are 50 ha (125 acres) of dry tailings. Actually, as is shown below, the dose commitments to all organs except the lung (from particulates) actually increase after the base case model mill closes because the dry tailings area is extended, due to evaporation of ponded liquids.

6.2.8.3.1 Individual Dose Commitments

Doses to individuals at the three hypothetical reference receptor points (fence, trailer, and ranch house) considered in detail for the operating phase were again calculated assuming that, as described in Chapter 5, 30 ha (75 acres) of existing wet tailings dry out while no attempt is made at reclamation. In this instance, the total dry tailings source area becomes 80 ha (200 acres). In Table 6.23 individual dose commitments for the fifth year of existence of a tailings pile of 80 ha (200 acres) are compared to similar values for the 15th year of mill operation.

Table 6.23 40 CFR 190 and Total Maximum Individual Doses at Hypothetical Locations During the Final Year of Mill Operation and the Fifth Year after Mill Decommissioning

Location	Exposure Pathway	Individual Doses Due to Exposure During the Final Year of Mill Operations: Bone Doses, mrem/yr: 40 CFR 190 Doses	Individual Doses Due to Exposure During the Final Year of Mill Operations: Bone Doses, mrem/yr: Total Doses	Individual Doses Due to Exposure During the Final Year of Mill Operations: Lung Doses, mrem/yr: 40 CFR 190 Doses	Individual Doses Due to Exposure During the Final Year of Mill Operations: Lung Doses, mrem/yr: Total Doses	Individual Doses Due to Exposure During the 5th Year After Decommissioning[a]: Bone Doses, mrem/yr: 40 CFR 190 Doses	Individual Doses Due to Exposure During the 5th Year After Decommissioning[a]: Bone Doses, mrem/yr: Total Doses	Individual Doses Due to Exposure During the 5th Year After Decommissioning[a]: Lung Doses, mrem/yr: 40 CFR 190 Doses	Individual Doses Due to Exposure During the 5th Year After Decommissioning[a]: Lung Doses, mrem/yr: Total Doses
I. Fence (site boundary)	External (ground)	0.12	4.09	0.12	4.09	0.15	5.84	0.15	5.84
Occupancy: 10%	External (cloud)	neg.	0.11	neg.	0.11	neg.	0.18	neg.	0.18
0.64 km ENE	Inhalation (part.)	7.27	7.27	18.4	18.4	7.35	7.35	6.22	6.22
	Inhalation (radon)	-	-	-	127.	-	-	-	200.
	TOTALS:	7.39	11.5	18.5	150.	7.50	13.4	6.37	212.
II. Trailer	External (ground)	0.33	10.5	0.33	10.5	0.40	15.0	0.40	15.0
Occupancy: 50%	External (cloud)	neg.	0.60	neg.	0.60	neg.	0.94	neg.	0.94
0.94 km ENE	Inhalation (part.)	19.6	19.6	52.0	52.0	19.4	19.4	16.7	16.7
	Inhalation (radon)	-	-	-	330.	-	-	-	520.
	Ingestion (veg.)	59.0	59.0	4.9	4.9	92.0	92.0	7.70	7.70
	TOTALS:	78.9	89.7	57.2	398.	112.	127.	24.8	560.
III. Ranch	External (ground)	0.17	5.29	0.17	5.29	0.21	7.56	0.21	7.56
Occupancy: 100%	External (cloud)	neg.	1.05	neg.	1.05	neg.	1.66	neg.	1.66
2.0 km ENE	Inhalation (part.)	10.3	10.3	27.1	27.1	10.5	10.5	9.29	9.30
	Inhalation (radon)	-	-	-	184.	-	-	-	289.
	Ingestion (veg.)	29.8	29.8	2.47	2.48	46.6	46.6	3.89	3.89
	Ingestion (meat)	4.66	4.67	0.38	0.38	7.31	7.31	0.59	0.59
	TOTALS:	44.9	51.1	30.1	220.	64.6	73.6	14.0	312.

[a]The area of dry tailings is assumed to expand linearly from 50 ha (62.5%) to 80 ha (100%) in 3 years, and remain in that condition during the final 2 years of the total 5-yr drying period.

From the data presented in Table 6.23 it is apparent that closing the mill and allowing the dry tailings area to expand from 50 to 80 ha (125 to 200 acres) will result in substantially increased annual dose commitments to nearby residents, except for the particulate dose to the lung. Over 80 percent of the annual particulate lung dose during mill operation, at the fence location, results from yellowcake dust emissions, and this source is eliminated when the mill shuts down. However, because of the much larger increase in doses to the bronchial epithelium from radon daughters, total annual lung dose commitments at all locations are increased substantially five years later.

This examination of the postoperational period shows that without reclamation of the tailings area, the annual dose commitments to bone, and lung (from radon plus particulates) will have increased markedly five years after shutdown. However, the situation will not have changed significantly relative to compliance with applicable radiation protection standards. Concentrations of airborne radioactivity will remain within the limits specified in 10 CFR Part 20, even at the fence location. On the other hand, the 25 mrem per year standard of 40 CFR Part 190 is again exceeded at the trailer and ranch locations. Maximum permissible occupancy at the fence location would be increased from 14% during operation, to about 33%.

6.2.8.3.2 Population Dose Commitments

The annual population dose commitments resulting from environmental contamination of the model region have been estimated for the fifth year after mill operation has ceased by following the same calculational procedures employed in the study of the operating phase. When ore crushing and grinding and yellowcake drying and packaging cease, the annual population dose commitments would be reduced less than a few percent if the tailings source remained constant. In the assumed case, in which the 30 ha (75 acres) of wet tailings are allowed to dry without concurrently covering any of the already-existing 50 ha (125 acres) of dry area, the annual dose commitments to the population of the region would increase by approximately 60% (or in the expected ratio of 80/50).

A comparison of regional population dose commitments from the 15th year of the mill operation and from the fifth year of storage of 80 ha (200 acres) of dry tailings is given in Table 6.24. Although the increases in dose commitments are appreciable, they remain at levels which are small in comparison to doses received by the same population from natural background radiation. Annual population dose commitments during the fifth postoperational year amount to no more than about 0.5% of those from natural background. It may be noticed that for lung doses due to particulate inhalation, population doses rise after mill shutdown while individual doses close to the mill decrease. This is due to the dominance of ingrown Rn-222 daughters, Pb-210 and Po-210, at large distances. At small distances, yellowcake particulate sources dominate inhalation lung doses.

6.2.8.3.3 Environmental Dose Commitments

The annual and 5-year total environmental dose commitments (EDC's) which would result from existence of 80 ha (200 acres) of dry uncovered tailings at the mill site are given in Table 6.25. Also presented are total EDC's resulting from 15 years of operational releases, and total EDC's resulting from the entire 20-year period. Ingestion EDC's included in Table 6.25 are totals and reflect complete consumption of the entire model region's food production. Because the regional population is assumed to consume less food than is produced within the model region, EDC's actually received by the regional population are less than the total EDC's presented in Table 6.25. EDC's received by the regional population are presented in Table 6.26.

6.2.8.3.4 Health Effects

In this section the estimates of health effects among the regional population as a whole and in maximally exposed individuals are presented and an effort is made to set them in perspective. These predictions have been developed in the same way as those that were summarized in Section 6.2.8.2.8, also utilizing the risk estimators from Appendix G-7. Since the five-year postoperational period cannot be dissociated from the previous 15 years of operation with regard to health effects, dose commitments have been combined.

Table 6.24 Calculated Annual Population Dose Commitments to the Regional Population, Comparison with Natural Background

Exposure Pathway	Annual Population Dose Commitments to the Regional Population, person-rem/yr							
	During the Final Year of Mill Operation				During the 5th Post-Operational Year[c]			
	Whole Body	Bone	Lung	Bronchial Epithelium	Whole Body	Bone	Lung	Bronchial Epithelium
External from ground surfaces	0.306	0.306	0.306	-	0.439	0.439	0.439	-
External from airborne activity	1.46	1.46	1.46	-	2.30	2.30	2.30	-
Inhalation of airborne activity	0.102	2.94	2.46	84.9	0.142	4.30	1.93	134.
Ingestion of vegetables[a]	1.46	21.6	1.46	-	2.26	33.2	2.26	-
Ingestion of meat[a]	0.062	0.977	0.062	-	0.095	1.51	0.095	-
Ingestion of milk[a]	0.107	1.20	0.107	-	0.162	1.79	0.162	-
Totals from the model mill	3.50	28.5	5.86	84.9	5.40	43.6	7.19	134.
Totals from natural background[b]	7910.	9000.	7910.	32100.	7910.	9000.	7910.	32100.
Fractional increase from model mill	0.0004	0.0032	0.0007	0.0026	0.0007	0.0048	0.0009	0.0042

[a]Ingestion doses shown are based on the assumption that of the regional food production, the regional population consumes about 77% of the vegetables, 15% of the meat, and 52% of the milk.

[b]Population doses from natural background are based on individual dose rates given in Table 4.14, excluding contributions from fallout.

[c]The area of dry tailings is assumed to expand linearly from 50 ha (62.5%) to 80 ha (100%) in three years and remain in that condition during the final two years of the total five-year drying period.

Table 6.25 Annual Postoperational and Total Environmental Dose Commitments

Exposure Pathway	Annual Environmental Dose Commitments from Postoperation Releases, person-rem/yr[a]			
	Whole Body	Bone	Lung	Bronchial Epithelium
External from ground surfaces	1.74	1.74	1.74	-
External from airborne activity	2.30	2.30	2.30	-
Inhalation of airborne activity	0.142	4.30	1.94	134.
Ingestion of vegetables	3.45	49.0	3.45	-
Ingestion of meat	0.890	13.4	0.890	-
Ingestion of milk	0.459	4.94	0.459	-
Annual Totals	8.98	75.7	10.8	134.
Total EDCs from first 5 years of postoperational releases[b]	39.9	336.	47.9	594.
Total EDCs from 15 years of operational releases[c]	86.9	738.	123.	2010.
Total EDCs from entire 20-year period[d]	127.	1074.	171.	2604.

[a]Ingestion doses shown are totals and reflect total population doses arising from complete consumption of the regional food production.

[b]Annual EDCs shown are computed on the basis of 80 ha (100% of pile area) of dry tailings. Five-year totals shown here are calculated assuming the area of dry tailings expands linearly from 50 ha (62.5%) to 80 ha (100%) during the first three years, and remains at 80 ha thereafter.

[c]Total EDCs shown are from data given in Table 6.14.

[d]Total EDCs shown are the combined result of 15 years of operational releases and the first five years of postoperational releases.

Dose commitments and risk to a maximally exposed individual living for 20 years near a mill are given in Table 6.27. The risk of the maximally exposed individual of dying from radiation associated with the mill is estimated to be 3.8×10^{-4}. This risk represents about a 26% increase over the risk of death from background radiation. About 90% of the risk to the individual is associated with lung cancer.

The resulting EDCs for the entire 20 years are given in Table 6.28 together with the prediction of premature cancer deaths.

In comparing the 20-year environmental dose commitments and their related effects with the data for the operating period, it will be observed that the premature deaths among the 57,300 residents of the model region throughout the entire 15- and 20-year periods are approximately 0.11 and 0.17, respectively. This is very small in comparison with the natural incidence of cancer in the region. For the average individual living in the model region, the probability of premature death from a cancer associated with the 20-year dose is 2.9×10^{-6}. This added risk is equivalent to a 0.0014% increase in the natural incidence of cancer.

The number of genetic defects predicted to occur among the offspring of the regional population as a result of mill-related radiation exposure during the 20-year period is about 0.026. This may be compared with approximately 800 defects which would be expected among this population in 20 years even without the mill.

6.2.8.3.5 Summary

1. Discontinuing operation of the model mill removes the major sources of uranium particulates (the yellowcake dryer and packaging operation) so that particulate dose commitments to the lungs of nearby residents are reduced in the years that follow the end of mill operation.

Table 6.26 Annual Postoperational and Total Environmental Dose Commitments Received by the Population of the Model Region

Exposure Pathway	Annual Environmental Dose Commitments from Post-Operational Releases Received by the Population of the Model Region, person-rem/yr[a]			
	Whole Body	Bone	Lung	Bronchial Epithelium
External from ground surfaces	1.74	1.74	1.74	-
External from airborne activity	2.30	2.30	2.30	-
Inhalation of airborne activity	0.142	4.30	1.94	134.
Ingestion of vegetables	2.68	38.0	2.68	-
Ingestion of meat	0.132	1.99	0.132	
Ingestion of milk	0.240	2.59	0.240	-
Annual Totals[b]	7.23	50.9	9.03	134.
Total EDCs from first 5 years of postoperational releases[c]	32.10	226.	40.1	594.
Total EDCs from 15 years of operational releases[d]	69.8	497.	105.	1273.
Total EDCs from entire 20-year period[e]	102.	723.	146.	1867.

[a]Ingestion doses included reflect the assumptions that, of the total regional food production, the regional population consumes about 77% of the vegetables, 15% of the meat, and 52% of the milk.

[b]The following percentages of annual regional dose commitments are due to radon releases (7.3 KCi/yr): whole body, 44%; bone, 42%; pulmonary region of lung, 44%; and bronchial epithelium, 100%.

[c]Annual EDCs shown are computed on the basis of 80 ha (100% of pile area) of dry tailings. Five-year totals shown here are calculated assuming the area of dry tailings expands linearly from 50 ha (62.5%) to 80 ha (100%) during the first three years, and remains at 80 ha thereafter.

[d]Total EDCs shown are from data given in Table 6.14.

[e]Total EDCs shown are the combined result of 15 years of operational releases and five years of postoperational releases.

2. Expansion of the area of dry tailings from 50 to 80 ha (125 to 200 acres) after the mill closes increases the annual whole body, bone, and bronchial epithelium dose commitments to individuals living near the mill and to the regional population by 50% to 60%. The total lung dose commitment, obtained by combining the particulate doses to the lung and the radon daughter doses to bronchial tissues, increases by a similar margin.

3. Compliance with the 25 mrem/yr limit imposed by 40 CFR Part 190 cannot be established at the ranch location; can be established only for very limited occupancy at the trailer location.

4. During the postoperational phase the annual dose commitments to residents at the ranch increase to more substantial fraction of doses from natural background. The risk of premature death during the 20-year period, including operation and decommissioning of the mill, is estimated to be about 3.8×10^{-4} for a person who lives at the ranch. This added risk is equivalent to a 26% increase in the risk from background radiation.

5. Following shutdown of the mill, the annual dose commitments to the population within an 80-km (50-mile) radius increase but remain at less than about 0.5% of the population doses from natural background.

6. The 100-year environmental dose commitments for the entire 20-year period of mill activity give rise to the following estimates of health effects in the model region: premature deaths related to milling, 0.17, and genetic defects, 0.026. The added risk associated with radiation from mills is equivalent to a 0.0014% increase in the natural risk from cancer.

Table 6.27 Dose Commitments and Risk to the Maximally Exposed Individual Living 20 Years near a Model Mill

Organ at Risk	Dose To Maximum Individual (mrem)[a] Operations	Postoperations	Total	Risk of Premature Death Death Due to Dose (10^{-6})	Fraction of Risk Due to Background(%)[b]
Whole Body	145	64	209	32	2.1
Lung	3300	1390	4690	338	23.
Bone	767	329	1100	7	0.4
				377	26.

[a]The dose to the maximum individual is based on a person living 2.0 km downwind from the mill. An occupancy factor of 100% is assumed.

[b]The risk of premature death due to background radiation is estimated to be 7.4 x 10^{-5} for one year or 1.5 x 10^{-3} for twenty years. The following annual background exposures are assumed for the model region: whole body, 143 mrem; bone, 250 mrem; and lung, 704 mrem.

Table 6.28 Environmental Dose Commitments and Health Effects from 20-Year Period (15 years operation plus five years postoperation)

Organ at Risk	100-year Environmental Dose Commitment from 15-yr Operation plus 5-yr Tailings Storage (organ or man-rem)	Premature Deaths Attributable to 20-year Period[a]	Deaths Attributable to Natural Background Radiation[b]	Natural Incidence of Cancer[c]
Whole body	102	0.016[d]	25[d]	-
Lung	2010	0.145	59	-
Bone	723	0.004	2	-
		0.17	86	1150

[a]Based on risk estimators given in Table G-7.1 of Appendix G-7.

[b]For population of 57,300 over 20 years.

[c]Approximately 20% of all deaths in the United States are due to cancer ("Cancer Facts and Figures," American Cancer Society, 1979). Assuming that 20% of the population in the model region would eventually die from cancer, approximately 1150 deaths from cancer would be expected.

[d]Includes leukemia and other forms of cancer correlated with whole-body exposure.

6.3 MULTIPLE-MILL IMPACTS

6.3.1 On Air Quality

6.3.1.1 Construction

For the multiple-mill analysis it was assumed that the mills in the cluster would be constructed in sequence. At the most only two mills would be under construction at any one time. Therefore, depending on siting, the local effects (i.e., concentrations of pollutants in any given area) could be essentially the same as for one mill, even though the total area affected would double because two mills would be under construction. It is possible, however, that the two construction sites would be sufficiently close to each other that overlapping air quality impacts would occur, thus doubling the local effects from the one-mill case.

6.3.1.2 Operation

The combined effluents of 12 operating mills would impact the air quality of the model site and the model region by increasing the total suspended particulates as a result of traffic operating on unpaved haul roads, windborne sand from the tailings piles, and dust from ore storage areas. During periods of dry roads and dry tailings piles, high wind speeds, and heavy traffic, concentrations of suspended particulates would probably exceed Federal standards (see Sec. 4.2). Maximum average annual concentrations of suspended particulates resulting from the operation of 12 mills in the model site would to be 30 μg/m³, in addition to preconstruction background concentrations of 35 μg/m³, for a total maximum annual average of 65 μg/m³. Therefore, while the contribution from mills in a cluster would not add a large amount to dust levels predicted for a central mill at the 1 km reference location (8 μg/m³ above the 22 μg/m³ predicted in Section 6.2.1), their contribution may be significant since the total 65 μg/m³ would exceed standards in some states. For example, Wyoming limits are 60 μg/m³. Concentrations would decrease to approximately 5% of background at the boundary of the model site.

Gaseous chemical effluents would also have an impact, although smaller than that of the particulate concentrations. The maximum average annual concentrations of SO_2, NO_2, and kerosene 1000 m (3300 ft) downwind of a given model mill and at the model site and model region boundaries are given in Table 6.29. Because of these small source terms and the site's meteorology, the added contribution from upwind mills would be negligible. Concentrations would be unmeasurable at the boundary of the model site.

Table 6.29. Calculated Maximum Annual Average Concentrations of Airborne Chemical Effluents from 12 Mills[a]

Effluent	Effluent Concentrations, μg/m³ 1000 Meters Downwind of a Model Mill[b]	Model Site Boundary[c]	Model Region Boundary[c]
SO^2	2.5	5×10^{-3}	2×10^{-3}
NO^2	0.3	4×10^{-3}	2×10^{-3}
Kerosene	4.5	5×10^{-2}	2×10^{-2}

[a]Calculated on the basis of estimated releases and model site meteorology with a Gaussian dispersion model recommended by D. B. Turner, "Workbook of Atmospheric Dispersion Estimates," Public Health Service, 1967.

[b]Concentrations 1000 m downwind resulting from operation of any given mill.

[c]Cumulative concentrations downwind resulting from operation of all 12 mills.

6.3.1.3 Postoperation

The primary postoperational impact of the 12 mills would result from windblown materials from the tailings areas. Because increasing amounts of the tailings surfaces would be dry, and thus increasingly subject to wind erosion, the postoperational impacts would be likely to be great. Until natural revegetation occurred, after a period of several years, the maximum annual average increase in suspended particulates would be expected to be 35 μg/m³ at 1000 m (3000 ft) downwind of any given tailings pile. The annual increase in the background concentration at the model site boundary would be 10 μg/m³, assuming 4.5 kg/ha-hr (4.0 lb/acre-hr) of dust removed from all the tailings piles during periods of wind speed greater than 5 m/s

(11 mph). During periods of locally dry soil and high wind speeds, short-term concentrations of suspended particulates would at times be in excess of state and Federal standards. Concentrations at the boundary of the model region are not expected to be measurable except during these periods of high wind speeds and dry soils.

6.3.2 On Topography and Land Use

6.3.2.1 Construction

The phased construction of 12 mills within a 40-km (25-mile) radius could alter the topography of the model site, resulting in a general leveling of the existing terrain. Construction of pits, water ponds, spoil piles, tailings ponds and similar features would further alter the topography of each mill site. Construction roads would be needed to transport machinery and workers to and from mill sites, and would result in the cutting of long, straight paths on the landscape between mills.

The model region is large enough and its landscape diverse enough that the construction of 12 mills would not result in drastic regional impacts. The estimated area of disturbance [600 ha (1500 acres) at any given time, totalling 3600 acres (9000 acres)] would be less than 0.2% of the area of aggregated site and region. The indirect impacts on land use in the model region would probably be greater than the direct ones, although more difficult to quantify. The need for housing and other services for incoming workers and their families would result in diversion of land from present uses (e.g., grazing) to urban uses.

Land use changes associated with construction may not be important when compared to other land use changes occurring within the model region. On the other hand, the impacts due to intensive construction would be largely adverse; thus, construction of 12 mills would pose more serious problems than would the construction of a single mill, and more active land use control might be necessary (see Supplement).

6.3.2.2 Operation

Operation of 12 mills on the model site would further deteriorate the topography. The expected 180 mill-years of operation could result in creation of piles of ore, overburden, and tailings of sufficient size to be dominant features on the local landscape. The impact of the overburden and tailings piles would be long-lived, since they would remain above ground beyond the operational phase. The impacts of roads on the topography of the site would continue as some haulage roads were abandoned and new ones cut. Impacts on regional topography would not be substantial.

The direct impacts on land use discussed above for the construction phase would continue because the land withdrawn from grazing during construction activities would be used for milling operations. The indirect impacts on land use would be intensified since a larger number of operations personnel would settle within the region. The semipermanent regional population increase associated with development of uranium milling would require that land formerly used for grazing, crops, and other nonintensive uses would be converted to urban use. Most of this land use change would occur on the private lands in the river valley and along the interstate highway, and much of this development could be uncontrolled. Furthermore, although urban land would still amount to only a small fraction of the region, urbanization would probably occur on the most fertile land. Another potential indirect land use impact would be reduction of the amount of irrigated land if water became scarce, as is probable in view of the limited groundwater resources of the site.

6.3.2.3 Postoperation

As operations at each mill were terminated, the topography of the model site would be subject to the effects of erosion, poor vegetative succession, and altered streamflows. Unless appropriate measures were taken to redress damage, postoperational impacts of 12 mills on the regional topography could be more severe than those impacts during construction and operational activities.

6.3.3 On Mineral Resources

6.3.3.1 Construction

The sequential construction of 12 mills would not have any effect on the quality or eventual exploitation of any mineral resource.

6.3.3.2 Operation

Operation of 12 mills within a 40-km (25-mile) radius would have roughly 12 times the impact on mineral resources as the single model mill. Metals in the tailings could be recovered. However, surface mining of mineral deposits immediately under the tailings impoundments and mill facilities would be precluded. (Angle drilling of oil and gas or deep mining to recover valuable ores at depth would not be affected.)

6.3.3.3 Postoperation

Aside from reworking, or otherwise disturbing the tailings, which would not be permitted, the above conclusions for the operational period are equally applicable to the postoperational period.

6.3.4 <u>On Water Resources</u>

Impacts to surface and groundwaters from the construction and operation of a cluster of uranium mills in a limited area are assessed in this section. It is assumed for the purposes of this assessment that some mills will have common water courses for mine dewatering and common areas of seepage influence from mill tailings.

6.3.4.1 Surface Waters

<u>Construction</u>

Construction of the mill facilities and access roads would result in modification of drainage patterns, increased wind and water erosion of soils in disturbed areas, and the routine release of such pollutants as cement dust and fuel combustion products. A portion of the particulates, soil particles, and chemical pollutants would be transported (via the wind, surface runoff, or snowmelt) into the beds of local streams and thus contribute to degradation of surface water quality. However, little impact to biota in Tributary River would result from material transport from the model site during periods when streamflow reached the river.

<u>Operation</u>

If the effluents from mine dewatering were to be released to the environment, rather than contained in evaporation ponds or the tailings ponds, most of Bone Gulch would change from an ephemeral stream into a perennial one immediately before and during operation of the 12 mills. Flows would vary from 3.9 to 57 m^3/min (1000 to 15,000 gpm), depending on the stream section (App. D). Although much of the stream would be flowing, the water would only come within about 1000 m (3000 ft) of the river during periods of dry weather and normal mine dewatering, because streamflows from mine dewatering would either have infiltrated into the stream bed or evaporated before reaching the river. A heavy rain or considerable snowmelt, however, would contribute to this flow and might cause the streamflow to reach the river.

Water in Tributary River and Bone Gulch would be subject to several types of impacts from milling activities, including those types that were addressed for the operation and tailings disposal aspects of the single model mill (Sec. 6.2.4.1).

The general nature of wind and seepage water dispersal of contaminants from milling activities at 12 mills would be similar to that from a single mill (Sec. 6.2.4.1) except that the magnitude would increase (Sec. 6.3.4.2). Seepage that intercepts the stream would be carried with the dewatering flow, diluted, and transported downstream toward the river. Dilution of this component of contamination from individual mills would result in a decrease in the initial impact from material transport following rain or snowmelt. However, since 12 mills would be contributing to the seepage, the overall quality of the water during rain runoff and snowmelt would be poorer than for one mill.

Contaminants could accumulate at specific locations along the water course when the streamflow ceases because of infiltration into the streambed and evaporation (App. D). Although this would occur in three sections of the drainage system (see Fig. D.1 in App. D) potential for water quality degradation and biological impact would be in that section between impoundment I and Middle Reservoir. Salts would accumulate on the surface and in the interstices of the streambed, and water quality would probably be poor during periods of low flow.

initial flows to the river might occasionally carry contaminants (e.g., selenium), the concentrations of which are already high in the river (see Table 4.6). The potential would then exist for an impact upon aquatic biota in Tributary River and also upon the potable and agricultural use of water in areas adjacent to the confluence of the stream and river.

Postoperation

Upon cessation of mining and milling, dewatering activities would cease and Bone Gulch would return to an ephemeral state. Transport of contaminants would be limited to periods of heavy rainfall or snowmelt when the stream would carry a flow to Tributary River. The impact to water quality in the stream and river from this source therefore would be a function of the amount of dilution water available and the periodicity of rainstorms.

During the postoperation period, seepage would have the highest potential for causing impacts on water quality in the region. Although seepage from tailings piles at multiple mills would move at a rate similar to that from a single mill, the concentration of contaminants in some areas might be higher because of overlapping of seepage plumes (Sec. 6.3.4.2). The maximum permissible concentration (MPC) for iron, manganese, sulfate, and selenium could be exceeded in seepage water intercepting all surface water downgradient from the area of mill activity. The impact of seepage on water quality would depend on the amount of dilution afforded by the receiving water.

6.3.4.2 Groundwater

Water Quality

There would be no impacts on groundwater during construction for the same reasons as for the single mill case (Sec. 6.2.3.2).

In general, the operation of a given number ("n") of mills within about 20 km (12 miles) of the center of the model site would cause "n" times the amount of groundwater contamination as would operation of a single model mill. If the hydrogeological parameters were the same at each site, the concentrations of contaminants and the rate of movement of each of the "n" plumes would be roughly the same as discussed in Section 6.2.4.2. Because of the phased nature of the operational periods of the mills, "n" would vary from 1 to 12 mills; the interval during which the value would be 12 would be short. Based on the assumption that one mill would be brought on line each year and that the mills have a 15-year lifetime, the weighted average value of "n" would be about eight.

During the postoperational period, the effects of seepage from 12 tailings impoundments would be similar to those discussed in Section 6.2.4.2, scaled upward; the ultimate discharge into Middle Reservoir would be 12 times as great. With 12 mills within a 20-km (12-mile) radius, it would be probable that some seepage plumes would overlap; thus, concentrations predicted in Appendix E would be increased.

Water Use

The primary source of mill process water would be from deep groundwater supplies. Dewatering of the 40 mines associated with the 12 mills would discharge at a rate of 240 m^3/min (63,400 gpm) and would be released to the local water courses. Most of this water would be evaporatively lost or would seep back to groundwater, as observed at existing mills. When this amount of withdrawal is considered relative to a large valley aquifer system with abundant recharge and to the small amount of withdrawal for domestic use and watering of stock, it does not appear that there would be a significant impact on patterns of groundwater use. This is especially the case since the mill sites are up to 32 km (20 miles) from local groundwater supplies. In the extreme, temporary lowering of water wells immediately near dewatering activities would occur.

The above conclusions are appropriate for the model region, where the water supply of the aquifer is plentiful and where there is little competing demand for the groundwater in the volume affected by mine dewatering. These conditions may not obtain in all of the areas in which uranium mining is a major activity. Some of the aquifers being pumped to dewater uranium mines are not so well supplied as the model aquifer, which represents the typical case, not the extreme. In many of the uranium mining areas, competition for water in the pumped aquifer is appreciable and growing. Much of this competition arises from other resource-exploitive industries, such as coal mining, and if the water is dissipated by evaporation, or is otherwise consumed, the result may be a net loss of water from the aquifer. In semiarid areas such a loss may represent a severe environmental impact.

A proper assessment of this situation is beyond the scope of this document, which is limited to uranium milling, in that all uses of groundwater in a given area would have to be tabulated and a water balance for each use carried out. These could then be encompassed into a regional study and a water balance for the entire region performed. The results of such a study are reported in Reference 25.

6.3.5 On Soils

The nonradiological impacts of 12 mills on soils of the model region are described in this section. The impact assessment was based on the assumption that the effects of a single mill (see Sec. 6.2.5) would, in general, be increased 12-fold.

6.3.5.1 Construction

The eventual construction of 12 mills within the model site would result in additional losses of the soil resource, i.e., about 2800 ha (7000 acres) of rangeland productivity and soils, comprising less than 1.0% of the site resource and about 0.2% of the regional resource. Impacts to soils of the region would be due mainly to increased grazing pressure, leading to increased soil compaction and erosion due to overgrazing. This would reduce the rangeland capability of the region, and thus voluntary reduction of domestic animal herds might be necessary.

6.3.5.2 Operation

Impacts to soils during operation of the 12 mills would be qualitatively similar to impacts from a single mill (Sec. 6.2.5.2); however, the magnitude of chronic seepage would increase by a factor of eight on the average, and the areas for potential salinization would therefore be greater than for a single mill. Similarly, the adverse effects from windblown tailings would increase by a factor of about eight over the case for a single mill.

Soils of the region would continue to be adversely affected by overgrazing if domestic herds were not reduced.

6.3.5.3 Postoperation

No additional impacts to soils would be expected after operation ceases, unless previously undisturbed soils were removed for reclamation of the mine and mill sites.

6.3.5.4 Summary

If few mitigative measures were employed, then the major impacts to soils resulting from construction and operation of 12 mills in the model region would include loss of about 2800 ha (7000 acres) of the soil resource and salinization of about 12 ha (30 acres) of land. This comprises about 0.2% of the regional soil resource. In addition, overgrazing, an impact that was of no concern in the case of the single mill, would be of more importance when 12 mills were in operation. Overgrazing by displaced livestock could result in adverse effects on soils outside the areas of the mills. Alternatives to reduce these impacts are described in Chapter 8.

6.3.6 On Biota

The nonradiological impacts of 12 mills on terrestrial and aquatic biota of the region are described in this section. It was assumed that the impacts from a single mill (Sec. 6.2.6) would, on the average, be increased eight-fold, reaching an ultimate magnitude of 12-fold.

6.3.6.1 Terrestrial

Construction

Construction of 12 mills within the model site would result in additive ecosystem losses as outlined in Table 6.30. Loss of primary and secondary productivity, as well as of small-mammal biomass, would comprise about 0.2% of the regional productivity, and be equivalent to 12 times the loss of animal biomass estimated for the single mill site. About 60 cattle or 300 sheep would be displaced into the surrounding areas. If domestic herds were not voluntarily reduced, the regional carrying capacity would be lowered because of reduced quantity and nutritive quality of forage.[9] Trampling of forage by cattle and sheep would result in forage losses that could range to over 60%, depending on the season and distance travelled by the foraging animals. Overgrazing also would tend to increase the abundance of less palatable plants (increasers) at the expense of more palatable plants (decreasers).

Antelope, which do not compete heavily with cattle, would probably be only slightly affected by construction of the 12-mill site and would probably continue to thrive in the region because of a higher proportion of increasers and invaders. Adverse impacts to antelope would probably result from human activity, such as increased road traffic and increased hunting pressure.

Based on studies of grazing effects on grassland bird communities,[26] it is probable that the heavy grazing or overgrazing in the region would tend to result in an overall decrease in bird species diversity.

Table 6.30. Site Biotic Losses due to Construction of 12 Mills[a]

Biotic Element	Quantity Lost
Primary production	1.5×10^{13} J
Seed production	3.3×10^{13} J
Secondary production	7.1×10^{10} J
Small mammal biomass	9.5×10^{4} g to 2.6×10^{6} g
Livestock	60 cows or 300 sheep displaced
Large game	36 to 180 pronghorn antelope displaced
Avifaunal biomass	4.7×10^{5} g

[a]Values are based on those for the single mill site, Table 6.5 of Section 6.2.6.

Operation

Impacts to terrestrial biota from operation of the 12-mill site would arise from seepage and deposition of windblown tailings on soils and vegetation, as described for the single mill site (Sec. 6.2.6.1). In the case of the multimill site, however, cumulative impacts would be, on the average, eight times greater and effects on biota of the region might be evident. As a result of the increased land area devoted to milling operations, the chances of a carnivore's (e.g., hawk or coyote) territory being composed mainly of lands closely associated with milling would increase, and therefore the probability of accumulation of toxic elements in carnivores would be greatly increased in the multimill case.

Impacts to biota arising from increased road traffic and hunting pressure would, on the average, be increased eight times; impacts to raptors from electric transmission lines would be somewhat less than eight times, since a single large transmission system, with additional distribution lines, would probably serve the 12 mills. Impacts on nongame birds of the region as a result of increased grazing would continue and result in lower species diversity.

Postoperation

As in the case of the single mill, nonradiological impacts to biota following cessation of operation would be due mainly to remnants of seepage and reduction of food resources on salinized areas. The extent of such areas would be, eventually, 12 times greater than for the single mill and might extend into the model region. The impacts of overgrazing in the region, initiated during the construction of the mills, would continue to be evident unless livestock herds were voluntarily reduced.

Summary

If few mitigative measures are employed, then the major impact of 12 mills on terrestrial biota would be loss of 0.2% of the primary and secondary productivity of the region. In addition, unless stock herds were reduced, displacement of cattle and sheep would result in overgrazing of rangelands in the region, thus further reducing regional productivity. These effects can be viewed as trade-offs for electric power, or can be viewed as irretrievable losses of long-term productivity. Alternatives to reduce these impacts are described in Chapter 8.

6.3.6.2 Aquatic

Construction

Changes in the biota in Tributary River would reflect the impacts of increased turbidity and suspended sediment loads resulting from construction of mills, support facilities, and access roads. Because of their adaptations for harsh environments,[27] species normally associated with ephemeral streams probably would not be directly affected. However, decreases in all trophic levels would occur if primary productivity were suppressed.

Operation

Impacts to aquatic communities during operation of 12 mills would be proportional to the quantity of contaminants entering the stream. The conditions that would mobilize the contaminants (e.g., heavy rainfall) eventually would also dilute them. However, because of the larger amounts of contaminants released during concurrent operation of 12 mills under conservative predictions, concentrations exceeding water quality criteria could be reached, and possibly persist, in the river.

Postoperation

Leaching of contaminants (e.g., selenium, iron, manganese) from the soils would continue for several years and might cause suppression of biological communities until concentrations returned to normal. Seepage of contaminants into impoundments H and I and stream sections downgradient from the mills would continue to degrade water quality during periods of streamflow and might impact what biota exists in the stream. Concentrations of selenium and sulfate in seepage water reaching impoundments I and H and Middle Reservoir could be at toxic levels for long periods (see Secs. 6.2.4.2 and 6.3.4.2);[28,29] therefore the severity of the impacts to biota in ephemeral streams and in the river would depend upon the amount of dilution by the receiving water.

6.3.7 On the Community

As for other topics, community impacts have been subdivided into three periods--construction, operation, and postoperation. However, the situation would in fact be more complex under the scenario assumed for this document--phased construction of 12 mills. The assessments of impacts on the community are believed to be conservative. Early in the construction phase, only construction workers would be present, but as construction of the first two mills was completed, members of the operational force would begin to move into the region, and for the duration of the "construction" phase, community impacts would result from the combined presence of a relatively stable number of construction workers [assumed to be the equivalent of four crews (see below)] and a steadily increasing number of operational workers as more and more mills were completed and put into production. As far as perceived magnitude of community impacts, the interim period, when the number of newcomers was steadily increasing in what had previously been a relatively stable, generally rural setting, would most likely be more disruptive than the operation phase. For the purposes of this impact assessment, however, it is assumed that the number of workers present during this interim period would generally not exceed the total number of operational workers after all mills were in operation.

It is extremely difficult, in most cases, to isolate the effects of uranium milling and mining from effects occurring as a result of other mineral resource exploitation and industrial developments which would be occurring in such a region, e.g., coal mining. In addition, it is difficult to predict the future level of these other industrial activities. In any case, the severity of impacts that can occur as a result of uranium milling and related mining activities would depend upon the proportion of the population and regional economy that would be devoted to these activities as well as the general social economic and political characteristics of a region. Furthermore, the potential socioeconomic impacts from uranium mining and milling are not unlike those occurring as a result of any similar sized industrial development.

6.3.7.1 Construction

Demography and Settlement Patterns

The projected distribution of the construction force for four mills is shown in Table 6.31 and further discussed in Appendix F-3. However, it is likely that the construction boom in the area would attract numerous workers. It is therefore assumed that at the end of the first eight months there would be the equivalent of four crews in the area at any one time. Two crews would be involved with the final construction of one set of two mills, while the other two crews would be involved with the starting of construction of the next set of two mills. However, the total community impacts being experienced in the region would be the sum of those from these construction workers and the growing number of operational workers moving in. Consequently, it would be impossible to separate out only "construction-induced" impacts.

The proportion of in-migrants for the different towns would be similar to the patterns identified for the single-mill scenario. East City would be expected to absorb more than half of the in-imigrants, and Green Town would absorb about 30%. Most available housing in both towns would be occupied by the end of construction of the first pair of mills, and land values would begin to increase. High land costs and lack of zoning, particularly around Green, would lead to the rapid establishment of mobile home parks and lots, similar to patterns actually experienced in some western areas undergoing rapid energy-resource developments.[30]

The rest of the work force would be scattered in other small towns further from the mill. As a result of population influx, Blue and Brown would begin to experience the start of a new settlement history similar to that described for Green Town; however, the magnitude would be much less. Purple is a nonreservation community primarily composed of Native Americans of the Beta Tribe. Most in-migrants to Purple would be reservation members moving into the model region to live with relatives.

Table 6.31. Summary of Demographic Effects of Construction (4 mills) and Operation (12 mills) of a Multiple-Mill Site[a]

City	Distance from Mill, kilometers	Population	Five-Year Projected Population without Development[b]	Construction Phase: Workers and Families		Construction Phase: Workers x 2.3 Family Members	Construction Phase: Secondary Workers and Families (0.6 multiplier)	Operational Phase: Workers and Families		Operational Phase: Workers x 2.3 Family Members	Operational Phase: Secondary Workers and Families (1.2 multiplier)	Operational Phase: Associated Increases in Development[c]	Operational Phase: Permanent Population Associated with Development[d]
				Non-Local	Local			Non-Local	Local				
Green	38	500	510	110	30	320	190	440	125	1300	1560	2860	
Brown	29	500	510	15	30	105	65	65	125	435	525	960	
East	48	13,000	13,330	175	70	565	340	700	235	2265	2720	4985	
Purple	64	500	510	5	20	60	35	15	65	185	220	405	
Blue	38	500	510	10	5	35	20	25	10	80	95	175	
West	80	22,000	22,550	0	20	45	25	0	65	150	180	330	
Red	70	1,500	1,540	0	0	0	0	0	0	0	0	0	
White	60	500	510	0	0	0	0	0	0	0	0	0	
Orange	63	500	510	0	0	0	0	0	0	0	0	0	
TOTAL		39,500	40,480	315	175	1130	675	1245	675	4415	5300	9715	19,430

[a]The values in this table have been rounded to the nearest 5 from estimates more fully explained in Appendix F-3.

[b]Based on growth of 2.5% for five years.

[c]Miners, equipment sales and repair personnel, etc. assumed to be equal to mill operation personnel.

[d]Includes mill workers and families, service personnel and families, and people associated indirectly with development--including mining, machine and equipment sales, repair, etc.

Social, Economic and Political Systems

The phased construction of 12 mills would dramatically alter the social, political, and economic organization of the region. The impacts would be concentrated in S_1 County and the communities of East, Green, Purple, and Brown, where a majority of in-migrant workers, service workers, and their families would reside (see Sec. 6.2.7). The area around these communities would experience some economic benefits and increased job opportunities, while at the same time experiencing severe impacts on the local sociopolitical structure and social service systems.

Social Structure and Services. The most dramatic impacts would be experienced in the towns of Green and, to a lesser extent, Brown as a result of multiple mill construction and operation. After four to six of the mills had been built and were operating, Green would experience many of the problems of a classic boom town, such as: (1) rapid population growth, (2) increased housing and service demands which could not be adequately met, (3) community financing problems, (4) perceived decrease in quality of life, (5) increases in social pathologies (e.g., crime, alcoholism), and (6) structural collapse of the local rural community.[31,32] Because of the homogeneous composition evident in Purple, the in-movement of a large number of non-Indians would be likely to create a strong, spatially and socially separate subgroup. The potential for problems would be disproportionately greater in this town, even though the number of in-migrants is expected to be smaller than elsewhere.

The multiple mill construction force would produce increases in demand and costs for some social services (especially health and education) in the region, as was indicated in Appendix F-4, Tables F-4.3 and F-4.7. The greatest impacts on public facilities would occur in County S_1. The cost is estimated to be millions of dollars. Among all of the impacted communities, Green would experience the most drastic needs as more mills were built. A new fire station and a public water system would be needed in Green.

Economic Structure. The average income and employment of the region would increase as more and better-paying jobs, in both base and service occupations, became available. West would be expected to receive many of these benefits without experiencing most of the sociopolitical costs expected at other towns. Some towns would experience increases in service demands. Wage increases would be needed to hold employees, and competition for the skilled and semiskilled workers would be strong among the long-established industries and the new mill industries.

Retail sales and property values would rise with an overall cost of living increase in the most rapidly developing areas.

Political Structure. The political structure of Green (and Brown to a lesser extent) and the County of S_1 would begin to change, and some governmental organizations could become ineffective. New staff and professional assistance would be required to meet new service demands, time-lag problems, and taxation considerations. Long-time residents might lose control of their communities as newcomers took over.[18,33]

Archeological and Historical Resources

Site preparation and construction of the 12 mills, with attendant earth-moving operations, would have the greatest potential for physical impact to archeological resources. Salvage, mitigation, and protection programs would have to be implemented. Moreover, population increase and improved accessibility to previously isolated areas would increase the chances for vandalism or disturbance by relic collectors.

Esthetics and Recreational Resources

The model site lacks spectacular scenery and the resources to accommodate intensive recreation use. Recreational resources in the region would not be as heavily impacted as esthetic resources because of the existing developed facilities that are available to the public, e.g., reservoirs, resorts, national forest, state park. However, there might be demands for additional municipal recreational facilities in those communities where large numbers of workers settle. The avoidance of recreational and esthetic impacts would be largely a question of siting. In general, the esthetic impacts of building 12 mills on the model site would be somewhat less than 12 times the impact of a single mill.

6.3.7.2 Operation

Demography and Settlement Patterns

The settlement pattern identified for the construction period would continue during the simultaneous operation of 12 mills. While settlement locations and housing availability would remain about the same, individuals in the operational force would change constantly during the life of the mills (see App. F-2).

Social, Economic, and Political Systems

By the time all of the mills were operational, the lifestyles and community structures in the eastern half of the region would have been irreversibly changed. Impacts of operation would be compounded by the impacts of associated industrial activities, such as mining and shipping.

The County of S_1 and East City would experience continuing increases in service demands and costs, as well as in economic benefits. Green probably would turn into a settlement of temporary residences jointly administered by the milling company(s), the State, and perhaps Federal agencies. Social pathologies would increase in the towns of Green, Brown, and Purple, but would be the most serious in Green.

Social Structure and Services. In general, social systems would become unstable because of short-term tenancy patterns and the influx of new residents with little or no ties to traditional local institutions or local goals and values. Green Town would no longer be a viable community; rather, it would have been changed into a "bedroom" community lacking many amenities, but attracting newcomers because of the availability of housing. Social pathologies would be disproportionately high among both long-time residents and newcomers. Many local residents would probably have moved elsewhere.

Brown would also experience stresses as newcomers move in and out of the area. The close homogeneous population would be able to accommodate people with similar goals and values, but otherwise a new housing area and social network might develop around the newcomers. Purple also would change in response to new economic patterns and the in-movement of some non-Indians. Traditional systems of rank and status would be altered and value conflicts would result. The traditional social mechanisms for minimizing conflict and redistributing economic goods might not be effective. In the short-term, tribal cohesion might be weakened; however, economic conditions would improve for some residents and could be expanded if training programs were implemented to qualify locals for milling-mining jobs.

The multiple mill operational force would pose serious demand and cost problems for the region, as shown in Appendix F-4, Table F-4.4. County S_1 and Green Town would receive the majority of the primary impacts. County S_1 would need approximately $39 million to accommodate its new students and approximately $12 million for new hospital facilities and personnel (if available). Green again would be the most severely affected town. About $6 million would be needed there to provide adequate services for residents. [It should be noted that these demands and costs reflect only the increases which could be associated with milling activities. Mining, heavy equipment businesses, etc., would also bring at least as many people into the areas as the milling activities. Therefore, the actual costs and demands for the county and communities would most likely be substantially greater than the estimates provided above.]

Economic Structure. The basic economic structure of the region would be shifted from agriculture and associated services to milling and mining. Unemployment would decrease and average incomes increase. As wages, population, and employment increased, so would retail sales and cost of living.[14,18] Inflation would probably be high during the first few years of operation, placing severe stress on persons with fixed incomes. Local businesses would have to pay higher wages to attract qualified workers and still would be likely to experience problems with frequent job displacements. Competition and demands for new expansions might result in old businesses selling out (because of their inability to adapt), and a flood of new businesses being built in and around the rapidly developing areas.[33]

Political Structure. The political structure of the County of S_1 and its communities would become increasingly more formal, and staffing requirements would increase. In Green, the socioeconomic disruptions might be so severe that outside assistance (from Federal and State agencies and/or from the operating companies) might be needed. Other towns, such as East and Brown, would also need some planning, staff, and financial assistance. Serious goal conflicts would probably develop among locals, newcomers, and companies.[30,34]

Archeological and Historic Resources

The types of impact situations for the multiple mill case will be the same as those discussed for the single mill site; however, the magnitude of the impacts will increase with the number of mills to be built.

Esthetics and Recreational Resources

Throughout the operational life of the mills, more and more land would be utilized for roads, tailings ponds, and mill support facilities. The normal operational activities at 12 mills in the model region could create adverse visual impacts that would be very difficult to mitigate. Recreational facilities would receive increased use with the influx of new residents. Although milling may interrupt dispersed recreational pursuits to a small degree, it would pose no threat to intensive use along the Tributary River or in the National Park.

6.3.7.3 Postoperational

Since the construction of the 12 mills would be phased, the cessation of operations would also be phased over a period of years; thus, although the impacts resulting from shutdown would be severe, they are postulated to occur somewhat gradually as more and more mills are closed.

Demography and Settlement Patterns

The operational force and associated service workers would be displaced when the mills closed. Some members of the work force are expected to find employment in the towns of West and East; others would leave the region.

Social, Economic and Political Systems

The postoperational impacts that would be encountered in the region as workers leave would be the most severe in those areas and towns that originally had the greatest influx of workers (Green, Brown, East, Purple). Services and facilities originally developed to meet the needs of the peak population would have to be readjusted or go unused as the population declined. Businesses would experience a drop in sales (to the extent that many would close) and in property values. A substantial increase in unemployment and underemployment would result. Many houses and small business premises would become vacant, and it is possible that ghost towns could develop, particularly in the case of Green, which would be most seriously impacted. Numerous people holding secondary employment (not directly employed by the mills) would also leave.

These impacts of the postoperation period could possibly be prevented if during the years of the mills' operation a predictive device could be developed to help the towns prepare for the shutdown of the mills. For example, new industries could be developed and placed into operation as the postoperational phase of uranium milling began.

Archeological and Historic Resources

Potential impacts to archeological and historic resources during the postoperational period would be similar to those discussed for the single model mill case, except the magnitude would be greater because 12 mill sites, rather than one, would be involved. Known archeological sites which were previously protected would no longer have protection.

Esthetics and Recreational Resources

The mill structures, support facilities, and utility structures left behind would constitute an intrusion on the landscape, and the overburden and tailings piles would not blend with the natural background. These esthetic consequences would be most noticeable by detracting from the site's potential for becoming a viable recreation resource. The esthetic quality of the model region would suffer from the presence of 12 abandoned mills. A significant contrast would exist between land used for milling and land that remained untouched.

6.3.8 Radiological Impact

This section addresses the combined radiological impacts to the model region of a well developed and highly localized uranium milling industry consisting of a total of 12 mills. Also of interest are the potential effects of 11 neighboring mills on the total individual doses received by persons at the three reference receptor locations employed to evaluate the single model mill.

The model mill's three reference receptor locations, although hypothetical in nature, are used as benchmarks for evaluating compliance with applicable government regulations regarding maximum individual radiation exposure, and for assessments of peak individual health risks. The applicable government regulations are embodied in 10 CFR Part 20, which is presently effective, and 40 CFR Part 190, which is to become effective for uranium milling operations as of December 1, 1980. The relevant limits of 10 CFR Part 20 are expressed as maximum annual average off-site air concentrations resulting from any one NRC-licensed facility. Thus concentrations from additional mills have no actual bearing on 10 CFR Part 20 compliance. However, total air concentrations from all 12 mills combined, as presented in Table 6.32, are within 10 CFR Part 20 limits. The 25 mrem/yr limit of 40 CFR Part 190 is a general limit for radiation exposure to any individual in the general environment, from all regulated nuclear fuel cycle facilities combined. Total 40 CFR Part 190 doses from all 12 mills combined are presented in Table 6.33 for the model mill's reference receptor locations. As the data in the table indicate, the relative importance of doses from neighboring mills increased by 14% and 20%, respectively. This evidences the potential significance of dose contributions from other nearby facilities in terms of any single facility's ability to comply with 40 CFR Part 190. For example, in Section 9.2.8 the model mill is shown to be capable of compliance with improved emission controls. If neighboring mills operated with only those controls assumed for the base case,

Table 6.32. Comparison of Total Air Concentrations Resulting from the Model Mill, 12 Mills, and Natural Background

		Concentrations During the Final Year of Operation for All Mills						
		Total Air Concentrations, pCi/m^3					WL Concentrations[a]	
		U-238	Th-230	Ra-226	Pb-210	Rn-222	Outdoors	Indoors
I. Range of Typical Natural Background Values:[b]	From...........	7.0×10^{-5}	2.0×10^{-5}	4.0×10^{-5}	1.0×10^{-3}	1.0×10^{1}	6.0×10^{-5}	1.5×10^{-3}
	To.............	1.7×10^{-4}	7.0×10^{-5}	7.0×10^{-5}	3.0×10^{-2}	1.0×10^{3}	8.0×10^{-3}	1.5×10^{-2}
II. Predicted Values								
A. Fence: (0.64 km ENE)	Model Mill......	6.16×10^{-2}	1.53×10^{-2}	1.51×10^{-2}	1.50×10^{-2}	2.04×10^{3}	3.72×10^{-3}	1.02×10^{-2}
	11 Other Mills..	1.92×10^{-3}	3.94×10^{-4}	3.86×10^{-4}	2.20×10^{-3}	1.76×10^{2}	1.60×10^{-3}	8.80×10^{-4}
	Totals........	6.35×10^{-2}	1.57×10^{-2}	1.55×10^{-2}	1.72×10^{-2}	2.22×10^{3}	5.32×10^{-3}	1.11×10^{-2}
B. Trailer: (0.94 km ENE)	Model Mill......	3.55×10^{-2}	7.98×10^{-3}	7.84×10^{-3}	7.85×10^{-3}	1.05×10^{3}	2.77×10^{-3}	5.25×10^{-3}
	11 Other Mills..	1.90×10^{-3}	3.82×10^{-4}	3.75×10^{-4}	2.19×10^{-3}	1.75×10^{2}	1.59×10^{-3}	8.75×10^{-4}
	Totals........	3.74×10^{-2}	8.36×10^{-3}	8.22×10^{-3}	1.00×10^{-2}	1.23×10^{3}	4.36×10^{-3}	6.15×10^{-3}
C. Ranch: (2.0 km ENE)	Model Mill......	9.14×10^{-3}	2.10×10^{-3}	2.07×10^{-3}	2.16×10^{-3}	2.94×10^{2}	1.43×10^{-3}	1.47×10^{-3}
	11 Other Mills..	1.95×10^{-3}	3.50×10^{-4}	3.42×10^{-4}	2.13×10^{-3}	1.73×10^{2}	1.56×10^{-3}	8.65×10^{-4}
	Totals........	1.11×10^{-2}	2.45×10^{-3}	2.41×10^{-3}	4.29×10^{-3}	4.67×10^{2}	2.99×10^{-3}	2.34×10^{-3}
III. 10 CFR Part 20 Limits[c]..............		3.0	8.0×10^{-2}	2.0	4.0	3.0×10^{3}	3.3×10^{-2}	3.3×10^{-2}

[a]WL denotes "working level." A one-WL air concentration is any combination of Po-218, Pb-214, Bi-214, and Po-214 in one liter of air that will yield a total of 1.3×10^{5} MeV of alpha particle energy in their complete decay to Pb-210. Predicted outdoor WL concentrations are calculated explicitly. Predicted indoor WL concentrations are based on 5.0×10^{-6} WL in indoor air per pCi/m^3 of Rn-222 in outdoor air (see Appendix G-5).

[b]Total air concentrations are from NCRP 45, Tables 20 and 26; outdoor WLs are derived using equilibrium factors from References 38 and 39, indoor WLs are from Reference 39.

[c]Values given are from 10 CFR Part 20, Appendix B, Table II, Col. 1. For particulates the lower of values for soluble and insoluble species is presented. For Rn-222, the value presented is appropriate for use when undetermined concentrations of short-lived daughters are also present; it is optionally replaceable by the WL limit, if WL concentrations are known.

Table 6.33. Total 40 CFR 190 Doses at Reference Locations from 12 Mills During the Final Year of Mill Operation

Location	Release Sources	40 CFR Part 190 Doses, mrem/yr		
		Whole Body	Bone	Lung
I. Fence (site boundary)[a] Occupancy: 10% 0.64 km ENE	Model Mill	0.439	7.39	18.5
	11 Other Mills	0.012	0.212	0.575
	Totals	0.451	7.60	19.1
II. Trailer[b] Occupancy: 50% 0.94 km ENE	Model Mill	6.09	78.9	57.2
	11 Other Mills	0.241	3.23	3.03
	Totals	6.33	82.1	60.2
III. Ranch[c] Occupancy: 100% 2.0 km ENE	Model Mill	3.47	44.9	30.1
	11 Other Mills	0.488	6.51	6.06
	Totals	3.96	51.4	36.2

[a]No food pathways assumed.

[b]Vegetable pathway assumed.

[c]Vegetable and meat pathways assumed.

the model mill might be required to implement much tighter emission controls. In effect, if neighboring mills contribute a bone dose of 6.5 mrem/yr to an individual at the ranch, then the model mill is allowed to contribute a further dose of no more than 18.5 mrem/yr, only about 74% of the 25 mrem/yr limit.

The combined annual population and environmental dose commitments of the 12 mills together, resulting from regional radioactivity contamination due to mill operation, are presented in Table 6.34. Total doses from all 12 mills are approximately 12 times those from the model mill alone. Some fluctuations in this ratio are induced because some of the additional mills are nearer to, or farther from, the regional population centers. For the purpose of preparing this table, ingestion pathway dose commitments resulting from the additional 11 mills were assumed to be 11 times those resulting from the model mill. This accounts for contamination of food crops within 80 km (50 miles) of all mills, regardless of location, and thus includes some impacts occurring as a result of contamination more than 80 km (50 miles) from the model mill.

In terms of health effects, the risk to the maximum individual (a person living 2.0 km downwind from the model mill) from 12 mills is increased by about 50% over the risk from one mill. Living for 20 years near the model mill the maximum individual would receive the following doses: whole body, 0.27 mem; bone, 1.3 rem; and lung, 7.2 rem. The lifetime risk of premature death due to cancer to a maximum individual, living 2.0 km downwind from a model mill, from 12 mills is 5.7×10^{-4}. This risk corresponds with a 38% increase in the cancer risk due to natural background radiation. The risk to the average individual from 12 mills in a region is about ten times the risk from one mill. The lifetime risk of premature death due to cancer to the average individual from 12 mills is 2.9×10^{-5}. This risk corresponds with a 0.015% increase in the natural risk from cancer.

6.4 CONTINENTAL RADIOLOGICAL IMPACTS

Because of the concern about possible health effects resulting from radon released by the entire uranium milling industry, estimates have been made of the environmental dose commitments throughout most of the North American continent which might be caused by existing mills and those expected to begin operation in the western United States prior to the year 2001. Continental radiological impacts can broadly be divided into far field and near field components. Far field radiological impacts [i.e., beyond 80 km (50 mi) from a model mill] are discussed in Section 6.4.1. Near field radiological impacts [i.e., within 80 km (50 mi) of a model mill] are discussed in Section 6.4.2. Far field radiological impacts are due to radon releases. Near field radiological impacts are due to both radon and particulate releases. Continental radiological impacts (i.e., far field plus near field) are given in Section 6.4.3.

6.4.1 Far Field Radiological Impacts

The basis for estimates of far field radiological impacts is a study by Oak Ridge National Laboratory (ORNL) that incorporates work by the National Oceanic and Atmospheric Administration (NOAA) using a continental scale transport, diffusion, and deposition model to estimate air concentrations of Rn-222 and Pb-210 and ground concentrations of Pb-210 in the northern Western Hemisphere arising from a unit release of 1 kCi/yr Rn-222 at four locations: Grants, New Mexico; Falls City, Texas; Casper, Wyoming; and Wellpinit, Washington.[35] Radiological impacts within 80 km (50 mi) of the model mill were excluded from the ORNL study; regional radiological impacts [i.e., within 80 km (50 mi) of the model mill] are presented in Section 6.4.2.

Integrated population exposures from inhalation were obtained by combining data on air concentrations of Rn-222 and Pb-210 with available demographic data for the United States, Canada, and Mexico. Estimates of these exposures are presented as man-pCi/m^3 in Tables G-8.1 to G-8.4 of Appendix G-8, which are modified from Reference 35. Inhalation dose estimates were based on conversion factors distinguishing dose due to radon and its short-lived daughters from dose due to the longer-lived daughter Pb-210 and the associated Bi-210 and Po-210 isotopes. A dose conversion factor of 0.625 mrem/yr per pCi/m^3 was used for continuous exposure to Rn-222 and its short-lived daughters. The dose conversion factors for Pb-210 and Po-210 inhalation were calculated by ORNL with the INREM-II computer code,[36] and are presented in Table G-8.5 of Appendix G-8. Because these conversion factors were calculated on the basis of a different model, there is no consistent relationship to the DCFs used elsewhere in this statement, although generally the ORNL values are higher. The dose conversion factors were combined with derived population exposures to obtain integrated man-rem doses to appropriate organs from inhalation of Rn-222 and its daughters per kCi released in 1978.

In order to estimate population dose from inhalation, the deposition of Pb-210 in 1978 and the subsequent resuspension of Pb-210 and its alpha-emitting daughter, Po-210, must be taken into account. The effect of resuspension on population dose for 100 years after deposition was considered. Projected population growth was incorporated into this calculation. It should be noted

Table 6.34. Annual Population and Environmental Dose Commitments Due to Operation of 12 Mills

		Annual Dose Commitments, person-rem/yr			
		Whole Body	Bone	Lung	Bronchial Epithelium
I. Population Dose Commitments During the Final Year of Mill Operation					
A. Total Dose Commitments:	Model Mill	4.38	41.5	6.74	84.9
	11 Other Mills	44.2	448.	62.6	778.
	Totals	48.6	490.	69.3	863.
B. Dose Commitments Received by the Regional Population:[a]	Model Mill	3.50	28.5	5.86	84.9
	11 Other Mills	34.5	305.	52.9	778.
	Totals	38.0	334.	58.8	863.
II. Environmental Dose Commitments Due to Annual Operational Releases					
A. Total Dose Commitments:	Model Mill	5.79	49.2	8.17	84.9
	11 Other Mills	56.0	529.	74.5	778.
	Totals	61.8	578.	82.7	863.
B. Dose Commitments Received by the Regional Population:[a]	Model Mill	4.65	33.2	7.03	84.9
	11 Other Mills	43.5	353.	62.0	778.
	Totals	48.2	386.	69.0	863.

[a]Ingestion doses included are those resulting from food consumption only to the extent necessary to satisfy requirements of the regional population.

that virtually the entire dose effect from resuspension occurs during the year of deposition and the next year following. Tables G-8.1 to G-8.4 of Appendix G-8 show doses to the population of interest from:

1. Inhalation of Rn-222 and short-lived daughters during 1978 (Table G-8.1).

2. Inhalation of Pb-210 during 1978, exclusive of resuspension (i.e., "primary dose" in Tables G-8.2 through G-8.4).

3. Inhalation of resuspended Pb-210 and Po-210 originating from a 1978 release (i.e., "resuspension dose" in Tables G-8.2 through G-8.4).

Because ingestion, rather than inhalation, is the more important pathway contributing to the total dose commitment from Pb-210, it was necessary to include it in this analysis of far field health effects from the milling industry. As the Pb-210 is being transported initially through the atmosphere, a portion may deposit on crops and ultimately be ingested by human beings. An additional amount will deposit on the soil, where because of its long half-life (22.3 years), it will remain available for root uptake for many years. For this analysis it has been assumed that no mechanisms other than radioactive decay operate to remove Pb-210 from its availability in the soil. The ingestion dose to the population has been calculated to include foliar deposition and root uptake in the first year and root uptake alone in the next 99 years following release of the radon parent. The basis for this calculation of 100-year environmental dose commitment is the study by Oak Ridge National Laboratory.[35] The starting point was the estimates of Pb-210 concentrations in air which were used to predict inhalation dose commitments as described above. Air-to-diet conversion factors developed by ORNL, together with data on standard diets, current agricultural production, dose conversion factors, and the previously available air concentrations and population projections, made it possible to calculate the exposures and 50-year dose commitments in 1978 and 1979 for a 1 kCi Rn-222 release from each of the four sites in 1978. These data are summarized in Tables G-8.6 through G-8.8 of Appendix G-8. The dose conversion factors used to calculate the 50-year dose commitments from ingestion of Pb-210 were 5.2×10^{-2} mrem/pCi for bone and 3.8×10^{-3} for the whole body. The 100-year environmental dose commitment (EDC) from ingestion of the Pb-210 produced by a unit release of radon from one of the four sites is simply the sum of the 1978 dose and the dose in each of the next 99 years. The annual dose commitments after 1978 were calculated from the 1979 values adjusted for radioactive decay and population growth. About half of the 100-year EDC is delivered in 1978, the year the release occurred.

For estimating integrated population exposures and doses attending releases of Rn-222 in 1978 and subsequent years, ORNL prepared population projections for the portions of the United States, Canada, and Mexico that were included in the dose predictions (the area between 20° and 60° north latitude). The ORNL population projections for the years 1978 to 2000 and between 2000 and 2100 are given in Tables G-8.9 and G-8.10 of Appendix G-8.

The 100-year dose commitments per kCi of Rn-222 (radon) released in 1978 from each of the four uranium milling centers in the western United States serve as the starting point for estimating dose commitments from mill operations from 1979 through the year 2000. In accordance with information provided in Chapter 3, uranium milling capacity and the associated aggregate radon releases through the year 2000 are assumed to be distributed over the four production centers as follows: Grants, 60%; Casper, 31%; Falls City, 5%; and Wellpinit, 4%. Doses delivered per kCi of radon released, as a function of the year of release, were determined by ratioing 1978-release dose estimates upward, in proportion with the growth of the U.S. population as shown in Table G-8.9; the U.S. population was assumed to remain constant at 293 million after the year 2100.

A total of 24 model mill equivalents were assumed to be operational during 1979, roughly approximating actual milling capacity during that year. These mills were assumed to be retired at a rate of one per year, beginning at the end of 1979, until all 24 were no longer operating. New model mills were assumed to come on line as needed to fulfill the capacity requirements shown in Table 3.9. Of the 55 model mill equivalents estimated to be operating in the year 2000, 52 are new and 3 are mills that were operating in 1979; total model mill equivalents in the year 2000 thus amount to 76 model mills, 55 of which are operating and 21 of which are retired. No new model mills added after 1979 were assumed to retire prior to the end of the year 2000. However, new model mills were assumed to retire after 21 years of operation, with the first being retired as of the year 2001 and the last being retired as of the year 2021.

All radon releases were estimated on the basis of model mill equivalents, and all model mills were assumed to process 0.10% ore throughout their operational lifetimes. All model mills were assumed to be as described in Chapter 5, processing ore at 1800 MT/day (2000 ST/day), with an 85% capacity factor and a 93% extraction efficiency, yielding 523 MT (575 ST) of U_3O_8 per year. Radon releases were taken to be 4500 Ci per model mill year of operation (50 ha of dry tailings area), to account for radon releases from impounded tailings and dispersed ore and tailings dusts, as well as from ore processing. The assumed retirement scenario for each mill included a three-year period during which ponded water decreased linearly from an area of 30 ha (75 acres) to zero. The average area of dry tailings during the first, second, and third years of retirement was estimated to be 55 ha, 65 ha, and 75 ha, respectively.

On this basis, annual radon releases from the full schedule of model mill equivalents were estimated to be 108 kCi in 1979 (24 operational model mills), 395 kCi in the year 2000 (55 operational and 21 retired model mills), and 547 kCi in the year 2024 and later years (76 retired model mills). Estimated cumulative radon releases and resulting dose commitments, for the periods 1979-2000, 1979-2100, and 1979-3000 are provided in Table 6.35. For the purposes of perspective, annual far-field doses from mill-related radon releases are also given and compared with those from background in Table 6.35. Based on conservative assumptions, uranium milling radon releases are shown to contribute less than 0.2% of natural background exposure in the U.S. alone, even though over 12% of the indicated milling exposures occur in Canada and Mexico. Table 6.35 also indicates that mill-related radon releases amount to less than 0.0005% of radon released from natural soils in the United States.

These estimates are all based on the assumption that tailings impoundments are abandoned after operations cease, with no reclamation being provided. Reclamation schemes which would reduce postoperational radon releases to low levels (comparable to background), their effectiveness in reducing population doses and health impacts, and their costs are described and evaluated in Chapters 8, 9, and 11, respectively. An overall evaluation is also provided in Chapter 12.

6.4.2 Near Field Radiological Impacts

Near field radiological impacts were calculated for a single model mill in Section 6.2.8. The cumulative radiological impacts presented here (Table 6.36) are based on a scaling up of the regional impacts presented in Section 6.2.8. Cumulative impacts are based on 833 model mill years being required to fulfill the conventional U_3O_8 requirements (436,000 MT of U_3O_8) over the time interval from 1979 through the year 2000, as indicated in Table 3.9, and the conventional model mill installation and retirement schedule described in Chapter 3 and in the preceding section (6.4.1). The model mill population was assumed to expand from its assumed initial 1978 level of 57,300 in direct proportion with the growth of the U.S. population as indicated in Appendix G-8; regional agricultural productivity was assumed to also grow at this rate. The model mill population is thus estimated to grow to a value of about 78,000 by the end of the year 2100, after which it is assumed to remain constant.

Table 6.36 provides estimates of cumulative 100-year regional environmental dose commitments (EDCs) for time intervals through the year 3000. After the year 2020 cumulative EDCs from operational releases remain constant as all model mill equivalents required through the year 2000 are assumed to have retired by that time, thus ending operational releases. Postoperational releases are assumed to continue unabated with no efforts being made to reclaim the abandoned tailings. Even under this "worst-case" assumption, annual regional EDCs are projected to amount to no more than about 0.5% of natural background radiation exposures to the same populations (EDCs given in Table 6.36 are totals and include doses resulting from the export of contaminated food products out of the affected regions).

6.4.3 Continental Radiological Impacts

Continental radiological impacts are equal to the sum of far field impacts (Section 6.4.1) and near field impacts (Section 6.4.2). Continental environmental dose commitments and somatic health effects are presented in Table 6.37.

The health effects which may be attributed to milling activity have been predicted on the basis of multiplying the risk estimators in Appendix G-7 with the dose commitments in Tables 6.35 and 6.36. The somatic effects are given in Table 6.37, and genetic effects are given in Table 6.38. In the years after 2100 when the population has reached its assumed maximum of 293 million people, a total of about six premature deaths due to cancer induced by radiation originating from uncovered tailings piles is predicted for each year. Lung cancer following irradiation of the bronchial epithelium by short-lived radon daughters is responsible for the majority of these predicted deaths. The total rate is about 0.001% of the expected cancer death rate for that size population.

About 21% of the continental health effects are estimated to occur within the region. The number of health effects within the United States is about 90% of the total continental health effects. Mexico and Canada account for the remaining 10% of the continental health effects. Exposure in Continental Europe and Asia would add about 25% more health effects to the number of effects predicted for North America. Persistent health effects in the U.S. due to milling are equivalent to about a 0.07% increase in health effects due to background radiation or a small fraction (1.2×10^{-5}) of the average annual risk of death due to cancer (about 1.6×10^{-3}).

Estimates of genetic defects produced in North America as a result of milling operations and storage of bare tailings are summarized in Table 6.38. About two per year are predicted, thereby causing an increase of about 0.002% in the spontaneous rate of defects observed in the U.S. population.

Table 6.35. Cumulative North American Continent Dose Commitments from Conventional Uranium Milling Radon Releases, Assuming No Reclamation

Time Interval, years	Cumulative Rn-222 Releases, kCi	Cumulative 100-Year Environmental Dose Commitments, person-rem		
		Whole Body	Bone	Lung
1979-2000:	5.33×10^3	4.97×10^4	6.78×10^5	3.71×10^5
1979-2100:	5.83×10^4	6.25×10^5	8.53×10^6	4.67×10^6
1979-3000:	5.51×10^5	6.10×10^6	8.32×10^7	4.55×10^7
Annually from milling after 2100:	5.47×10^2	6.08×10^3	8.30×10^4	4.54×10^4
Annually from natural background after 2100 (U.S. only):[a]	1.2×10^8	2.34×10^7	5.04×10^7	5.10×10^7
Milling contribution as fraction of U.S. background:	4.6×10^{-6}	2.6×10^{-4}	1.7×10^{-3}	8.9×10^{-4}

[a]Background U.S. radon releases are those from natural soil as given by Reference 35. Background U.S. dose commitments are based on the projected year 2100 population of 293 million and annual per capita doses of 80 mrem to the whole body, 172 mrem to bone, and 174 mrem to lung derived from NCRP Report No. 45, "Natural Background Radiation in the United States," National Council on Radiation Protection, 1975.

Table 6.36. Cumulative Regional Dose Commitments from Conventional Uranium Milling Releases, Assuming No Reclamation

Time Interval, years		Cumulative 100-Year Environmental Dose Commitments, person-rem		
		Whole Body	Bone	Lung
1979-2000:	Operational	5.40×10^3	4.59×10^4	8.68×10^4
	Postoperational	2.25×10^3	1.90×10^4	3.62×10^4
	Total	7.65×10^3	6.49×10^4	1.23×10^5
1979-2020:	Operational	9.38×10^3	7.97×10^4	1.51×10^5
	Postoperational	1.28×10^4	1.07×10^5	2.05×10^5
	Total	2.21×10^4	1.87×10^5	3.56×10^5
1979-2100:	Operational	9.38×10^3	7.97×10^4	1.51×10^5
	Postoperational	8.51×10^4	7.17×10^5	1.37×10^6
	Total	9.45×10^4	7.97×10^5	1.52×10^6
1979-3000:	Operational	9.38×10^3	7.97×10^4	1.51×10^5
	Postoperational	9.09×10^5	7.66×10^6	1.46×10^7
	Total	9.19×10^5	7.74×10^6	1.48×10^7
Annually from milling after 2100:	Radon	3.68×10^2	3.17×10^3	1.41×10^4
	Particulates	5.48×10^2	4.55×10^3	6.09×10^2
	Total	9.16×10^2	7.72×10^3	1.47×10^4
Annually from natural background after 2100:[a]	Total	8.48×10^5	1.48×10^6	3.58×10^6
Milling contribution as fraction of natural background after 2100:		1.08×10^{-3}	5.22×10^{-3}	4.11×10^{-3}

[a]Natural background doses are calculated on the basis of 76 regions each with a population of 78,000. Per capita dose rates assumed are those given in Table 4.14.

Table 6.37 Continental Environmental Dose Commitments and Somatic Health Effects Due to U.S. Uranium Milling Activity Over The Period 1979 to 3000

	Whole Body	Bone	Lung[a]	Somatic Health Effects
	Cumulative (1979-2000) (organ-rem)			(Premature Deaths)
U.S. Regional	7.7×10^3	6.5×10^4	1.2×10^5	10.4
U.S. Non-Regional, Mexico and Canada	5.0×10^4	6.8×10^5	3.7×10^5	38.3
Total	5.8×10^4	7.5×10^5	4.9×10^5	49
	Cumulative (1979-2100) (organ-rem)			(Premature Deaths)
U.S. Regional	9.5×10^4	8.0×10^5	1.5×10^6	127
U.S. Non-Regional, Mexico and Canada	6.3×10^5	8.5×10^6	4.7×10^6	485
Total	7.3×10^5	9.3×10^6	6.2×10^6	610
	Cumulative (1979-3000) (organ-rem)			(Premature Deaths)
U.S. Regional	9.2×10^5	7.7×10^6	1.5×10^7	1270
U.S. Non-Regional, Mexico and Canada	6.1×10^6	8.3×10^7	4.6×10^7	4740
Total	7.0×10^6	9.1×10^7	6.1×10^7	6000
	Persistent (organ-rem/yr)			(Premature Deaths/yr)
U.S. Regional	9.2×10^2	7.7×10^3	1.5×10^4	1.3
U.S. Non-Regional, Mexico and Canada	6.1×10^3	8.3×10^4	4.5×10^4	4.7
Total	7.0×10^3	9.1×10^4	6.0×10^4	6.0[b]
U.S. Background	2.4×10^7	5.2×10^7	5.7×10^7	8060

[a]Sum of doses to pulmonary lung and bronchial epithelium.

[b]Persistent health effects in the U.S. represent about a 0.07% increase in health effects due to background radiation, or about 1.2×10^{-5} of the average annual risk of death due to cancer. The average annual risk of death due to cancer (1.6×10^{-3}) is taken from "Vital Statistics of the United States 1970, Volume II - Mortality, Part A," U.S. Dept. of Health, Education and Welfare, pp. 1-7, 1974.

Table 6.38 Estimated North American Continent Genetic Health Effects from U.S. Uranium Milling Activity

	Specific Defects	Defects with Complex Etiology	Total
Efects from total dose commitment 1979-2100	115	73	190
1979-3000	1110	700	1800
Maximum rate of induction of genetic defects (years after 2100) - per year	1.1	7.0×10^{-1}	1.8
Spontaneous incidence for 293 million - per year[a]	6.0×10^{4}	2.6×10^{5}	3.2×10^{5}
Fractional increase in U.S. incidence of genetic defects due to milling	1.8×10^{-5}	2.7×10^{-6}	2.1×10^{-5}

[a]Based on data from report WASH-1400, U.S. Nuclear Regulatory Commission, Table VI 910, October 1974.

In addition to radon released as a result of uranium milling activity, radon is also released from uranium mines. In order to place these two sources in perspective, they are compared in Table 6.39. It is estimated that over the period 1979-2000, uranium mines will release about 6.2 million Ci of Rn-222. Calculation of the radon emission from mines was based on a release of 3 Ci/MT of U_3O_8 from open pit mines and 19 Ci/MT of U_3O_8 from underground mines, and on DOE estimates that during 1978-2000, 70% of future U_3O_8 requirements will be provided by underground mines and 30% by open pit mines.[37] The amount of radon released as a result of milling activity from 1979 to 2000 was estimated by the method described earlier in this section.

The cumulative numbers of health effects produced by radon from mines (56 premature deaths) are about 17% higher than from mills (48 premature deaths) over the time period 1978 to 2000.

6.5 SUMMARY

6.5.1 General

Potential impacts in a variety of narrow categories were considered in this chapter including air quality, land use, mineral resources, water resources, soil resources, biota, community, and radiological impacts. While complete summary is not possible, the nature and extent of potential impacts are characterized by the following sections, which include selected examples identified in the base case evaluation of the model mill. The base case features a low-level of emission control to form a basis upon which to analyze the effects of alternative control measures. Base case controls are representative mostly of past milling practice. For this reason, analysis of the base case brings into sharp focus the potential environmental and public health impacts which can occur.

6.5.2 Radiological Impacts

Radiological impacts resulting from operation of a single base-case model mill are described in Section 6.2.8 of this chapter. These impacts have been evaluated on the basis of an assumed ore grade of 0.10% U-238, slightly lower than the estimated industry average ore grade of 0.12% during 1979, and markedly lower than average ore grades now being processed at some mills. In considering the following discussion, it should be kept in mind that individual mill impacts are directly proportional to the grade of the ore processed and variation by a factor of two in either direction would not be unrealistic, if all other factors remained constant. Cumulative radiological impacts from the aggregate milling industry, however, are more directly related to the amount of uranium product to be produced and are essentially independent of assumed ore grade. Cumulative uranium milling industry impacts, as projected in Section 6.4 of this chapter, and summarized below, would not be significantly altered even by relatively large shifts in the assumed industry-average ore grade.

With respect to overall health impacts, the critical mill-released radionuclides and their primary sources are, in descending order of importance: Rn-222 from the tailings pile; Ra-226 and Pb-210 from the tailings pile; and U-238 and U-234 from yellowcake operations. Health impacts

Table 6.39 Comparison of Continental Environmental Dose Commitments and Somatic Health Effects From Radon Releases From U.S. Uranium Mining and Milling Activities, 1979-2000

Source	Cumulative Release (Ci of Rn-222)	Environmental Dose Commitment (organ-rem)			Somatic Health Effects (Premature Deaths)
		Whole Body	Bone	Lung	
Uranium mines	6.2×10^6	6.2×10^4	8.3×10^5	5.7×10^5	56
Uranium mills	5.3×10^6	5.3×10^4	7.1×10^5	4.9×10^5	48

from Rn-222 result from inhalation of in-grown daughters and ingestion of the ground-deposited long-lived daughter Pb-210. Because Rn-222 is released in gaseous form, it is transported long distances exposing large populations, albeit at extremely small levels above background. The impacts of Ra-226 and Pb-210, released in particulate form from the tailings pile, result primarily through ingestion pathways. Emissions from impounded tailings materials have an enhanced importance due to their persistence beyond the operational lifetime of the mill itself. Yellowcake emissions result in localized impacts, primarily via inhalation, and terminate when the mill shuts down.

The following summarizes radiological impacts resulting from mill operations with the low level of emission control assumed for the base case. First, exposures are summarized in terms of applicable individual exposures limits (the EPA Uranium Fuel Cycle Standard (40 CFR 190)). Exposures at one of the several reference locations examined in the base case analysis, a person occupying a permanent residence 2 km downwind of the tailings pile (referred to here as the "nearby" individual), are summarized to illustrate the problems of meeting exposure limits. Exposures calculated for comparison with 40 CFR 190 limits do not include contributions of radon and its daughters, since these radionuclides are not covered by the limits. Second, total exposures (including radon and daughter-contributions) and associated health risks are summarized for the nearby individual, for an "average" individual in the model mill region (exposures determined by dividing total regional population exposure by number of people in the region), for the average mill worker and, finally, for the continental North American population.

Individual Exposure Limits - 40 CFR 190

- 40 CFR 190 limits are not met at permanent residence locations near the mill. Doses received by the nearby individual exceed the maximum 25 mrem per year permitted by 40 CFR 190. Bone and lung doses resulting from radionuclides covered by 40 CFR 190 (all but radon and its daughters) are 45 and 30 mrem, respectively. Analysis indicates the limit could not be met within about three km downwind from the mill.

- The effect of a potential worst case concentration of milling activity, where a cluster of 12 mills is postulated in year 2000, is illustrated by doses to the nearby individual that are limited by the 40 CFR 190 Standard. Doses to bone and lung would increase by about 15 to 20 percent. While not a large fractional increase, this shows that the contribution from surrounding mills could be important in situations where meeting 40 CFR 190 was otherwise a borderline case.

Total Individual Risks

- Total exposure estimates, which include radon and daughters, indicate that radon is the greatest single contributor to risk. When total exposures are considered, the chances that the nearby individual would prematurely die from cancer as a result of living near the model mill for 20 years (a period assumed to include the full operation and decommissioning cycle of the mill) would be about 380 in a million. Because of the considerable uncertainties that exist in the health risk estimators used (risks could be one-half to two times those estimated), comparison with risks posed by background radiation provides valuable perspective. The estimated risks to the nearby individual would be an increase of about 25 percent above risks from background radiation exposures. Exposures and risks to an average individual in the region over a similar time span would be a small fraction (about one percent) of those for the nearby individual.

- The effect of concentrated milling activity would be to increase risks to the nearby individual, as discussed above, by about 50 percent over the risk from a single mill. The milling cluster would have a more dramatic effect on risks for the average individual, raising them by a factor of about ten, from about 3 to 30 chances in one million of premature cancer death. This risk would be about 2 percent of that due to natural radiation exposures.

- The risks to an average individual living in a region of maximum mining and milling activity in year 2000 is very roughly estimated to be double those described above for milling alone. This estimate is based on radon measurements around open-pit and underground mines which indicate that releases from active mining will be roughly equivalent to those which would occur from tailings under the base case. (No attempt was made to study radon release from mining in detail in this study. Estimates are provided of these releases for perspective only.)

<u>Occupational Risks</u>

- Average annual occupational exposures are estimated to be about 2000 and 7100 mrem to bone and lung, respectively. This level of exposure would lead to a lifetime risk of premature cancer death of about 30 in 1000 if the work period were about 50 years. This is about eight times risks due to natural radiation exposure. At these exposure levels, a total of about 39 potential premature deaths is estimated to occur among workers from operations of the U.S. milling industry to the year 2000. These risks are smaller than risks of death faced by workers from nonviolent causes alone in at least several other industries, such as mining (Sec. 6.2.8.2.7).

<u>Risks to Populations</u>

- The most significant impact from mill operations under the base case would occur from persistent radon releases from the tailings. About 6000 premature deaths are predicted over the period 1979 to 3000 in the United States, Canada, and Mexico, from tailings which would be generated by the full operation of mills in existence in the U.S. in the year 2000.

- These cumulative potential impacts are a 1.2×10^{-5} fraction of the overall U.S. incidence of cancer.

- The continuing annual rate of premature deaths from this volume of tailings is estimated to be about six per year. This annual rate could be used to develop estimates of health effects beyond 1000 years if this were desired; this would require making very uncertain assumptions on long-term factors such as climate, population growth, and the like.

The information just summarized about base case radiological impacts on individuals is tabulated in Table 6.40.

6.5.3 Nonradiological Impacts

<u>Air Quality</u>

In general, the impact of mill operations on air quality occurs as a result of dust which is produced. Dusting from the tailings piles and traffic on dry ore hauling roads increases suspended particulates.

- In the single mill case, concentrations at a reference location nearby the mill (one km) are close to but within Federal limits. An annual average concentration of 57 $\mu g/m^3$ (22 $\mu g/m^3$ above the background concentration of 35 $\mu g/m^3$ which includes contributions from other nonmilling sources) is predicted. This compares with a limit of 60 $\mu g/m^3$ existing in some States.

- While the operation of a cluster of mills does not cause a large increase in dusting over that resulting from a single mill (about a 33 percent increase), the increment may be important in meeting allowable limits on suspended particulates near the mill. A concentration of 65 μ/m^3 which would exceed some State standards is predicted for the reference location near the model mill. The relative effect of the mill cluster becomes greater as distances from the model mill increase (a doubling of suspended particulate concentration contributed by mills occurs at a distance of 40 km), but total concentrations (37 $\mu g/m^3$) are within allowable limits.

<u>Land Use</u> (Secs. 6.2.2, 6.3.2)

Land use impacts from milling operations and tailings disposal are both direct and indirect. The most significant impact is permanent commitment of land to tailings disposal.

Table 6.40 Radiological Impacts on Individuals for Base Case

Receptor	Dose Commitment[a] (mrem) Whole Body	Bone	Lung	Risk from Mill as Percentage of Risk Due to Background (%)[c,d]
Nearby Individual[b]				
Annual 40 CFR 190 doses (excluding radon)				
1 mill	3	45	30	--
Mill cluster	4	51	36	--
Total dose (including radon)				
1 mill	9.7	51	220	25
Mill cluster	13	61	340	38
Average Individual[e]				
1 mill	0.061	0.50	1.6	0.19
Mill cluster	0.66	5.8	16	1.9
Average Worker[f]				
Annual	450	2000	7100	800
Career[g]	2.1×10^4	9.3×10^4	3.35×10^5	800
Background	143	250	704	--

[a]All doses shown are total annual 15th-year dose commitments except where noted as being those covered by 40 CFR 190 limits.

[b]The nearby individual occupies a permanent residence at reference location about 2 km downwind of the tailings pile.

[c]The range in risks due to uncertainties in health effects models extends from about one-half to two times the central value (App. G-7). This range does not include uncertainties in other areas (e.g., source term estimates and dose assessment models).

[d]Risk comparisons are presented for exposure received during entire mill life; that is, 15 years of exposure during operation of the mill, and 5 years of exposure post operations while tailings are drying out, are considered. This value is greater than that from annual exposure presented because tailings dust releases increase in the period when tailings are drying.

[e]The "average" individual exposure is determined by dividing total model regional population doses by the number of people in the region.

[f]The "average" worker exposure is determined by averaging exposures expected for various locations in the mill.

[g]The career dose is based on a person who has worked 47 years in the milling industry (that is, from ages 18 to 65).

- Approximately 150 ha are devoted to milling and allied activities during operations at the model mill. During a brief period of mill construction, a total of 300 ha may be impacted.
- Deposition of windblown tailings may restrict use of land near tailings. Levels of contamination extend several hundred meters beyond the model site boundary in the prevailing wind direction affecting an area of 25 ha. Experience at inactive sites and ongoing field studies at active mills confirm the potential for such land contamination.
- In the multiple mill case, indirect impacts on land use occur; for example, the needs for housing and other services for incoming workers divert a small amount of fertile land in the model region to urban uses.

- The major potential land use impact is permanent commitment of 100 ha of semi-arid land for tailings disposal and restricted use of adjacent land that is contaminated by continued blowing of tailings dust from the poorly controlled mill tailings pile in the base case.

Groundwater

Tailings solutions contain a wide range of trace metal, radioactive, and chemical contaminants in concentrations significantly above existing State and Federal water quality limits. Seepage of such solutions can potentially adversely affect groundwater aquifers and drinking water supplies.

- About 50 percent of tailings solutions, or about 600 MT per day, are disposed of by seepage in the base case.

- Transport of contaminants is a complex function of parameters such as conductivity and dispersivity of subsoils and underlying strata, hydraulic gradients of underlying groundwater formations, ion-exchange and buffering capacity of subsoils, and amounts of precipitation and evaporation. In general, natural subsoil conditions will tend to remove many heavy metals and radionuclides such as radium and thorium from the tailings seep. This will occur primarily as a result of chemical precipitation and sorption processes.

- Some heavy trace metals such as selenium, arsenic, and molybdenum may form ions which behave similarly to anion contaminants such as sulfates which do not tend to be removed by sorption.

- Using conservative assumptions about transport parameters, seepage in the base case results in contamination of the underlying aquifer, and eventually nearby wells, with concentrations of selenium and sulfate significantly above established limits. Radium and thorium are predicted to be retained by underlying soils.

- Following operation, rainfall will cause a continued, small amount of seepage from the tailings area.

Surface Water

There are no direct discharges from tailings impoundments to surface streams. Minor impacts could occur indirectly from contaminated groundwater formations which intercept surface streams.

Water Use

Water used in the mill process typically comes from deep-lying aquifers. About 1260 MT of solution will be deposited in the mill tailings area per day. Tailings solutions will be disposed of by evaporation and seepage. 1240 MT of solution (which includes contribution of moisture from both the mill and rainfall) evaporate from the tailings impoundment per day. In some areas, where concentrated uranium development in conjunction with other heavy mining activity occurs, evaporative losses could result in temporary lowering of water wells tapping affected aquifers.

Soils and Terrestrial Biota

Generally, impacts on soils supporting growth of vegetation and on terrestrial biota will be minor and localized. On the other hand, what impacts occur may be important because of the slow rate of soil formation in arid and semi-arid regions of the West.

- 150 to 300 ha of soils and wildlife habitat will be destroyed directly by construction and operation of the mill and mill tailings disposal site.

- Indirect impacts occur from seepage and spread of windblown particulates from the tailings pile. These lead to soil salinization, and contamination of soils and vegetation, with toxic elements. Extent of impacts would increase over the long term as tailings continue to blow.

- In the multiple mill case, impacts on biota of the region resulting from overgrazing might be evident.

- The amount of land potentially disturbed is relatively small. Only a few tenths of a percent of primary and secondary productivity in the model region (80 km radius), typical of sparsely populated and semi-arid western milling areas, would be affected even in the multiple-mill case.

Socioeconomics

In an effort to assess the socioeconomic impacts from uranium mining and milling the following areas were examined: 1) demography and settlement patterns; 2) social, economic and political systems; 3) archeological and historical resources; and 4) esthetics and recreational resources. Negative socioeconomic impacts in the case of an isolated mill would be minor in terms of regional impact. Cumulative impacts might occur where multiple mills are located in a region. However, it is extremely difficult, in most cases, to isolate the effects of uranium milling and mining from effects occuring as a result of other mineral resource exploitation and industrial developments which could be occurring in a region, such as coal mining. In addition, it is difficult to project the level of these other industrial activities. In any case, the severity of impacts that can occur as a result of uranium milling and related mining activities would depend upon several factors including the proportion of the population and regional economy that would be devoted to these activities, as well as the general social, economic and political characteristics of the area. Generally speaking, the potential socioeconomic impacts from uranium mining and milling are not unlike those occurring as a result of other similar sized industrial developments.

6.5.4 Variants Examined

The staff evaluated the potential difference which could occur in impacts for two situations which vary from routine operation of the 1800 MT/day, acid leach mill: operation of alkaline leach mills and operation of much larger (7200 MT/day) mills. These various situations are discussed in Appendices H and I. The differences are summarized as follows:

Alkaline Leach Mill

The model mill is an acid leach mill; however, 20 percent of the conventional milling industry utilizes the alkaline leach process. Radioactive exposures would be virtually the same for acid and alkaline mills. The major differences between impacts of alkaline and acid leach mills are:

- Water requirements of and, hence, seepage at the alkaline mill are 30 to 80 percent of an acid mill.
- Concentration of contaminants will be generally less in the alkaline leach mill. However, toxic anonic salts such as selenium and arsenic will tend to be present in greater concentrations.

Large Mills

General conclusions drawn from the comparison of large (7200 MT/day) and average size (1800 MT/day) mills are:

- Combined capital and operating costs of the 7200 MT/day mill are 70 percent of the 1800 MT/day model mill per unit of mill throughput.
- For comparable siting situations, total population exposures will not significantly change per unit of mill throughput.
- Problems of meeting individual limits will be more difficult at large mills, since emissions will increase with mill size.
- Factors offsetting increased emissions might be increased operating efficiency of control devices and greater management attention to emissions controls which could be afforded as a result of large mill economic efficiencies.
- Larger mills would reduce the number of separate sites being committed to mill tailings, and hence reduce the long-term problem of site surveillance.

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7. ENVIRONMENTAL EFFECTS OF ACCIDENTS

The environmental effects of accidents involving the release of radioactive materials or harmful chemicals that could occur at the model site are covered in this chapter. Accidents which might occur during mill operations have been conceptualized on a generic basis and the potential environmental impact of these postulated accidents are evaluated. The descriptions of the site and model mill considered in this analysis are contained in Chapters 4 and 5 of this report. Two situations are considered--(1) operation of a single mill and (2) operation of as many as 12 mills. Both the nominal consequences and corresponding probabilities are evaluated by use of realistic assumptions in regard to release and transport of radioactive materials. In cases of doubt or where information adequate for realistic evaluation was unavailable, very conservative assumptions were used to compute environmental impacts. Thus, the actual environmental effects from the accidents that are postulated would be, in most cases, significantly less than those predicted in this assessment.

7.1 SINGLE MODEL MILL

The radioactive materials handled at the model mill typically have low specific activities (LSA);* i.e., $\sim 10^{-9}$ Ci/g for the tailings, $\sim 10^{-9}$ Ci/g for the ore, and $\sim 6 \times 10^{-7}$ Ci/g for the refined yellowcake product. The quantities of materials handled, on the other hand, could be relatively large--as much as 580 MT (635 ST) of yellowcake per year, representing about 350 Ci of radioactivity.

The very low specific activities require the release of exceedingly large quantities of material in order to be of concern; driving forces for such releases are generally lacking at the model mill. For this assessment, postulated plant accidents involving radioactivity are considered in the following three categories:

1. Trivial incidents; i.e., those not resulting in a release to the environment,
2. Small releases to the environment (relative to the annual release from normal operations),
3. Large releases to the environment (relative to the annual release from normal operations).

Typical trivial incidents include spills, ruptures in tanks or plant piping containing solutions or slurries, failures of the centrifuge used for yellowcake dewatering, and rupture of a tailings disposal system pipe in which the tailings slurry is released into the tailings pond. Small releases include failure of the air-cleaning system serving the concentrate drying and packaging area, a fire or explosion in the solvent extraction circuit, and a gas explosion in the yellowcake dryer. Large releases include a major tornado strike and releases to the watercourse from the tailings pond or tailings distribution system.

In most cases for which a postulated accident results in a release to the environment, the estimated magnitude of the release, the corresponding maximum individual dose,** and the estimated annual probability of occurrence are presented below. The likelihoods are estimates based on a variety of sources, including incidents on record, chemical industry statistics, and failure prediction methodologies. The dispersion model was taken from NRC Regulatory Guide 1.4,[1] and the dose conversion factors are based upon the recommendations of the International Commission on Radiological Protection (Committee II),[2] updated by the lung model advocated by the Environmental Protection Agency.[3]

*In contrast to the relatively high specific activities of a number of prominent radionuclides; i.e., $\sim 10^{-1}$ Ci/g for Pu-239 and $\sim 10^{3}$ Ci/g for Co-60.

**To place the results of the accident analysis in perspective, the annual lung dose from natural background radiation to individuals living within an 80-km (50-mile) radius of the model mill is about 8.2×10^{3} man-rem. This dose was estimated using the annual dose from background radiation (Sec. 4.12) and population data for the region.

During the three decades of nuclear facility operation, the frequency and severity of accidents have been markedly lower than those in related industrial operations. The experience gained from the few accidents that have occurred has resulted in improved engineering safety features and operating procedures, and the probability that similar accidents might occur in the future is considered low. In light of past experience, it is believed that even if major accidents did occur radiation exposures would be too small to cause any observable deleterious effect on the health of the human population.

7.1.1 Trivial Incidents Involving Radioactivity

The following accidents at the model mill caused by human error or equipment failure would not result in the release of radioactive material to the environment.

7.1.1.1 Leaks or Rupture in Tanks or Piping

Uranium-bearing slurries and solutions are contained in several tanks comprising the acid leach, washing and clarification, and solvent extraction stages of the model mill circuit. Human error during the filling or emptying of tanks or the failure of valves or piping in the circuit would result in spills which might be expected to occur several times annually during operations. Large spills from tank failures or uncorrected human error might involve the release of several hundred pounds of uranium in the liquid phase to the room. However, the entire content of the tanks would be contained within the mill sumps and therefore would not reach the environment.

7.1.1.2 Centrifuge Failure

Prior to drying, the thickened yellowcake slurry is likely to be dewatered by the use of a centrifuge. The centrifuge may be located in the vicinity of a tank containing uranium in solution or as a slurry. If the centrifuge rotor were to fail, it could conceivably penetrate one of these tanks and release radionuclides to the room. However, the entire contents of a tank would be contained by dikes constructed around the tank and therefore would not reach the environment.

7.1.1.3 Rupture of a Pipe in the Tailings Disposal System

The throughput of the model mill is 1800 MT (2000 ST) of ore per day. At this rate, approximately 65 MT (70 ST) per hour of sand, silt, and clay-sized particles are transported to the tailings pond through the tailings disposal system piping. This material, usually transported as a slurry ($\sim$ 50% water), contains mill chemicals and radioactive materials. Ruptures in the piping would be expected to occur; however, the majority of the length of the piping would probably parallel the tailings pond, and the flow of the slurry released from the ruptures would be toward the tailings pond, where it would be contained along with the existing tailings material. Should a rupture occur in the length of piping between the mill and the tailings area, the slurry could conceivably reach the watercourse. This case is considered along with tailings pond releases in Section 7.1.3.

7.1.2 Small Releases Involving Radioactivity

The following accidents, caused by human error or equipment failure, would release small quantities of radioactive materials to the environment. The estimated releases, however, are expected to be small in comparison with the annual release from normal operations.

7.1.2.1 Failure in the Air Cleaning System Serving the Yellowcake Drying Area

The off-gases from the model mill drying operation, which contain entrained solid particles of yellowcake, typically pass through a wet scrubber which is expected to collect roughly 98% of the solid material, depending on particle size. The emission rate to the scrubber is assumed to be approximately 1400 g/hr (3.1 lb/hr) of uranium oxide. Should the scrubber fail, all of this material could be released to the environment. Although the stack is routinely monitored for uranium, the circuit also is usually checked every one-half hour as a part of the formal plant procedures. A drop in pressure would indicate failure of the scrubber, in which case operations would be terminated until the scrubber was repaired. If the failure occurred during daylight hours, the plume would be visible to an observer.

For purposes of analysis, it is assumed that the scrubber totally fails to function for eight hours during the night shift and that the pressure goes unchecked for the entire shift. This would result in the release to the environment of approximately 11 kg (25 lb) of insoluble uranium oxide particles, assumed to be in the respirable size range. For this magnitude of release at the model mill, it is conservatively estimated that an individual at the closest permanent residence [2000 m (6500 ft)] would receive a 50-year dose commitment to the lung of approximately 86 mrem.

Although quantitative data are unavailable, catastrophic scrubber failure is highly unlikely. Progressive failure, in which case the plugging of vents causes back pressure, would be readily detectable during operational checks and would probably produce inefficiencies, rather than complete failure.

7.1.2.2 Fire or Explosion in the Solvent Extraction Circuit

The solvent extraction circuit is generally in a separate building and could contain as much as 1300 kg (2900 lb) of uranium. Major fires have occurred in solvent extraction circuits of uranium mills in recent history.[4] The tanks, containing about 380,000 L (100,000 gallons) of solvent (kerosene and amines), are typically fitted with sprinkler systems containing an extinguishing agent.

It is conservatively assumed from previous estimates[5,6] relating to both uranium and plutonium solutions that in the event of a major fire, as much as 1% of the uranium would be dispersed.* This would result in the ultimate release to the environment in the vicinity of the model mill of about 13 kg (29 lb) of soluble uranium and 0.65 kg (1.4 lbs) of thorium. The maximum individual 50-year dose commitments at the fence [500 m (1600 ft)] and nearest residence [2000 m (6500 ft)] resulting from this incident are estimated to be approximately 1.36 rem and 0.15 rem to the bone, respectively.

From chemical industry data, the probability of a major fire per plant-year is estimated to be 4×10^{-4}.[5] However, at least two major solvent extraction circuit fires are documented in the literature.[4] There have been over 570 plant-years of mill operation in the United States. Thus, from the historical incidents, the likelihood of a major solvent extraction fire is in the range of 0.4 to 1×10^{-2} plant-year. Using these two estimates to bracket the probability, the staff estimates the likelihood of a major solvent extraction fire at the model mill to fall in the range of 4×10^{-4} to 1×10^{-2} per year.

7.1.2.3 Gas Explosion in the Yellowcake Drying Operation

A propane- or natural-gas-fired furnace is generally used to remove the water remaining in the yellowcake slurry after the centrifuge operation. The furnace, which usually consists of several tiers of hearths enclosed within a large cylinder, is generally contained in an isolated enclosed area on a concrete slab. For the model mill, the inventory of yellowcake in the dryer is taken to be approximately 1500 kg (3300 lb). The off-gas from the dryer, as discussed earlier, is usually vented through a wet scrubber. An explosion in the dryer or the fuel piping, however, could blow off the duct work associated with the ventilation system and disperse yellowcake into the room.

The consequences of explosion accidents are limited by the concentration of heavy material that can be maintained in the air, estimated to be approximately 100 mg/m^3 (6.25×10^{-6} lb/ft^3).[5] For a room with a volume on the order of 10^4 m^3 (3.5×10^3), the quantity of yellowcake released to the room air is estimated to be approximately 1000 g (2.2 lb); this estimate is based on the conservative assumption that all of the material would be swept out into the environment when the room is ventilated. It is estimated that if 100% of the insoluble particles are in the respirable size rnage, individuals at the fence line [500 m (1600 ft)] and at the closest residence [200 m (6500 ft)] would receive 50-year dose commitments to the lung approximately 6.5×10^{-2} rem and 6.9×10^{-3} rem, respectively.

No quantitative data have been found relating either to propane or natural gas furnace explosions. Failure rates observed for piping used in the transmission of natural gas can be converted to equivalent failure rates per plant year.[7] The result of this analysis indicates approximately 5×10^{-3} failures per plant year. This is probably an upper limit of the likelihood of a gas explosion because it is based upon the conservative estimate of 52,000 m (170,000 ft) of piping per plant and does not take into account the probability of ignition given a failure.

*It is estimated that a smaller fraction of the uranium inventory would be released to the room, and subsequently to the environment, in the event of an explosion.

7.1.3 Large Releases Involving Radioactivity

For operations at the model mill, there are conceivable accidents which could release larger quantities of radioactive materials to the environment that would be released annually from normal operations. By virtue of complex and highly variable dispersion characteristics, however, the individual impacts will not necessarily be proportional to the total amount of radioactivity released to the environment.

7.1.3.1 Tornado

Thunderstorms, occasionally spawning tornadoes, are frequent in spring and summer. These tornadoes tend to be less destructive than tornadoes occurring further east. Dust devils are frequent in the area and may occasionally cause slight damage in their paths. The area is categorized as Region 3 in relative tornado intensity;[8-10] i.e., for a typical tornado, the wind speed is 110 m/s (240 mph), of which 85 m/s (190 mph) is rotational and 25 m/s (50 mph) is translational. Generally, the mill structures in the model region are not designed to withstand a tornado of this intensity.

The nature of the milling operation is such that little more could be done to secure the facility with advance warning than without it. Accordingly, a "no warning" tornado is postulated. Moreover, since it is not possible to predict accurately the total amount of material dispersed by the tornado, a highly conservative approach is adopted. It is assumed that (1) three days production of yellowcake is free and not packaged in containers, (2) the maximum inventory of 45 MT (50 ST) of yellowcake is onsite when the tornado strikes, and (3) 15% of the contained material is released. Thus, it is assumed that the tornado lifts about 11,400 kg (25,100 lb) of yellowcake (equivalent to the contents of twenty-six 55-gallon drums).

A conservative model, in which it is assumed that all of the yellowcake is in a respirable form, was used for the dispersion analysis.[11] It is assumed that all of the material is entrained as the vortex passes over the site. Upon reaching the site boundary, the vortex dissipates, leaving a volume source to be dispersed by the trailing winds through an arc of 45°. Because of the small particle sizes assumed, the settling velocity is considered to be negligible.

The model predicts a maximum exposure at a distance of approximately 4 km (2.5 miles) from the mill, where the 50-year dose commitment to the lungs of an individual is estimated to be 8.3×10^{-7} rem. For individuals at the fence line [500 m (1600 ft)] and at the closest residence [2000 m (6500 ft)], the 50-year dose commitments are estimated to be 2.2×10^{-7} rem and 4.8×10^{-7} rem, respectively.

7.1.3.2 Release of Tailings Slurry

The underflow from the washing and clarification step in the model mill is pumped to the tailings disposal pond. Approximately 1800 MT/day (2000 ST/day) of sand, silt, and clay-sized particles entrained in approximately an equal weight of solution constitutes the tailings slurry. Over the projected life of the milling operation, approximately 9.9×10^6 MT (10.9×10^6 ST) of barren tailings could be generated and retained in the disposal area, typically 1×10^6 m^2 (1.1×10^7 ft^2). Inadvertent release of the tailings slurry to the environment might result from an overflow of the tailings slurry, a rupture in the tailings distribution piping, or a failure of the tailings embankment plus washout. Failure of the tailings dam could be caused by a destructive earthquake, flood-water breaching, or structural failure.

For the expected rates of precipitation during the life of the model mill, the tailings pond could overflow only if the processing system were allowed to operate unattended for several weeks. A minimum of 1.5 m (5 ft) of freeboard is generally provided, which is approximately 8.0×10^8 L (2.2×10^8 gallons) of emergency storage. The predicted runoff, with diversion ditches installed, to the tailings pond from the postulated 100-year storm is 7.9×10^7 L (2.1×10^7 gallons). Moreover, it is assumed that if the diversion ditches fail and a 500-year return-period storm occurs, only 3.7×10^8 L (9.8×10^7 gallons) of water would be input to the tailings pond. The maximum monthly precipitation recorded in the model mill site area is 12.3 cm (4.8 inches). Assuming a maximum 24-hour precipitation event of 6.0 cm (2.4 inches), an inflow to the tailings pond of 2.1×10^8 L (5.6×10^7 gallons) is estimated. The sum of these inflows does not exceed the reserve capacity of the tailings pond. (It is concluded in an independent analysis that the Bear Creek tailings dam would not be overtopped by a 100-year return-period flood or by one-half of the probable maximum precipitation event.)[12]

In any event, if tailings are deposited above grade, current regulations require that the tailings dam be designed to withstand the probable maximum flood.

Failure of the tailings dam because of earthquake would be unlikely since the model site is postulated to be in a zone of low seismicity.[13,14] Within the model region, an earthquake of intensity MM VI might be expected to have occurred within recent history. (As indicated in the Supplement, this is the general situation in U.S. uranium resource regions.)

From the foregoing discussion it is clear that sufficient data are not available to estimate the small probability of the occurrence of a natural disaster with sufficient intensity to result in a release of tailings slurry to the environment. Even if the probability were known accurately, however, it would be difficult to predict the magnitude of the release. However, tailings slurry releases have occurred in the past, and the consequences associated with these events have been documented to varying levels of detail in reports to the NRC (AEC) and to Agreement States and will be used to estimate the nominal model mill release. Table 7.1 contains a summary of recorded incidents in the period 1959 through 1979.

Table 7.1. Summary of Accidental Tailings Slurry Releases, 1959-1979[a]

Cause	Solids Released, kg	Liquids Released, liters	Reached Watercourse
Flash flood	14×10^6	1.2×10^7[b]	Yes
Dam failure	9×10^5[b]	9.1×10^5	Yes
Dam failure	5×10^5	4×10^5[b]	No
Dam failure	2×10^5	2×10^5[b]	Yes
Pipeline failure	3×10^5	2×10^5	Yes
Flooding	1×10^8[b]	8.7×10^7	Yes
Pipeline failure	6.4×10^4[b]	6.1×10^4	Small amount
Pipeline failure	2×10^6[b]	1.7×10^6	Yes
Dam failure	$1\text{-}14 \times 10^6$[b]	$1\text{-}11 \times 10^6$	Yes
Pipeline failure	1×10^5[b]	1.3×10^5	Yes
Dam failure	9×10^3[b]	8×10^3	No
Pipeline failure	4.5×10^7	$8\text{-}30 \times 10^6$	No
Dam failure	8.2×10^6[b]	7.6×10^6	No
Pipeline failure	1.1×10^3	1.5×10^4	Yes
Dam failure	1.0×10^6	3.8×10^8	Yes
Pipeline failure/dam failure	No quantitative information		

[a]From "Environmental survey of the Uranium Fuel Cycle," WASH-1248, U.S. Atomic Energy Commission, Fuels and Materials, Directorate of Licensing, April 1974, and "Summary of Tailings Slurry Releases 1972-1977," prepared by Teknekron, 28 February 1978.

[b]This value is based on the assumption that equal weights of solids and liquids are released, and that the density of the liquids is approximately 1.6 g/cm^3 (100 lb/ft^3).

From these historical data, the average releases from tailings embankment failure or flooding were approximately 5.5×10^7 L (1.4×10^7 gallons) of liquids and 1.4×10^7 kg (3.2×10^7 lb) of solids. Six out of ten of the releases from embankment failure or flooding reached the watercourse. Thus, considering the 430-odd mill-years of operation in the period, the likelihood of release from the tailings pond to the watercourse is approximately 1 to 2×10^{-2} per plant year. Mills having dikes similar in construction to those that failed were required to strengthen the dikes, and for new mills the design of the embankment retention system is expected to conform to Regulatory Guide 3.11.[15]

As discussed in Section 7.1.1, most failures in the tailings distribution piping would result in release of the slurry to the tailings pond and not to the environment. However, if the failure were to occur in the length of piping between the mill and the tailings area, the slurry could conceivably reach the watercourse. Based on the historical data given in Table 7.1, the average releases to the watercourse from piping failure were approximately 3.5×10^6 L (9.1×10^5 gallons) of liquid and 8.2×10^6 kg (1.8×10^7 lb) of solids. Furthermore, on the same basis as embankment failure estimates, the likelihood of tailings release from failure of the piping is less than 1×10^{-2} per plant-year. Since both the historical consequences and likelihood of piping failures are lower than those of embankment failure, only releases from embankment failures or flooding are considered in the discussion that follows relative to the impact of a tailings slurry release.

For the model mill the fractions of the uranium, thorium, and radium originally present in the ore that remain in the tailings are about 7%, 99.8%, and 100%, respectively. Generally, the solid tailings are coated with acid solutions and are estimated to have a radiological composition of approximately 20 μCi/MT each of U-238 and U-234, 280 μCi/MT of Th-230, and 280 μCi/MT of Ra-226. Because of losses due to seepage, evaporation from the disposal area, and entrapment in the tailings solids, the composition of the liquid phase is difficult to predict. In addition to dissolved minerals from the ore, the tailings solution contains trace quantities of the components of the organic phase of the solvent extraction step in the milling circuit. In Table 7.2 the composition of typical tailings solution from an acid leach mill is compared with standards.

Table 7.2. Typical Concentrations of Radionuclides and Chemicals in Tailings Solution

Radionuclide	Concentration, μCi/mL	Maximum Permissible Concentration in Unrestricted Areas,[a] μCi/mL
U-238	1.7×10^{-6}	4×10^{-5}
U-234	1.7×10^{-6}	3×10^{-5}
Th-230	9.0×10^{-5}	2×10^{-6}
Ra-226	2.5×10^{-7}	3×10^{-8}
Pb-210	2.5×10^{-7}	1×10^{-7}
Po-210	2.5×10^{-7}	7×10^{-7}
Bi-210	2.5×10^{-7}	4×10^{-5}
Chemical	**Concentration, mg/L**	**NAS Water Quality Standards for Livestock,[b] mg/L**
As	0.2	0.2
Na	200	--
Fe	1,000	--
Al	2,000	--
F	5	--
V	0.1	--
Ca	500	--
$SO_4^{=}$	30,000	250
Cl^-	300	3000
NH_3	500	--

[a]From Rules and Regulations, Title 10 - Chapter I, Code of Federal Regulations, Part 20, Standards for Protection Against Radiation, U.S. Nuclear Regulatory Commission.

[b]"Water Quality Criteria 1972," A report of the Committee on Water Quality Criteria, National Academy of Sciences, National Academy of Engineering, prepared for the U.S. Environmental Protection Agency, 1972.

The estimated 1.4×10^7 kg (3.2×10^7 lb) of solid tailings released from the impoundment area in the event of an overtopping or failure of the embankment would be expected to settle out below the embankment. The extent of the area covered would depend upon the specifics of the failure and is difficult to calculate. Scaling from previous estimates on the basis of the total mass of tailings released,[16] the material may be assumed to follow the tributary stream channel for a distance of approximately 2100 m (6800 ft), covering a width of approximately 130 m (425 ft), and forming a wedge 3 cm (1-1/4 inches) in average thickness.

The main radiological concern associated with the deposition of the tailings material is the small increase in background radiation levels in the affected and adjacent areas and the eventual transport of these low levels of contamination by wind and rain. These long-term effects may be prevented by removing the contaminated material from the environment. Accordingly, a measure of the impact associated with the release of the solid tailings from the pond is the estimated cost of excavating, removal of the tailings and contaminated soil, and transporting the material back to the tailings impoundment. Estimates of a similar operation have been made in connection with the Vitro mill.[17] Using the Vitro mill unit costs and assuming that (1) 15 cm (6 inches) of contaminated soil would require removal along with the tailings, and (2) the approximate travel distance back to the tailings impoundment is 3.5 km (2 miles), the staff estimated the total cost for excavation, removal of tailings and contaminated soil, and the truck transport of the material back to the tailings impoundment to be approximately $120,000.

The fate of the estimated 5.5×10^7 L (1.4×10^7 gallons) of tailings solution released with the tailings slurry resulting from embankment failure or flooding would depend upon the flow at the time in the tributary stream to Reservoir I. This is assumed to be an ephemeral stream that has maximum flow in June and July and is dry from September to February. The soil in the central area of the model site consists mainly of the Petula-Tomahawk association (see Ch. 4). A thin, approximately 100-m (325-ft) surficial deposit of terrace and pediment alluvium caps the Triassic siltstone, which is an alluvial soil of moderate to high permeability. The typical tailings pond effluents would tend to move downward through the soil profile; part of the acidity of the tailings would be neutralized by the calcareous nature of the soils, but there would still be substantial leaching of organic matter and cations from the surface horizons. If the tributary stream were not dry, much of the liquid could conceivably flow via the tributary stream to Reservoir I, approximately 10 km (6 miles) downstream from the tailings pond. The average volume is assumed to be 2.8×10^7 m^3 (7.4×10^9 gallons), with an average minimum of approximately 1.4×10^7 m^3 (3.7×10^9 gallons). If all of the tailings solution were to reach the reservoir, and if the reservoir volume was at the minimum value, the dilution provided by the reservoir would lower the concentration by a factor of approximately 250. The larger volume of water now containing the radionuclides could conceivably place a larger population at risk; but this effect is outweighed by the dilution.

Reservoir I may be used for the watering of livestock and for irrigation of crops. It is assumed that 100 head of cattle may be using the reservoir at any one time, and occasionally throughout the year the reservoir may be frequented by antelope and deer. If the estimated concentrations of chemicals in the tailings solution were as given in Table 7.2 and if the dilution provided by the reservoir was at the average minimum volume, the estimated concentrations of arsenic, sulfate, and chloride ions in the reservoir from the tailings solution would be well within water quality standards for livestock use.[18] Water quality standards for livestock have not been promulgated for the other chemicals.

Of the radioisotopes released to the reservoir in the event of a tailings slurry release from the model mill, Th-230 is of primary concern,* with typical concentrations in the tailings solutions approximately two orders of magnitude in excess of the maximum permissible concentration (MPC) for unrestricted areas, as specified in 10 CFR 20.[19] The actual concentration of thorium would be expected to be considerably lower than this value because of sorption onto the stream bed sediment and precipitation in the reservoir as the pH of the solution approaches neutrality. Nevertheless, an individual consuming meat derived exclusively from livestock watered from Reservoir I could conceivably receive significant bone exposure by virtue of the potentially high concentration factors in meat from ingestion of thorium. However, should a release of tailings slurry occur, the NRC or the Agreement State must be notified and informed of the approximate time of the accident and be furnished estimates of the quantities of liquids and solids that have been released from the tailings pond. If the tailings solution were to reach Reservoir I, the radioactivity of the water, including its thorium concentration, would be monitored prior to its use for the watering of cattle or for irrigation. Alternative sources of water would have to be provided for these uses if the concentrations of radionuclides were found to be excessive. In the extreme case of irreversible contamination of the Reservoir I stream bed the top 15 cm (6 inches) of sediment from Reservoir I could be excavated and hauled to the tail-

*The estimated concentration of Ra-226 in the reservoir is less than the EPA drinking water standard of 5 pCi/L.

ings pond [approximately 4.4 × 10^5 MT (4.8 × 10^5 ST)]. Using the unit costs estimated for the Vitro Mill,[17] the staff estimates that for the model mill the cost of excavation and transportation would be $470,000 and $480,000, respectively. The total costs then would be $950,000.

7.1.4 Accidents Not Involving Radioactivity

The potential for environmental effects from accidents involving nonradiological materials at the model mill is expected to be small. Failure of the boiler that supplies process steam to the acid leach stage of the mill circuit could release low pressure steam to the room, possibly causing minor injuries to workers, but neither chemicals nor radiological materials would be released to the environment. Typically, forced-air ventilation systems will be provided in the acid leach and solvent extraction stages of the process to dilute the chemical vapors emitted and protect the workers from the hazardous fumes. Failure of these ventilation systems might result in the interim collection of these vapors in the building air. Since the vapors would ultimately be discharged to the atmosphere in either case, such a failure would have no incremental effect on the environment.

A number of chemical reagents used in the process are expected to be stored in relatively large quantities at the model mill site. Specifically, storage tanks are provided for 1.4 × 10^6 L (3.6 × 10^5 gallons) of sulfuric acid, 2.5 × 10^4 kg (5.6 × 10^4 lb) of sodium chlorate, 8.2 × 10^3 kg (1.8 × 10^4 lb) of kerosene, and 6.0 × 10^4 L (1.6 × 10^4 gallons) of ammonia. Each of the tanks containing a liquid reagent is surrounded by a dike of sufficient capacity to contain the entire contents of the tank. Also, even if an overflow of a dike were to occur, drainage of the liquid at the model site would generally be toward the tailings pond.

The only chemical which might seriously impact the environment is ammonia. The anhydrous ammonia storage tank is generally located in proximity to the mill. A break in the tank's external piping would result in only a minor release, since an internal safety valve automatically closes when pressure drops, thus preventing further escape of ammonia. Department of Transportation (DOT) regulation 10 CFR Part 178.377 requires the use of this safety valve.[20] It is possible that the line carrying ammonia to the storage tank from the tank truck could be ruptured, in which case the release rate is assumed to be limited to 100 g/s (0.2 lb/s) of vapor. The resulting concentration of ammonia at the closest residence [2000 m (6500 ft)] is conservatively estimated to average approximately 35,000 μg/m^3 over the entire period of release. This concentration is less than the 40,000 μg/m^3 minimum concentration which produces a detectable odor, and the 69,000 μg/m^3 recommended limit for prolonged human exposure,[21] but greater than 600 μg/m^3 short-term air quality standard derived from typical state regulations (at 1/30 threshold limit values). Thus, the ammonia would pose no substantial health risk.

7.1.5 Transportation Accidents

Transportation of materials to and from the model mill can be classified into three categories--(1) shipments of refined yellowcake from the mill to the uranium hexafluoride conversion facility, (2) shipments of ore from the mine pit to the mill, and (3) shipments of process chemicals from suppliers to the mill. An accident in each of these categories has been conceptualized and analyzed, and the results are given below.

7.1.5.1 Shipments of Yellowcake

At the model mill, the refined yellowcake product is generally packed in 55-gallon, 18-gauge drums holding an average of 430 kg(950 lb) and classified by the Department of Transportation as Type A packaging (49 CFR Parts 171-189 and 10 CFR Part 71). The yellowcake is shipped by truck an average of 2400 km (1500 miles) to a conversion plant, which transforms the yellowcake to uranium hexafluoride for the enrichment step of the light water-cooled reactor fuel cycle. An average truck shipment contains approximately 40 drums, or 17 MT (19 ST) of yellowcake. Based upon the projected annual yellowcake yield of 580 MT (635 ST), approximately 34 such shipments will be required annually.

Based on published accident statistics the probability of a truck accident is in the range of 1.0 to 1.6 × 10^{-6}/km (1.6 to 2.6 × 10^{-6}/mile).[22-24] Truck accident statistics include three categories of events: collisions, noncollisions, and other events. "Collisions" are between the transport vehicle and other objects, whether moving vehicles or fixed objects. "Noncollisions" are accidents involving only the one vehicle, such as when it leaves the road and rolls over. Accidents classified as "other events" include personal injuries suffered on the vehicle, persons falling from or being thrown against a standing vehicle, cases of stolen vehicles, and fires occurring on a standing vehicle. The likelihood of a truck shipment of yellowcake from the mill being involved in an accident of any type during a one-year period is approximately 11%. This probability was obtained by multiplying the probability of accident per vehicle-km (1.3 × 10^{-6}/km) by the number of shipments per year (34) and the distance per shipment (2400 km).

A generalized evaluation of accident risks by NRC classifies accidents into eight categories, depending upon the combined stresses of impact, puncture, crush, and fire. On the basis of this classification scheme, conditional probabilities (i.e., given an accident, the probability that the accident is of a certain magnitude) of the occurrence of the eight accident severities were developed. These fractional probabilities of occurrence for truck accidents are given in Column 2 of Table 7.3.[24]

Table 7.3. Fractional Probabilities of Occurrence and Corresponding Package Release Fractions for Each of the Release Models for Low Specific Activity (LSA) and Type A Containers Involved in Truck Accidents[a]

		Release Fractions	
Accident Severity Category	Fractional Occurrence of Accident	Model I LSA & Type A	Model II LSA & Type A
I	0.55	0	0
II	0.36	1.0	0.01
III	0.07	1.0	0.1
IV	0.016	1.0	1.0
V	0.0028	1.0	1.0
VI	0.0011	1.0	1.0
VII	8.5×10^{-5}	1.0	1.0
VIII	1.5×10^{-5}	1.0	1.0

[a]From "Final Environmental Report on the Transportation of Radioactive Materials by Air and Other Modes," U.S. Nuclear Regulatory Commission, NUREG-0170, 1977.

In order to assess the risk of a transportation accident, it is necessary to know the fraction of radioactive material that is released when an accident of a given severity occurs. For this analysis, two accident models are considered: Model I assumes complete loss of drum contents, and Model II, based upon actual tests,[24] assumes partial loss of drum contents. The packages are assumed to be Type A drums containing low specific activity (LSA) material. The fractional releases to the environment for each model are shown in Columns 3 and 4 of Table 7.3.[24] Integrating the fractional occurrence and the release fractions (loss) for Model I and Model II, the expected fractional release in any given accident is approximately 0.45 for Model I and 0.03 for Model II. The quantity of yellowcake released from the containers in the event of a truck accident is estimated to be about 7700 kg (17,000 lb) for Model I and 530 kg (1200 lb) for Model II. Most of the yellowcake released from the container would be deposited directly on the ground in the immediate vicinity of the accident. Some fraction of the released material, however, would be dispersed to the atmosphere. Expressions for calculation of the dispersal of plutonium oxide to the environment have been developed at Battelle Northwest Laboratories on the basis of actual laboratory and field measurements over several years.[23] The following empirical expression was derived for the dispersal of plutonium oxide via the air following an accident involving a release from the container:

$$f = 0.001 + 4.6 \times 10^{-4} \, (1-e^{-0.15ut}) \, u^{1.78} ,$$

where: f = the fractional airborne release,

u = the wind speed at 15.2 m (50 ft) expressed in m/s, and

t = the duration of the release, in hours.

In this expression, the first term represents the initial "puff" immediately airborne when the container fails in an accident. If the above expression is also valid for U_3O_8 dispersal, if the wind speed is 5 m/s (10 mph), and if 24 hours are available for the release, it is estimated that the environmental release fraction would be 9×10^{-3}. For insoluble uranium, all particles of which are in the respirable size range, a 5° sector, and a population density of 2.9 persons/km^2 (7.5 persons/mi^2) characteristic of the model region (see Ch. 4), the consequences of a truck accident involving a shipment of yellowcake from the mill would be 50-year dose commitments of approximately 9 and 0.7 man-rem to the lungs of the general public for Models I and II, respectively. It is equally likely that this accident could occur in the more densely populated regions of the country where the uranium conversion plants are located. Using the population density [61 persons/km^2 (160 persons/mi^2 (160 persons/mi^2)] of the Eastern United States, it is found that the 50-year dose commitments to the lungs of the general public would be about 200 man-rem and 14 man-rem for Models I and II, respectively.* It is possible that the postulated accident could occur on a bridge, such that the containers could be knocked into the water. No actual data are available from which to estimate the probability of such an event; however, it is possible to use indirect data to arrive at an estimate. In a recent study by Sandia Corporation,[25] it was conservatively estimated that there are a total of 160 km (100 miles) of bridges and that most of the bridges are on Federal highways. A value of 240,000 km (150,000 miles) of roads under Federal control was used.[26] This leads to a conditional probability of 6.7×10^{-4} that if an accident occurs, it takes place on a bridge. Moreover, many of the accidents are relatively minor, and most deepwater bridges are heavily protected, such that the occurrence of an accident on a bridge would probably not result in immersion of the containers in the water. For purposes of this analysis, however, it is conservatively postulated that the truck and all of the containers involved in the accident would be immersed and that 45% of the containers would be ruptured and would release their contents to the river. If the accident rate for trucks of 1.3×10^{-6}/vehicle-km (2×10^{-6}/vehicle-mile) is combined with the conditional probability of an accident occurring on a bridge, the probability of the yellowcake becoming immersed is about 8.7×10^{-10}/vehicle-km (1.4×10^{-10}/vehicle-mile).

The yellowcake will be transported east from the model region to the conversion facility. The first major river to be crossed other than dry drainage ditches and ephemeral streams would be the Tributary River. Additional rivers would be crossed during the assumed 2400-km (1500-mile) trip to the conversion facility. In the unlikely event of a transportation accident on a bridge, two situations are postulated. In the first, the drums rupture and spill their contents on the bridge or partially on the bridge and on the riverbank below, but not in the river. For this situation, the accident probabilities and consequences are the same as previously described for the Model I and II releases. For the other, the truck crashes through the guardrail and breaks up on impact with the water. For this situation, it is assumed that 45% of the containers rupture and release their contents of yellowcake concentrate to the river.

Under the first situation described above, the yellowcake should be cleaned up as rapidly as possible to prevent spread of the contamination. The cleanup should be directed by qualified personnel from the state radiological emergency assistance team. Should the accident be judged by the state personnel to be beyond their capability, the Nuclear Regulatory Commission would be requested to provide assistance. The NRC regional office would assist by dispatching a radiological emergency assistance team to the scene of the accident to: identify and assess the hazard, advise on emergency operations to protect the health and safety of the public, provide or prescribe procedures which will minimize injury or deleterious effects on the surrounding environment, and generally provide assistance as may be necessary.

Under the second situation, where the containers are immersed in water, it is estimated that 7.7×10^3 kg (1.7×10^4 lb) of yellowcake containing approximately 4.3×10^3 μCi of radioactivity would be released to the river. If the Tributary River is typical of the rivers on route, the flow rate would vary from a minimum of 5 m^3/s (1400 gps) to a maximum of 80 m^3/s (23,000 gps). For a minimum flow rate, the concentrations of radioisotopes would be diluted to maximum permissible concentrations in a matter of a few minutes. Even in the highly unlikely event that water for a public water supply system were being withdrawn immediately below the point of accidental release, an individual would only receive a small fraction of the Radiation Protection Guide (RPG) of 500 mrem per year. In order to be exposed to this dose, an individual would have to drink the water at the MPC level for one year. It is expected that the yellowcake concentrate released by the accident would pass down the river as a slug and during its transit would be further diluted until it was not detectable above the background radiation level of the river. It is not possible in this generic analysis to estimate the time and distance for the material to reach background levels.

In a recent accident (September 1977) a commercial carrier with 50 drums of uranium concentrate overturned and spilled an estimated 3200 kg (7000 lb) of concentrate on the ground and in the truck trailer. Approximately three hours after the accident, the material was covered with plastic sheeting to prevent further release to the atmosphere. Using the formula given earlier for the three-hour duration of release, approximately 24 kg (53 lb) of U_3O_8 are estimated to have been released to the atmosphere. The consequence for the area in which the accident actually occurred, where the population density is about 1.0 person/km^2 (2.5 persons/mi^2), is estimated to be 1.2 man-rem.**

*A population density of 900 persons/km^2 out to 5 km from the point of the accident in East City, and 2.9 persons/km^2 from 5 to 80 km was assumed. A 5° sector was used.

**5° angle of dispersion, 80-distance.

Inhalation of yellowcake dust might produce some health effects due to the chemical toxicity of uranium. In the case of the September 1977 accident, no clinical effects were observed among the individuals who were involved with the spill and subsequent cleanup.[27] Also, uranium bioassays of 27 persons who were in the vicinity of the spill (including the law enforcement and rescue personnel) indicated that chemically toxic levels of uranium intake did not occur.

It is possible that in the future yellowcake will be transported as a slurry to the conversion facility. One milling company has applied to the NRC for a permit to transport yellowcake in such a form and is designing tank cars which would be subject to Department of Transportation approval. If the yellowcake were transported as a slurry, the consequence of an accidental release of the material on land or in the water probably would be less than for the dry concentrate. It is expected that the slurry would be transported from the model mill in specially designed 9.9×10^3-L (2.6×10^3-gallon) stainless steel tanks with 1/4-inch-thick walls. The slurry in such a tank would contain an average of 6 to 7 curies of radioactivity.* It is expected that the tank truck would be able to withstand the impact of most collisions, or under the most severe conditions, an accident would result in a rupture of the tank and release of only a portion of the slurry. To prevent the spread of contamination, the slurry would need to be cleaned up as rapidly as possible under the direction of a state radiological emergency assistance team. It is expected that eventually there would be some drying out of the slurry and release of yellowcake to the atmosphere in the immediate vicinity of the accident, depending upon how long it took to clean up the material. Although sufficient data are not available for a quantitative analysis of such an accident, it is expected that the consequences would be considerably lower than those estimated for the shipment of dry concentrate.

7.1.5.2 Shipments of Ore to the Mill

For the model mill, the uranium ore is usually shipped to the ore stockpiles adjacent to the mill in 23-MT (25-ST) batches. The average distance from the initial uranium mine pit to the mill stockpile is approximately 50 km (32 miles). Based upon the mill capacity of 1800 MT (2000 ST) of ore daily, approximately 29,000 trips per year will be required. Although the ore will be hauled on private roads, it is assumed that the probability of a truck accident is in the range cited in the previous section; therefore, the estimated likelihood of an ore truck being involved in an accident during a one-year period is about 0.4. However, because of the low specific activity of the material and the ease with which the contamination can be removed, the radiological impact in the model region site is not considered significant.

As it comes from the mine, the ore contains a significant fraction of moisture and has a lower percentage of fines than ore that has been crushed. For the purpose of this analysis, it is conservatively assumed that the ore contains 1.0% respirable dust by weight, and that in an accident all of this dust would be released from the truck and be available for dispersal. Furthermore, the environmental release factor of 9×10^{-3} derived in the previous section from the Battelle formula is assumed valid. Based on the foregoing assumptions, the quantity of dispersible ore released to the atmosphere in the event of a truck accident is estimated to be about 2.1 kg (4.6 lb). If all of the dust is in the respirable range, the consequence of a truck accident involving a shipment of ore from the mine to the mill would be a maximum individual 50-year lung dose commitment of 0.13 rem at 500 m (1600 ft) and 0.014 rem at 2000 m (6500 ft) from the accident scene.

7.1.5.3 Shipments of Chemicals to the Mill

Truck shipments of anhydrous ammonia to the mill, if involved in a severe accident, could result in a significant environmental impact. Approximately 39 shipments of anhydrous ammonia are made annually in 19,000-L (5000-gallon) tank trucks from the nearest supplier. It is assumed that the supplier is about 400 km (250 miles) from the mill.

The annual United States production of anhydrous ammonia which is shipped in that form is approximately 6.9×10^6 MT (7.6×10^6 ST). It is estimated that about 26% of the shipments are made by truck (with the remainder by rail, pipeline, and barge). Based on the assumption that the average truck shipment is about 19 MT (21 tons), approximately 93,000 truck shipments of anhydrous ammonia are made annually. Based on accident data collected by DOT,[28] there are about 140 accidents per year involving truck shipments of anhydrous ammonia.** For an estimated average shipping distance of 560 km (350 miles), the resulting accident frequency is roughly 2.7×10^{-6}/km (4.3×10^{-6}/mile). The DOT data also reveal that a release of ammonia [770 kg

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*J. Deuel, Consultant, Kerr-McGee, private communication.

**The DOT accident statistics are extrapolated from the number of shippers reporting, estimated to constitute approximately 10% of the total number of shippers.

(1700 lb) on the average] resulted from approximately 80% of the reported incidents, and that a member of the general public was injured in about 15% of the reported incidents involving a release. (Most of the injuries were sustained by the driver.)

On the basis of these data, the probability of an injury to a member of the general public resulting from an average shipment of anhydrous ammonia is about 3×10^{-7}/km (4.8×10^{-7}/mile). This would be expected to be an overestimate for shipments in the vicinity of the model mill because of the relatively low population density. Nevertheless, on the basis of this estimate, the likelihood of an injury to a member of the general public resulting from shipments of ammonia to the mill is predicted to be about 5×10^{-3} per year.

7.1.6 Regional Variations

Potential accidents at a model mill located in each of the six physiographic regions described in the Supplement are examined to determine the regional variations in the potential environmental effects.

7.1.6.1 Trivial Incidents Involving Radioactivity

Trivial accidents involving leaks or ruptures in tanks or piping, centrifuge failure, or rupture in the tailings disposal system are not expected to result in releases of radioactive material to the environment at the model site. Similarly, no factors can be identified that could lead to such releases in any of the six regions.

7.1.6.2 Small Releases Involving Radioactivity

Short-term atmospheric dispersion is expected to be similar in all regions; thus, the estimated short-term dispersion factor used in the model site analyses of failure in the air-cleaning system serving the yellowcake drying area, fire in the solvent extraction circuit, and gas explosion in the yellowcake drying operation would also apply to the analysis of these accidents in the six regions. Consequently, the estimated 50-year dose commitments to individuals located at a fence line 500 m (1600 ft) away and at the closest residence, 2000 m (6500 ft), would be the same in each of the six regions as that for the model mill. It is expected that the only regional variation in the consequences of these accidents would be in the 50-year population dose commitments, which are a function of population density. The population densities corresponding to the subregions of the physiographic regions, as shown in the Supplement, were selected for this analysis because it is assumed that uranium mills would be located close to known uranium deposits. The predicted 50-year population dose commitments for each of the six regions are compared to that of the model region in Table 7.4.

Table 7.4. Comparison of the Predicted 50-Year Population Dose Commitments in Each of the Six Regions with that at the Model Region for Selected Accidents

Region	Failure in the Air Cleaning System, man-rem to lung	Fire in the Solvent Extraction Circuit, man-rem to bone	Gas Explosion Yellowcake Drying Area, man-rem to lung
Model Region	1.5	2.5	0.12
Northern Rocky Mountains	1.4	2.4	0.11
Western Great Plains	1.1	1.8	0.09
Wyoming Basin	0.72	1.2	0.07
Southern Rocky Mountains	0.68	1.1	0.06
Colorado Plateau	1.3	2.2	0.1
Texas Coastal Plains	3.1	5.2	0.24

7.1.6.3 Large Releases Involving Radioactivity

7.1.6.3.1 Tornado

The annual frequency and probability of occurrence of a tornado in the model region are approximately 0.15 and 1.1×10^{-4}, respectively. Using the method described by Thom,[9] the mean annual frequency and probability of occurrence of tornadoes for the six regions are compared with those for the model region in Table 7.5. The relative tornado intensity, as described in the NRC Regulatory Guide 1.76,[8] is included in this table. The Western Great Plains and Texas Coastal Plains are in Category I of relative tornado intensity, whereas the Northern Rocky Mountains, Wyoming Basin, Colorado Plateau, and Southern Rocky Mountains are in Category III, as is the model region. For a typical tornado in Category I, the wind speed is 160 m/s (360 mph), of which 134 m/s (300 mph) is rotational and 26 m/s (60 mph) is translational. Generally, the mill structures are not designed to withstand tornadoes in either Category I or III.

Table 7.5. Comparison of Tornado Probabilities in Each of the Six Regions with that in the Model Region

Region	Mean Annual Frequency	Annual Probability	Tornado Intensite Category
Model Region	0.15	1.1×10^{-4}	III
Northern Rocky Mountains (Spokane, WA)	0.1	8.8×10^{-5}	III
Western Great Plains (Rapid City, SD)	0.6	4.8×10^{-4}	I
Wyoming Basin (Casper, WY)	0.4	3.2×10^{-4}	III
Southern Rocky Mountains (Denver, CO)	0.6	4.5×10^{-4}	III
Colorado Plateau (Grand Junction, CO)	None reported	---	III
Texas Coastal Plains (Beeville, TX)	1.6	1.1×10^{-3}	I

The conservative dispersion model[11] and the assumed value of 11,400 kg (25,100 lb) of yellowcake lifted by a tornado (used in Sec. 7.1.3.1 are also applied to the evaluation of population exposures in the six NURE regions. The model predicts a maximum exposure at a distance of 4 km (2.5 miles) from a mill located in any region, such that the 50-year dose commitment to the lungs of an individual is estimated to be 8.3×10^{-7} rem. The 50-year population dose commitments for people living in a 45° sector within 80 km (50 miles) of the mill in each region are given in Table 7.6.

The Western Great Plains and Texas Coastal Plains are in Category I of relative tornado intensity. It is conservatively estimated that in the event of a tornado strike at a mill in these regions, the 50-year population dose commitments would be 6.9×10^{-4} and 2.0×10^{-3} man-rem, respectively.

7.1.6.3.2 Release of Tailings Slurry

Historical tailings slurry release data were used in predicting the nominal quantities of solids and liquids released to the environment in the event of a tailings embankment failure at the model site. It is not possible from these sparse historical data to identify regional trends that influenced either the quantities released or the probabilities of release. Consequently, the quantities of tailings slurry released to the environment from pipeline breaks or from failure of the tailings embankment in each of the six regions are assumed to be roughly the same as those assumed at the model site. However, since flooding has been the initiating event for tailings releases at a number of mills, it is reasonable to assume that the probability of release is higher in those regions that have high rates of precipitation than those with relatively low rates, although it is not possible to relate the probability of release to the precipitation rate. The annual rates of rainfall and snowfall are given in Table 7.7 for each of the six regions.

Table 7.6. Comparison of Predicted 50-Year Population Dose Commitments in the Six Regions with the Model Region from a Tornado Accident

Region	Population Density,[a] people/km^2	Population in 45° Sector within 80 km	50-Year Population Dose Commitment, man-rem
Model Region	2.9	7,200	9.6×10^{-4}
Northern Rocky Mountains	2.7	6,700	8.9×10^{-4}
Western Great Plains	2.1	5,200	6.9×10^{-4}
Wyoming Basin	1.4	3,500	4.6×10^{-4}
Southern Rocky Mountains	1.3	3,200	4.3×10^{-4}
Colorado Plateau	2.5	6,200	8.3×10^{-4}
Texas Coastal Plains	6.0	15,000	2.0×10^{-4}

[a]From subregion (mill environs) data, Table 12.2 of the Supplement.

Table 7.7. Annual Rates of Rainfall and Snowfall in the Six Regions

Region	Precipitation: Average Annual, cm	Precipitation: Time of Year	Average Annual Snowfall, cm	Monthly Max. Precipitation, cm	Evaporation Potential, cm (exceeds precipitation)
Northern Rocky Mountains (Spokane, WA)	30-50	November-February, May	October-May 17-58	May 14.5	100-160
Western Great Plains (Rapid City, SD)	40-60	April-September	September June 10-42	May 18.7	100-150
Wyoming Basin (Casper, WY)	30-40	April-September	September-June 18-54	April 14.6	100-180
Colorado Plateau (Grand Junction, CO)	20-40	April-September	September-May 8-33	August 8.8	150-200
Southern Rocky Mountains (Denver, CO)	25-80	April-October	September-June 14-16	May 18.6	100-150
Texas Coastal Plains (Beeville, TX)	35-115	January-December	0.3-2.9	September 51.6	165-215

The highest monthly precipitation at the model site is 12.3 cm (4.8 inches), whereas in the NURE regions the maximum monthly precipitation varies from a low of 8.8 cm (3.5 inches) for the Colorado Plateau to a high of 51.6 cm (20.3 inches) for the Texas Coastal Plains. This value is representative of the area assumed for the model site. Although the maximum monthly precipitation for a region would be taken into consideration in the design of a tailings impoundment for a mill located in that region, flooding of the tailings impoundment possibly still could occur. The fate of tailings solution released with the tailings slurry during an embankment failure or flooding would vary from region to region, depending upon the location of the tailings impoundment and the flow in the rivers or stream below. The typical rivers in each region have a maximum flow that varies 9 to 60 times that of the Tributary River in the model region. Although the exact location of the uranium mills in each region is not specified, it is assumed that they are located in the central subregions designated in the Supplement to this document and at a considerable distance from the typical river. During the months of April through September in the Northern Rocky Mountains, Wyoming Basin, Western Great Plains, Colorado Plateau, and Southern Rocky Mountains regions, and throughout the year in the Texas Coastal Plains, the monthly rainfall and snowmelt make it possible for flooding to occur. In the event of flooding of the impoundment and breaching of the embankment during these months, the tailings solution would most likely flow to the major river, where it is expected that the high flow rates would dilute the approximately 5.5×10^7 L (1.4×10^7 gallons) of tailings solutions by several orders of magnitude, depending on the flow rate at the time of flooding. For mills located in the Northern Rocky Mountains, Wyoming Basin, Western Great Plains, Colorado Plateau, and Southern Rocky Mountains region, it is likely that the streams would be dry most of the period November through March. Thus, during these months of the year, it is expected that the tailings solutions released in the event of a tailings embankment failure would tend to move downward through the soil profile and the environmental impact would be similar to that described in Section 7.1.3 for the model site.

In each of the six regions there are most likely to be local problems that reflect the presence of municipal water treatment centers, irrigation uses, or areas of industrial concentrations that need to be evaluated on a case-by-case basis. Furthermore, for the Northern Rocky Mountains, Colorado Plateau, and the Southern Rocky Mountains regions, the radioactive material could be carried by the river to a reservoir where it would be further diluted. Of the isotopes in the tailings slurry, Th-230 would be of primary concern and should be monitored prior to use of the receiving water as a municipal water supply or irrigation water source. It is expected that the NRC or the Agreement State would be notified should a release of tailings slurry occur, and the assessment of the consequences of the accident would be made by the state's radiological emergency assistance team. If a state were unable to respond, the NRC could be requested to provide assistance.

Most of the regions where uranium is milled are in areas of low or moderate seismic risk. When the tailings disposal area is designed, the geologic and seismologic investigations needed would be determined on a site-specific basis in accordance with the provisions of revised Regulatory Guide 3.11.[15] The dynamic stability analysis to be carried out is stipulated in that Guide, which requires that the embankment be designed to withstand an earthquake of greater magnitude than would reasonably be expected to occur in that area.

7.1.6.4 Accidents Not Involving Radioactivity

As discussed in Section 7.1.4, ammonia is the only chemical which might seriously impact the environment in the event of an accident. The consequences of an ammonia release in any of the six regions would not be expected to be significantly different than those for the model site, since the short-term dispersion factors are comparable (see Sec. 7.2.3). Moreover, no factors can be identified that would lead to an increase in the probability of such a release.

7.1.6.5 Transportation Accidents

Transportation of materials to and from mills within each region involves shipment of refined yellowcake to the uranium hexafluoride facility, shipments of ore from the mine pit to the mill, and shipments of process chemicals from suppliers to the mill.

7.1.6.5.1 Shipments of Yellowcake

For the uranium mills in each region, it is assumed that the yellowcake will be packaged and shipped by truck in the same quantities as for the model mill discussed in Section 7.1.5. The probabilities of an accident occurring during shipment of yellowcake to the UF_6 facility from mills located in each of the six regions are given in Table 7.8. The values indicate that for each region the probability of a transportation accident during yellowcake shipments is comparable to that for shipments from the model mill, and varies with the distance of the mill from the UF_6 facility. In the event that the postulated accident occurs on the highway in an area of low population density or on a highway bridge, the consequences most likely would be the same as those estimated in Section 7.1.5 for the model region. It is possible, however, for such an accident to occur in or close to a city along the route to the UF_6 facility. If the accident were to occur in the largest city on the truck route from the regions in the West to the locations of the two existing UF_6 facilities, and for the worst case (Model I) release fraction, a 50-year population dose commitment of 840 man-rem is computed.

Table 7.8. Accident Probabilities for Shipments of Yellowcake

Region	Distance to Conversion Facility		Probability of Accident	
	Metropolis, IL	Gore, OK	Metropolis, IL	Gore, OK
Model Region	2400 km	1400 km	0.11	0.06
Northern Rocky Mountains	3240 km	2920 km	0.14	0.13
Western Great Plains	1860 km	1600 km	0.08	0.07
Wyoming Basin	2000 km	1630 km	0.09	0.07
Southern Rocky Mountains	1680 km	1180 km	0.07	0.05
Colorado Plateau	2050 km	1575 km	0.09	0.07
Texas Coastal Plains	1420 km	760 km	0.06	0.03

7.1.6.5.2 Shipment of Ore to the Mill

For the model region, it was assumed that the average distance from the uranium mine pit to the mill is about 50 km (32 miles) and that about 29,000 trips per year would be required. In the absence of specific data on the location of the uranium mines and mills in the six NURE regions, it is assumed that the transportation distance is about the same as that for the model mill. Thus, the probability of an ore shipment accident is assumed to be roughly the same as that described for the model site, also, there are no specific environmental factors that could be identified in any of the six regions that would change the estimated consequences discussed in Section 7.1.5.

7.1.6.5.3 Shipments of Chemicals to the Mill

As discussed in Section 7.1.5, if a shipment of anhydrous ammonia to the mill were involved in a severe accident, a significant environmental impact could result. The typical shipping distance to the mills located in each of the six NURE regions is comparable to that assumed for the model site [approximately 400 km (250 miles)]. Therefore, the probability of an ammonia shipment accident in the six NURE regions is not expected to be significantly different than that for the model regions. Moreover, since the short-term dispersion factors in the six NURE regions are comparable to that at the model region (see Sec. 7.3.2), the consequences of an ammonia shipment accident should be similar for all regions and comparable to that in the model region.

7.2 MULTIPLE-MILL SITE

7.2.1 Trivial Accidents Involving Radioactivity

None of the trivial accidents discussed in Section 7.1.1 in connection with the one-mill site are expected to result in the release of radioactivity to the environment. Although more of these incidents might be expected to occur if there were 12 mills, there are no circumstances which can be foreseen that would result in an environmental impact.

7.2.2 Small Releases Involving Radioactivity

The probability of an accident involving small releases of radioactivity from one mill is independent of the likelihood of an accident at any other mill within the region, since the mills would be well separated and the initiating events for the accidents postulated in this category are independent. Therefore, the probability of any of these accidents occurring at the 12-mill site is 12 times larger than the probability of occurrence at a site containing a single mill. The consequences from these small releases are described in the following sections.

7.2.2.1 Failure in the Air Cleaning System Serving the Yellowcake Drying Area

The estimated quantity of yellowcake released to the atmosphere in the event of a catastrophic failure of the scrubber is the same for any one of the 12 model mills on the site. However, the 50-year dose commitment to the lungs of individuals in the nearest residence [2 km to 20 km (1.3 miles to 13 miles)] would range from .09 rem to 0.003 rem, depending upon which mill experienced the failure. The dose commitment to individuals at the fence line and the population dose commitment would be the same as for the one-mill site, regardless of which mill experienced the failure.

7.2.2.2 Fire or Explosion in the Solvent Extraction Circuit

The estimated quantity of uranium released to the atmosphere in the event of a fire or explosion in the solvent extraction circuit is the same for any of the 12 mills on the site. The dose commitment to an individual at the fence line and the population dose commitment would be the same as for the one mill, regardless of which mill experienced the failure. However, the 50-year dose commitment for an individual at the nearest residence [2 to 20 km (1.3 to 13 miles)] would range from 0.15 rem to 0.006 rem to the bone.

7.2.2.3 Gas Explosion in the Yellowcake Drying Operation

The estimated quantity of yellowcake released to the atmosphere in the event of a gas explosion in the yellowcake drying operation is the same for any of the 12 model mills on the site. The dose commitment to an individual and the population dose commitment would be the same as for the single model mill, regardless of which mill experienced the failure. However, the 50-year lung dose commitment for an individual at the nearest residence [2 to 20 km (1.3 to 13 miles)] would range from 6.9×10^{-3} to 2.8×10^{-4} rem.

7.2.3 Large Releases Involving Radioactivity

7.2.3.1 Tornado

It is conceivable that a tornado could pass through the model region and damage from one to five of the 12 operating mills, depending upon the direction of its passage through the region. Sufficient data are not available to estimate the probability of a tornado impacting five mills during a single pass through the region; however, such an event is considered to have a very low probability. Even if this unlikely common mode event were to occur, and the tornado were to lift the same quantity of yellowcake from each mill, the population dose to the lungs of the general population out to a distance of 80 km (50 miles) is estimated to be only 4.8×10^{-3} man-rem.

7.2.3.2 Releases of Tailings Slurry

It is conceivable that a common initiating event, such as a severe flood or a high intensity earthquake, could breach or overtop each of the 12 tailings ponds in the model region, releasing all of the solution contained in the ponds. The quantity of tailings slurry released from each of the 12 mills is assumed to be the same as that postulated for the single model mill, as considered in Section 7.1.3. Although difficult to evaluate quantitatively, the probability of an event occurring of sufficient magnitude to release tailings solution from all 12 ponds is significantly lower than the probability of a single pond release estimated in the previous section.

Middle Reservoir, having a capacity of 1.8×10^7 m^3 (4.7×10^9 gallons) and located about 50 km (32 miles) downstream from the mills, would be the most likely destination of any tailings solution which does not seep into the ground from uranium mills 1-6 and 10-12. West Reservoir, having a capacity of 1.0×10^7 m^3 (2.6×10^9 gallons) and located about 60 km (38 miles) downstream from the mills, would be the most likely destination of any tailings solution from uranium mills 7, 8 and 9. Under the 100-year flood condition, the flow in Tributary River could reach 100 m^3/s (3500 ft^3/s).

Based on these values, the dilution factors for Middle Reservoir and West Reservoir are 0.017 and 0.018, respectively. The isotopes released would result in a 50-year dose commitment of 0.1 mrem to the maximally exposed individual drinking from the reservoirs in West City. This 50-year dose commitment is not significantly greater than that from drinking water with only background radioactivity present.

7.2.4 Accidents Not Involving Radioactivity

The probability of an accident involving the steam boiler, ventilation system, or tanks of toxic chemicals at the one mill site is independent of the likelihood of an accident at any other mill within the region. The mills are well separated and the initiating events are independent. The potential for environmental effects at the 12-mill site is expected to be small. The consequences described in Section 7.1.4 for a release of anhydrous ammonia would be the same for each mill in the 12-mill site.

7.2.5 Transportation Accidents

Transportation of materials to and from a one-mill site have been conceptualized and analyzed in Section 7.1.5. A postulated transportation accident at one mill is not related to an accident at any other mill within the region, since the mills are well separated and the initiating events are independent.

7.2.5.1 Shipments of Yellowcake

The likelihood of an accident at the one-mill site is 0.11 per year, or 1.3 per year for 12 mills. The consequences are the same as those described in Section 7.1.5.

7.2.5.2 Shipment of Ore to the Mill

The likelihood of an accident at the one-mill site is 0.4 per year, or 5 per year for 12 mills. A collision between two ore trucks on the site can be postulated because of the large number of shipments (approximately 350,000 annually). The consequences of such an event would be twice that of a single truck accident, or approximately 0.05 man-rem to the lungs of the population in the vicinity of the model mill.

7.2.5.3 Shipments of Chemicals to the Mill

The likelihood of an injury to the general public from the shipment of anhydrous ammonia to the one-mill site is estimated to be roughly 5×10^{-3} per year. Consequently, the estimated likelihood is increased to approximately 6×10^{-2} per year for the 12-mill site.

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8. ALTERNATIVES FOR MITIGATING IMPACTS OF MILLING OPERATIONS

8.1 INTRODUCTION

Alternative techniques considered by the staff to be capable of mitigating the impacts of uranium milling (Ch. 6) are described in this chapter. Three categories of alternatives are considered:

a. Those which could control emissions during milling operations,

b. Those encompassing tailings disposal programs,

c. Those involving decommissioning of the mill facilities, excluding the tailings disposal area.

The degree to which alternatives described here could mitigate impacts is discussed in Chapter 9, and associated costs are presented in Chapter 11.

The purpose of evaluating means of controlling emissions during milling operations is not to set standards for offsite radiation exposures, but to illustrate methods that can be employed to comply with existing standards. Some radioactive emissions during operations are limited by standards recently developed by the U.S. Environmental Protection Agency (40 CFR 190). Under these standards, dose commitments to offsite individuals cannot exceed 25 mrem per year (doses to whole body or single organ, excluding doses from radon and its daughter products).

The situation differs, however, with regard to radioactive emissions after operations cease, because no formal regulations exist for disposal of mill tailings. Interim performance objectives (discussed in Chapter 13) were issued in 1977 to guide these disposal activities. Alternative tailings disposal programs described in this chapter are evaluated later to support the establishment of formal regulations covering tailings management and disposal.

The decommissioning alternatives presented in this chapter are evaluated to support establishing requirements concerning the general mode of mill-site decommissioning. It is not the purpose of the evaluation to support establishment of specific numerical limits on levels of residual contamination. Interim guidance on such levels has been issued (Appendix J), and the staff is currently conducting more detailed studies aimed at establishing formal guidance.[1]

All of the alternatives selected for evaluation focus on control of emissions. Extension of mill site boundaries and exclusion of receptors are considered not to be primary methods of dose reduction and thus are not identified explicitly as alternatives in this chapter. Some of the alternatives described in this chapter are not evaluated in detail (not treated in later chapters) and are discussed only to the extent needed to establish the basis for their discard.

8.2 ALTERNATIVES FOR EMISSION CONTROL DURING OPERATION

A number of gaseous, liquid, and particulate emissions (both radioactive and nonradioactive) may occur during uranium milling. The milling process can be subdivided into various activities to identify origins of mill effluents. The following is a list of mill activities that are potential problem areas, the possible emissions, and the control systems available to limit those emissions:

Milling Activity or Area	Possible Emissions	Potential Controls*
Ore stockpile	Particulates, stockpile leachate, and runoff	1,2,4,6
Ore crushing and grinding	Particulates, radon	3,7,8a-c,9,10,11,12
Yellowcake drying and packaging	Product particles, NH_3 gas	8c,11,16
Tailings disposal area	Particulates, radon	13,14,15
Roads	Particulates	5

*Numbers are keyed to the listing of alternatives in Section 8.2.1

8.2.1 Alternatives

1. Windbreaks Around Ore Unloading Area

Windbreaks can be constructed around the ore unloading area to reduce drying of the ore by wind and the resulting dust problems.[2] Such windbreaks may be concrete or wooden fences around ore stockpiles. Because of its natural moisture content, ore normally is trucked to the mill as it is needed, unloaded, and fed to the grizzly, all with relatively little emission of dust. If the mine is some distance from the mill, or if ore blending is necessary, the ore will have to be stockpiled to maintain a steady supply, and winds blowing across such stockpiles could cause dusting problems because of drying of the ore. In such cases, the use of windbreaks can be helpful in suppressing dust.

2. General Mill Drainage System

Leachate and surface runoff resulting from precipitation falling on ore stockpiles can be collected in a general mill drainage system and the collected water eventually used for mill process water or disposed of in the tailings pond. Such drainage features as ditches and small canals would be within and around the ore storage area and would also facilitate the movement of vehicles in and around the area during wet (and cold) weather.

3. Hooded Conveyor Belts

Hooded conveyor belts can be used to transport the ore from the grizzly, and, after crushing and screening, to the fine-ore bin. This system of conveyance, coupled with wetting the ore, will help control fugitive dusts by providing an enclosure around the ore as it is being conveyed. Wet semi-autogenous grinding of the ore will eliminate fugitive dusts between ore pad and leaching tank.

4. Sprinkling or Wetting of Ore Stockpile

In general, ores having a moisture content of about 4% or more do not cause dust problems; however, for particularly dry ores, an alternative method of reducing fugitive dust would be periodic sprinkling of the stockpiles. This practice would require, as an example, the use of a tank truck equipped with pumps and hoses with spray nozzles. With effective programs, water sprays are estimated to achieve a 50% reduction in dusting rates. The addition of chemical wetting agents can increase optimum control efficiency to about 90%[3] but more careful mixing, application, and management are required. Therefore, the efficiency of chemical wetting agent application is taken to be 80%, somewhat less than optimum.

5. Sprinkling or Wetting of Roads

To suppress dusting caused by traffic, primarily ore-hauling equipment, roads can be sprinkled to keep them wet. Tank trucks equipped with pumps and hoses can be utilized for this purpose. Chemical wetting agents are useful additives, and the effectiveness of the treatment is expected to be comparable to the results obtained in controlling dusting from the ore stockpile.

6. Ore Warehouse

Storage of ores in a large warehouse would prevent escape of fugitive dust to the atmosphere. However, a substantial expenditure would be involved [approximately \$235/m^2 (\$22/ft^2) plus foundation cost, 1980 dollars[4]].

7. Wet ("semi-autogenous") Grinding

The assumption that the model mill utilizes dry grinding of the ore has been made for the base case so that the effect of this practice on ambient air quality might be assessed.

Use of a wet, "semi-autogenous" grinding mill can eliminate dry ore-crushing operations and the associated dusting which occurs. The semi-autogenous grinder can perform the ore sizing that is done by primary and secondary crushing, as well as final grinding, as shown in Figure 8.1. The amount of dry ore handling which can contribute to dusting (for example, where ore drops between conveyors) is significantly reduced, if not eliminated. Ore also can be handled wet, whereas this may cause problems in dry crushing operations.

The semi-autogenous grinding mill is a rotating steel cylinder lined with heavy steel wear plates and lifters. Hot water is mixed with the ore to produce a thick slurry, [internal temperature approximately 50°C (125°F)]; the tumbling action of the lifters, large pieces of ore, and small charge of 8- to 10-cm (3- to 4-inch) steel balls scrub the sand grains free from the clay and carbonaceous cementing agents.

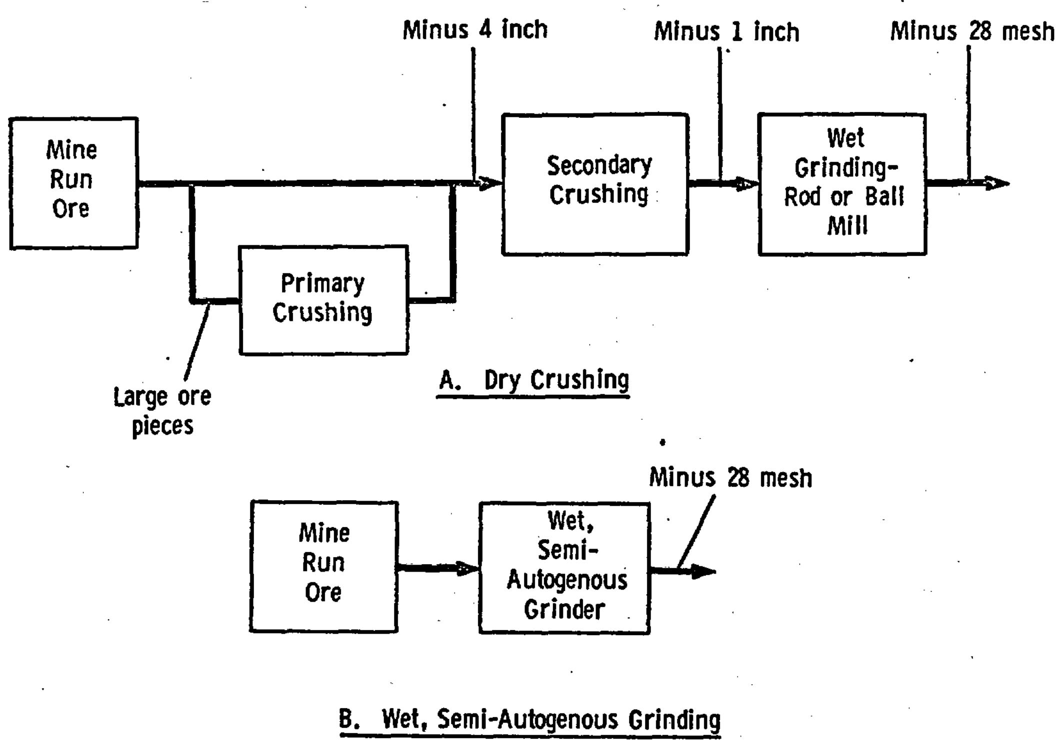

Fig. 8.1. Comparison of (A) Dry Crushing and (B) Wet, Semi-Autogenous Grinding Procedures

8. Wet Scrubbers

Wet scrubbers generally remove particles by impacting them with scrubbing liquid (water) droplets. Wet scrubbers currently in use may involve three mechanisms for ensuring contact between particles and scrubbing liquid. These are inertial impaction, interception, and diffusion.[4] Particles larger than about 1 μm in diameter (the diameter of the collector droplet) are contacted principally through inertial impaction, whereas particles of 1 μm or less diameter are contacted by interception. Diffusion of the particulate into the liquid droplet governs the contacting of particles smaller than about 0.1 μm. These wet scrubbers recover the particulates as a slurry, which is recycled to the process either as a waste stream or for retreatment (leaching). Soluble gases, such as ammonia and sulfur oxides, can also be removed through reaction with the scrubbing liquid.

Before scrubbing can occur, the carrying gas first must be collected by enclosing the operation involved and then be conveyed by ductwork into the scrubbed enclosure. This system requires special blowers to create a reduced pressure around the operation generating the particulates. Because this collection system is separate from the milling operation, and sometimes expensive, its applicability is limited to recovery of expensive or highly toxic materials. It might be applicable to the U_3O_8 drying and packaging operations, but not to the precipitation tanks, where ammonia fumes are generated.

Three types of wet scrubbers are currently in use in the uranium milling industry:[2]

a. Orifice or Baffle Scrubber.[6] Orifice-type scrubbers are devices in which the velocity of the air from the collection system is used to provide liquid contact. The flow of air through a restricted, usually curved, passage partially filled with water causes the dispersion of the water. In turn, centrifugal forces, impingement, and turbulence cause wetting of the particles by the liquid. Orifice scrubbers have a reported removal efficiency of 93.6% and are widely used in the uranium milling industry.

b. Wet Impingement Scrubber.[2] The collected dust-laden air stream first passes through preconditioning sprays, where it entrains water droplets, and then proceeds through perforated plates to impinge on baffle plates. Water is atomized on the perforated plate because of the relatively high air velocity. Particles are collected on vaned mist eliminators and are withdrawn along with the solids collected in the liquid overflow from the impingement plate. A collection efficiency of 97.9% has been reported, and was assumed in estimating the yellowcake emission rate in the base case. For the ore crushing and grinding operation a reduced scrubber efficiency of 97% was assumed in the base case.

c. Venturi Scrubber.[6] In the Venturi scrubber, the gas stream passes through a Venturi tube in which water is added at the throat at low-pressure. Gas velocities at the throat are from 75 to 100 m/s (15,000 to 20,000 fpm), and pressure drops are from 25 to 75 centimeters (10 to 30 inches) of water. In spite of the relatively short contact time, the extreme turbulence in the Venturi promotes very close contact, and the principal removal mechanism is believed to be impaction. The wetted particles and droplets are collected in a cyclone spray separator. Very high collection efficiencies, ranging from 99.5 to 99.9%, have been reported.

9. Bag or Fabric Filters[5]

Bag or fabric filters, usually in the form of baghouses, remove particles by filtering the gas through a porous flexible fabric made of a woven or felted material. The mechanisms of particulate collection with fabric filters--impaction, interception, and diffusion--are similar to those in scrubber operations. The nature and extent of the collecting surface in a fabric filter, however, change with the buildup of the layer of collected particles from one cleaning to the next. The accumulation of particles on the fabric causes a larger resistance to gas flow and a greater pressure drop. The differences in the cleaning methods distinguish the various types of baghouses, e.g., shaker type, reverse flow, reverse jet, and reverse pulse.[7] Typical baghouse collection efficiencies are greater than 99.9% for gas pressure drops of 5 to 10 cm (2 to 4 inches) of water; however, in evaluating alternative emission controls an average efficiency of 98% has been assumed in order to account for off-normal performance and occasional failures of the filter material. Bag filters are used at a few mills for the control of dust from ore handling and/or to collect particles from the packaging air stream.[2]

10. Dust Control Spray System

A dust control spray system can be installed at points of potential dust emission, such as where ore is withdrawn from hoppers in which considerable turbulence is created by falling ore. It is used when the handling of particularly dry ores creates abnormal dusting problems. Water or appropriate chemical agents under normal transmission pressure (e.g., 3×10^5 Pa, or 40 psig) are sprayed through nozzles. This method is usually employed throughout milling operations when spillage or leaks occur. It is immediately effective and useful until repairs are made or spills are cleaned up.

11. High Efficiency Particulate Air (HEPA) Filters[8,9]

HEPA filters are expendable (single use), extended-medium, dry filters constructed of pleated mats of woven fiber glass having (1) a minimum particle removal efficiency of no less than 99.97% for 0.3-μm particles; (2) a resistance of 2.5 cm (1 inch) H_2O when clean, and up to 15 to 25 cm (6 to 10 inches) of H_2O when in service and operated at the rated airflow capacity; and (3) a rigid casing extending the full depth of the medium. A modular HEPA filter has a cross section of 60 cm × 60 cm (2 ft by 2 ft), a depth of 30 cm (1 ft), and a capacity of about 0.5 m^3/s (1000 cfm). The modules are mounted in banks to achieve the required capacity for filtering air. To prevent clogging of the HEPA filters, roughing filters are usually installed upstream to remove large particles.

A high efficiency for the filters can be ensured by constructing a tight installation so that all of the gas to be treated passes through the filters. HEPA filters have been used for many years for the removal of radioactive particulates from air streams.

As in the case of scrubbers (see item 8), the effectiveness of the HEPA filter depends entirely upon the effectiveness of the collection system, which must begin at the operation being controlled. HEPA filters are expensive and not reusable, once plugged with the material being collected. They are suitable only as a final filter and justified only when the collected material is highly toxic and collectible. Disposal of the HEPA filter must be as a discrete unit; it usually cannot be incinerated to recover entrapped materials, thus resulting in the loss of valuable yellowcake.

12. Charcoal Adsorber Delay Trap[2]

The trap system is used in a dynamic adsorption process, where a gaseous species such as radon in a flowing carrier gas stream, is physically adsorbed on the surface of a solid adsorbent such as charcoal. Although the adsorbed material is not bound permanently to the adsorbent, its exit from the adsorption bed is delayed with respect to the carrier gas. Thus, a gas such as radon, with a half-life of 3.82 days, disappears by radioactive decay while it is retained on the charcoal bed. Theoretically, a five-stage charcoal bed containing 1.5×10^6 kg (3×10^6 lb) of charcoal should remove 99% of the radon from a 2.5 m^3/s (5000 cfm) air stream.[2] A filter is needed upstream of the charcoal bed to prevent plugging, and a HEPA filter is needed downstream because Rn-220 daughters, commonly attached to very small dust particles, are not quantitively retained in the bed.

For the control to be truly effective for a uranium mill, all controlled operations would require either hoods or air-tight rooms to ensure collection of the radon. Such systems are expensive (they could double or triple the cost per unit area of working space) and would not be justified in meeting present standards or for uranium ores now being milled. Furthermore, the capital and operating costs of the unit itself are quite high (~ \$3.5 million and \$60,000/year, respectively).[2]

13. Chemical Stabilization of Dried Tailings Areas

Resinous adhesives; lignosulfonates; elastomeric polymers; milk of lime; mixtures of wax, tar, and pitch; potassium and sodium silicates; and neoprene emulsions have been used to form crusts on mill tailings surfaces and thus reduce their susceptibility to wind erosion.[10,11] In Bureau of Mines testing of calcium lignosulfonate and an elastomeric polymer on uranium tailings it was found that considerable breakage of the crusts occurred from physical causes, such as human traffic, and therefore yearly maintenance was required.[11]

"Cut-back" asphalt and asphalt-in-water emulsions also have been tested for use in protecting soils against wind erosion.[12] Both were shown to be effective for periods up to two months when applied as a fine spray on sand soils. On clay soils, the film disintegrated within two weeks, apparently because of expansion and contraction of the clays during cycles of wetting and drying. The film was porous, allowed infiltration of water, and did not interfere with germination of wheat, grass, or legume seeds. The film is injured by insects and rodents, and respraying may be necessary. Three to five years after application of the asphalt treatment, the percentage of dry erodible fractions in the tested soils had increased, suggesting that asphalt treatments may not be desirable under all conditions; however, as a temporary film on sandy tailings that would eventually be covered by a few meters of earth, asphalt treatments may be one alternative for protecting against wind erosion, while allowing infiltration of rain and continued evaporation.

The effectiveness of chemical stabilization in controlling fugitive dust from tailings piles is reported to be 80%.[3] This value is assumed for the purpose of comparing alternative control methods in the sections which follow. Chemical stabilizers applied to dry tailings are assumed to have no effect on radon exhalation.

14. Wetting of Dried Tailings Surfaces

Keeping tailings surfaces wet with tailings solution or sprinkling them with water can suppress dusting. This can be accomplished, for example, by arranging the discharge of tailings slurry to occur from multiple, as opposed to a single-point, discharge so that a wide area of the tailings surface remains wetted. Alternatively, sprinkling systems or tank trucks could be employed to spray dried areas. Because surfaces of the tailings impoundment can dry out rapidly, particularly in dry and/or windy climates, this method of dust suppression will require continuous management attention. It is assumed to be 50% effective in reducing dust emission, and 20% effective in reducing radon emission.

15. Progressive Reclamation of Tailings Area

Several recent tailings impoundment designs have incorporated progressive reclamation schemes into overall tailings management programs.[13-15] These schemes involve the segmentation of a large tailings area into a number of smaller cells, with sequential construction, filling, and reclamation. Such schemes substantially reduce the available surface area of exposed tailings for dust and radon emission. Assuming a six-cell impoundment with each cell being operated (filled) for 2.5 years and reclaimed during the following 2.5 years, the average available dusting area would be only about one third of the 50 ha (125 acres) in the base case model mill. This estimate includes 75% of the area of an operating cell and 50% of the area of a cell being reclaimed. Progressive reclamation is therefore estimated to reduce base case tailings area dust and radon emissions by 67%. An additional benefit would derive from being able to perform final reclamation in 2.5 years, due to the smaller areas involved, as opposed to the 5-year drying period estimated for the model mill.

16. Wet Shipment of Yellowcake

Instead of drying U_3O_8 before shipment, yellowcake could be shipped from the mill as a wet cake or slurry. In a recent development, one UF_6 conversion plant will accept a slurry of U_3O_8 as an input to the conversion operation. Where used, this would obviate the need for scrubbers and/or baghouses at the U_3O_8 drying and packaging mill operations by elimination of the drying operation. Occupational exposure also could be reduced considerably. On the other hand, there is currently limited capacity at conversion plants to accept such shipments (only one of the two existing UF_6 conversion plants is capable of processing yellowcake shipped to it in a wet state), a charge is levied by the conversion plant operator for receipt of this kind of shipment, and transportation costs would increase. Other aspects of this development are discussed in Chapters 9 and 10.

8.2.2 Summary

Several available alternatives suitable for the control of emissions from various units of the mill process circuit, as well as from the tailings disposal area, have been described briefly. Many of these systems attain the same end. For this reason and because the purpose of this evaluation is to illustrate how an established standard (40 CFR 190) can be met, as opposed to developing a new one, the staff has chosen only representative controls to illustrate in subsequent chapters the effect of reducing emissions.

Ore Storage. Of the possible methods of controlling emissions from ore stockpiles, the use of windbreaks and sprinkling (including the addition of wetting agents) will be considered in the following chapters. Windbreaks are much less costly than warehouses and are chosen for this reason. Sprinkling is used to reduce particulate entry into the airborne pathway. Particulate emission is decreased further by use of a chemical wetting agent to reduce evaporation of moisture from the ore.

Ore Crushing and Grinding. The effect of utilizing a bag filter in combination with dry grinding or substituting wet, semi-autogenous grinding for dry crushing operations will be evaluated. A hooded conveyor belt is assumed to be used in conjunction with dry crushing operations.

Yellowcake Drying and Packaging. The assumed filtering efficiency for yellowcake particles in the base case is 98%. Of the filtering devices considered here, only two, the Venturi scrubber and HEPA filter, are capable of raising this efficiency. The Venturi scrubber has been chosen as the representative control because the mill product, yellowcake, can be recovered from solution; it is virtually impossible to recover yellowcake particles from the HEPA filter. Also evaluated are the effects of shipping wet yellowcake, where drying operations are eliminated.

Tailings Disposal Area. As means by which emissions (both particulate and radon) from the tailings area may be reduced, the staff has selected coverage by water (30 of the 80 ha of tailings in the base case, supplemented by spraying of water or appropriate chemicals to stabilize dry beach area (50 ha in the base case). Another alternative is a progressive reclamation program which reduces the exposed dry beach area to substantially less than the 50 ha which is assumed to exist in the base case. For example, six individual pits or cells rather than a single 80 ha impoundment could be dug, filled, and covered sequentially, so that only one-sixth of the area, i.e., 13 ha, would be dry and a source of radon and particulates at any time. This type of program is described more fully in Section 8.4.

The alternative, representative controls and associated control levels (expressed as a percentage of an uncontrolled source) considered in the evaluation of later chapters are summarized in Table 8.1.

Table 8.1. *Alternatives Considered for Control of Emissions during Operations*

Ore Storage

- No control (base case)
- Windbreak (20%)
- Water spraying (50%)
- Chemical wetting agents (90%)

Ore Crushing and Grinding

- Wet impingement scrubber (base case) (97%)
- Bag filters (98%)
- Wet, semi-autogenous grinding (100%)

Yellowcake Drying and Packaging

- Wet impingement scrubber (base case) (98%)
- Venturi scrubber and demister (99.8%)
- Wet shipment of slurry product (100%)

Tailings Disposal Area

- 80 ha of tailings, 30 ha maintained wet (base case) 38%
- Sprinkling of beach area (70%)
- Chemical stabilization (90%)
- Progressive reclamation (85%)

8.3 ELEMENTS OF MILL TAILINGS DISPOSAL PROGRAMS

A satisfactory tailings disposal program should attain the following objectives:

(a) Reduce or eliminate airborne radioactive emissions (radon emissions are the primary concern because of the ease of dispersion of this inert gas);

(b) Reduce or eliminate impacts on groundwater; and

(c) Ensure long-term stability and isolation of the tailings without the need for continued active maintenance.

Numerous strategies for attaining these objectives have been suggested. For purposes of discussion, elements of these proposed strategies may be classified into four categories:

(a) Preparation of tailings for disposal; (some methods involve changes in mill operations);

(b) Location of the tailings disposal area;

(c) Preparation of the tailings disposal area; and

(d) Stabilization and covering of the tailings.

A list of alternatives broken down into these categories is presented in Table 8.2. None of these alternative methods in themselves represents a complete tailings disposal program; that is, each offers potential for solving one or several, but not all, of the problems identified above. They must, therefore, be combined to form a complete tailings disposal program, and it is obvious that numerous combinations exist. It would be extremely difficult to evaluate the full range of combinations; hence, a limited number of tailings disposal programs selected to incorporate the principal alternatives are described in Section 8.4. These programs are evaluated in later chapters.

As is noted in Section 8.4, the nine alternatives described were developed as examples of complete individual tailings management systems for comparison purposes and not as examples of optimum combinations of features. The nine alternatives might be used in combination and/or modified to include sequential or staged development, as is described conceptually in Alternative 5 of Section 8.4.

Satisfactory solutions to tailings waste disposal problems are highly dependent upon site-specific factors, such as climate, topography, and geology. The specific combination of elements producing an optimal tailings disposal program must be developed on a case-by-case basis, taking into account site-specific features. The general analysis of alternative tailings disposal programs presented herein is primarily an illustrative exercise intended to support the establishment of various requirements to be included in regulations governing the development of site-specific programs.

In Sections 8.3.1 through 8.3.4, specific alternatives listed in Table 8.2 are described; comprehensive tailings disposal programs incorporating features of these alternatives are then described in Section 8.4.

8.3.1 Process Alternatives

8.3.1.1 Nitric Acid Leaching

Both sulfuric acid and sodium carbonate extract uranium from sandstone-derived uranium ores but uranium-234 progeny in the tailings contain 85% of the radioactivity originally present. Of the commercially available reagents, only nitric acid will dissolve radium and thorium as well as uranium. The resulting nitrate solution can then be treated to separate uranium from the other nuclides. The concentrated liquid radioactive waste resulting from this separation is then converted to a form suitable for permanent storage. Laboratory tests have shown that nitric acid can leach more than 90% of the thorium-230 and radium-226, and about 93% of the uranium originally present in the ore.[16]

As a modification of the above process, tailings from the sulfuric acid process may be leached with nitric acid and salt solutions, but this alternative is considered to be less attractive than direct nitric acid leaching of the ore to remove all radionuclides in one step.[17]

Table 8.2. Alternative Tailings Treatment and Disposal Methods

<u>Tailings Preparation</u>

. Nitric acid leaching of ore to produce innocuous tailings
. Segregation of slimes from sands for separate treatment
. Neutralization
. Barium chloride treatment
. Removal of toxicants by ion-exchange
. Removal of water by solar evaporation, in situ dewatering, thermal evaporation or filtration.
. Fixation of tailings in asphalt or cement

<u>Disposal Location</u>

. Above grade
. Below grade, near surface
. Far below surface

<u>Tailings Area Preparation</u>

. None
. Soil compaction
. Clay liner
. Synthetic liner

<u>Tailings Stabilization and Covering</u>

. None
. Soil cover
. Vegetation
. Gravel, crushed rock, and riprap
. Artificial covers and sealants
. Combinations of above

In the nitric acid process, ground ore is leached with 3-molar HNO_3 at 85°C (185°F) in a series of tanks.[2] The leached ore is then thoroughly washed in a series of thickeners so that losses of soluble radionuclides with the discarded sands and slimes represent only a small fraction of that present in the leach solution. Thus, the levels of dissolved radionuclides in the tailings liquid (slurry) are quite low. The pregnant solution is concentrated in an evaporator and the uranium is recovered by conventional solvent extraction. Nitric acid is recovered from the evaporator vapor and recycled to the process circuit. Radioactive metal nitrates in the waste raffinate are converted to oxides in a calciner; in the oxide form they are amenable to various disposal techniques (e.g., being fixed in asphalt prior to burial). The oxides of nitrogen from the calciner are recycled as nitric acid.

The effluents from the nitric acid leach mill would be similar to those from the model mill. The characteristics and quantities of particulates and radon emitted from ore storage, washing, and grinding would be identical in the two cases, since these are independent of the leaching agent employed. Effluents from the leaching, thickening, and precipitation circuits would be similar, with nitrogen oxides replacing sulfur oxides. Effluents from yellowcake drying and packaging operations would differ only in that the radium content of yellowcake produced in the nitric acid leach mill would be incrementally higher than that of yellowcake produced in the sulfuric acid leach mill. General characteristics (physical and chemical) of airborne effluents from tailings produced in the nitric acid leach mill would be similar to those of airborne effluents from ordinary tailings, but the radionuclide content of the effluents would be reduced by a factor of about ten. Any seepage liquid would contain nitrate ions in the place of sulfate ions.

Use of nitric acid instead of sulfuric acid would increase the cost of leaching. Even if the nitric acid were recirculated so that three-fourths were recovered, the total lifetime cost still would be almost double that of sulfuric acid. The equipment for regenerating nitric acid is also quite expensive; furthermore, all of the mill equipment in contact with leach solution would have to be constructed of materials capable of withstanding the effects of nitric acid. Such materials are expensive, and the staff estimates that the major portion of the mill equipment would cost several times that for a sulfuric acid leach mill. Comparative capital equipment and reagent costs for 1800 MT/d (2000 ST/d) sulfuric and nitric acid plants are listed in Appendix K (Table K-2.1.).

Laboratory tests for leaching with nitric acid showed that at best 98% of the nuclides could be leached from typical U.S. ores with hot 3-molar nitric acid. The concentration of radium then remaining in the tailings was at least an order of magnitude greater than that considered typical of soils in the western U.S. mining districts and ranged from 17 pCi/g to 60 pCi/g.[16] Tailings from this process would still require some special disposal treatment.

The staff has reviewed all of the most recently available, published studies of uranium ore leaching with nonconventional leachates, both in the U.S. and abroad. Appendix B, Section 3.3, contains a brief summary of the results of those studies.

8.3.1.2 Separation of Fines (slimes) from Coarse (sands) Fractions of Tailings for Separate Treatment[2]

In ores now being mined and milled in the United States, the slimes (less than 200 mesh) comprise 20% to 30% of the feed to the leaching process and contain 40% to 60% of the desired uranium. After leaching, these slimes contain 70-90% of the radium and gamma-emitting isotopes. It is assumed that other daughter products in the decay chain concentrate in the slimes, so that slimes in the tailings are therefore considerably more hazardous (radiologically) than are sands.

Separation of sands and slimes can be accomplished readily by subjecting the effluent from counter current decantation to a cyclone* treatment. This is often done in operating mills to allow separate treatment of the slimes slurry for further removal of uranium. Once separated, the slimes tailings could be kept separate for treatment different from that given the sands. The separation does not completely solve the tailings problem because 10% to 30% of the radium and thorium remain in the sands, which would still require treatment and isolation.

8.3.1.3 Lime Neutralization[2]

For the process assumed for the model mill, the slurry would be acidic, with a pH of about 2. Neutralization (implying the raising of the pH to 7 or above) with lime (a calcium-containing basic mineral) not only would immobilize the sulfates, but also would precipitate radium, thorium, iron, copper, cobalt, arsenic, uranium, vanadium, and other heavy metal ions as insoluble oxides or hydroxides. Ammonia or sodium hydroxide could also be used, but lime would be more effective in removing radium and less expensive. The potential for contamination by radionuclides in seepage would be reduced by neutralization.[18]

In the process of neutralization, solid calcium sulfate would be formed, which would tend to form a scale on valves, pipes, and cover all metal surfaces, such as tank sides. The precipitated radium could also redissolve if fresh water washed over the precipitates. For the above reasons, neutralization of tailings is not common practice, but would be mandatory if tailings treatment involved processes which would not tolerate the acid present, as in the case of fixing tailings in cement. Appendix B, Section 4.3, contains a more complete discussion of lime neutralization.

8.3.1.4 Barium Chloride Treatment[2]

The addition of barium chloride ($BaCl_2$) to tailings slurries is not effective in removing radium. If, however, barium chloride is added to clear sulfuric acid solutions containing radium ions, a precipitate forms that will remove 90% to 99% of the radium. The precipitate formed must be allowed to settle before the solution is released to the environment. $BaCl_2$ currently is used to treat uranium mine waters. The chemical (technical grade) costs \$400 per ton and is used at a strength of about 100 mg/L.

8.3.1.5 Removal of Toxic Substances by Ion Exchange

Ion-exchange processes depend on organic resins specially compounded to gather certain ions from dilute slurries (~ 10%), as in resin-in-pulp process, or from clear solutions. The resins are particulate in nature and are usually contained in columns through which the solution passes. Very high concentration ratios can be obtained. Ion-exchange processes are used widely in nuclear chemical applications and in some of the current mill processes, where they are used to absorb uranium from pregnant liquors. The ions on the surface of the resins are then chemically stripped to form solutions from which U_3O_8 can be precipitated. The resin is then activated for reuse.

Many ions can be recovered by ion exchange. Radium, for instance, can be removed from carefully filtered acid wastes, the resin eluted, and the radium precipitated by use of barium chloride.

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*A cyclone is a mechanical device resembling a centrifuge that segregates the heavier fraction of the tailings by the combined action of gravitational and centrifugal forces. The sands are withdrawn from the conical bottom of the cyclone, and the slime fraction plus tailings liquid are withdrawn as overflow from the top.

The resulting solid, having been concentrated, would be much more radioactive than the original solution, and would present disposal problems.

Costs involved in building and operating ion-exchange plants have been reported; they depend on the freedom of the solutions from solids (it will cost more to treat a slurry than a clean liquid), the required purity of the effluent liquid, and the volume of liquid to be treated. This option is not considered to be practicable for the treatment of tailings, for the reasons outlined above, and is not examined further.

8.3.1.6 Removal of Water by Solar Evaporation, In-Situ Dewatering, Thermal Evaporation, or Filtration

Past and current uranium tailings disposal methods have relied exclusively upon exposure of the surface of the impounded tailings to sunlight and winds for drying. Rates of evaporation vary considerably with climate, but are very high in those states which produce most of the uranium. Rates as high as one meter (40 inches) of water per year have been reported.

Process alternatives that reduce the liquid content of impounded tailings also reduce the potential for seepage problems at the disposal site, by reducing the source of and driving head for seepage. In addition, tailings with a low moisture content will consolidate more rapidly and add to the stability of the tailings mass, thus reducing problems associated with final impoundment drying and reclamation (covering). Liquid removed from tailings could be routed to an evaporation pond and/or returned to the leach circuit for reuse to save water and chemicals, although a portion of the recycled liquid would have to be disposed of in order to avoid a buildup of undesirable chemicals.

Perhaps the simplest method of reducing the water content in tailings is by in-situ dewatering in the tailings impoundment itself. This can be accomplished by discharging the tailings and permitting gravity draining of liquids to a system low point from which clear decanted liquid is withdrawn and recycled and/or transported to an evaporation pound. An underdrain system on the floor of the impoundment is used to withdraw from the tailings free liquid that is "squeezed" out as the tailings depth increases and the tailings consolidate. The underdrain system will generally consist of a network of slotted PVC piping covered by a blanket of sand and/or gravel and supported by the low-permeability impoundment bottom. This not only reduces the phreatic surface of liquids in the tailings (the driving force for seepage), but also increases the stability of the tailings mass and thus enables reclamation to begin earlier and helps prevent long-term stability problems such as differential settlement of the installed reclamation cover. In-situ dewatering of tailings has recently been studied[19] and has been considered as an alternative in recent uranium mill project proposals. Appendix B, Section 4.2, provides a more complete discussion of this process alternative.

When liquid wastes are thermally evaporated, dissolved or suspended materials that are not volatilized remain in the liquid phase. Liquid from mill wastes can be evaporated at around 120°C (250°F) to produce a concentrated solution that subsequently can be treated for disposal, while the recovered evaporate can be recycled to the mill and used as process water. This liquid generally will be purer than raw water.[20] Acid mill wastes should be neutralized prior to evaporation. If the nitric acid leach process were to be used, evaporation could be carried out with the aid of a rectification tower to recover water and 13-molar nitric acid for recycle to the mill. However, use of thermal evaporation to remove specific contaminants must be regarded as an expensive solution to the problem, in terms of energy requirements and costs. In the technology, a large volume of water is removed from a small amount of dissolved material, and the energy requirement is fairly constant, because it is based on the amount of water to be evaporated, regardless of the concentration of dissolved solids. Correlation between costs involved in a thermal evaporation system and plant capacity has been reported in the literature.[20-22]

Another means by which mill tailings slurry can be dewatered into a relatively dry solid is by the use of a belt vacuum filter. The equipment consists of a slotted or perforated endless elastomer belt supporting a filter fabric, which is also in endless-belt form and traveling across a suction box. The tailings slurry is pumped and evenly distributed onto the filter at one end. If desired, wash liquor may be applied at one or more points along the path of belt travel. The filter cake is discharged at the other end, where the support belt and the filter medium are parted, to be directed along separate lines of pulleys beneath the filter. The filter medium may be washed on its return journey to the head of the filter, where it rejoins the drainage belt. Advantages in the use of horizontal belt vacuum filter include complete cake removal and the opportunity for effective washing of the filter medium. Effective filtering areas can range from 0.2 to 60 m^2 (2 to 650 ft^2).

Other types of filters in common use are those operating by pressure, e.g., filter presses, and rotary drum and rotary disk vacuum filters. To simplify the evaluation of the tailings disposal programs, these will not be considered further

8.3.1.7 Solidification of Tailings by Incorporation of Asphalt or Cement

Various solidifying agents have been suggested for incorporation into tailings, so that the resulting solid form would have the desirable characteristics of low leachability and high resistance to the diffusion of radon. Such agents presumably would be added after the tailings slurry had been concentrated and neutralized. A variation of this technique might incorporate a sand-slime separation, to reduce the amount of solid to be produced. A commonly suggested agent is asphalt, which, if it can be incorporated as an impervious coating on the tailings particles, would retard the diffusion of radon and its release to the environment and would effectively prevent the leaching of water-soluble toxicants. A facility for heating the asphalt and for the mixing of asphalt with the tailings would be required for implementation of this alternative. It has been estimated that about 330 kg of asphalt per metric ton (670 lb/ST) of tailings would be required to produce a suitable mix.[2]

After the selected pretreatments, the tailings could also be mixed with cement to produce, upon setting, a type of low-grade concrete. With proper design, the steps of required neutralization and concretion could be carried out in the same facility. A minimum of one part of cement for 20 parts tailings has been estimated; a ratio of 1:5 is said to yield better strength and leach resistance at a higher cost.[2]

8.3.2 Tailings Disposal Locations

8.3.2.1 Above-Grade Disposal

Surface emplacement of tailings is a convenient mode of disposal and has been the conventional practice to date. Tailings can be disposed of in any of several types of surface impoundments near the mill. Such impoundments can be constructed as four-sided structures in relatively flat areas; they can also be formed by constructing a dam or embankment in an existing natural drainage area. In the latter case, diversion ditches are constructed to divert runoff around the impoundment. Embankments for impoundments have, in the past, been constructed of tailings, but newer impoundments have been constructed from local earthen materials. Heights of tailings embankments vary from 10 to 30 m, (30 to 100 ft) above surrounding terrain. (Appendix B contains a discussion of tailings dam construction.)

8.3.2.2 Below-Grade, Near-Surface Disposal

Tailings could be disposed of in such a manner that the tailings and the isolating cover materials were below grade, thus virtually eliminating exposure of the tailings to surface erosional effects. Tailings could be disposed of in existing open mine pits or in special excavations. Open mine pits range in depth from about 20 m to 100 m (65 to 330 ft) and commonly cut through aquifers or water tables. Figure 8.2 shows several views of open pit uranium mines. Overburden removed can be stored and later used as backfill and cover for tailings deposited in the pit. Generally, since tailings deposited in such pits would displace the overburden, the resulting cover would be of greater thickness than that which might otherwise be required.

8.3.2.3 Deep Disposal

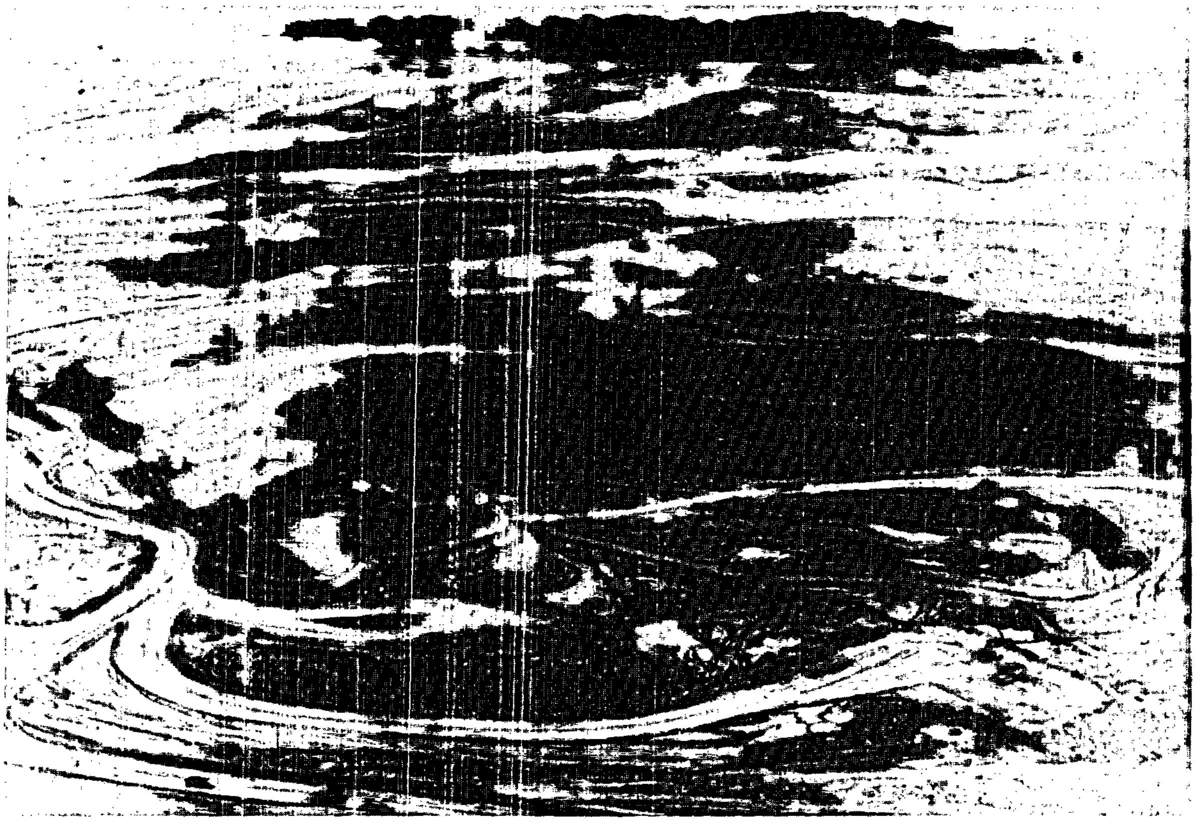
Tailings could be disposed of in locations far below the surface [deeper than 100 m (330 ft)]. The potential advantage of this method is that the depth of cover would eliminate all radon emissions and provide an enormous physical barrier, so that the need for long-term institutional controls or monitoring could be greatly reduced or eliminated. Abandoned deep mines could be used for such disposal. Such mines are usually opened by a shaft from the surface (or a tunnel from a hillside) and tunnels are extended under the ore bodies. Introduction of tailings into the mined-out volumes via the underlying tunnels would be difficult. The tailings would probably have to be introduced from above, through a specially drilled hole, after existing "below-cavity" tunnels had been sealed.

Another deep disposal option would be to utilize existing open-pit copper or coal mines in western regions, which can extend to depths of more than 100 m; special deep open-pit excavations could also be made. In any event, groundwater formations would probably be encountered in any excavation used for deep disposal of tailings.

8.3.3 Tailings Area Preparation

8.3.3.1 No Subsurface Preparation

The undisturbed ground surface would act as an interface between the tailings and whatever lay underneath. Drainage of the tailings water would occur naturally, and the soils would act as chemical absorbers and ion-exchange agents in their natural manner. Liquid would drain from the tailings until all moisture in the tailings had either evaporated or seeped away. The underlying soil would become contaminated, and any natural moisture (from rain or snow) would propagate the contamination, even after drying of the tailings.



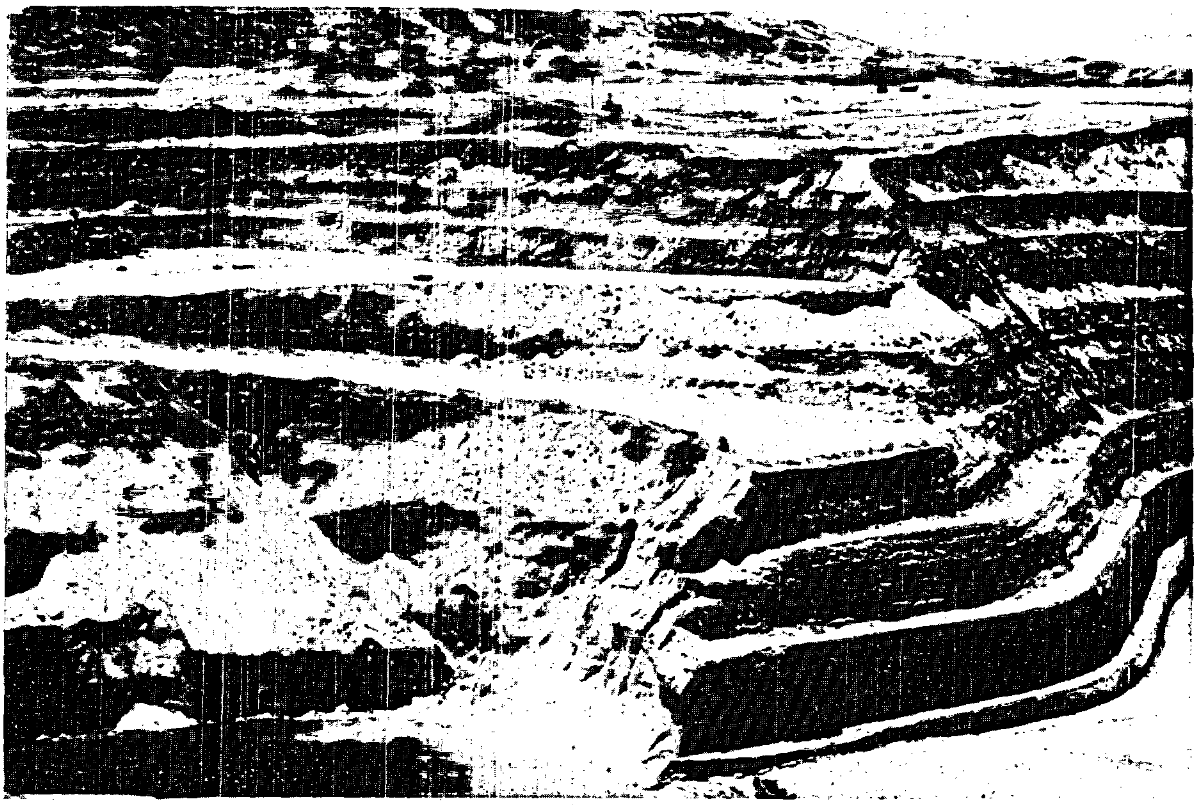


Figure 8.2 VIEWS OF TYPICAL OPEN PIT URANIUM MINES

8.3.3.2 Soil Compaction

Soil compaction would increase the potential for the soil/tailings interface to inhibit seepage from the tailings, but would not totally prevent such seepage. Compaction would affect the density of the soil (or clay), reducing permeability, but only to a depth of about one-quarter meter.

8.3.3.3 Clay Liners

Emplacement of clay over compacted soil would act as a sealant and would inhibit seepage from the tailings. Compaction of the clay would enhance this effect. Also, the ion-exchange characteristics of clay are enhanced, compared with most western soils. Layers of less than about one-third meter (1 ft) over large areas probably would not ensure complete coverage.

Although soils contain widely varying proportions of the three particle size categories: sand (50-2000 µm), silt (2-50 µm), and clay (<2 µm), they are generally referred to in terms of the predominant particle size fraction, e.g., clay soils are considered to contain greater than 40% clay-sized particles (<2 µm). Because the small clay particles contain various proportions of clay minerals, of which seven clay mineral groups are recognized, and because the variation of chemicals in the clay groups gives rise to approximately 50 clay-mineral species, there is great diversity of clays in nature. The clay mineral group smectite is of value in tailings management systems, because it has a loosely-layered, fine-grained structure resulting in pronounced properties of absorption and adsorption. Montmorillonite, which is a well known smectite species, tends to swell and exhibits thixotropic properties when wet, and particularly when saturated with the sodium cation. Section 8.3.4.2 contains additional information on clay materials.

The bentonite mined in the Black Hills region of Wyoming and South Dakota consists of about 85% montmorillonite and 15% nonclay minerals such as quartz, cristobalite, gypsum, calcite, and feldspar.[23] Wyoming has extensive deposits of bentonite, a montmorillonitic-type clay. One commercial bed occurs in the Mowry shale of Cretaceous age and extends into Montana and South Dakota.[24] In some cases it may be desirable to treat clay with a sodium compound (e.g., rock salt) before final compaction. Such treatment renders the montmorillonite predominantly in the sodium form to achieve maximum swelling of the clay lattice and maximum dispersion of the clay particles. Some naturally occurring montmorillonitic clays, including the bentonite found in Wyoming, occur as mixtures of sodium montmorillonite and calcium montmorillonite.[23] Bentonite found in Texas, Arizona, and California is mainly of the calcium type.[24] Calcium bentonites exhibit marked differences from sodium bentonites when placed in water, e.g., calcium bentonites do not have the tendency to swell to any appreciable extent, and settle in water as floccules.[25]

Recent studies[26] indicate that sodium montmorillonite may not be stable in the environments normally encountered beneath a uranium mill tailings pond. The stability diagrams of Reference 26 imply that ground sodium montmorillonite (i.e., a ground-up clay liner) exposed to uranium mill waste water would be broken down and to a large extent dissolved. It is not clear that a highly acid wetting front moving slowly into a compacted clay liner would produce such a deleterious effect, for rate coefficients under these conditions could be vastly smaller and the rate of decay of the liner correspondingly slower. Other recent studies[18,27] indicate that mineral dissolution is not a significant factor in clay liner permeability changes and, in fact, that dissolution of clay minerals may be countered by precipitation reactions and secondary mineral formation, causing a decrease in permeability, with time, due to pore plugging. Needless to say, further study of these phenomena is warranted.

8.3.3.4 Synthetic Liners

There are many types of synthetic sheeting available for lining ponds. Various kinds of synthetic liner materials that could be used to inhibit seepage are listed in Table 8.3. Rigid liners would have limited application in connection with tailings disposal, that is, only where a hard rock foundation was involved. This study considers only use of flexible liners which are normally reinforced with a fabric material such as polyester. Most successful liners have been employed for water storage only (no solids above the liner). They require gentle slopes to minimize any tendency to fold or bend; application on steep slopes would be difficult at best. Careful preparation of the base (absence of rocks or sudden changes in slope and subsoil compaction) is also required, if long life without perforation is to be expected. Also, a protective soil cover is required to avoid damage to the liner. All liners are flexible initially, but some tend to lose this property after long periods of exposure to sunlight or certain chemicals. The liner should extend beyond the water line, and interface with soil only. If completely successful, liners should be able to contain the tailings water and eliminate seepage. The capacity of such liners to endure for long periods cannot be determined, because such endurance will depend less on the liner itself than on preparation and installation procedures and care and maintenance during use. Ground movement will also affect the permanence of the installation. Once perforated, the liner will lose a portion of its effectiveness. Very long-term stability of bottom liners is not as important as tailings covers; the primary purpose of the liners is to contain solutions during mill operation, when about 1200 MT (1300 ST) of water is disposed of daily.

Table 8.3. Synthetic Liners and Cover Materials

Plastics[a]
. Polyvinyl chloride (PVC)
. Polyethylene (PE)
. Chlorinated polyethylene (CPE)
Elastomers[a]
. Hypalon
. Neoprene
. Ethylene propylene diene monomer (EPDM)
Asphalt Coatings
Rigid Liners
. Gunnite
. Cement grout

[a]Many of these materials are used with polyester or nylon reinforcement. The materials differ in tensile strength, resistance to puncture, flexibility and change of flexibility with temperature, resistance to air and sunlight, resistance to chemicals, ease of making good joints in the field, lifetimes and other properties.

8.3.4 Tailings Stabilization and Covering

Covering and stabilization of the tailings as a part of the tailings management program are addressed in this section; temporary stabilization of tailings during mill operation is discussed in Section 8.2.

8.3.4.1 No Cover or Stabilization

If a tailings pile is allowed to dry out, wind and water erosion will begin to spread the tailings over an ever increasing area. Experience indicates that without further treatment, most tailings surfaces will not support vegetation, even if efforts are made to replant indigenous flora. Emissions would be maximal for this situation.

8.3.4.2 Soil Cover

Soil covers can protect the tailings from being dispersed by wind and surface water. They also help return the reclaimed tailings impoundment to a condition similar to the surrounding environment.

In sufficient thicknesses, soil covers are also effective in reducing radon emissions. The moisture content of the soil appears to be the dominant soil parameter affecting radon attenuation,[28] owing to the very low diffusion coefficient of radon in water. Although grain size and porosity have a minor effect on radon migration through the soil, their major influence is on the amount of moisture that can be retained by the soil for long periods of time. The very small sized grains in clays have a large surface-to-volume ratio (see Section 8.3.3.3), so that clays tend to hold relatively large quantities of moisture tightly, due to attractive forces between water molecules and the clay grains themselves.

Clays high in sodium-saturated montmorillonite would provide for the retention of a large quantity of moisture in the soil. However, although montmorillonite-type clays tend to predominate in the soils of arid and semiarid regions (where weathering and leaching is less intense and the silica and alkali components are retained), it is expected that clay material used in a cover would be obtained from the vicinity of the site and would not be obtained from commercial clay deposits such as bentonite (which contains a high proportion of montmorillonite). As the moisture of the clay soil is directly related to the relative humidity of the atmosphere with which it is in contact, it is expected that over the long-term, the moisture in the clay will tend to decrease to the point at which it is in equilibrium with the moisture in the air in the surrounding dry soils.

Placement of a highly compacted clay layer over tailings may not be practicable. Although compaction results in higher bulk density and greater uniformity in properties, it is not expected that most hydraulically deposited tailings would have sufficient strength, after a few years drying period, to remain structurally stable under a high compactive effort.

In summary, soil covers can be used to protect tailings from disruption and to reduce the exhalation of radon. As radon attenuation is primarily a function of moisture content, soils high in clay content tend to be good cover materials. However, the behavior of clay in tailings impoundment system covers is complex. Whereas clay in liners can be compacted to a high bulk density with properties of uniformity, strength, and low permeability, it might not be possible to compact a high bulk density clay layer because of low strength of hydraulically placed tailings. In addition, highly compacted clay would tend to have a less than optimum moisture content (resistance to radon flux), although the moisture added to a clay cap during compaction would tend to decrease in the long term in arid and semiarid regions, until it is in equilibrium with moisture in the surrounding (dry) soils. Clay is not suitable for direct exposure to atmospheric influences, because it is unstable under drying/wetting (shrink/swell) and freeze-thaw cycling and because the fine particles are highly susceptible to erosion. Finally, it is not likely that a highly suitable clay material will be available in the vicinity of the site, i.e., material that is available is not likely to have high clay content and/or clay minerals which are optimum.

8.3.4.3 Vegetative Cover

Use of native soil to cover the tailings would be desirable from the viewpoint of facilitating establishment of indigenous plant species. Native soil cover, if applied in several layers after settling has occurred, has provided adequate resistance to wind and water erosion in some cases. In a few cases, vegetative growth has further enhanced erosion resistance. Even if compacted, however, native Western soil is usually rather ineffective in reducing radon emissions.

Methods of reclamation of covered tailings impoundments using vegetation are discussed in Appendix N. A brief consideration of regulatory requirements for reclamation and suggested criteria for the evaluation of reclamation efforts is included.

8.3.4.4 Gravel, Crushed Rock, or Riprap Cover

A layer of coarse gravel or crushed rock decreases wind erosion and allows infiltration of water. Studies of wind and water erosion on a sandy loam soil using a portable wind tunnel to produce an equivalent 85 mph (38 m/s) wind velocity for three minutes at 50 ft (15 m) above the ground indicated that "insignificant" amounts of wind erosion [less than 25 lbs/ acre (28 kg/ha)] occurred when at least 20, 50, or 100 ST/acre (45, 110, or 225 MT/ha) of fine, medium, or coarse gravel, respectively, were spread uniformly on the ground surface.[29] For gravel sizes greater than 2 mm in diameter, the finer the gravel, the lesser the amount required. Amounts of gravel or crushed rock in excess of that required to completely cover the ground appeared unnecessary under the conditions of the study. Section 9.4.1. and Appendix B, Section 4.5, contain additional information on the use of gravel or crushed rock to protect exposed impoundment surfaces.

Riprap is a substantial rock cover which is applied to control erosion of soil on slopes or other surfaces which are subjected to potentially severe erosional forces, such as those which might be encountered at existing tailings impoundments. Used in applications such as slopes of highway embankments[30] or flood control channels,[31] it could be employed to stabilize tailings embankments and overburden cover. Figure 8.3 shows riprap placed on an embankment slope. While applications of riprap to date have been to handle shorter term erosion concerns than those faced in tailings disposal, the guidance developed for such applications as presented in various engineering and design texts such as Reference 31 can be of some use. For example, they describe optimum stone shape, size and gradation. Riprap, in addition to providing an "armoring" of the tailings cover against erosion,[32] may enhance the growth of vegetation. It may provide protection for the collection of eolian soil particles, which will form a favorable habitat for vegetation to grow between rocks.[33]

8.3.4.5 Artificial Covers and Sealants

Artificial covers, such as a layer of asphalt or a synthetic membrane, could be placed over the tailings to reduce wind and water erosion and radon emissions. However, synthetic membrane materials containing plasticizers, e.g., polyvinyl chloride (PVC) are not suitable for direct exposure because they are susceptible to damage by ultraviolet radiation (sunlight), and a thin, synthetic sheet, even if protected by soil from direct exposure, would have questionable mechanical strength in the long term. Similarly, although asphalt emulsion sealants have been shown to provide very good attenuation of radon,[34] (work on such emulsions indicates that radon exhalation can be reduced by several orders of magnitude, with thin coatings of about one centimeter), potential problems arise concerning pinholes that can form during application and also uncertainty about long-term performance of asphalt coatings. Exposure to air and sunlight would also result in deterioration of the sealant; of greater concern is uncertainty about the ability of a thin coating to withstand mechanical stresses and dislocations which may occur over the long term.

In general, the long-term integrity of thin artificial covers, even if protected from atmospheric influences, would be difficult to establish. Therefore, relative to long-term stability, artificial covers appear to be inferior to soils having a high clay content. Integrity would be

Figure 8.3 RIP RAP COVER ON EMBANKMENT SLOPE

difficult to maintain, and such materials lack the selfhealing properties of clay should rupture occur. In addition, they are considerably more expensive. For these reasons, the covers considered in this document involve use of layers of soil to reduce radon exhalation from the tailings.

Asphalt emulsions might be useful if mixed with a sufficient thickness of tailings or overburden material to form a "volumetric" seal, as opposed to just a thin coating of the tailings surface. This mode of application might be acceptable if asphalt mixing depths were sufficient to provide reasonable strength to minimize the potential for, and effects of, dislocations at the tailings surface. Recent research[35] indicates that a cationic asphalt emulsion might be used to reduce the exhalation of radon by either pouring or spraying on or admixing with the tailings, although the long-term stability of asphalt when used in such a seal would be questionable and would depend upon conditions in the surrounding environment. Field tests at one tailings site, using various methods of asphalt application (such as mixing asphalt and tailings in thicknesses of 15 cm (6 in)) illustrate the benefits as well as potential stability problems experienced with such liners.[36] Additional examination of the effectiveness, reliability and economics of asphalt and other synthetic products for use in isolating tailings from the environment appears warranted.

In summary, most recent studies indicate that relatively thin layers of artificial cover materials are not likely to remain intact under any reasonable long-term scenario. However, such materials currently must be applied in relatively thin covers in order to be economically competitive.

8.3.4.6 Combinations of Cover Types

None of the covers described above, if used alone, would be completely effective in eliminating radon emissions for long periods of time. All of the effects of covering and stabilizing described above are very site-specific. A combination of soil (to reduce radon emissions) and topsoil planted with native flora should be effective at impoundments for which there will be the continuing conditions necessary for a full and self-sustaining vegetative cover, for example, ample annual rainfall. For impoundments in semiarid regions with generally low rainfall or subject to conditions that would not ensure a full and self-sustaining vegetative cover, recourse to a cover of soil protected by a layer of rock might be necessary. This latter situation would not return the surface to its original use (grazing for cattle and local fauna).

8.3.5 Potential Tailings Disposal Alternatives Rejected

Some of the tailings disposal alternatives listed in Table 8.2 were eliminated from detailed evaluation after an initial screening process by the staff. Prominent among these were alternatives for disposal of tailings in very deep locations [at least 100 m (300 ft)] as described in Section 8.3.2.3. Because these alternatives offer the major potential advantage of eliminating the need for any institutional controls of the disposal site, it is appropriate to review the reasons for not performing a detailed evaluation. Some of the drawbacks of these alternatives are common to others carried through for detailed evaluation; however, it was the accumulation of negative factors which led to dismissal of the alternatives to be discussed below.

8.3.5.1 Disposal in Existing Deep Open-Pit Mines

The potential advantage offered by deep disposal is elimination of the need for any long-term institutional controls to preclude human intrusion and direct exposure to the tailings which could occur in the case of surface or near-surface disposal.

The first deep disposal option that was rejected involves using one of the existing deep pits excavated in the western United States to mine nonuranium ores. Tailings from several, if not all, mills in a region would be placed in such a pit. In this sense, the disposal option would constitute a regional repository of tailings. Under this alternative it would be necessary to transport the tailings long distances, since it is not likely that existing deep nonuranium mine pits would be very close to the uranium mining and milling areas. Considerable transportation and energy costs and environmental impacts would be incurred. If transported by rail or truck, these impacts would include loss of tailings dust during loading, shipment, and unloading. Review of the situation indicates that average shipping distances would likely be on the order of from 500 to 1000 km (300 to 600 miles). Estimates of losses from transportation are based on similar milling operations and knowledge of losses from shipment of other materials, such as coal. Shipments of this nature also would result in common transportation accidents. Each day there would be as many as 100 twenty-ton trucks making shipments to such a deep pit. If shipment were by rail, a number of carloads of tailings would be required from each mill each day.

Another problem with deep-mine alternatives is that groundwater formations inevitably intercept the pits. While steps might be taken to fix the tailings to eliminate potential groundwater contamination problems, the costs for doing so would be on the order of those computed for Alternative 8, which are shown in Chapter 11 to be very large. The high cost of fixing the tailings is significant in screening out this alternative, since these costs would be incurred in addition to those of transportation and environmental concern.

Finally, institutional barriers would have to be surmounted in order to implement this option. For example, it would be necessary to locate and acquire a mine which essentially would become a "waste dump" isolated from the "money-making" venture of the mill. It would then suffer from the same siting problems as do other forms of waste from the nuclear fuel cycle. Waste deposition would no longer be directly connected to the economically profitable part of the venture; hence, it would likely be difficult to obtain acceptance of the repository by nearby communities regardless of actual risks involved. A similar institutional barrier would make difficult the utilization of a slurry pipeline to transport tailings from the mills to the deep pit. A slurry pipeline would offer potential for reducing costs and impacts, but siting the line and obtaining right-of-way for it would suffer from the same kind of problems encountered in siting electrical transmission lines. The fact that the tailings would be a waste material as opposed to a useful commodity such as electricity would likely exacerbate such problems.

8.3.5.2 Specially Excavated Deep Open Pit

Another kind of deep-open-pit disposal option initially considered but eliminated from detailed review was placement of tailings in a specially excavated pit in a geological formation where groundwater was sufficiently deep to avoid contact with the tailings. Initial review by the staff indicated that it would not be likely that such formations would be found near uranium mining and milling regions, because the process which resulted in the initial deposition of uranium in the ore is associated with groundwater movement, and it is not likely that significant changes have occurred. Although there is evidence that such formations do exist in the southwest,[37] the cost of excavation to permit deep open pit burial of tailings would be prohibitive.

8.3.5.3 Disposal in Lined Deep Mine

The staff gave consideration to the concept of lining a deep mine with impermeable coatings to isolate the tailings from groundwaters. This basic concept has been explored by the Bureau of

Mines in sealing deep mine walls for the purpose of reducing radon emanation. In that case, combinations of cement and epoxy coatings were applied to sections of deep mines, with some success in sealing radon reported.[38]

A major problem of this alternative is the extreme uncertainty about the performance of coatings, particularly over the long term. Subsidence and large differential movements around the deep mine cavity are likely; this would result in failure of at least portions of coatings, providing a path for contaminants to enter the groundwater. Furthermore, application of coatings are expected to be relatively difficult and expensive. This alternative is not expected to be appreciably different from disposal of untreated tailings in deep mines over the long term. The technology has not been carried out on a commercial scale; the extent of experience is on the level of a pilot study (tests have been carried out in limited sections of actual mines). It is expected that extreme care would be required in applying the coatings to ensure that there would be an effective bond with the mine rock, especially in the overhead portions. Also, the area to be covered would be relatively large because typical mines are lengthy and tortuous in their configurations. Estimates by the staff, allowing for uncertainties and the large scale of such an operation, are that costs to apply the lining could be on the order of from $100 to 140 million.

8.4 DESCRIPTION OF TAILINGS DISPOSAL PROGRAMS

8.4.1 Introduction

The specific measures discussed in Section 8.3 should be combined to form a complete tailings disposal program. Each alternative offers potential for solving one or more, but not all, of the problems which must be addressed. For this reason, and because of interrelationships among the objectives of tailings disposal programs, the general approach adopted by the staff was to evaluate a range of complete disposal programs, as opposed to evaluation of individual methods to achieve each objective exclusively. The tradeoffs, for example, between the desire to avoid contamination of groundwater and the advisability of isolating tailings from surface erosion for long-term stability, can be more clearly illustrated by this approach.

If the various aspects of tailings management are combined into different overall programs, a vast number (literally thousands) of tailings management alternatives are possible. In considering these many schemes, the staff reduced the number of alternatives by dividing tailings management into the four interdependent categories listed in Section 8.3. Within these subdivisions, various options were considered; that is, four locations (above ground, open pit, specially dug pit, deep mine) were visualized; four methods for preparation of these locations to receive tailings [none, compaction of the earth, natural liner (e.g., clay), synthetic liner] were examined; three types of tailings [wet, dried, mixed with solidifiers (e.g., asphalt)] were taken into account; and three postoperational treatments (covering with a specially selected clay soil, covering with local overburden, a combination of these two) were incorporated.

These 14 options can be combined into 144 alternatives; however, some of these combinations (e.g., compacting the earth in a deep mine) are incongruous. When the staff eliminated such incongruous combinations, 96 alternatives remained for consideration. The staff examined these remaining alternatives from the viewpoint of comparison of environmental impacts presented in Chapter 6. In addition, such factors as monetary cost, long-term reliability, availability of necessary technology, and regional applicability were introduced. A rough ranking of the alternatives was then carried out by categorizing each as better, average, or worse with respect to each of the factors. This ranking proved to be instructive but not conclusive; it permitted the elimination of some of the alternatives, but left a still unwieldy number of closely ranked alternatives. Close examination of these alternatives indicated that the close ranking resulted, at least in part, from the circumstance that many could be regarded as variations on one basic type. As a result of these considerations, the staff has selected nine alternatives for detailed examination and evaluation in addition to the base case. Each of these alternatives is taken to be representative of a type of tailings management program; variations within the type are possible, and some of the most readily evident will be discussed as "options." These discussions and other elements of the evaluation of alternatives are given in Chapters 9, 10, and 11.

It should be emphasized that most of the specific tailings management alternatives presented in this section are provided as examples of complete individual systems for comparison purposes and are not intended to represent optimum combinations of features. In fact, a far greater number of potential systems would be possible by slightly modifying and using the alternatives in combination. For example, tailings sands and slimes could be separated as in Alternative 8, but the sands could be deposited as a slurry with cement in the deep mine (providing structural support to prevent mine subsidence) while the slimes are deposited in pits such as those described in Alternative 4 or in trenches such as those described in Alternative 5. Similarly, a number of the alternatives could be carried out in a sequential or "staged" fashion, that is, the tailings disposal area could be developed as operations progress. For example, a given tailings impoundment area could be developed in a number of "cells" which allows deposition of tails in one cell while simultaneously operations are underway to reclaim the previously filled cell with material being excavated from the next cell to be used. Staged or sequential development of a tailings impoundment area has the benefits of (1) reduced initial capital investment, (2) reduced handling of excavation and cover materials, and (3) reduced quantity of tailings exposed at any one time. In addition, modifications can readily be made in the tailings management system as operations progress; experience acquired during operations can be used in optimizing tailings disposal operations with regard to public health and safety, environmental, economic, and other considerations. Similarly, there is greater confidence that unanticipated adverse impacts can be mitigated without resorting to extreme measures, for example, complete shutdown of operations. Finally, financial risk and exposure during the critical site decommissioning period, when the mill is shutdown and no longer producing revenue, are dramatically reduced. Alternative 5 is representative of staged tailings disposal systems and is similar to recent tailings management system proposals.[13-15]

The major aspects of nine tailings disposal programs evaluated by the staff are summarized in Table 8.4. The alternative programs all address, to some degree, concerns of reduction of airborne radioactive emissions (particularly radon) and of the potential for groundwater contamination; however, there are major differences among the programs. The programs can be categorized according to the degree of tailings isolation provided and the associated levels of ongoing care and monitoring required. The three categories or modes assessed are (1) active care mode; (2) passive monitoring mode; and (3) potential reduced care mode. These three modes are discussed briefly below in Sections 8.4.1.1 through 8.4.1.3, and specific alternatives are described in more detail in Sections 8.4.2 through 8.4.10. The matter of groundwater protection is highly site-specific; the approach taken by the staff to account for this in evaluating alternatives is discussed below in Section 8.4.1.4. A more detailed description of alternatives is provided in Appendix K.

8.4.1.1 Active Care Mode

The first mode encompasses those alternatives which would require active care and maintenance, indefinitely, to ensure continued isolation of the tailings. Although the tailings would be covered with overburden and soils, the isolation area would be susceptible to natural erosion capable of causing relatively rapid deterioration of an unmaintained pile. One tailings disposal program is described to illustrate this level of protection (Alternative 1).

8.4.1.2 Passive Monitoring Mode

In the passive monitoring mode, tailings would be isolated from erosional forces so as to eliminate the need for ongoing care. Five alternatives are described to illustrate the several basic approaches which can be taken to achieve this level of protection. These alternatives involve primarily below-grade, near-surface burial of the tailings (Alternatives 2-5); however, one case (Alternative 6) constitutes an above-grade disposal scheme, whereby selection of proper siting and design features would result in protection equivalent to that provided by below-grade disposal. The below-grade alternatives include use of available open pit mines or excavation of special pits for disposal (Alternatives 4 and 5). These alternatives, although described in idealized fashion in this generic study, are much like disposal programs developed for actual mills. The description of such programs is provided in individual mill environmental statements,[39-44] environmental assessments,[13-15,45] and staff presentations on the subject of tailings disposal.[46,47]

8.4.1.3 Potential Reduced Care Mode

The third mode (Alternatives 7, 8, and 9) is a loose collection of alternatives that represent departures from current technology or practice. To one degree or another they have the potential to provide an added measure of isolation and protection, as well as a reduced level of ongoing care, beyond that provided by the two other categories. Unique features of the alternatives in this category are: (1) disposal of tailings in relatively deep locations; (2) fixation of tailings slimes in asphalt or concrete; and (3) nitric acid leaching of ore.

8.4.1.4 Groundwater Protection

Most of the alternative programs conservatively provide groundwater protection by isolating tailings and tailings solution through use of bottom liners and location above groundwater formations. It may be possible to treat tailings to allow contacting sands or sands and slimes, with groundwater, or to eliminate liners altogether. Proposals involving this would have to be evaluated on a case-by-case basis. Data from tests performed on tailings treated in the manner proposed and on site-specific soils, hydrology, and geology would be needed. For Alternatives 7 and 8 it is assumed that washed sands could be contacted with groundwater; in real cases, this would have to be evaluated as just discussed.

Table 8.4. Mill Tailings Disposal Program Alternatives

Areas of Concern	Base Case	Active Care Mode	Passive Monitoring Mode					Potential Reduced Care Mode		
		Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9
LONG-TERM STABILITY AND ISOLATION	Above-grade disposal.	No measures to eliminate surface weathering and erosion effects. Active care required.	Below-grade disposal, isolation from surface weathering and erosion effects. Above water table.	△	△	△	Above-grade disposal.	Below-grade disposal as in Alts. 2-5. Placed in groundwater.	Deep mine disposal at greater than 100 m virtually eliminates potential for human intrusion.	Nitric acid leaching of ore with 90% Ra-226 and Th-230 removal.
			Available open pit mine utilized.	△	Special pit excavated.	Special "landfill" trench.	Design and siting features to eliminate negative surface erosion and weathering effects included.	Available open pit mine used.		Residual tailings disposed of as in Alt. 6, with less clay/overburden material applied. Tailings contain 10% original activity.
							Tailings dam includes low-permeability clay core. Designed to Reg. Guide 3.11.			
	No covering of tailings.	Cover of 3 m of soil and 15 cm topsoil with[a] revegetation.	△	△	△	△	△	Thick cover of available overburden stripped during mining.		
AIRBORNE EMISSIONS										
During Operations	No treatment of dry beaches; 50% of tailings are wet.	△	No treatment. Below-grade disposal reduces wind dusting. 50% of tailings wet.[b]	△	△	Staged reclamation of tailings reducing exposed area. Also below-grade wind protection.	Dry beach areas wetted or stabilized with chemical spray.	Fixation of slimes eliminates particulate emission; radon emissions reduced.	Fixation of deep mine location eliminate emissions.	No treatment of residual tailings; tailings contain 10% of original activity.
Long Term	No covering of tailings.	Cover 3 m of soil and 15 cm topsoil with revegetation.	Cover same as Alt. 1. Return of overburden stripped in mining potentially facilitates covering process and reduces cost.	△	Cover same as Alt. 1.	△	△	Thick overburden cover; on the order of 10 m.	Very deep isolation; greater than 100 m.	Residual tailings covered with 1.5 m of overburden
SEEPAGE	No treatment.	Compaction of subsoil.	Lined sides and bottom.	Lining of bottom only.	No liners needed.	Lined sides and bottom. Same as Alt. 2.	Lined bottom. Tailings dam has low permeability clay core.	No liner.	△	Residual tailings treated as in Alt. 6; NO_3 instead of SO_4 ions present.
			Clay and synthetic liner options considered.	△						
				Tailings are dewatered. In-situ dewatering and belt filter options considered.	Natural low permeability. Subsoil exploited. No liners needed.	Clay and synthetic liner options considered.	△	Fixation of slimes fraction in cement or asphalt. Sands washed and dewatered.	△	Ra-226 and Th-230 concentrates are fixed in cement or asphalt.
			Tailings above groundwater.	△	△	△		Treated tailings contact groundwater.	△	
	Recycle 40%.	△	△	△	△	△	△			
			Lined evaporation pond for excess water.	△	△	△	△	Optional disposal of excess water considered; thermally heated evaporator or lined evaporation pond.	△	

[a]For comparison purposes, the same kind of tailings cover is assumed for alternatives 1 through 6. To bound realistic cases, various cover types, thicknesses and combinations are analyzed in Section 9.3.8 as they contribute to reduction of airborne emissions (particularly radon). Also, in actual cases where tailings are disposed of in open pit mines, the degree to which tailings can be covered beyond minimum specified thickness will be controlled by distance to water table and available volume of the open pit.

[b]50% of tailings are assumed to be submerged under tailings solution or wet except for alternative 3, 7, 8, and 9. The effects of increased surface water cover or other temporary stabilization techniques are analyzed in Section 9.2.8, which addresses emissions during operation.

8.4.2 Alternative 1

Under Alternative 1 the disposal site is taken to be at grade level, or slightly above, so some surface soil would be removed and the subsoil compacted. An earthen berm would be constructed on the four sides of the impoundment. Tailings would then be moved from the mill to the tailings impoundment by slurry pipeline, and water would be recycled to the mill. Diversion ditches, drains, and dikes would be emplaced where necessary. The total area disturbed would be about 100 ha (250 acres).

As large areas of beaches became thoroughly dry, the surface would be covered with a minimum of 3 m of soil. The 3 m cover thickness was selected for all alternatives, to permit a comparison of other aspects of tailings disposal. (The issue of actual thickness of cover is addressed fully, but separately, in appropriate sections of Chapters 9, 11, and 12 and in Appendices K and P.) Topsoil [15 cm (6 inches)], saved from the original preparation, would then be used to cover the entire area. It would be contoured and then vegetated with native plants. This alternative is depicted schematically in Figure 8.4.

8.4.3 Alternative 2

Under Alternative 2, the untreated tailings would be deposited in a partially backfilled and lined open pit mine and then suitably covered (Fig. 8.5). Implementation of Alternative 2 would be predicated on the availability of an open pit mine relatively close to the mill. The disposal operations might take place in stages within a large open-mine pit, with temporary dams constructed between the tailings area and areas being actively mined. After final drying of first stages, overburden being stripped from newly opened mine areas could be directly placed over the tailings for cover. Thus, it may be possible to conduct sequenced reclamation of the tailings disposal areas.

There would be two options under this alternative relative to lining of the pit. In one option, a low-permeability liner, either of clay or synthetic material, would be installed before backfilling the pit to a plane above the water table. In the second option, the pit would first be backfilled above the water table plane and then the liner would be installed. Care would be required in preparation of the cavity to ensure that side slopes would support the clay or synthetic liner and not crumble or bend.

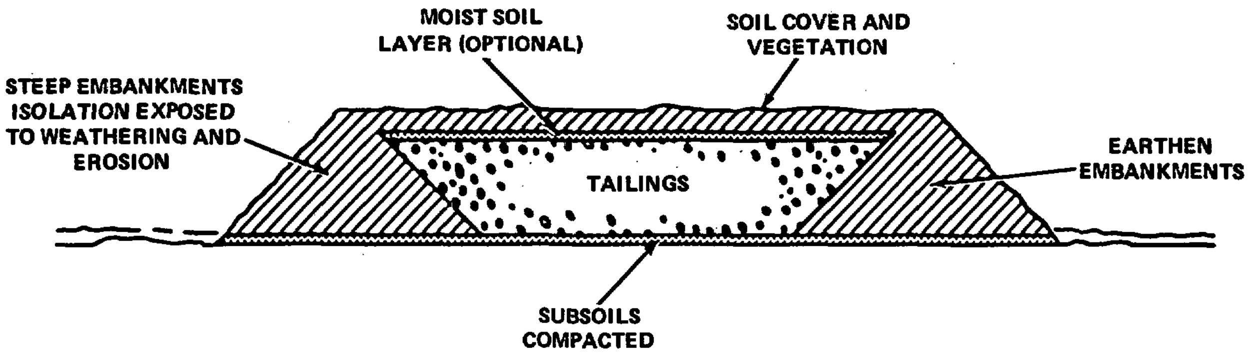
The tailings would be transported to the disposal area by pipeline and deposited as a slurry in the prepared pit. A return pipeline would be required for water removed by a floating decant system from the tailings deposited in the pit. Some water would be recycled to the mill; the excess would be evaporated from an auxiliary pond [~40 ha (100 acres)]. When mill operations ceased, the decanted tailings would be allowed to dry out naturally, then the pit would then be backfilled with overburden, and the surface restored to a condition required by regulations.

8.4.4 Alternative 3

Alternative 3 is similar to the first option of Alternative 2 [disposal in a pit after backfilling and lining only the bottom (not the sides) with clay or synthetic membrane], except the tailings would be dewatered before being deposited or while being stored in the pit. The major advantage of Alternative 3 is that only the bottom of the pit would have to be prepared and lined; dewatering the tailings would decrease the possibility that moisture could migrate horizontally from the disposal area. Dewatering of the tailings also would make final covering and reclamation of the tailings disposal area easier, since an extended drying period would not be required, and the use of heavy equipment for tailings-covering operations would be facilitated. The sequence of tailings disposal could be coordinated with mining plans as described for Alternative 2.

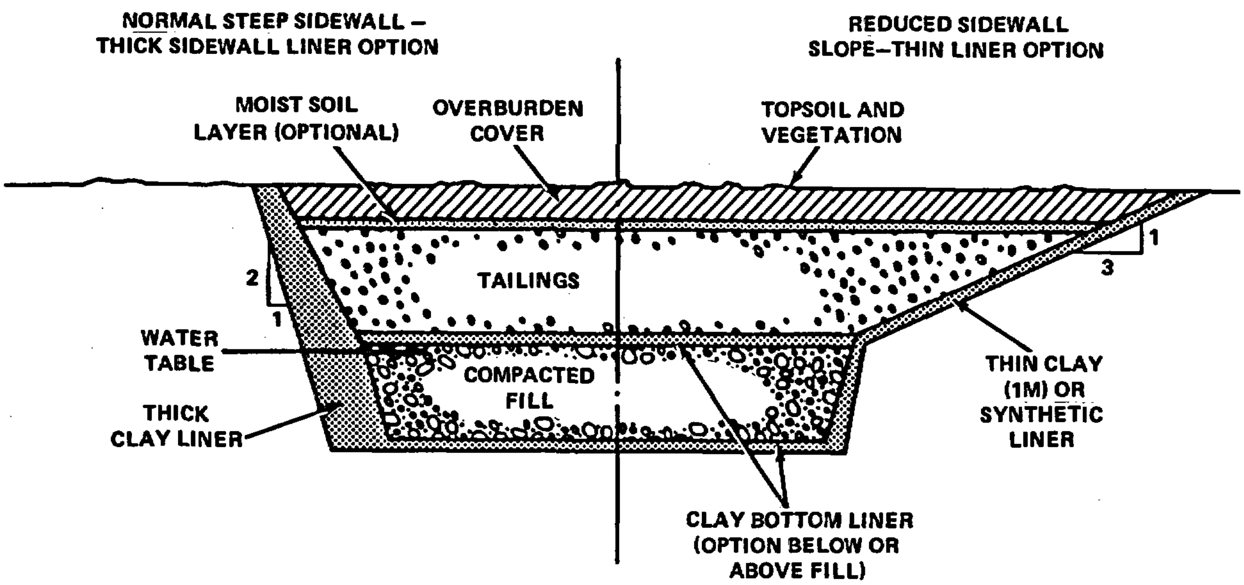
Tailings slurry would be transported to the disposal site in a pipeline, then the slurry would be either (1) filtered on a horizontal vacuum filter to remove part of the water, or (2) gravity drained by means of an in-situ dewatering system. If the first procedure were followed, the filtering device would convert the slurry into a semidry cake (moisture content of 20% or more) which would then be hauled to the disposal pit by truck or by a belt conveyor system. Under the second procedure, the slurry would be discharged directly into the tailings impoundment, the bottom of which has been prepared to promote the gravity draining of liquids. Water from (1) the horizontal filter and (2) dewatering system would be pumped to an evaporation pond [area of about 40 ha (100 acres)].

After additional drying in the disposal pit to allow for movement of heavy machinery, the tailings would be covered as in Alternative 2. Alternative 3 is depicted schematically in Figure 8.6.



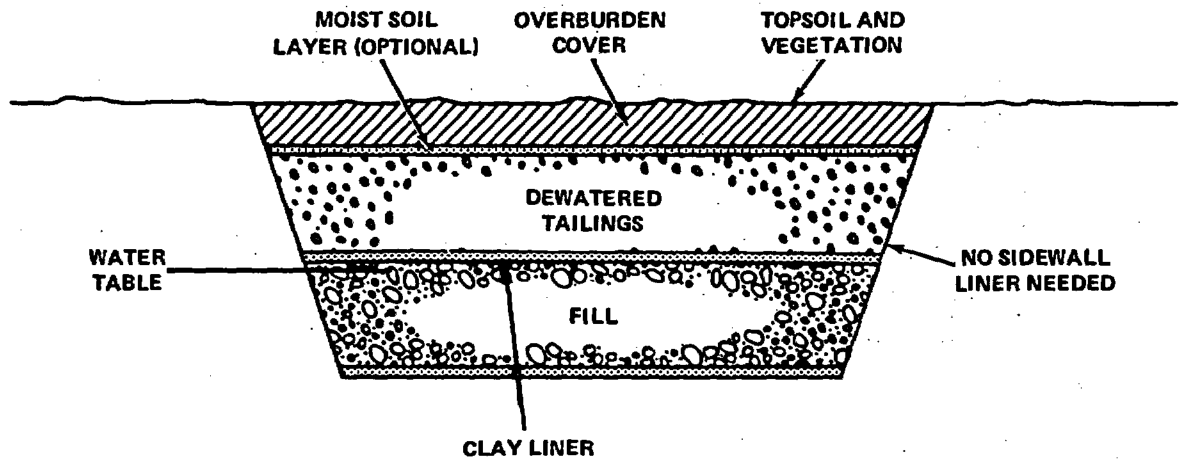
– ALTERNATIVE 1 –

Figure 8.4 Above Grade Disposal – Continued,
Active Care Required



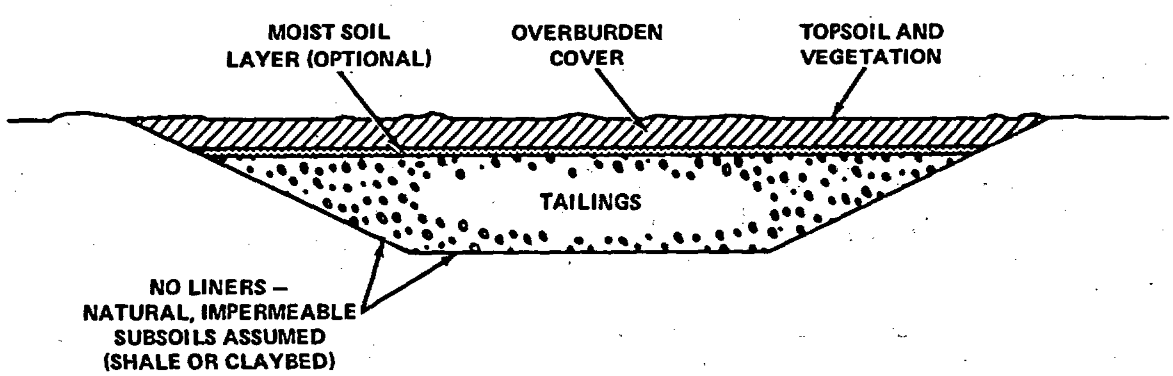
– ALTERNATIVE 2 –

Figure 8.5 Disposal of Tailings Slurry in
Available Open-Pit Mine



– ALTERNATIVE 3 –

Figure 8.6 Disposal of Dewatered Tailings in Available Open-Pit Mine



– ALTERNATIVE 4 –

Figure 8.7 Disposal in Specially Excavated Below-Grade Pit

8.4.5 Alternative 4

Alternative 4 would allow more freedom in selection and design of the disposal site, and no liners would be needed. It represents a case where an open pit mine is not available for tailings disposal, so a specially excavated pit is dug. An isolated area having relatively impermeable subsoils, such as shale or clay, would be located and a pit excavated. Untreated tailings slurry then would be sent to the pit from the mill by pipeline and placed within the shale or clay layer. Part of the water would be recycled and the tailings would dry in the pit as a result of evaporation due to solar heat and dry winds; however, it is likely that an auxiliary evaporation pond would be required.

At the end of mill operations, the tailings would be allowed to dry completely and then would be covered with overburden stockpiled during the initial excavation. The surface would be restored and vegetated to conform with current regulations. Alternative 4 is shown schematically in Figure 8.7. Such special excavations could be constructed in "cells" which would hold several years' worth of tailings at a time instead of as one large impoundment; such an approach would reduce the initial investment required, would reduce the amount of overburden handling required, and would allow for a phased covering and reclamation of the tailings area.

8.4.6 Alternative 5

Under Alternative 5, as under Alternative 4, a special impoundment would be excavated for the disposal of untreated tailings; however, the tailing impoundment would be lined because no impermeable geologic formation is assumed. The total tailings disposal area would be in the form of a rectangle 1060 m (3500 ft) by 1200 m (4000 ft), within which a series of trenches similar to those used in landfill disposal of waste would be excavated (see Fig. 8.8).

A section of the trench of sufficient size for about two years' worth of tailings would be excavated and lined first. Later sections would be built as needed. Temporary dikes would be built across the trench, to isolate tailings water from construction areas. The water balance would be similar to that of Alternative 4. Sealing, backfilling, and restoration could follow in a few years after a trench area was filled with tailings. Construction, filling with tailings, and restoration would move along the length of the trench in sequence. The length of pipeline used to deliver the slurried tailings would vary; however, an average length of 16 km (10 miles) is assumed.

The potential advantages of Alternative 5 are that the reclamation of the mill tailings would be staged, and the exposed tailings areas during operation would be reduced from those of the other alternatives, where reclamation is not staged. Another potential advantage of this option would be that slimes could be segregated from sands and covered by careful deposition of the tailings slurry. If introduced at the upstream end of the trench, tailings would form a "ramp," with sands depositing first and slimes being carried to the lower end by the tailings solution.

Alternative 5 is generally representative of staged management systems. A number of recently proposed systems[13-15] would fall into this general category.

8.4.7 Alternative 6

Although tailings would be disposed of above grade in Alternative 6, design and siting features incorporated into the disposal program would minimize or eliminate the effects of natural erosion, to an extent reasonably equivalent to that under Alternatives 2 through 5. Topography is one of the primary factors which would determine the degree to which the tailings disposal area will be exposed to erosion forces. However, because topographic features are so highly variable, it would be inappropriate to define them in any great detail in this generic study. The kind of general features which would make this alternative reasonably equivalent to below-grade burial are:

(a) A site is chosen where the upstream drainage area is very small. This would mean, for example, that the impoundment would be near the top of a divide.

(b) Site topographic features provide shelter of the tailings area from wind, i.e., the face of the embankment is not exposed directly to prevailing winds.

(c) Final reclamation is carried out in such a manner that embankments and cover are contoured to make very gradual slopes.

(d) Tailings are covered with reasonably thick soil and overburden materials. The overburden is stabilized with vegetation, or rock riprap and cobbles as appropriate, to reduce any wind and water erosion to negligible levels.

(e) The dam is constructed according to accepted geotechnical engineering standard practices to ensure stability during the operational period (principles outlined in Regulatory Guide 3.11 are followed).

(f) The tailings disposal area is not sited near a potentially active geologic fault.

(g) Design features combine to cause deposition of sediment on the tailings area from what runoff does occur across the impoundment area.

A more detailed discussion of long-term stability and the factors which influence it are presented in Section 9.4.1.

Water would be recycled to the mill and/or routed to an evaporation pond. A final covering of soil would be emplaced as in Alternative 1. Alternative 6 is shown schematically in Figure 8.9.

8.4.8 Alternative 7

Under Alternative 7, tailings slurry (50% solids) would be transferred by pipeline to the edge of a depleted open mine pit; sands (coarse fraction) and slimes (fine fraction) of the slurried tailings then would be separated. The slimes would be neutralized with lime and dried with disk filters, then fixed (along with the aqueous mill wastes) in cement or asphalt before final disposal in the old surface mine. The slimes constitute 30% of the solids but contain 70% of the radioactivity in the tailings. If the slimes are fixed in cement or asphalt, their potential for radioactive contamination of the environment would be greatly reduced. The sands would be washed with clean water, filtered by horizontal belt filter, and deposited in the unlined mine pit.

The type of drying used for the slimes would depend on their chemical and physical properties. Heated mechanical dryers would require a source of heat, assumed here to be western coal with a heat content of 8500 Btu per pound. Filtration rates for certain slimes are impractically slow, or the water cannot be removed by filters to a level where direct mixing with asphalt or cement would be feasible. Drying of slimes by use of a heated mechanical dryer (rotary, spray, or wiped film) may not be feasible. In such cases, the outdoor slimes drying area and separate evaporation pond may be the only practical drying methods.

When sufficiently dry, the slimes would be combined with portland cement (1 part cement to 5 parts tailings) or asphalt (1.5 parts asphalt to 2 parts tailings) and deposited in the mine pit for hardening. Both the fixed slimes and the washed sands are assumed to be sufficiently resistant to leaching that exposure to groundwater would be permissible. On completion of tailings operations, the mine pit would be backfilled with overburden and the surface restored. Alternative 7 is shown schematically in Figure 8.10.

8.4.9 Alternative 8

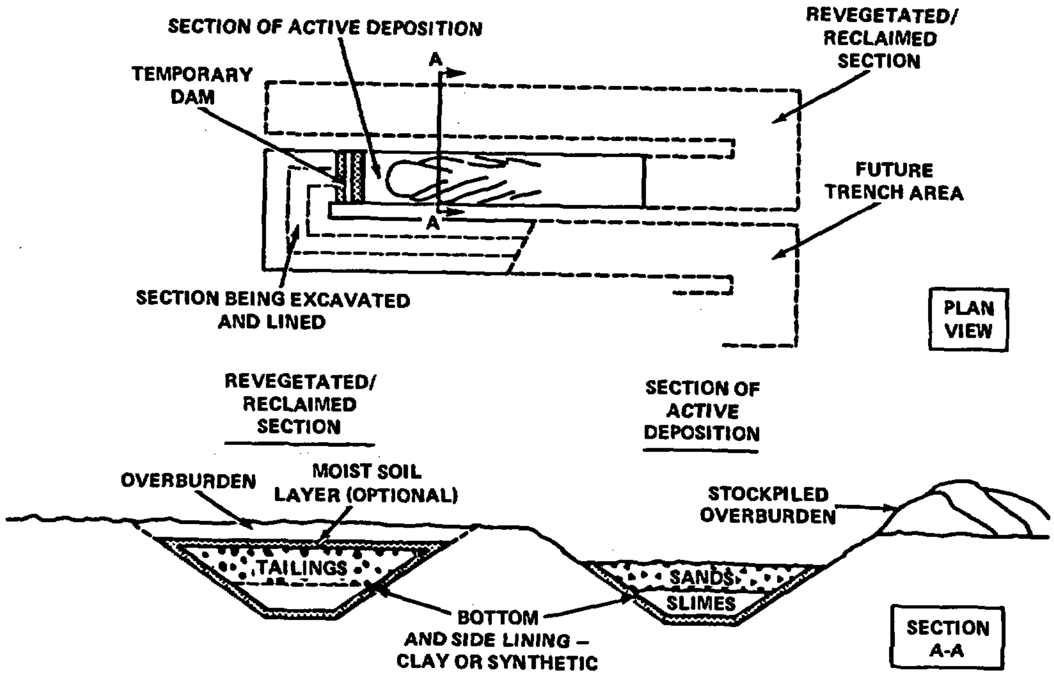
Alternative 8 differs from Alternative 7 in that an available deep mine of sufficient size, rather than a surface mine, would be used for tailings disposal. As in Alternative 7, the sands would be washed and filtered and the slimes neutralized, dried, and fixed in cement or asphalt before deposition. It is assumed that the cement and pretreatment plant would be adjacent to the disposal area, and that the cement or asphalt slurry could be pumped to the shaft. The shaft could be either an old ventilation shaft or a rough-cased access boring [about 0.4 m (16 inches)] installed for this purpose. This alternative is depicted in Figure 8.11.

The existing tunnel system and entrances from the tunnel used to mine the ore cavity would have to be carefully and completely sealed to prevent any leakage of waste into these tunnels, which lie below mined ore cavities. Such care would be especially critical if the tunnels were still in use.

The advantages of Alternative 8 would be fixation and deep burial, which would eliminate surface emissions and fix radionuclides in place. Also, the potential for human intrusion would be virtually eliminated.

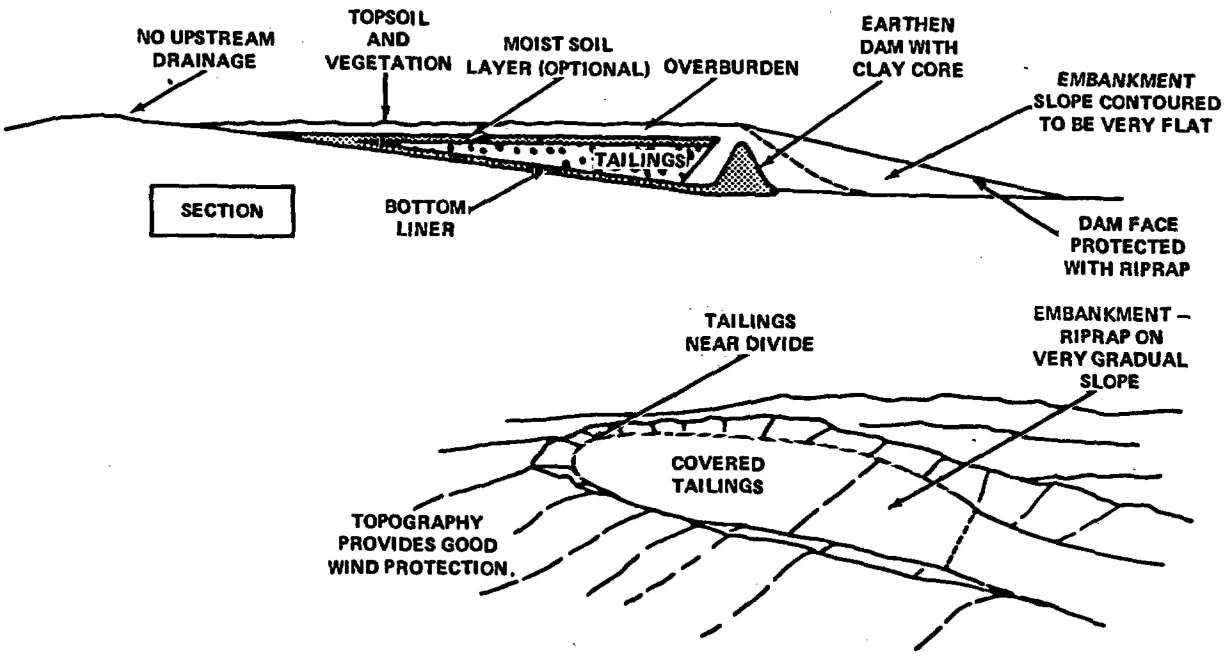
8.4.10 Alternative 9

Alternative 9 is the only one described in this section which is based on a major change in the mill process. It involves substitution of nitric acid for sulfuric acid, as the leaching agent for the ore. Since nitric acid would remove more than 90% of the radium and thorium in the ore, less than 10% of the radioactive materials would be contained in the tailings; thus the potential impacts of the tailings on the environment would be reduced. However, the radioactivity transferred from the tailings to the liquid process stream, which also contains the uranium, would require special in-plant treatment and would still have to be disposed of in a safe



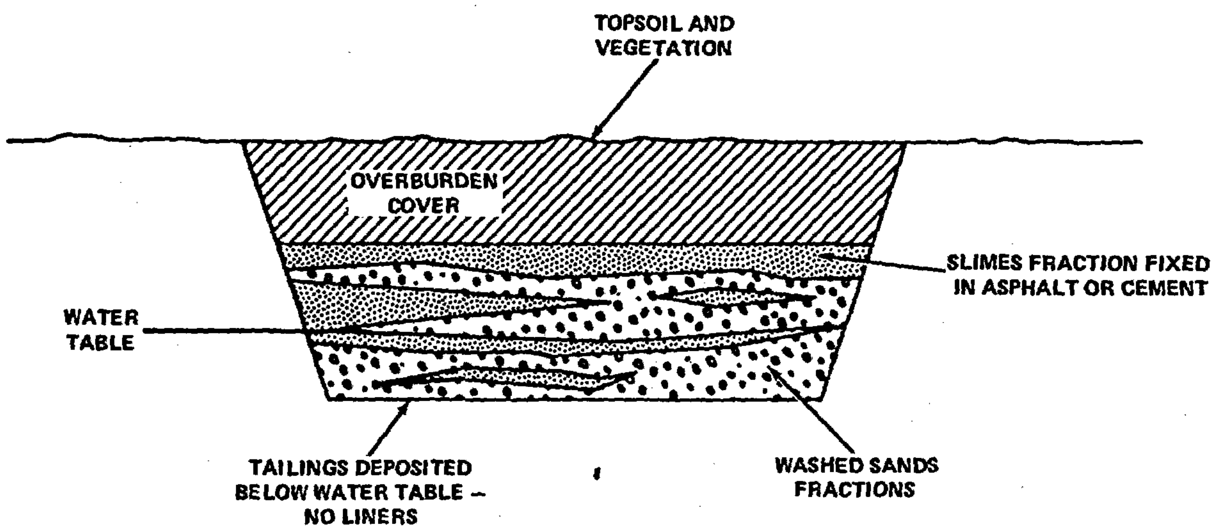
– ALTERNATIVE 5 –

Figure 8.8 Disposal in Specially Excavated Below-Grade Trench



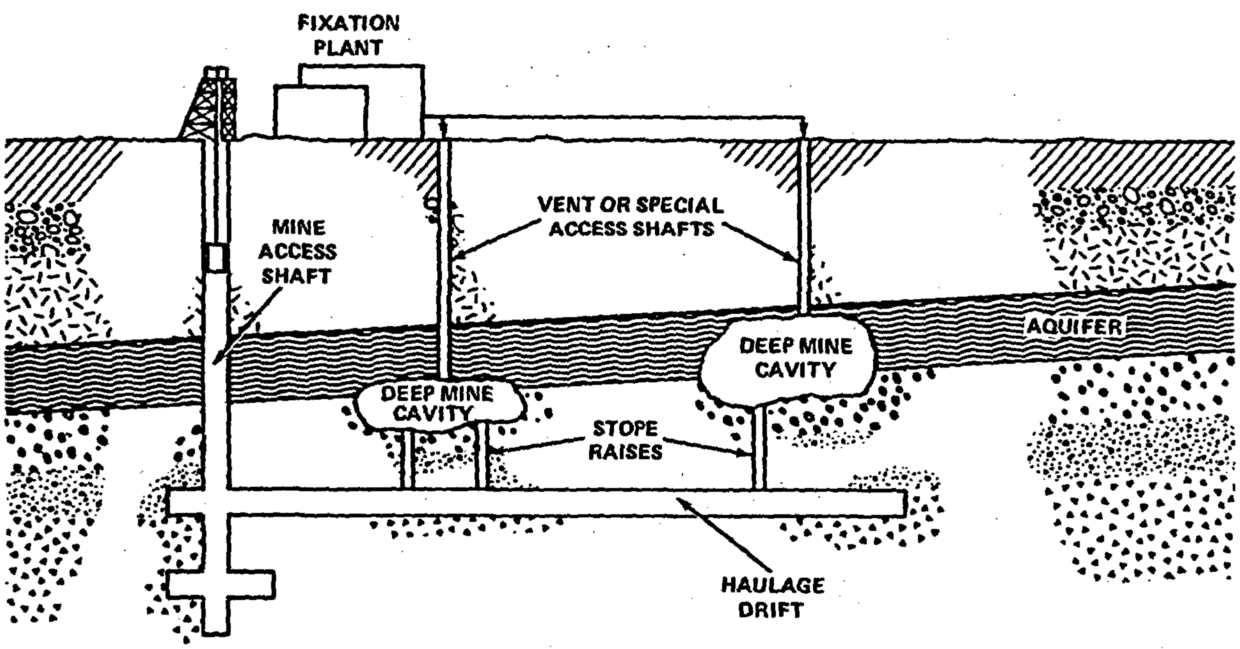
– ALTERNATIVE 6 –

Figure 8.9 Tailings Disposed of Above Grade With Special Siting and Design Features



– ALTERNATIVE 7 –

Figure 8.10 Fixation of Slimes Tailings Fractions With Asphalt or Cement – Disposal in Available Open Pit



– ALTERNATIVE 8 –

Figure 8.11 Fixation of Slimes Tailings Fractions With Asphalt or Cement – Disposal in Deep Mines manner. Ra-226 and Th-230 concentrates would be calcined and fixed in cement or asphalt and buried at 10m (30 ft) depth, thus eliminating radioactive surface emissions. Also, since removal of the radium and thorium would not be complete, the tailings would still require careful disposal. This process is described in more detail in Section 8.3.1.1.

More detailed information on these nine alternatives is presented in Appendix K.

8.5 ALTERNATIVES FOR DECOMMISSIONING OF MILL AND MILL SITE

Alternative modes of decommissioning are described in this section and the environmental consequences of these actions are examined in Section 9.5. The monetary costs of the actions required to return the mill site (excluding the tailings area), the mill buildings, and any offsite contaminated areas to conditions suitable for unrestricted general use are described in Section 11.3. It is assumed that no tailings material would have been removed for use in offsite construction and, therefore, that no decontamination of offsite buildings would be necessary.

The alternatives to be considered are: (1) the retention and use of some or all of the buildings and equipment after decontamination; and (2) the complete removal of all buildings, foundations, and equipment, with the restoration of the site to its original state. The abandonment of the mill and site without decontamination, and with or without fences and guards, is not considered a feasible alternative.

On cessation of mill operations, all salvageable equipment would be decontaminated to acceptable levels of surface radioactivity. Nonsalvageable equipment would be removed from the buildings and buried in the tailings impoundment area. Concrete floors, foundations, sumps, and subsurface piping with unacceptably high levels of uranium and daughter nuclides would be broken up, removed, and buried in the tailings area. Contaminated earth beneath the foundations and equipment removed would be excavated to the required depth and also taken to the tailings area. The building would be decontaminated; any porous contaminated material, such as concrete block, would be removed. For Option 1, equipment could be removed from the buildings as desired, and the buildings would then be available for unrestricted use. For Option 2, the buildings would be removed, and uncontaminated foundations broken up and used as fill or riprap, on steep or erodible slopes.

Areas outside the buildings and not covered with equipment would be treated identically in the two options. Heavily contaminated areas, such as ore pads and sludge or collection ponds, would be excavated, generally to a depth of a few meters, and the dirt removed to the tailings pile. The extensive onsite and offsite areas lightly contaminated by dust blown from the ore pad, mill and tailings is expected to be excavated to a relatively shallow depth [10 to 15 cm (4 to 6 inches)], with contaminated dirt being taken to the tailings impoundment. Finally, all excavated areas would be backfilled and graded, topsoil would be added where necessary, and the areas would be revegetated.

Generally, all metal-surfaced equipment can be decontaminated and reused. The types of equipment salvageable include crushers, grinders, rod mills, valves, pumps, steel tanks, and various other special items. For decontamination, simple procedures, such as sandblasting or scrubbing with detergents, should be successful.

Soft-surfaced or porous materials, e.g., wood, fiberglass, plastic, concrete, concrete block, or rubber-surfaced equipment, generally cannot be decontaminated economically, and must be removed and buried in the tailings area. Electric motors exposed to radioactive solutions usually cannot be decontaminated. In some cases, high-quality lumber used for tank shells can be reused in new uranium mills, but not otherwise.

Mill buildings of bolted prefabricated steel construction, as assumed for the model mill, have rarely presented any decontamination problems. In some mills, however, large amounts of yellowcake dust or of uranium daughter nuclides have accumulated in inaccessible areas, such as overhead support members or rafters; such hazards must be guarded against when the building is dismantled. In areas where acid solutions are handled, uranium and its decay products have penetrated concrete foundations and the earth below to a depth of a few meters. The contaminated foundations and dirt must be removed regardless of whether the entire building is to be reused or removed. In the case of the model mill, it is assumed that extensive areas of concrete and dirt contamination would be present. Although the decontamination of equipment and buildings is not generally hazardous or difficult, protective equipment and proper supervision of workers are required.

In several mills where production has ceased, the salvageable equipment has been sold or transferred to new mills owned by the same company. Much of this equipment is of use in general ore-processing operations, and thus markets should be available. For the model mill, it is assumed that the salvageable equipment would be removed without cost to the mill operator.

A more complete discussion of decommissioning operations is given in Appendix K-7.

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9. ENVIRONMENTAL IMPACTS OF ALTERNATIVES

9.1 INTRODUCTION

The analysis of the base case model mill in Chapter 6 identified four major potential impacts for the single mill: (1) the probability that during the operation of the mill particulate emissions due to dusting of tailings materials and other radioactivity sources would result in an unacceptable degree and extent of ground contamination and dose commitments to nearby individuals in excess of applicable standards (40 CFR 190); (2) the existence of very low doses to large numbers of people over long periods of time resulting from radon releases from uncovered tailings piles; (3) the potential for contamination of groundwater by toxic ions (e.g., sulfate and selenium) seeped from unlined tailings ponds; and (4) the permanent commitment of land to waste disposal. Various alternative methods of reducing these impacts are described in Chapter 8.

The purpose of this chapter is to evaluate the effects of applying alternative methods of emission control and waste management to uranium milling operations. The environmental impacts of the various alternatives described in Chapter 8 are analyzed by considering what the effects would be in the model region if the alternatives were implemented at the model mill. This approach facilitates the comparison of the alternatives among themselves and with the base case (Ch. 6); in particular, it demonstrates how the impacts identified for the base case may be reduced.

A wide range of alternatives is considered in varying degrees of detail and depth. Most attention is devoted to tailings management alternatives, because the environmental impacts from continued existence of the tailings extend over a long period of time compared with the operational period of the mill. The analysis of the base case indicates that the tailings area would be the major source of radiological effects, both during and after milling; thus, an assessment of alternatives suitable for mitigation of these effects is desirable.

All of the alternatives were evaluated in the same manner as was the base case; i.e., the impacts to air quality, water quality, soils, etc., were considered, and then a comparison to the base case was made. An attempt was made to evaluate the incremental improvement that would result from implementation of each alternative; in those cases where this proved feasible (Secs. 9.2 and 9.3), a quantitative estimate of the improvement was possible. This provides a measure of the "benefit" of the alternative to be weighed against its "cost" (Ch. 11). A final cost-benefit evaluation of major aspects of alternatives, as identified in Chapters 9 and 11, is presented in Chapter 12 with corresponding proposed actions.

The long-lived nature of the radiological hazard of uranium mill tailings makes long-term institutional control of the disposal site a major consideration in evaluation of disposal programs; thus, alternatives are also evaluated in Section 9.4, with respect to the degree to which tailings are isolated. In the light of this evaluation, consideration is given to the type of long-term control likely to be needed to supplement engineered and natural barriers to radioactivity.

The tailings isolation provided by various alternatives is assessed by examination of two separate, but related, questions:

(1) How well will the isolation provided withstand natural forces, such as erosion, to which the disposal site will be exposed (Sec. 9.4.1);

(2) What risks are associated with potential human activities at or near the site (Sec. 9.4.2).

Although the questions are interrelated, they are treated separately because of their different nature. The former poses the problem of isolation of the tailings from the inevitable, continual processes of nature; if the problem can be solved, continuing active care of the disposal site can be avoided. The second question, involving as it does human activities, deals with risks that are very difficult to predict. The worst-case scenario, which postulates unknowing encroachment into the tailings sometime in the future, poses the problem of inadvertent human contact with excessive radioactivity; the necessity for land use control to avoid unacceptable exposures is examined. Consideration of long-term monitoring and control activities at tailings disposal sites that includes consideration of both natural forces and human activities is presented in Section 10.3 and further discussed in Appendix R.

9.2 CONTROL SYSTEM ALTERNATIVES

The function of the control system alternatives described in Section 8.2 would be to limit gaseous and particulate emissions during mill operation. The changes that would occur in environmental impacts if these alternatives were implemented are described in the following sections.

9.2.1 On Air Quality

As indicated in Sections 6.2.1 and 6.3.1, the most significant potential impact on air quality from milling operations is the increase in suspended particulates that will occur from dust produced. The major sources of dust will be those produced by blowing over dried tailings surfaces and by traffic on haul roads. In the uncontrolled base case involving operation of a 12-mill cluster, it was shown that air quality limits could be exceeded at a reference location 1 km from the central mill. (An annual concentration of 65 $\mu g/m^3$ is predicted; this would exceed limits in some states such as Wyoming where the limit on suspended particulates is 60 $\mu g/m^3$.) With application of dust controls identified in Chapter 8 such as sprinkling of roads, and wetting or chemical stabilization of dried tailings beaches, resultant concentrations could be reduced to levels well within limits. For example, with 50% and 90% control of road dusting and tailings surfaces respectively, concentrations at the 1 km reference location would be reduced to about 45 $\mu g/m^3$. Achieving these levels of control would require constant management attention, particularly during dry periods, since the chemical spraying or wetting controls will only last for relatively short periods of time.

9.2.2 On Topography and Land Use

Control systems would significantly reduce the degree of land contamination that would occur as a result of blowing tailings. To the degree that such contamination is reduced or eliminated, restriction of land uses would be avoided. The costs and disruptive effects of eventual site decontamination would also be reduced.

9.2.3 On Mineral Resources

All control system alternatives considered would have impacts identical to those of the base case.

9.2.4 On Water Resources

9.2.4.1 Surface Water

The control system alternatives that would reduce the dispersal of particulates to ephemeral stream beds or mine dewatering streams would reduce the impact on water quality proportionately. Confinement of contaminant-carrying runoff from the mill site would still be necessary.

9.2.4.2 Groundwater

The impacts of the alternatives considered would be similar to those of the base case.

9.2.5 On Soils

Effective dust control measures would minimize the incremental addition of sodium, sulfate, chloride, and nitrate compounds to natural concentrations in the soil. Also, the reduction of primary production by dust deposition on leaf surfaces under conditions of the base case would be prevented by the dust control option; indirectly, this would reduce soil erosion by providing for better growth of vegetation.

9.2.6 On Biota

9.2.6.1 Terrestrial

Effective dust control would reduce impacts from deposition of tailings particles on vegetation; such impacts include decrease in primary productivity and increase in toothwear of grazing animals. The effects of tailings dust inhalation by animals would also be decreased by dust control.

9.2.6.2 Aquatic

The effect of dust on the aquatic habitat in the model region is minimal; therefore, the control system alternatives considered for particulate emission control would have only a slight positive influence on water chemistry and aquatic biota.

9.2.7 On the Community

The alternatives considered would have impacts identical to those of the base case.

9.2.8 Radiological

9.2.8.1 General

In the base case analysis, a low level of emission control was assumed for the major radioactive sources at the mill: the ore storage pad, crushing and grinding operations, ore bins, yellowcake dryer and tailings. Under the base case no steps were taken to control dusting from the ore storage pad or from dried areas of the mill tailings impoundment (which comprised 62.5% of the tailings surface area). Less than the most efficient rated stack control devices were employed. As a result, individual exposure limits (40 CFR 190) were not met at the reference locations evaluated.

Section 8.2 identified alternative control methods which can be used to reduce emissions during mill operations. Table 9.1 summarizes representative, available methods selected by the staff from among those described in Chapter 8, to illustrate the effects of increasing the level of emission control in increments above the base case. These controls include the following: using water sprays or chemical stabilizers at the ore pad; improved filtering and wet, semi-autogenous grinding to reduce or eliminate dusting which occurs from dry crushing of ore; improved filtering or wet shipment to reduce or eliminate yellowcake emissions; and, stablizing dry tailings surfaces with surface wetting or chemical spraying. Effluent reductions attributable to the use of progressive tailings area reclamation schemes are also evaluated.

Table 9.1, and Tables 9.2 and 9.3, which show what contributions to offsite individual and population exposures are made by various sources under the base case, provide an indication of the relative importance of mill sources. From the releases and resultant exposures summarized, it is clear that fugitive dust releases from the ore pad and grinding and crushing operations are relatively insignificant. Furthermore, these releases do not present an obstacle in terms of meeting the requirements of 40 CFR Part 190. However, in order to meet the 25 mrem/yr limit of 40 CFR Part 190 at all three locations, tailings pile particulate releases and yellowcake emissions would have to be simultaneously reduced by substantial fractions. Tailings pile and yellowcake releases are also dominant in the production of regional population dose commitments, as shown in Table 9.3.

The effects of incorporating available emission controls into the base case model mill are shown in Table 9.4 for individual doses at the three reference receptor locations, and in Table 9.5, for regional population dose commitments. At all three reference receptor locations, air concentrations resulting from operation of the model mill under the base case were previously shown in compliance with the limits for unrestricted areas specified in 10 CFR Part 20. For the base case model mill, doses at the fence post location are within the 25 mrem/yr limit of 40 CFR Part 190, for limited occupancy with no ingestion of locally grown food. At the trailer location, compliance with 40 CFR Part 190 depends on emission controls, and also on the assumed occupancy and ingestion pathways. For an occupancy factor of 50% with the vegetable ingestion pathway present, compliance with 40 CFR Part 190 would require, as a minimum, that base case particulate emissions from dry tailings be reduced by about 80% and that yellowcake emissions be reduced by 50%; this would create a very borderline situation wherein the particulate lung dose would be almost precisely equivalent to the 25 mrem/yr limit, leaving no margin for off-normal releases, allowance for contributions from other nearby facilities, or recognition of the increased tailings area effluents after operations cease and the pile dries out. As indicated in Table 9.4, 40 CFR 190 compliance would be achieved at the trailer location, with sufficient margin, with base case emission reductions of 40% for ore pad and grinding releases, 90% for yellowcake stack releases, and 80% for tailings area particulate releases. These control levels would also be sufficient to establish compliance for the ranch location.

Total population doses would not be markedly reduced, however, unless radon emissions from the tailings area were abated, because radon from the tailings is the primary source of population exposure both within the site region and beyond 80 km (50 miles). The most effective way to reduce operational radon releases is to progressively reclaim tailings disposal areas, as they are filled by utilizing a series of small impoundments rather than a single large impoundment. As indicated in Table 9.5, population doses from mill operation can be reduced greatly by employing available control technology and sequential cell tailings impoundment construction, filling, and reclamation.

Two relatively recent developments are noteworthy in that they can potentially eliminate yellowcake and dry ore crushing emissions. These alternatives are use of wet, semiautogenous ore grinding and wet product shipment from the mill. Tables 9.2 and 9.3 show that employing these methods can reduce offsite exposures but also show that the incremental benefits will be only modest, because the affected sources are small in comparison to the tailings source. Greater potential benefits are offered in the area of occupational exposure, which is discussed below.

Table 9.1 Effect of Improved Controls on Radioactive Emission Rates from Model Mill

Source and Control Level[a]	Emission Rate: Particulates (mCi/yr)	Emission Rate: Radon (Ci/yr)
Ore Pad		
Base case (0%)	0.67[c]	68[b]
Windbreak (20%)	0.54[c]	
Water Sprinkling (50%)	0.34[c]	
Chemical Stabilization (90%)	0.07[c]	
Ore Crushing and Grinding		
Base case (0%)	0.90[c]	
Bag filter (33%)	0.60[c]	
Semi-autogenous grinding (100%)	0	
Yellowcake Drying and Packaging		Negligible
Base case (0%)	150[d]	
Venturi scrubber and demister (90%)	15[d]	
Slurry product (100%)	0	
Tailings Pile		
Base case (0%, 50 ha dry)	120[e]	4500[f]
Water Sprinkling (50%)	60[e]	3600[f]
Chemical stabilization (80%)	24[e]	4500[f]
Progressive reclamation (67%)	40[e]	1500[f]

[a]Percentage of reduction in emissions from the base case particulate source is given in parentheses.

[b]Total release from ore through all stages before leaching; unaffected by application of controls.

[c]Emission rate for each of the long-lived isotopes (U-238, U-234, Th-230, Ra-226, Pb-210, Po-210).

[d]Emission rate for U-238 and U-234, others are much lower.

[e]Emission rate for Th-230, Ra-226, Pb-210, Po-210. Values are about 93% lower for uranium isotopes.

[f]Radon releases shown include those from the tailings area and those arising from dispersed ore and tailings particulates.

Table 9.2 Base Case Individual Doses at Reference Locations, by Release Source, During the Final Year of Mill Operation

Location	Source of Releases	40 CFR Part 190 Dose, mrem/yr			Total Dose, mrem/yr			
		Whole Body	Bone	Lung	Whole Body	Bone	Lung	Bronchial Epithelium
I. Fence (site boundary)[a]	Ore pad, G. and C.	0.017	0.493	0.853	0.055	0.531	0.891	2.01
Occupancy: 10%	Yellowcake D. and P.	0.178	2.28	13.7	0.181	2.28	13.8	0.0
0.64 km ENE	Tailings Pile	0.244	4.62	3.92	4.28	8.66	7.96	125.
	All sources	0.439	7.39	18.5	4.52	11.5	22.7	127.
II. Trailer[b]	Ore pad, G. and C.	0.076	1.56	1.94	0.166	1.19	2.03	5.20
Occupancy: 50%	Yellowcake D. and P.	0.590	7.75	40.1	0.595	7.76	40.1	0.0
0.94 km ENE	Tailings Pile	5.43	69.7	15.3	16.1	80.4	25.9	324.
	All sources	6.10	79.0	57.3	16.9	89.4	68.0	329.
III. Ranch[c]	Ore pad, G. and C.	0.034	0.677	0.808	0.085	0.728	0.858	2.93
Occupancy: 100%	Yellowcake D. and P.	0.306	4.04	20.6	0.310	4.05	20.6	0.0
2.0 km ENE	Tailings Pile	3.13	40.2	8.64	9.25	46.3	14.8	181.
	All sources	3.47	44.9	30.0	9.65	51.1	36.3	184.

[a]No ingestion doses included.

[b]Vegetable ingestion doses included.

[c]Vegetable and meat ingestion doses included.

Table 9.3 Base Case Dose Commitments Received by Regional Population, by Release Source, Person Rem/Year

Source of Releases	Whole Body	Bone	Lung	Bronchial Epithelium
I. Annual Population Dose Commitment[a]				
Ore pad, G. and C.	0.048	0.406	0.111	1.28
Yellowcake D. and P.	0.055	0.841	1.24	0.0
Tailings Pile	3.40	27.2	4.51	83.6
All Sources	3.50	28.5	5.86	84.9
II. Annual Environmental Dose Commitment[b]				
Ore pad, G. and C.	0.060	0.463	0.123	1.28
Yellowcake D. and P.	0.072	0.901	1.26	0.0
Tailings Pile	4.52	31.8	5.64	83.6
All Sources	4.65	33.2	7.03	84.9

[a]Dose commitments shown are those due to all exposure during the final year of operation.

[b]Dose commitments shown are those due to releases during the final year of operation.

In summary, Table 9.4 shows that 40 CFR 190 limits can be met at locations near the model mill but only with a high degree of tailings surface control and with an efficient yellowcake dust collection system. Since tailings dust controls are not automatic, constant vigilance and management attention to the status of tailings surfaces will have to be exercised in order to meet offsite dose limits. With regard to yellowcake emissions, a factor which is just as important as rated collection device efficiency is proper and continuous control operation. It is imperative that yellowcake drying and packaging operations that can produce yellowcake dust be secured when the stack control is not operating properly. This obviously calls for frequent checks of the yellowcake stack control device to determine when it is not operating properly, as well as effective administrative controls barring product operations during periods of malfunction.

The previous discussion focuses primarily on the effects of controls in a case involving operation of a single mill for one year, and on the problem of meeting individual exposure limits. Table 9.6 presents a broader perspective on the potential health risks associated with the relatively high level of control required to meet 40 CFR 190 at nearby locations. Total exposures (including contributions from radon and daughters) are presented for the individual living at the ranch, and an average individual living in the milling region, for both the cases involving isolated mill operations and operation of a mill cluster (12 mills). The table shows what potential health risks are faced by these selected individuals as a result of exposure to releases from a full 20-year mill lifetime. More specifically, the table indicates the following:

1. Total exposures and risks to the maximum individual would be reduced to about one third of those risks presented by background radiation, in the case of 12 mills operating in a region. These risks would amount to a chance of about 1 in 2000 of premature death, due to cancer induced by radiation exposure resulting from 20 years of mill existence, by each of 12 mills.

2. The risks to the average individual in the milling region would reduce to small fractions (less than 2%) of background radiation-induced risks, even in the worst-case mill cluster situation.

The above risks are those associated with a level of tailings dust control which would be a significant improvement over the base case, which is representative of past practice at mills. However, notwithstanding the facts that the risks estimated for this level of control would be small, compared to those occurring as a result of background radiation, and individual dose

Table 9.4 Effects of Emission Controls on Individual Doses at Reference Locations during the Final Year of Mill Operation

Location	Added Effluent Controls[a]	40 CFR Part 190 Dose, mrem/yr			Total Dose, mrem/yr			
		Whole Body	Bone	Lung	Whole Body	Bone	Lung	Bronchial Epithelium
I. Fence (site boundary) Occupancy: 10% 0.64 km ENE	None (base case)	0.439	7.39	18.5	4.52	11.5	22.7	127.
	A, B, and C	0.150	2.83	3.84	2.32	4.92	5.94	102.
	A, B, and D	0.077	1.45	2.67	1.02	2.39	3.62	127.
	A, B, and E	0.109	2.06	3.19	1.48	3.44	4.57	43.7
	A, C, and F	0.044	0.832	2.14	0.373	1.16	2.48	43.7
II. Trailer Occupancy: 50% 0.94 km ENE	None (base case)	6.10	79.0	57.3	16.9	89.4	68.0	329.
	A, B, and C	2.83	36.6	12.8	8.38	41.9	18.4	264.
	A, B, and D	1.20	15.7	8.23	3.90	18.1	10.9	329.
	A, B, and E	1.92	24.9	10.3	5.53	28.3	13.9	113.
	A, B, and F	0.467	6.36	6.19	1.41	7.03	7.13	113.
III. Ranch Occupancy: 100% 2.0 km ENE	None (base case)	3.47	44.9	30.0	9.65	51.1	36.3	184.
	A, B, and C	1.62	20.9	6.87	5.04	24.3	10.3	148.
	A, B, and D	0.681	8.85	4.28	2.80	11.0	14.1	184.
	A, B, and E	1.09	14.2	5.43	3.93	16.3	7.51	63.3
	A, B, and F	0.260	3.49	3.12	0.994	4.24	3.86	63.3

[a]Key to Effluent Controls:
A - ore pad, grinding, and crushing particulate releases reduced by 40%.
B - yellowcake releases reduced by 90%.
C - tailings particulate releases reduced by 50%; radon reduced by 20% (water sprinkling).
D - tailings particulate releases reduced by 80%; radon unchanged (chemical stabilizer).
E - tailings particulate and radon releases reduced by 67% (progressive reclamation).
F - tailings particulate releases reduced by 93.3%; radon reduced by two thirds (D&E together).

Table 9.5 Effects of Emission Controls on Dose Commitment Received by the Regional Population, Person-Rem/Year[a,b]

Added Emission Controls[c]	Annual Population Dose Commitments				Environmental Dose Commitments			
	Whole Body	Bone	Lung	Bronchial Epithelium	Whole Body	Bone	Lung	Bronchial Epithelium
None (base case)	3.50	28.5	5.86	84.9	4.65	33.2	7.03	84.9
A, B, and C	2.33	17.9	3.20	68.2	2.92	21.2	3.78	68.2
A, B, and D	2.29	16.3	3.07	84.9	2.56	17.6	3.34	84.9
A, B, and E	1.17	9.49	1.71	29.2	1.56	11.9	2.10	29.2
A, B, and F	0.795	5.70	1.16	29.2	0.889	6.98	1.26	29.2

[a]Dose commitments are those received by the model regional population from the final year of mill operation.

[b]Since food export is assumed, the total dose commitments would be larger than those presented in this table (see Table 6.15).

[c]Key to emission controls:
A - ore pad, grinding, and crushing particulate releases reduced by 40%.
B - yellowcake releases reduced by 90%.
C - tailings particulate releases reduced by 50%; radon reduced by 20% (water sprinkling).
D - tailings particulate releases reduced by 80%; radon unchanged (chemical stabilizer).
E - tailings particulate and radon releases reduced by two thirds (progressive reclamation).
F - tailings particulate releases reduced by 93.3%; radon reduced by two thirds (D&E together).

limits are met, the fact that any potential health effects can occur calls for reducing emissions to as low as reasonably achievable. This is also necessary to avoid unnecessary ground contamination, which will lead to problems in final site decommissioning and cleanup.

The emission controls evaluated in terms of reductions in radiation exposures and associated risks in Table 9.6 were only those necessary to establish an adequate margin of compliance with the 25 mrem per year maximum individual exposure limit specified in 40 CFR 190, which does not apply to exposures from radon or its radioactive daughters. It should be noted that although these controls are estimated to be quite adequate to assure 40 CFR 190 compliance, they do not provide substantial reductions to overall radiation risks. Residual risks amount to greater than 84% of those arising from base case radioactivity emission levels. This is because base case risks arise primarily from radon emissions from the tailings impoundment, and these emissions are essentially unaffected by emission controls necessary to meet the 25 mrem per year limit of 40 CFR 190. The residual risks indicated in Table 9.6 are almost exclusively due to radon emissions from the tailings area. In order to reduce these residual risks, it is necessary to reduce the area of exposed dry tailings. This may be accomplished either by increasing the fraction of the tailings impoundment which is covered by standing water, which would greatly exacerbate reclamation problems, or by reducing the operational impoundment area, by progressively reclaiming a series of smaller tailings impoundments as they are filled.

Table 9.6 Radiological Impact to Selected Individuals with Control

	Dose Commitment, mrem/yr[a]			Risk of Premature Death from Exposure to Mill Releases Over 20 years	Risk from Mills as % Increase in Risk Due to Background
	Whole Body	Bone	Lung	per 10,000[b,c]	Radiation[e]
Maximum Individual[d] (Ranch Location)					
1 Mill	2.8	11	200	3.2 (3.8)	22
Mill Cluster	5.4	16	310	5.0 (5.7)	34
Average Individual[d]					
1 Mill	0.040	0.28	1.5	0.026(0.029)	0.18
Mill Cluster	0.40	3.4	16	0.26(0.29)	1.8

[a] All doses are total annual 50-year dose commitments per year of operation. All doses are rounded to two significant figures.

[b] The range in risks due to uncertainties in health effects models extends from about 1/2 to 2 times the central value (App. G-7). This range does not include uncertainties in other areas (e.g., source term estimates and dose assessment models).

[c] Risks are presented for exposure received after entire mill life; that is, 15 years of exposure during the operation of the mill, and 5 years of exposure post operations while tailings are drying out are considered. This value is greater than 20 times the risk from annual exposures presented, because tailings releases increase in the period when tailings are drying. Figures in parentheses state risks estimated for base case.

[d] The effluent control levels assumed are those necessary to provide an adequate margin of compliance with 40 CFR 190. Reductions from base case emissions provided by these controls are: 40% for particulates from the ore pad, grinding, and crushing; 90% for yellowcake emissions; and 80% for particulates from the tailings area.

[e] The risk of premature death due to background radiation is estimated to be 7.4×10^{-5} for one year, or 1.5×10^{-3} for twenty years. The following annual background exposures are assumed for the model region: whole body, 143 mrem; bone, 250 mrem; and lung, 704 mrem.

Because increasing water cover in the tailings area is impractical, progressive reclamation schemes appear to offer the only feasible alternative for markedly reducing radiation risks associated with conventional uranium milling operations. Such a scheme as described in Chapter 8 would reduce base case operational radon releases by about 3,000 Ci per year, or by about 45,000 Ci over 15 years of operation. In the base case, or even with those emission controls necessary to comply with 40 CFR 190, about 32,000 Ci of radon would be released from the tailings area within 5 years of the end of active milling. With an equivalent 6-cell tailings impoundment system wherein each cell operates for 2.5 years and is dried and reclaimed in the ensuing 2.5 years, final reclamation could be accomplished within 2.5 years of the end of milling, with postoperational prereclamation radon releases amounting to perhaps only about 3,000 Ci (assuming one cell completely dry for 2.5 years). Thus, an additional 29,000 Ci of radon releases could be avoided, bringing the 20-year total radon release difference to a figure of about 74,000 Ci. These avoidable radon releases would yield health effects estimated to total about 0.11, due to regional exposures, and about 0.47 due to continental exposures (based on 1978 population data). Thus, employing a progressive reclamation scheme at the model mill, as opposed to a single large impoundment, is calculated to avert about 0.6 premature cancer deaths by reducing radon emissions. Other benefits would accrue from reduced particulate emissions and subsequent ground contamination.

Section 9.3 evaluates in a more comprehensive manner the overall problems of tailings management and disposal. In that section, 9 alternative tailings disposal methods are evaluated from a broader perspective than just control of emissions during operation.

9.2.8.2 Cumulative Dose Commitments and Health Effects to Occupational Workers

Cumulative dose commitments to occupational workers in United States uranium mills over the period 1979 to 2000 were estimated for the model mill base case (Sec. 6.2.8.2.7). Cumulative dose commitments based on the model mill are given again in Table 9.7, along with estimates of the occupational exposure incurred if improved controls were added to the model mill. Wet yellowcake shipment would greatly reduce one of the largest sources of radiological risk to occupational mill workers by essentially eliminating yellowcake dust in product handling areas. The combination of wet, semi-autogenous grinding with wet shipment of yellowcake would decrease the average radiological risk to occupational workers by about 49%. Cumulative somatic health effects to occupational workers are given in Table 9.8 for alternative operating modes. Table 9.9 shows the effects of the alternative operating modes on the average worker; risks are presented in comparison with those faced due to exposure to background radioactivity.

Table 9.7 Cumulative Dose Commitments to Occupational Workers in United States Uranium Mills (1979-2000) for Alternative Operating Modes

	Dose Commitment (organ-rem)			
			Lung	
Mode	Whole Body	Bone	Avg. Lung	Bronchial Epithelium
Base Case	2.98×10^4	1.32×10^5	2.74×10^5	2.00×10^5
With wet semi-autogenous grinding	2.68×10^4	4.88×10^4	1.80×10^5	2.00×10^5
With wet shipment of yellowcake	2.83×10^4	1.08×10^5	1.19×10^5	2.00×10^5
With wet semi-autogenous grinding and wet shipment of yellowcake	2.53×10^4	2.53×10^4	2.53×10^4	2.00×10^5

9.3 MILL TAILINGS MANAGEMENT ALTERNATIVES

Implementation of the several tailings management alternatives described in Section 8.4 is evaluated herein in terms of the environmental impacts expected to occur in the model region. The evaluations are valid for comparison of the alternatives, but are not necessarily valid for any existing or future real situation. It is realized that the relative merits of the alternatives may change when they are applied in different geophysical regions; thus regional variations and other factors that might affect implementation of alternatives are discussed when pertinent.

The potential impacts on a given environmental component (e.g., soil, biota) are evaluated for each of the alternatives successively, so that the impacts on that component can be readily compared. The purpose is to illustrate to what degree the base-case impacts can be reduced by each of the alternative tailings management programs. Inasmuch as the programs contain various process alternatives, they are evaluated as parts of the programs. The various monetary costs associated with implementation of the alternatives are summarized in Section 11.2; a more complete discussion is given in Appendix K-4. Chapter 12 contains a final benefit-cost evaluation of major aspects of mill tailings management and disposal alternatives.

Table 9.8 Cumulative Somatic Health Effects to Occupational Workers in United States Uranium Mills (1979-2000) for Alternative Operating Modes

Operating Mode	Premature Deaths due to Milling	Increase in Cancer Death Rate due to Career Dose[a] %	Average Decrease in Radiological Health Risk to Occupational Workers by Alternative Operating Mode %
Base Case	3.9×10^1	25	0
With wet, semi-autogenous grinding	3.2×10^1	20	19
With wet shipment of yellowcake	2.8×10^1	18	29
With wet, semi-autogenous grinding and wet shipment of yellowcake	2.0×10^1	13	49

[a]The career dose is based on a person working in the milling industry for 47 years (that is, from age 18 to 65). The increase in cancer death rate is based on an average annual risk of death due to cancer of 1.6×10^{-3} (Ref. 1), and a 70-year lifetime.

Table 9.9 Potential Health Risks to Average Worker for Alternative Operating Modes

Operating Mode	Dose Commitment (mrem/yr)			Risk of Premature Death for Total Career - Chances per 10,000	Risk as a Multiple of Exposure to Background Radiation (%)[a]
	Whole Body	Bone	Lung		
Base case	450	2000	7100	280	800
Semi-autogenous grinding	400	730	5700	220	640
Wet U_3O_8 shipment	430	1600	4800	200	570
Semi-autogenous grinding and wet U_3O_8 shipment	380	380	3400	140	410

[a]Refer to Table 4.14 for natural radioactivity exposure levels.

9.3.1 On Air Quality

The primary impact of the tailings area on air quality would be an increase in suspended particulate matter downwind of the piles. The alternatives are assessed relative to emissions of dust and gases or vapors that probably would result during operation and before reclamation. It is presumed that after reclamation, all emissions would be indistinguishable from the natural release of dust in surrounding areas.

9.3.1.1 Before Reclamation

Relative to air quality impacts, the alternatives fall into three classes: (a) those for which impacts would be virtually the same as for the base case (or the improved base case if the control alternatives of Sec. 9.2 were used); (b) those for which impacts would be incrementally lessened; and (c) those for which impacts might be more severe than those of the base case. Members of class (a) are Alternatives 1, 4, and 6, all of which duplicate the base case during operations and require a drying-out period of several years.

Class (b) consists of Alternatives 2, 3, and 5. Some decrease in air quality impacts is expected under Alternatives 2 and 3, because the drying surface of the tailings would be below grade and protected by relatively steep walls; impacts would be substantially reduced under Alternative 5, as a result of the phased nature of drying and covering.

Alternatives 7, 8, and 9 are placed in class (c) because of the additional emission of pollutants resulting from the drying and fixing operations and from emission of oxides of nitrogen from the nitric acid process.

9.3.1.2 After Reclamation

With respect to the maintenance of ambient air quality after vegetation is established, all the alternatives are good (and much better than the base case); some are better than others, however, when long-term effects are considered. Tailings areas resulting from the programs of Alternatives 1, 6, and 9 would be relatively more susceptible to erosion effects and the likelihood of particulate dispersion would be correspondingly greater. The disposal areas of Alternatives 2-5 and 7 would be better protected from erosion, whereas that of Alternative 8 would be immune.

9.3.1.3 Conclusion

The impacts occurring before reclamation are weighted less heavily because they are temporary; the following remarks are based largely on effects expected during the postreclamation period. Relative to air quality impacts during such periods, all of the alternatives are generally acceptable, although Alternative 1 should be avoided, if at all possible, because the steep embankments of the tailings pile are likely to result in relatively severe erosion problems with blowing dust, over long periods of time. Of the remaining alternatives, 6 and 9 are less favored, and 8 is ideal.

9.3.2 On Land Use

Land use aspects of the various tailings management alternatives can be considered from two related but slightly different points of view: (1) the removal of land from premilling use and (2) restriction of future land use. The evaluations in this section will be restricted to the former consideration; questions of land use control are discussed in Section 9.4.2.

9.3.2.1 Evaluation of Alternatives

Alternatives 1, 4, 6, and 9 all would require the use of about the same amount of land as the base case. Assuming that a "self-maintaining" vegetative cover were established on the overburden covering the tailings, the land possibly could be used for grazing. The suitability of the land for such use would depend on the degree to which vegetation was successfully established so as to both stabilize the overburden (to prevent wind and water erosion) and stand up under grazing pressure (of either livestock or wildlife). Such land use would probably not be possible under Alternative 1, in that continued active care to maintain a cover of vegetation would be required. Range and livestock management on surrounding lands would also affect the use of the tailings land.

Alternatives 2, 3, and 7 also would require about the same amount of land as the base case. Since a depleted open pit mine would be used, some of the land use restrictions which existed because of the presence of the mine would be removed. This land also possibly could be used for grazing. There could be a net gain of about 100 ha (250 acres) for this activity.

Implementation of Alternative 5 would require about twice as much land as would those above; however, the phased nature of the operation would allow earlier return of the land to productive use and the ultimate use of the area would be identical.

The above analyses apply to the model region. In those regions of the United States substantially different from the model region (e.g., the Southern Rocky Mountains, Northern Rocky Mountains, and Texas Coastal Plains regions, which have a high percentage of land in woodland and forest, or the Great Plains, which has a high percentage of cropland) the above evaluation must be modified. It is doubtful that forest could be reestablished on the tailings. In the case of cropland, it may be desirable to prohibit any agricultural practices which involve tilling the soil or growing human foodstuffs over the tailings, as discussed in Section 9.4.2.

Tailings disposal in a deep mine, as in Alternative 8, would result in little or no additional disturbance of surface land. Filling of the mine with tailings might, in some cases, lessen the potential for surface subsidence over the mine.

9.3.2.2 Conclusion

Relative to land use, Alternative 8 appears optimal. The small amount of land disturbed during implementation of the alternative could be restored rapidly; furthermore, there appears to be little chance that unrestricted land use would be precluded in the future.
Alternatives 2, 3, and 7 would allow the reclamation of an open pit mine, which would result in additional productive land, but the probability that this use might have to be abandoned in

the future is higher than for Alternative 8. The same consideration applies to Alternatives 4 through 6 and 9; furthermore, in these cases no previously restricted-use land would be reclaimed. Alternative 1 appears to be the least desirable, because the potential for productive use of the reclaimed tailings disposal site is the least.

9.3.3 On Mineral Resources

Those aspects of the tailings management alternatives that impinge on mineral resources consist primarily of the perceived difficulty of future recovery of those mineral values in the tailings and, in some cases, those lying below the tailings area. The evaluation of future recoverability is made on the basis of currently available mining techniques. It is recognized, however, that ongoing development of these techniques may obviate some of the difficulties now perceived. From this viewpoint, the base case is highly rated, inasmuch as the lack of covering would facilitate the recovery of residual mineral values from disposed tailings.

9.3.3.1 Evaluation of Alternatives

The placement of a liner below the tailings might make the recovery of any mineral resources located below the tailings somewhat more difficult, but would not affect the recovery of any minerals left in the tailings themselves. The placement of a cap over the tailings would be an impediment to the recovery of any mineral resources below the tailings or of minerals left in the tailings, but would not preclude their recovery. Fixing the tailings in concrete, asphalt, or another agent would seriously impede future recovery of any minerals in the tailings. In addition, the recovery of any mineral resources below the tailings would be made more difficult.

On the basis of the above discussion, Alternative 1 appears desirable relative to this consideration, for only the cover would impede recovery of mineral values. Those alternatives that involve only emplacement of a liner and cover (Alternatives 4 through 6 and 9) would make recovery somewhat more difficult, but not materially so. (The presence of shale in Alternative 4 and the more dispersed character of the tailings in Alternative 5 are considered to be inconsequential.) The presence of substantial quantities of backfill in Alternatives 2 and 3 would add another increment to the difficulty of recovery, but again a rather small one. Such is not the case for Alternatives 7 and 8, under which fixing of the tailings could seriously impede recovery; indeed, returning fixed tailings to a deep mine virtually precludes future mining of the tailings.

9.3.3.2 Conclusion

Relative to recoverability of residual mineral values, all the alternatives except 7 and 8 are satisfactory, although minor differences exist among them. The fixed tailings under Alternative 7 would be difficult to mine and those under Alternative 8, very difficult.

9.3.4 On Water Resources

The contamination of water resources from uranium milling activities can result from introduction of deleterious substances into groundwater or soil strata or their deposition on the soil surface, with subsequent movement in surface water. Recharge of aquatic habitats by contaminated groundwater will influence surface water quality during dry seasons, when recharge maintains base flows in streams or minimum levels in other bodies of water. Degradation of surface water quality may also occur when contaminants deposited on the soil surface from wind dispersal and seepage are transported to aquatic habitats in runoff or soil interflow, following precipitation; however, this mode of transport is not likely to be important.

9.3.4.1 Surface Water

9.3.4.1.1 Before Reclamation

Of the various processes incorporated into the tailings management alternatives, only nitric acid leaching of the ore would have impacts to surface water quality different from those of the base case. This process differs from the sulfuric acid leach process by releasing nitrogen, as nitrate, a more toxic chemical than sulfate.[2] The nitrate ion does not adsorb on soil as readily as does the sulfate ion and thus will be transported to groundwater by seepage and thence to surface water by recharge.[3] The resultant impacts to aquatic systems would exceed those of the base case.

9.3.4.1.2 After Reclamation

For the base case model mill, with no reclamation cover provided, it was conservatively estimated in Appendix E-3 that continued long-term seepage flow would be about 5% of the rate of seepage occurring during mill operation. This conclusion resulted from the estimation that about 4% of annual precipitation moisture would not be lost through evapotranspiration and would eventually percolate downward, through the tailings, to the underlying aquifer (groundwater recharge). The staff considers this to be a markedly conservative assumption for the site characteristics chosen to describe the model region, which include an annual evaporation potential of 1.5 m/yr, a factor of 5 greater than the annual precipitation of 31 cm. Furthermore, as indicated in Table 7.7, average evaporation potential will exceed average precipitation by a factor which ranges from 2.4 to 5.8 over the six major uranium resource areas; evaporation can exceed precipitation in the southwest by as much as a factor of 20.[4] Based on a review of pertinent literature, Winograd suggested that in much of the southwest, precipitation moisture rarely if ever infiltrates to water tables of even intermediate depth (10 to 100 m).[4]

Long-term groundwater seepage may or may not be a reality, depending on site-specific conditions. To prove or disprove groundwater recharge at any given site would require detailed measurement of ambient soil moisture and one or more potentials (matric, gravitational, osmotic, and pneumatic) affecting unsaturated flow, as a function of both depth and recent climatic conditions. Given the available evidence, the staff concludes that continued groundwater seepage in areas of existing uranium milling operations will occur only sporadically and in small amounts, if at all. However, the evaluation that follows in based upon the long-term seepage rate of 11,000 m^3/yr, as conservatively estimated in Appendix E-3.

Analysis of impacts to surface waters from each of the tailings management alternatives is based on an evaluation of potential contamination routes in comparison to the base case. The surface water contamination mechanisms considered are wind dispersion, seepage to surface water, seepage to ground surface, and seepage to groundwater and subsequent recharge of surface water.

Many of the alternatives would involve installation of a clay or synthetic (plastic) liner to reduce or eliminate operational seepage. A 1-m (3-ft) layer of compacted bentonite clay installed as a liner in the tailings pond would reduce the operational seepage rate to 6% of that typical for the base case (unlined). On the other hand, the contaminants in the seepage would be concentrated to 3.6 times the values for the base case (from increased evaporation). The effect of clay liners on potential surface water quality degradation therefore is difficult to estimate, since the impact of reduced seepage rates must be offset by the increase in pollutant concentration. In addition, the distance that the seepage traveled would influence its chemical composition and the concentrations of the pollutants.

Synthetic (plastic) liners are nearly impermeable barriers to seepage of tailings discharge. Proper installation of a plastic liner over the tailings pond bottom and all inner embankments would virtually eliminate seepage if the integrity of the liner were maintained.

The thick earthen cover used in all the alternatives would retard, and perhaps even eliminate, deeper infiltration of atmospheric precipitation. This procedure would reduce potential continued seepage from the pile and might aid in the retention of the integrity of the liner. Installation of a thick earthen cover would eliminate aerial distribution of tailings particulates.

The use of asphalt, cement, or other "tailings binders" to immobilize heavy metals and soluble salts discharged in mill wastes would further reduce or eliminate the potential for these substances to degrade surface water quality.

No liner is provided under Alternative 1; hence, seepage and its resultant effects on ground and surface waters might be as described in Section 6.2.4.

Liners would be provided under Alternatives 2 through 6, and 9. If the liners were of clay, the remarks above would apply; the potential for continued seepage would be reduced, but perhaps not eliminated. It is assumed that if plastic liners were used, seepage would be eliminated for a limited time, but over longer periods some seepage might occur (see Sec. 9.3.4.2) so that the overall effect could be the same. The effects on surface water quality could be similar to, but less than, those discussed in Section 6.2.4.1; no quantitative statement can be made for the complex system.

The partial drying of tailings before deposition (Alternative 3) would reduce (to about 40%) the potential for seepage as compared to other alternatives in this group, assuming that the integrity of the liner were maintained. The shale layer of Alternative 4 would be intermediate between clay and synthetic liners, with regard to seepage. The character of the seepage under Alternative 9 would be different (see Sec. 9.3.4.1.1), but the overall effects would be comparable.

The fixation of tailings with cement or asphalt would eliminate impacts from dispersal of dust and minimize seepage problems, so long as integrity of the bonds were maintained. Implementation of Alternative 7 or 8 is thus desirable, relative to maintenance of surface water quality; placement of the fixed tailings in a deep mine (Alternative 8) is regarded as the better choice.

9.3.4.1.3 Conclusion

The impacts on surface water quality resulting from implementation of any of the tailings management alternatives would be small. Seepage to the groundwater and deposition of airborne toxicants likely to result under Alternative 1 would lead to some contamination of surface waters, via the indirect mechanisms mentioned above. Liners provided in some alternatives beneath the tailings would be needed only in the short term, until the tailings pond dried out. Because the fixed tailings in Alternatives 7 and 8 would be deposited in contact with groundwater, potential for damage to aquifers would be higher, and surface water quality might be impaired via recharge from contaminated groundwater. Emplacement of the standard covering for Alternatives 1 through 7 is considered desirable, in that it would mitigate the potential impacts of continued seepage to groundwater and eliminate particulate dispersion.

The discussions above are primarily based on the characteristics of the model region. Some discussion of potential impacts in the six physiographic regions of the United States in which uranium mining and milling occurs is given in Appendix M.

9.3.4.2 Groundwater

9.3.4.2.1 Before Reclamation

Several of the processes incorporated into the tailings management alternatives could result in impacts to the groundwater quite different from those discussed for the base case. Because these impacts would occur during operations, they are discussed here, although some might continue into the post-reclamation period.

Nitric Acid Leach Process. The nitric acid leach process would result in a tailings pond liquid composition essentially the same as that for the base case (Table 5.3), except that nitrate ions would replace sulfate ions and the concentrations of radionuclides would be reduced by a factor of ten. Rates of seepage and groundwater contamination would be the same as for the base case, except that high concentrations of nitrate, instead of sulfate, would occur in groundwater. Because the maximum permissible concentration for nitrate is 10 mg/L (based on health considerations) and that of sulfate is 250 mg/L (based on objectionable odor) there would be a demonstrably greater groundwater contamination and health hazard in using the nitric leach process.

Neutralization of Slimes. If the tailings pond liquid were neutralized, most toxic solutes would precipitate. The rate of seepage from the tailings pond and the distribution of seepage water in groundwater would not change from the base case; however, most of the toxic constituents of the tailings liquid would not be present in the seepage water. Anions such as sulfate, selenate, and arsenate might not be removed, however, and hence some groundwater contamination would still occur.

Solidification of Tailings by Incorporation in Asphalt or Cement. Conversion of tailings to a solid form by incorporation with asphalt, cement, or other material before disposal would minimize groundwater contamination by seepage and percolation because of the low leachability of the fixed material. Some experiments have been performed to determine leachabilities of this type of material.[5] These studies indicate that because portland cement concrete hardens with an open-cell, porous structure, ions from uranium tailings used as concrete aggregate may be leached relatively easily (compared to tailings solidified in a bitumen). The actual surface area exposed to a leachant may be 8×10^3 times greater than the geometric surface area of the concrete. Leaching rates from concretes containing radioactive wastes other than tailing have been measured to be between 2×10^{-8} and 10^{-1} g/cm^2-day.[6] As with unsolidified tailings, certain ions are more easily leached than others. Leaching rates for all ions are greatest when:

1. The ratio of tailings to cement is high, and the tailing surface area exposed to interconnecting pores within the cement is large.
2. The ratio of basic and acidic oxides in the final product (a function of the chemistry of the tailings and cement) does not fall within the narrow range of desirable values and results in the concrete having a poor mechanical strength. This leads to cracking, spalling, and increased surface area. Slimes are neutralized to minimize this possibility.

Leaching may be minimized by:[6]

1. Incorporating bentonite, grundite, or other clays into the concrete mix to adsorb some of the ions.

2. Coating the surface of the concrete with bitumen or a similar material to fill the pores and prevent water from seeping through the concrete.

3. Impregnating the surface pores with styrene monomer, which is then polymerized by heating to 50-70°C (120 to 160°F). This can decrease the leachability by two orders of magnitude, but it may be impractical for the large volumes of tailings-concrete.

The leaching rate of ions from tailings incorporated in asphalt (bitumen) is expected to be between 10^2 and 10^3 times lower than for similar cement mixes, because of the superior coating characteristics and insolubility of asphalt.[5] Actual leach rates of actinide tracers have been determined to be between 10^{-7} and 10^{-3} g/cm^2-day.[6] As with the cement mixes, leaching rates vary with the individual ions.

Experiments at Oak Ridge National Laboratory indicate that the leaching rate of an asphalt mix is highly dependent on the ratio of waste to asphalt.[5] Again, incorporation of clays or other chemical adsorbents into the asphalt mix is a good mitigative measure.

All of the tailings management programs considered herein include placement of a cover over the tailings. Relative to groundwater contamination, this has the advantage that because precipitation might not enter the abandoned tailings, if the cover retains its integrity there might be no long-term seepage as was predicted for the base case. The lack of seepage would be a definite advantage, because contaminants would be permanently isolated at the level to which they advanced at the end of mill operation [0.26 m (10 inches) below the tailings for radium for the base case].

Most of the alternatives would include installation of a liner--1 m (3 ft) of compacted clay or a sheet of Hypalon--to reduce seepage from the tailings. If a synthetic liner were used, there would be no seepage during mill operation if the liner retained its integrity. Although synthetic liners have been known to fail because of subsoil settlement, puncture by rocks, splitting at seams, or entrapped air bubbles, the probability of failure can be greatly reduced by careful placement and the use of reliable liners. Synthetic liners resistant to sulfuric acid are available, but the long-term reliability of these liners is not known.

Where tailings are to be deposited as a slurry, proper placement of a clay liner will render the holding area relatively impermeable. The clay layer would consist of clay containing a high proportion of montmorillonite, an expanding-lattice type clay mineral which, when wet, tends to swell and exhibit thixotropic properties, particularly when the predominant cation of the clay mineral is sodium. If properly placed and allowed to dry, the resulting surface is relatively impermeable. Experience with clay liners at existing tailings impoundments has shown that the major problems encountered with this type of impervious layer are faulty material and the difficulties associated with bonding of the clay to sloping rock surfaces. In the latter case, blasting a trench into the rock and packing the trench with clay can provide satisfactory bonding. On slopes of less than 45°, compaction and clay bonding is not expected to be difficult.[7]

Some concern exists regarding the reliability of clay liners when exposed to highly acidic tailings solutions; i.e., will there be significant decomposition of clay mineral structures by acids? Recent research indicates that the effects on permeability of clays, due to contact with acid tailings solutions, can vary with clay type and tailings solution composition. In one case, clay mineralogy was observed to change only slightly.[8] Any acid dissolution that occurred appeared to be countered by precipitation reactions and secondary mineral formation, which results in plugging of pores. Permeabilities actually decreased somewhat, with time. In another study, an initial decrease in permeability was observed, but after extended contact with the acid solutions, a relatively rapid and significant increase in premeability was observed (permeability increased to greater than 10^{-7} cm/sec from an initial value of about 10^{-8} cm/sec).[9] Exchange of sodium by multivalent cations was considered to be the probable cause of the permeability changes. While these studies do not allow firm conclusions to be drawn relative to clay liner reliability, site-specific testing of clay materials proposed for impoundment linings, by exposure to representative acid tailings solutions, is certainly a prudent measure to take.

Assuming that the clay liner is satisfactorily installed and that equilibrium conditions apply (i.e., no additional water is furnished to maintain coverage of the tailings surface), the expected seepage rate can be computed. Following the method of Appendix E, the hydrologic budget can be written as:

$$Q_{ppt} + Q_{mill} = Q_{entr} + Q_{evap} + Q_{seep} \qquad (1)$$

where $Q_{ppt} = 2.79 \times 10^5$ m^3/yr (9.9×10^6 ft^3/yr) and $Q_{mill} = 4.60 \times 10^5$ m^3/yr (1.6×10^7 ft^3/yr) (from App. E). Leakage through the liner would be slow, but it can be assumed that gravitational water in the tailings would eventually drain out, and $Q_{entr} = 6.6 \times 10^4$ m^3/yr (2.3×10^6 ft^3/yr) as in the base case. Use of a liner would result in the development of a large pond, and seepage would be likely to occur through the entire area of 80 ha (200 acres).

$Q_{unit\ seep}$ can be found from the Darcy equation, where the head loss (H) is taken as 5 m (15 ft) [4 m (12 ft) of saturated tailings and 1 m (3 ft) of bentonite liner], and the hydraulic conductivity (K) and thickness (L) of the clay admixture are taken as 10^{-8} cm/s (4×10^{-9} inches/s) and 1 m (3 ft), thus,

$$Q_{unit\ seep} = KA\frac{H}{L} \tag{2}$$

$$= (10^{-8}\ \text{cm/s})\ (1\ \text{ha})\ (\frac{5\text{m}}{1\text{m}})$$

$$= 1.58 \times 10^2\ \text{m}^3/\text{yr-ha}$$

$$= (2.3 \times 10^3\ \text{ft}^3/\text{yr-acre})$$

[Thus, for the clay liner, $Q_{unit\ seep}$ is about 4% of $Q_{unit\ seep}$ (3.65×10^3 m^3/yr-ha) for the model mill.] Multiplying by 80 ha, $Q_{seep} = 1.3 \times 10^4$ m^3/yr (4.6×10^5 ft^3/yr). Substituting known values into equation (1) above, $Q_{evap} = 6.60 \times 10^5$ m^3/yr (2.3×10^7 ft^3/yr).

Under equilibrium conditions, the evaporating area (A_e) would increase by about 50% over that for the model mill, i.e.:

$$A_e = \frac{6.60 \times 10^5\ \text{m}^3/\text{yr}}{1.5\ \text{m/yr}}$$

$$= 44\ \text{ha (110 acres).}$$

The rate of seepage during mill operation would be only (0.13×10^5 m^3/yr)/(2.2×10^5 m^3/yr) = 6% of that of the base case. This does not mean, however, that the groundwater impacts would be reduced to 6% of those of the base case, because the reduced seeping causes increased evaporation, resulting in a more highly mineralized seep.

The net loss of pure water would be 3.81×10^5 m^3/yr (1.3×10^7 ft^3/yr), so the increased concentration is:

$$\frac{4.60 \times 10^5\ \text{m}^3/\text{yr}}{4.6 \times 10^5\ \text{m}^3/\text{yr} - 3.81 \times 10^5\ \text{m}^3/\text{yr}} = 582\%.$$

This increase in dissolved contaminants would increase the concentrations shown in Table E-3.1, Column B, Appendix E, by a factor of 3.6. Because the subsoil would still be able to neutralize the advancing acid seepage water, however, the concentration of all substances in groundwater is expected to be roughly the same as shown in Table 6.3 of Section 6.2.4.2, except for selenium, sulfate, arsenic, and other anions not affected by pH.

The travel times and dispersion predictions of Appendix E (Fig. E-2.2) would be roughly the same as the base case because the downgradient groundwater flow velocity is the same. The movement of radium would probably be slightly less than 0.26 m (10 inches) below the bottom of the tailings pond area after 15 years, because of the greater adsorption capacity of clayey materials in the liner.

In summary, the benefit of using a low-permeability liner (reduction of seepage to 6% of base case) is offset to some degree by the fact that the contaminants in the seepage will be more concentrated (3.6 times).

9.3.4.2.2 Postreclamation

Continued seepage of tailings contaminant carrying moisture to underlying aquifers can occur only in areas of groundwater recharge, i.e., areas where surface precipitation moisture is capable of percolating downward to the saturated zone. As discussed in Section 9.3.4.1.2, and as indicated by the data presented in Table 7.7, average evaporation potential greatly exceeds average precipitation in all six major uranium rescurce areas in the U.S. It is thus expected that, on average, moisture lost from soil surfaces by evapotranspiration will essentially equal that gained through precipitation events.

Unsaturated groundwater flow (flow in the unsaturated zone, above the water table) is a complex phenomenon depending on many physical parameters, and is not reasonably predictable on other than a site-specific basis. Thus, the depth of infiltration of precipitation moisture is highly variable, depending on site conditions as well as the timing and magnitude of prior precipitation. Given sufficient precipitation rates and durations, infiltration through permeable media to almost any depth can be postulated. Therefore, infiltration to underlying aquifers must, under almost all conditions, be considered to be a possibility. However, on the basis of available information, it is possible to conclude that groundwater recharge via infiltration of precipitation moisture occurs only infrequently and in small amounts, if at all, in most arid and semiarid areas (such as the U.S. southwest).[4] Therefore, while the staff considers that continued seepage after reclamation has occurred is a distinct possibility, the likelihood and magnitude of any potential recurring seepage are quite limited in those areas where uranium mills now operate. Any seepage that does occur would be expected to be negligible in terms of both quantity and frequency. Irrespective of these considerations, the evaluation of the relative effectiveness of the various alternatives presented below is based on the conservative assumption made in Appendix E-3 that 4% of precipitation moisture will provide a constant driving force for continued long-term seepage.

Inasmuch as all of the alternatives have virtually identical cover properties, they will be discussed from the aspect of potential seepage and the resultant groundwater impacts. From this vantage point the alternatives fall into three classes: (1) those similar to the base case; (2) those related to the base case, but with lower seepage rates; and (3) those quite different from the base case.

There is only one member of class (1), viz., Alternative 1. It differs from the base case in that installation of the earth cover would retard infiltration by precipitation, and thus lessen seepage somewhat, but in other ways it greatly resembles the base case, and the discussion in Section 6.2.4.2 applies, although the magnitude of the impacts would be smaller.

A liner would be emplaced under Alternatives 2 through 6 and 9, and they all fall into class (2). The discussion above on seepage through clay liners would apply directly if a 1-m (3-ft) clay liner were used; if a Hypalon sheet were emplaced, permeability values would be lower. The general conclusions would be similar.

The two options of Alternative 2 are essentially identical with respect to seepage, and Alternatives 5 and 6 are sufficiently similar to Alternative 2 that they all may be discussed together. Drying of the tailings, as in Alternative 3, would reduce the amount of liquid available to seep, whereas Alternative 9 differs from Alternative 6 only in the quantity of cations present in solution. The presence of a shale layer (Alternative 4) would result in a permeability intermediate between clay and Hypalon. If these differences are borne in mind, all the alternatives in this class can be discussed together. The general features of seepage from the lined basins of these alternatives are discussed above. Ion-exchange properties of the soils below the liners are site-specific; thus, groundwater impacts are considerably affected by regional geological variability (Sec. 6.2.4.2.4). The effects of these variations on the analysis above would be mainly to change the possible benefits of placing liners over subsoils which already have low permeability. If the subsoil were a thick shale bed, for example, placement of a clay liner might not result in any significant reduction in seepage.

In summary, these alternatives appear to be roughly equivalent; allowance for minor differences would yield a ranking (decreasing merit) of: 4, 3, 5, 9, 6, 2, but the differences are small.

Under the two remaining alternatives, 7 and 8, the tailings would be mixed with asphalt or cement with the intent of producing an impermeable mass. Even though the mass would be placed below the water table in the open pit mine, groundwater penetration is considered unlikely in the short term.

Over the long term, some groundwater infiltration of the tailings would occur; however, similar infiltration might take place under the programs of the other alternatives, so these alternatives are still considered the most desirable from the viewpoint of groundwater contamination. The use of a deep mine, as in Alternative 8, is favored, because any groundwater contamination that might occur probably would be below the level of drilling of domestic water wells.

9.3.4.2.3 Water Use

Operation of the mill will result in the use of about 4.6×10^5 m^3 of water per year. Most of the alternatives evaluated in this section include the installation of a liner under the tailings to retard seepage. The decrease in seepage results in an increase in evaporation, hence an increase in the consumption of groundwater. For the case considered, the consumption of water by evaporation for the model mill is increased about 50%, from 4.5 x 10^5 m^3/yr to 6.6 x 10^5 m^3/yr (these figures include contribution of moisture from rainfall as well as that from the mill, which are about 40% and 60% of these totals respectively). The water pumped from the mines furnishing ore to the model mill amounts to about 10^7 m^3/yr (2.6 x 10^9 gallons/yr) (see App. D). An unknown fraction (probably a few percent) of this water evaporates and thus is lost to the regional aquifers; the loss from the tailings pond represents 3.8% of the water pumped from the supporting mines.

9.3.4.2.4 Conclusion

Implementation of any of the alternatives, except Alternative 1, would be satisfactory from the viewpoint of groundwater contamination. These alternatives could reduce seepage from the tailings pond until the tailings had dried out and no longer represented a major source of water for seepage. If the tailings were not fixed, construction of a disposal area in a highly impermeable formation such as in a bed of clay or shale would be preferred. If no such impermeable formation is available, deposition of dried tailings in a lined repository appears most appropriate.

9.3.5 <u>On Soils</u>

The major impacts to soils of the model site as a result of uranium mill tailings disposal would be (a) soil loss from the disposal area and (b) salinization of the soil as a result of seepage and leaching of salts from the tailings impoundment. These impacts would arise during construction and operation of the mill (see Sec. 6.2.5), but would have long-term effects that would likely persist after decommissioning of the mill. Other effects of tailings disposal, such as deposition of wind-blown tailings dust, ordinarily are not expected to be of such magnitude as to cause adverse impacts to soil, if adequate stabilization and reclamation measures are taken. Indirectly, undisturbed soil can be adversely impacted by overgrazing, as a result of displacement of livestock from previous grazing land; such effects are minor if only a single mill in the region is considered, but have the potential to be of more concern, if 12 mills are situated within an area the size of the model site (see Sec. 6.3). Soil loss and salinization, as affected by the tailings management alternatives described in Chapter 8, are discussed in this section. The discussion includes consideration of regional variability.

9.3.5.1 Soil Loss

For the base case it is assumed that 100 ha (250 acres) of land are required for disposal of the tailings from a single mill. The same amount would be required for Alternatives 1, 4, 6, and 9; therefore, soil loss under these alternatives would be no different than under the base case. Alternative 5 is expected to result in disturbance and soil loss from twice the area as for the base case. Relative to soil, therefore, this alternative would be less satisfactory than the base case. For Alternative 8, no additional land would be required for tailings disposal, assuming that an abandoned mine was already in existence. If none existed, then a site for temporary storage of tailings would be needed, until an empty deep mine became available. Such storage temporarily would remove land from productivity. Alternative 8 thus would be less satisfactory than disposal in an open pit mine. For Alternatives 2, 3, and 7 (mine pit disposal of tailings), no additional disturbance or loss of soil would be required, other than that caused by mining; for this reason, any of these alternatives would be superior to the base case or any of the other alternatives, in terms of minimizing the area of soil loss or disturbance from tailings disposal.

9.3.5.2 Soil Salinization

As described in Section 6.2.5, salinization of soil can result from seeping and leaching of salts from the tailings into or onto the soil. For assessment of impacts at the model site, it is assumed that only a small seep from the dam, and no upward movement of seepage or soil water occurs. Realistically, such upward movement through the soil can occur, particularly under the influence of the high evaporation rate of the region. Any alternative that would prevent or minimize seepage and leaching of salts from the tailings to the soil would thus prevent soil salinization and its consequent adverse effects. Placement of a liner, either clay or synthetic, can reduce seepage markedly, unless the liner fails sometime during the 20-year operation period. Alternative 1 (compaction of the natural earth bottom) would essentially be no different from the base case, since the model site is predominantly sandy material that does not compact to an impermeable layer (see Ch. 4). Alternatives 6 and 9, which involve placement of tailings with a liner, would permit seepage to soil if the liner failed. Alternatives that involve placement of tailings in the mine pits (Alternatives 2, 3, 7, and 8), with or without liners, are expected to have essentially no potential for salts to reach the rooting zone of vegetation or the soil surface, particularly in the case where the tailings are deposited dry (Alternative 3). Alternatives 4 and 5, which involve near-surface placement of tailings and liner, fall between these extremes but would more closely resemble the mine pit disposal alternatives.

A coincidence of events in which the groundwater aquifer intersects the tailings, the liner fails, and the groundwater rises to the soil surface, thus introducing salts into the soil, is considered unlikely at the model site. In terms of preventing soil salinization, therefore, deep mine or open pit disposal of dried or fixed tailings, is optimum.

9.3.5.3 Regional Variability

Impacts to soil under the various tailings management alternatives were addressed above in terms of the model site. It also is informative to consider the alternatives in terms of regions with characteristics markedly different from those of the model region. Regional variability and the tailings management alternatives are related in two general ways: (a) some characteristic of a given region may be a large factor in the feasibility of a given alternative, and/or (b) the magnitude of impacts from a given alternative is partly a function of the characteristics of the given region. One example of category (a) is a region such as the Northern Rocky Mountains, where uranium ore may be extracted by surface mining only. In that case, Alternative 8 is more likely to be excluded from consideration in selecting a tailings disposal method. Another example of category (a) is the Texas Gulf Coast region, where a high proportion of the soils are Vertisols, which have high shrink-swell potential (see Ch. 4 of the Supplement). An alternative that employs a compacted earth, clay, or synthetic liner on the ground surface (Alternatives 1, 5, 6, and 9) may not be feasible, because of the potential for rupture and deep cracking of the supporting soil base. In general, however, the effect of the regional characteristics upon feasibility of a given alternative is of less importance than the effect of regional characteristics on the impacts of a given alternative.

As indicated previously, impacts to soils from tailings disposal arise from (1) loss of the soil resource by preemption of land, and (2) soil salinization. The magnitude of these effects will vary with the alternative and the region. For example, in the Northern Rocky Mountains, the soils are mainly Inceptisols and Mollisols (see Supplement), relatively deep soils, supporting grasslands, agriculture, and forest. Salinization due to seepage is not likely to occur because of the relatively high rainfall [40 to 125 cm (15 to 50 inches)] and, in general, good drainage in the region. The major impact in this region will accrue from loss of forest, agricultural, and grassland soils, all of which have higher fertility and greater productivity than the soils of the model site. Any tailings management alternative that would reduce the overall commitment of land area (Alternatives 2, 3, 7, and 8) would be optimal in terms of impacts to soils in this region.

In arid and semiarid regions, such as the southern Great Plains, Wyoming Basin, and Colorado Plateau, rainfall is relatively low, and soil salinization becomes important. Physical location of the tailings thus becomes less important than prevention of seepage. In the northern Great Plains, where wind erosion tends to be a critical problem, placement of tailings in a deep mine (Alternative 8), if one is available, may be preferred to surface placement where the tailings are exposed to wind and dry out. Alternative 3, under which tailings would be deposited dry, would be especially undesirable in the Northern Great Plains, unless adequate measures to prevent wind erosion of the dry tailings were implemented.

Effects on soils due to some distinctive feature of a given alternative include deposition of cement dust from the cement plant required for Alternatives 7 and 8, and impacts from mining and transportion of clay for use as liners. (There are impacts due to manufacture of synthetic liners, but the ramifications of this upon soils are less direct and significant.) Deposition of cement dust on soils is not expected to have direct adverse effects on soils; however, effects such as those on vegetative growth can have indirect impacts on soil. For example, deposition of cement dust on vegetation is expected to reduce photosynthetic activity; plant growth therefore would be reduced, resulting in less ground cover, with increased potential for wind and water erosion. In addition, organic matter in soil would be reduced, leading to poorer soil structure, which also would increase the potential for wind and water erosion of the soil. The magnitude of these effects is expected to be unimportant if adequate measures are taken to prevent release of cement dust outside the plant building.

9.3.5.4 Summary

The major impacts to soils as a result of uranium mill tailings disposal are: (1) loss of the soil resource from the disposal area, and (2) salinization of the soil as a result of seepage from the tailings impoundment.

Any alternative that provides for disposal of tailings in a mine pit is superior to the base case and to any of the other alternatives considered, in terms of impacts to soils. This is because no land would be disturbed other than that already disrupted by mining, and because the tailings would be sufficiently deep in the earth that seepage of chemicals from the tailings to the soil surface would be unlikely.

9.3.6 On Biota

9.3.6.1 Terrestrial Biota

Impacts to terrestrial biota from uranium mill tailings disposal accrue mainly from loss of habitat, as a result of physical disturbance of the land, and from introduction of toxic elements and ions into the biosphere (see Sec. 6.2.6). Impacts from loss of habitat can be alleviated to some extent if the tailings disposal area is revegetated. Eventually, over subsequent decades, replacement habitat will become established. Effects of seepage of toxic material, however, will tend to persist for a longer period. Additional loss of habitat due to soil salinization can also result from excessive amounts of seepage from the tailings impoundment. Any tailings management alternatives that would minimize these effects would thus be optimal in terms of the terrestrial ecosystem. The tailings management alternatives are evaluated in view of these considerations.

9.3.6.1.1 Comparison of Alternatives

Alternatives 1, 4, 5, 6 and 9 would result in loss of habitat and small animals from the areas preempted for tailings impoundments, in addition to land lost to the mine and other mill facilities. These losses of habitat would be temporary, depending on the success of reclamation efforts, and would continue at least through the period of decommissioning. These alternatives differ from the base case, in that reclamation efforts would hasten the establishment of replacement habitat.

Alternative 8 would require additional land area for temporary storage of tailings, unless an abandoned deep mine were already in existence. The area required for temporary storage would be equivalent to the land required for the impoundment in the base case. Alternatives 2, 3, and 7 would cause no habitat loss or disturbance in addition to that from mining and other mill facilities.

Unlike the temporary loss of habitat due to physical disturbance, loss of rangeland habitat due to soil salinization is essentially a permanent loss. This and other impacts of seepage from the tailings impoundment may not be immediately apparent, but can be chronic and persist for decades or more. For these reasons, curtailment of seepage is of greater importance than temporary loss of habitat for the model site.

Alternatives that decrease the potential for adverse seepage effects on soil (see Sec. 9.3.5) are also those with the least potential for causing adverse effects on terrestrial biota. This is because seepage from the tailings impoundment must enter the soil and surface seeps, before it can interact with terrestrial biota. As discussed in Section 9.3.5, Alternatives 1, 6 and 9 (ground-level placement of tailings with compacted earth or liner) have the greatest potential for adverse effects to the terrestrial ecosystem, if the liner fails. Disposal of tailings, preferably dry or fixed, in mine pits (Alternatives 2, 3, 7, and 8) would pose the least threat of adverse seepage effects.

One distinctive feature of Alternatives 7 and 8 (tailings fixed in cement) is the potential for dust from the cement plant to be deposited on vegetation outside the building. In several studies (reviewed in Ref. 10), cement-kiln dust has been found to have direct adverse effects on vegetation, such as crust formation on leaf surfaces, reduction of growth, prevention of pollen germination, and prevention of normal gas exchange due to plugging of stomata. Indirect effects, such as changes in soil pH and nutrient availability, can affect the vegetation community structure, as has been demonstrated in studies with forest communities subjected to long-term exposure to cement-kiln dust.[11,12]

The question of post-disposal covering of tailings can be of major importance relative to terrestrial biota. This is because the cover would act as a physical barrier between the possibly toxic tailings and the organisms on the earth's surface. Alternative 8 (deep mine disposal) provides the best barrier in this respect, since only a relatively small area (the mouth of the shaft) is required to be filled in. The chance of breaching the shaft cap is thus relatively small.

Alternatives 2, 3, and 7 (mine pit disposal) would allow the next best isolation of the tailings from surface organisms, both plants and animals, since the depth of most open pits would make it easier than other, near-surface disposal alternatives, to provide very thick cover of the tailings. In general, however, covering with overburden to depths of several meters would preclude penetration of the tailings by plant roots, in most cases. This would, in turn, prevent uptake of potentially toxic ions by the vegetation, translocation to aerial portions, and introduction into the surface ecosystem.

A few species of plants can be identified that might penetrate through the cover and below. For example, roots of big bluestem, switchgrass, and Indian grass can extend down to depths of over 2 m (7 ft), 3.4 m (11 ft), and 2.8 m (9 ft), respectively.[13,14] Plant root growth in the earth cover would increase the porosity of the cover, allowing some infiltration of water, possibly to the tailings. Burrowing animals also may penetrate overburden cover; in general, the thicker the cover provided, the less likely it is that this will lead to significant disruption of the tailings isolation.

9.3.6.1.2 Effects of Process and Control Options

In general, the process and control options are expected to have little effect on the impacts of the tailings management alternatives to terrestrial biota, except as discussed in Section 9.3.5. Since the soil is an interacting component of the terrestrial ecosystem, options that decrease adverse effects on soil also decrease adverse effects on terrestrial biota. One process option that warrants some discussion in this respect is nitric acid leach. As described in Chapter 8, the process can be designed so that the concentration of the nitrate ion in the tailings slurry does not exceed 10 mg/L, the maximum allowable concentration in domestic water.[2] [For livestock and poultry (and presumably, other animals) the recommended limit is 100 mg/L nitrate.][15] However, in the past, the use of nitric acid leaching has resulted in nitrate concentrations on the order of several hundred mg/L in monitor well water.[3] Selection of this option thus implies a necessity for continual surveillance and control of the milling operation.

9.3.6.1.3 *Regional Variability*

The feasibility of the various alternatives in any given region is subject to constraints similar to those discussed for soil, and has little to do with the biotic characteristics of the regions. The severity of impacts of the various alternatives upon the terrestrial biota characteristic of a given region varies from region to region. Regions such as the Northern and Southern Rocky Mountains, and the Texas Coastal Plains, that have the largest diversity of wildlife habitats, will tend to be more adversely affected by preemption of land for tailings impoundments, than the other regions. In particular, the Texas Coastal Plains region has twice as many federally listed endangered species as any other region, not necessarily because this region has been more disturbed than the other regions, but because this region has a greater diversity of habitats, particularly wetlands, that are used by migrating and resident species.

The Wyoming Basin, Colorado Plateau, and Western Great Plains regions include areas with seleniferous shales.[16] The tailings characteristic of these areas will tend to have higher concentrations of selenium than tailings from other areas; seepage from the impoundment sites for these tailings would thus tend to have more toxic concentrations of selenium than the seepage from tailings in nonseleniferous formations. Similar conditions would exist in areas relatively high in arsenic, molybdenum, and vanadium. In these regions, therefore, the alternatives that have the greatest potential for seepage to the ground surface (base case and Alternative 1) would be less attractive.

9.3.6.1.4 Summary

The major impacts to terrestrial biota from uranium mill tailings disposal would be: (1) loss of habitat due to preemption of land for the disposal site; and (2) introduction of toxic material into the biosphere because of seepage from the impoundment.

Adequate revegetation of the site after operation, and natural vegetational succession, will tend to restore wildlife habitat. Over the long term, therefore, loss of habitat can be considered a temporary effect. Seepage effects, on the other hand, will persist for decades and thus are of the most concern. The tailings management alternatives that tend to maximize the isolation of the material from the biosphere (e.g., disposal in a deep mine or in an open pit mine) appear to be superior to the other alternatives, with respect to impacts on terrestrial biota. However, tailings alternatives which reduce seepage emissions, such as Alternatives 2 through 6, should be adequate in eliminating problems of seepage and soil salinization.

9.3.6.2 Aquatic

Impacts to aquatic ecosystems which may affect aquatic biota can be classified as either physical, chemical, or biological. Physical impacts are alterations of habitat; chemical impacts are alterations of water quality; and biological impacts are introduction of new species or removal of resident species. Impacts to aquatic biota from uranium mill tailings are principally chemical impacts. Surface water quality can be degraded by contamination from mill tailing wastes that can reach aquatic systems either as particulates carried by wind, dissolved in precipitation runoff, and soil interflow from areas where seepage has reached the ground surface and evaporated, or dissolved in groundwater.

9.3.6.2.1 Effects of Process Alternatives

Those process alternatives that could (indirectly) affect aquatic biota are:

Nitric Acid Leach Process. The major difference between the nitric acid leach process and the base case is the substitution of nitrate (NO_3^-) ion for the sulfate ($SO_4^=$) ion. If releases of nitrate were limited to levels acceptable under EPA guidelines, resultant impacts to aquatic systems could be less than those caused by the sulfuric acid leach process.

Segregation of Slimes from Sands. If the segregated slime fraction were properly disposed of, impacts to aquatic biota should be reduced from the levels expected for the base case. Fixation of the slime fraction in asphalt or cement also would greatly reduce its leachability, and the potential impact on aquatic biota would be much smaller.

Separation of Toxic Material. Neutralization of tailings would decrease the solubility of many heavy metals, which then would be less available for contamination of surface waters; however, other elements, such as selenium and vanadium, are more soluble under neutral or basic conditions. On the whole, neutralization of tailings would improve surface water quality over that of the base case; hence, impacts to aquatic biota should be reduced. Similarly, removal of toxic materials from the tailings should provide adequate protection of aquatic biota.

Solidification of Tailings. The conversion of tailings to solids would effectively eliminate the tailings pond, so the potential for contaminated seepage to reach surface waters also would be eliminated. Because there would then be no change in surface water quality, aquatic biota would not be affected.

9.3.6.2.2 Evaluation of Alternatives

Comparison of impacts to aquatic biota from the tailings management alternatives with those from the base case will be based on the projected impacts to surface water quality (Sec. 9.3.4.1).

Alternative 1 would involve only compaction of the disposal basin bottom, which would be ineffective in reducing seepage; hence, impacts to aquatic biota would be the same as those discussed in Section 6.2.6.2.

The tailings disposal programs of Alternatives 2 through 6 and Alternative 9 would involve emplacement of either a synthetic or clay liner. Seepage would be virtually eliminated by the synthetic liner and reduced to 6% of the base case by the clay liner. However, with a clay liner, materials in the seepage would be 3.6 times as concentrated as in the base case. The already-small impacts to aquatic biota from contamination of surface water by tailings pond seepage should be reduced (clay liner). Impacts to aquatic biota from windborne contaminants would be less than those for the base case during mill operation because there would be less dry tailings surface area. During the postoperational period, however, a cover of earth or overburden should protect against impacts to aquatic biota from wind-dispersed contaminants.

Alternatives 7 and 8, by fixing the tailings with either cement or asphalt before placement in the pit, would eliminate the potential for wind dispersal of tailings contaminants. However, certain control options (e.g., dust control), might be necessary to prevent wind dispersal of contaminants from the fixing plant. There should be very little seepage from the fixed tailings. Compared with the base case, impacts to aquatic biota from contaminants generated if these alternatives were implemented should be greatly reduced.

Regional variability of aquatic biota might affect the severity of impacts, e.g., biota in perennial streams in the southern regions (Texas Coastal Plains) might respond differently to certain contaminants than biota of northern (Northern Rocky Mountains) intermittent streams. However, based on a recent literature survey,[17] the variability of response to a specific toxicant is extremely large between species of different phyla; this variability is probably much more significant than regional variability in the assessment of impact.

9.3.7 On the Community

Implementation of tailings management alternatives would do little to change the impacts on the community from those analyzed for the base case. Some process alternatives such as those involved in special chemical processing, would require workers with special skills. Consequently, either more nonlocal people with special training would have to be recruited from areas further away, increasing the possibilities for sociocultural differences between locals and in-migrants, or companies could institute training programs and possibly recruit local residents to fill the positions. Depending on the magnitude of the training program, the tenancy of a part of the work force, as well as the total number of employees, could be increased.

The only other altered effect apparent would involve archeological/historical sites and would depend upon the amount of land required and the nature of the site-specific resources. The more land utilized for a certain alternative, the greater the potential for discovery of previously unreported archeological/historic sites, and the larger the area that must be covered by a qualified archeological survey team.

9.3.8 Radiological

In this section, the radiological consequences of the various alternatives for mill tailings management are assessed. In Section 6.2.8 it was shown that the tailings were the major source of radon gas and that the radon daughters were responsible for approximately 80% of the predicted health effects within the model region during mill operation, and for an even higher proportion after decommissioning. Because of the mobility of radon, compared with particulates, this inert gas and its daughter products are considered the only sources of radioactivity originating at a mill to which the populace beyond the 80-km (50-mile) radius of the model region might be directly exposed. The consequences to the North American population of radon released from the entire U.S. milling industry were predicted in Section 6.4. The health effects attributable to milling and tailings storage are expected to be a very small fraction of the total effects which would occur in any case, or of the number produced by unavoidable background radiation, including radon from natural sources. Nevertheless, the basic principle of maintaining all radiation exposure as low as reasonably achievable (ALARA) requires a careful analysis of the costs and benefits of reducing radon emissions from tailings. The benefits are examined in this section, in terms of health effects that may be averted through application of various tailings management alternatives. The costs are considered in Chapter 11, and conclusions concerning the balance of benefits versus costs are summarized in Chapter 12.

With reference to radiological impact, good tailings management requires that sufficient cover material remain in place to maintain physical isolation and to reduce radon exhalation to the desired rate. In general, a cover thickness that produces a substantial decrease in radon flux will be more than adequate to reduce the external gamma exposure rate on top of the pile nearly to the background rate. Even a very thin cover, if it remains intact, will eliminate windblown tailings as a source of radioactive particulates. Because of the importance of cover thickness in determining the impact and cost of a given management plan, this subject is discussed before the alternatives are considered.

9.3.8.1 Estimation of Radon Flux Attenuation by Cover Material

The radon exhalation rate from tailings deposits depends on many factors, including the emanating power, density, porosity, moisture content and, of course, the radium content. Much of the radioactivity is in the slimes fraction, which may be concentrated toward the top or bottom of the tailings or mixed rather homogeneously with the sands, depending on how the material was deposited. The vertical distribution of these fractions, as well as the total thickness of tailings, will affect the surface exhalation rate. Estimation of the radon flux from uncovered tailings is discussed in Chapter 5 and Appendix G-1, where it is concluded that a specific emission rate of 1.0 pCi Rn-222/m^2-s per pCi Ra-226/gram of tailings is a conservative but reasonable value to use in this generic study. In calculations throughout this document, the average radium content of 280 pCi per gram of tailings has been applied to yield an exhalation rate of 280 pCi/m^2-s from uncovered tailings. Estimates of the exhalation rate and cumulative radon releases from covered, permanently stored tailings also are based on a rate of 280 pCi/m^2-s from a bare pile. Appendix S reviews the uncertainties involved in various factors, such as the specific emission rate, which determine cumulative releases of radon and discusses the effect of assuming values other than those assumed here.

Radon migrates through a porous media such as a cover material by diffusion and also as a result of transport phenomena which depend to an important extent on meteorological conditions.[18] Therefore, field measurements of radon exhalation rates are highly variable, and great care must be exercised in order to obtain flux values which approximate average or steady-state conditions. Despite the experimental difficulties, simple diffusion theory has proven to be useful in the prediction of average radon flux and concentrations in a variety of materials. The general, one-dimensional equation described in Section 3.2 of Appendix G-1 (equation 2) provides a basis for estimation of the flux from the surface of multiple layers of cover; however, even for the case of a single, homogeneous layer containing no radium, the exact solution is a complex hyperbolic equation. In most situations of interest, both the tailings and the cover will be relatively thick, and the equation may be simplified. In this case the depth of cover, x (cm), needed to reduce the flux to the desired level, J (pCi/m^2-s), is found by use of the relationship:

$$J = J_0 \exp [-x(\lambda P/Dh)^{\frac{1}{2}}] = J_0 f \exp [-x(\lambda P/D)^{\frac{1}{2}}] \qquad (1)$$

where J_o is the radon flux from the uncovered tailings, $\lambda = 2.10 \times 10^{-6}$/second is the radon-222 decay constant, D (cm^2/s) is the bulk diffusion coefficient of radon in the covering media, and P is the porosity of the material. The variables h and f are used here to represent the very complex mathematical expressions (functions) presented in full detail in Appendix P. These functions act as dimensionless correction factors and allow the expression of the full mathematical formulation in the compact form shown above. Under normal ranges of their dependent variables, which include cover thickness and porosity, and effective bulk diffusion coefficient of both the tailings and cover materials, the values of both h and f are near unity. In all cases, the accuracy of the predicted surface radon flux will depend upon the degree to which the various diffusion parameter values used are representative of actual conditions. Nevertheless, the expression above would remain an approximation, based on the assumptions of an infinitely thick plane source and homogeneous cover and tailings materials. Actual radon fluxes could, therefore, be either higher or lower than as predicted.

Because of the wide range of values which have been assigned to the bulk diffusion coefficient for various soils from various geographic areas, and even within a limited area, and because of the variability of the field and laboratory conditions and procedures under which they were obtained, it is unreasonable to select a single value as being typical. This is evident even from a historical perspective, based upon Tanner's 1964 review of early literature values.[19] More recent research has continued to indicate high degrees of variability, but has culminated in the identification of moisture content as the key quality governing radon attenuation.[20] The large variability of the effective diffusion coefficient as a function of moisture content clearly dominates and obscures the much smaller pertubations induced by variation of other soil properties. Hence, the most important single characteristic of earth cover materials, with respect to radon attenuation, is the ability to retain moisture. Recent experimental results, some of which are summarized in Table 9.10, have enabled the following general empirical correlation of bulk diffusion coefficient with soil moisture:[20]

$$D = 0.106\ P \exp(-0.261\ M) \qquad (2)$$

where M denotes the moisture content of the attenuating material, in percent by weight. As further discussed in Appendix P, this expression is not exact and would not account for the full range of variability of other involved paramèters. It does, however, serve to illustrate the functional dependence of the diffusion coefficient on soil moisture.

Unsaturated soil moisture (vadose soil water) is highly variable, depending upon soil type and associated properties, and also environmental and site conditions. Vadose soil water may be classified as being either gravitational (removable under the influence of gravity), capillary (held by surface tension), or hygroscopic (held by electrostatic attraction). Gravitational moisture is, in all cases, temporal; it exists only temporarily, during infiltration of precipitation, for example. Capillary moisture, although stable under steady-state equilibrium conditions, may be reduced or removed by relatively weak pressure differentials, such as those causing evaporation or created by the presence of plant roots. Hygroscopic moisture is removed only by extreme pressure differentials that are not likely to be encountered in the natural environment (e.g., heating to over 100°C for several hours). Thus, hygroscopic moisture may be relied upon with high confidence. To a lesser extent, capillary moisture could also be relied upon, based on evaluation of site-specific conditions.

Figure 9.1 illustrates the effect various thicknesses of cover material will have in reducing tailings radon exhalation if applied to the model mill. These curves are based upon the detailed analytical models described in Appendix P, and a bare surface radon emission rate of 280 pCi/m^2-sec. They also effectively illustrate the strong dependence of radon attenuation capability on residual moisture content. The range of moisture contents for which results are displayed, 6 to 12%, roughly encompasses the range that would be expected for ordinary earthen material, such as mine overburden, and loosely compacted clay-type soils of commonly available quality. This range was selected on the basis of a staff review of available soil moisture data for actual mill site areas. This review is summarized in Appendix P and includes data from a wide range of geographic areas, including the more arid milling areas in New Mexico.

The curves presented in Figure 9.1 are largely intended to be illustrative, to serve as examples of the radon attenuation properties attributable to various thicknesses of soils with various moisture contents. For this reason, and in consideration of the cost increments and engineering difficulties involved in placing a high quality, well-compacted clay layer over hydraulically placed tailings, the effects of such a clay layer with or without additional fill material are not shown. Also weighing in this decision is the relative radon attenuation effectiveness that could be attributed to such a layer over the long term, given the problems involved in preventing the adverse effects of cracking due to differential settlement and eventual moisture loss. The staff considers it doubtful that the relatively high moisture content potential of freshly installed high quality clay can indeed be established and maintained with sufficient reliability as to make such a clay layer genuinely cost-effective.

Table 9.10 Laboratory Measurements of Diffusion Coefficients for Radon[a]

Soil Location/Method[b]	Moisture Content, %	D/P (cm^2/sec)[c]
Wyoming/Flux		
Powder River #1	5	2.3 E-2
	9	2.2 E-2
	17	2.6 E-4
	30	8.2 E-5
Powder River #2	6	2.5 E-2
Shirley Basin #1	5	9.1 E-3
	12	1.8 E-2
	20	1.7 E-4
Background Soil #1	11	8.2 E-3
Background Soil #2	1	8.9 E-3
New Mexico/Flux		
Ambrosia Lake #1	10	5.3 E-2
	20	6.4 E-3
Ambrosia Lake #2	2	3.5 E-2
	6	2.0 E-2
Wyoming/Concentration		
Powder River #1	5	1.9 E-2
	9	1.9 E-2
Powder River #2	6	1.8 E-2
Shirley Basin #1	5	1.6 E-2
	12	1.5 E-2
Shirley Basin #2	8	1.7 E-2
	15	3.6 E-3
Background Soil #1	11	1.9 E-2
Background Soil #2	1	1.7 E-2
New Mexico/Concentration		
Ambrosia Lake #1	20	3.8 E-3
Ambrosia Lake #2	2	2.7 E-2
	6	1.1 E-2

[a]V. C. Roger, et al. "Characterization of Uranium Tailings Cover Materials for Radon Flux Reduction," U.S. NRC Report NUREG/CR-1081, March 1980.

[b]Methods used included surface radon flux measurements and radon concentration profiles in cover soil gas.

[c]The diffusion coefficients displayed in this table are model dependent. Basic diffusion theory assumptions and calibrations are made in NUREG/CR-1081 (see footnote a above) which would make these values for D/P inappropriate for other models, which are described in the literature. The compatibility of these values with any other models must be determined before they are used.

Since cover materials are expected to contain up to several pCi of radium-226 per gram, the cover itself may contribute a substantial fraction of the total surface flux when the radon produced by the tailings is attenuated down to several pCi/m^2-s. For example, it is shown in Figure 9.1 that approximately 3.2 m of soil D is needed to reduce the flux from 280 to 2 pCi/m^2-s. A more elaborate calculation assuming soil D contains 4 pCi/g predicts that a 3.2 m thick layer will result in a total surface flux of about 3 pCi/m^2-s. However, in the calculation of the thickness of cover required, as described in Appendix P, the contribution from the cover itself to the surface radon flux is ignored (i.e., the soil contribution is considered to be background exhalation).

9.3.8.2 Effects of Various Levels of Radon Exhalation

The benefits expected as a result of covering the tailings and maintaining the radon flux at a reduced level should be evaluated in the immediate vicinity of the mill and on a much wider scale.

During operation of the mill, access to the tailings pile is controlled and the closest possible temporary residence is considered to be a trailer located 0.7 km (0.4 mile) downwind. The

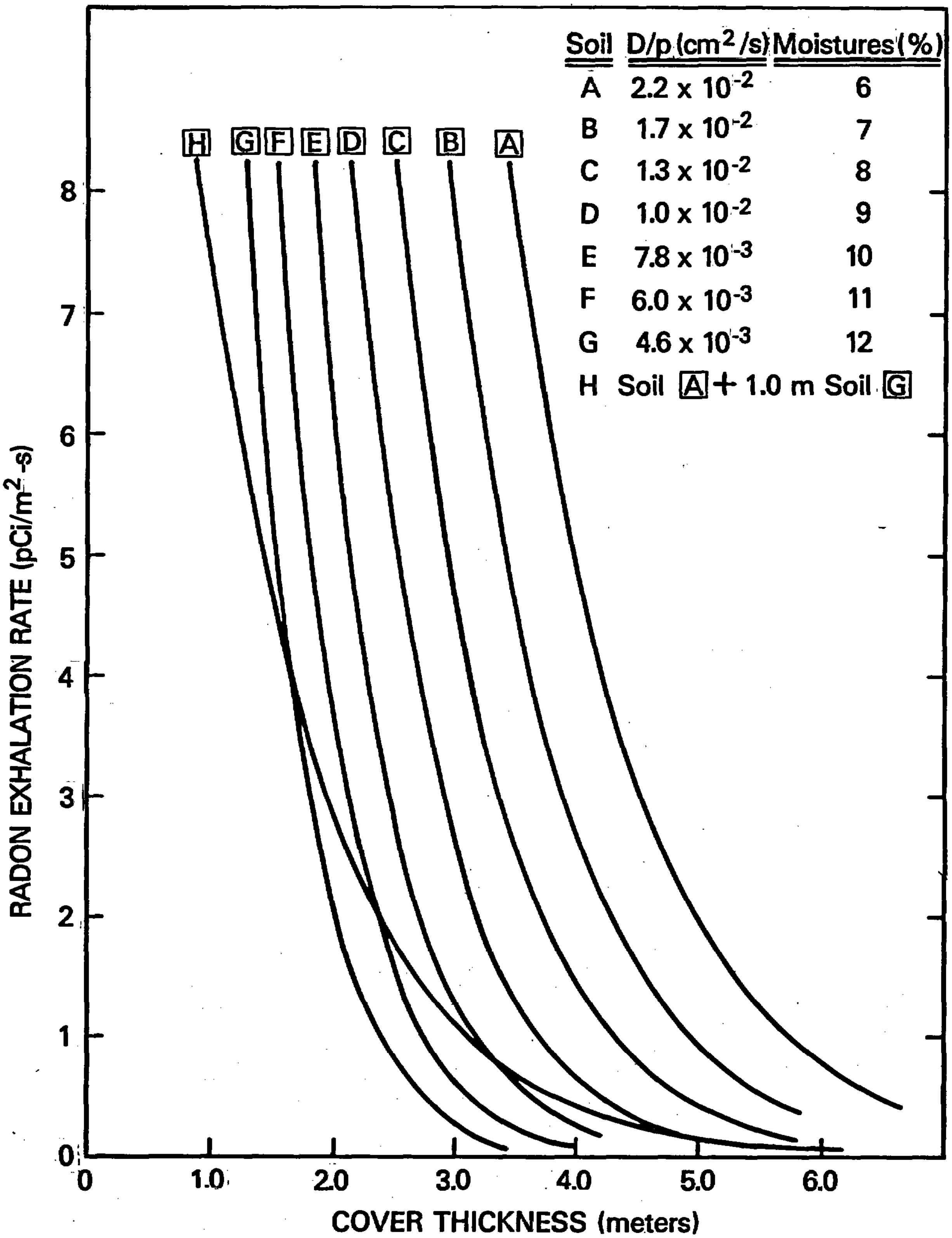

Fig. 9.1. Effect of Soil Thickness on Radon Exhalation Rate.

annual dose commitments to individuals at the trailer and other nearby points were predicted in Section 6.2.8.2 for the operational period and in Section 6.2.8.3 for the postoperational period, during which the dry area of the tailings pond is assumed to expand to 80 ha (200 acres).

As indicated in Table 6.23, at the end of this five-year period, the radon dose to the bronchial epithelium would be about 0.52 rem/yr at the trailer (based on 50% occupancy). Presumably, after decommissioning and in the absence of controls, a permanent residence could be built even closer to the tailings, perhaps in an extreme case directly on the pile. Estimates have been made of the radon daughter concentrations that might exist within a dwelling on or very near the tailings. These estimates are presented in Table 9.11 for various levels of radon exhalation.

Table 9.11 Radon Daughter Concentrations In Air (WL) in Structures Above and Near Uranium Tailings Piles[a]

Radon Flux (pCi/m^2-s)	Radon Daughter Concentration--Working Level above Background		
	Above Tailings[b]	Near Edge of Disposal Area[c]	Ranch at 2.0 km
280	0.50	1.6×10^{-2}	2.3×10^{-3}
100	0.18	5.7×10^{-3}	8.2×10^{-4}
10	0.018	5.7×10^{-4}	8.2×10^{-5}
5	0.0090	2.8×10^{-4}	4.1×10^{-5}
3	0.0054	1.7×10^{-4}	2.5×10^{-5}
2	0.0036	1.1×10^{-4}	1.6×10^{-5}
1	0.0018	5.7×10^{-5}	8.2×10^{-6}
0.1	0.00018	5.7×10^{-6}	8.2×10^{-7}

[a]Assumed to be 80 ha in area. Working level values are derived from calculated radon concentrations, assuming that 1 pCi/L of Rn-222 is equivalent to 0.005 WL. The estimates of this table are above average background concentrations, which are about 0.005 WL, inside a well-ventilated structure. For an estimate of dose to bronchial epithelium, multiply WL exposure level by: 25 CWLM/WL X 5 rem/CLWM. So, for example, exposure to 0.005 WL continuously for one year would result in a dose to the bronchial epithelium of about 630 mrem.

[b]See Sec. 9.3.8.2 for assumptions used to calculate these concentrations.

[c]About 100 m downwind (ENE) from the edge of the tailings pile.

For the calculation for a house built on the pile, it is assumed that all of the radon comes through a floor which attenuates the flux to 0.3 of its value at the surface of the tailings or the cover material, i.e., at the interface with the underside of the floor. Also, the house is assumed to have 3-m (10-ft) high ceilings and to be ventilated at the rate of one air change per hour. The calculated radon concentration is converted to working level (WL) by assuming that 100 pCi/m^3 equals 5×10^{-4} WL. A range of exposure levels can be predicted. For example, using the assumptions stated, 2 pCi/m^2-s yields an exposure level of 0.0036 WL; other reasonable assumptions, if stacked up in the extreme directions, could lead to a range of 0.0006 to 0.006 WL from the same flux. The WL concentrations at nearby locations (not on top of the pile) are derived from radon concentrations calculated as described in Appendix G-2 and converted to WL, using this same 5×10^{-4} WL per 100 pCi/m^3 factor.

In Section 6.2.8.3, it was shown that the annual lung dose commitment to the population of the model region within 80 km (50 miles) of the mill did not exceed 0.5% of the background dose from radon, when the exhalation rate was 280 pCi/m^2-s from an area of 80 ha (200 acres). Reducing the exhalation rate to a few pCi/m^2-s would reduce the population dose commitment correspondingly to less than 0.01% of the dose from "natural" radon (radon released as a result of other than mining, milling, or other human activity).

By application of the methodology described in Section 6.4, the annual and cumulative 100-year environmental dose commitments to the population of North America have been estimated for a range of average radon exhalation rates. The results are summarized in Table 9.12. The annual dose is for years after 2100, when the population is assumed to remain constant in size. With uncovered tailings (average exhalation rate of 280 pCi/m^2-s), the annual dose commitment to the lung is projected to be 6.0 x 10^4 organ-rem. Of this total, 5.5 x 10^4 organ-rem is delivered to residents of the United States. This is about 0.1% of the dose to a United States population of 290 million from radon gas released from natural soil, released by evapotranspiration, and released into the interior of buildings from several sources (see Ch. 12). Reduction of the average rate of release to a few pCi/m^2-s will limit the contribution of mill tailings to about 0.001% of the total population dose from radon.

The annual and cumulative dose commitments from Table 9.12 have been expressed as equivalent health effects in Table 9.13, by applying the risk estimators of Table G-7.1. The uncovered tailings are predicted to cause about six premature deaths per year throughout North America, but if substantial cover is applied, the rate will be greatly reduced.

9.3.8.3 Radiological Impact of Alternatives for Tailings Disposal

For the sake of benefit-cost comparisons, most of the tailings disposal programs described in Chapter 8 (Alternatives 1 through 6) were given equivalent tailings covers (see Table 8.4). Section 9.3.8.2 evaluates the general effects on long-term radioactive emissions of varying from this fixed cover; both different cover types and thickness are examined. To illustrate some of the practical differences that would occur among actual disposal programs, the matter of final tailings covering is now treated in the context of the tailings disposal programs evaluated. Also, Section 9.2.8 treated the matter of controlling emissions from tailings during operations without considering the effect various tailings disposal alternatives will have on the matter; these effects are also now discussed.

9.3.8.3.1 Final Tailings Cover

Disposal of tailings in an available open pit may make it easier to provide cover of tailings than might be the case where tailings are disposed of above grade or in specially excavated pits. This may occur since a large quantity of overburden is normally stripped to reach ore zones (review of preliminary data obtained on operating mines indicates that the depth of overburden, on average, is over 60 m). As a result, the distance from the top of the disposed tailings to surface grade may very likely be significantly greater than the thickness required to reduce radon emissions to prescribed levels. Under the open mine pit disposal alternatives examined, the final distance from the tailings surface to ground level is controlled partly by the depth to the water table, since, in all cases, tailings are kept above groundwater. However, the distance to groundwater should in most cases be sufficient to allow providing relatively thick cover just by returning to the mine the overburden stripped in mining the ore.

Alternatives of the Potential Reduced Care Mode would generally result in a lower level of radon emissions than occurs with Active Care and Passive Monitoring Mode Alternatives (Alternatives 1 through 6) involving radon control by soil cover alone. Fixation of slimes in cement or asphalt (Alternatives 7 and 8) could, if the fixed slime fractions covered the upper tailings surface, cause radon emissions from the tailings to be virtually eliminated. Furthermore, fixing the slimes fraction of tailings and cleaning sands to a degree which permits deposition of tailings in open pits below the groundwater table would assure that very thick covers are placed over the tailings. The amount of overburden cover would not be constrained by the distance from the water table to surface grade. It would only be a function of the depth to the bottom of the ore zone.

In the case where nitric acid leaching was employed to remove radium and thorium from tailings (Alternative 9), thicknesses of tailings cover could be reduced from that required for tailings having normal concentrations of these nuclides. Other significant differences between Potential Reduced Care Mode alternatives and the alternatives examined related to the different levels of physical isolation provided. These are discussed in Section 9.4.1, Stability Against Natural Forces, and Section 9.4.2, Land Use Controls.

9.3.8.3.2 Emissions during Operation

The controls discussed in Section 9.2.8 for reducing dust emissions from tailings impoundments involve maintaining a tailings solution cover, surface wetting, or spraying surfaces with chemical stabilizers. While the latter two methods involving stabilization of the tailings surfaces to control dusting, these methods are expected to be less effective in attenuating

Table 9.12 100-Year Environmental Dose Commitments to Population of North American Continent from Radon Releases from Mill Tailings[a,b]

Exhalation Rate (pCi/m^2-s)	Annual Dose Commitment (organ-rem/year)			Cumulative Dose Commitment 2000-2100			Cumulative Dose Commitment 2000-3000		
	Lung	Bone	Whole Body	Lung	Bone	Whole Body	Lung	Bone	Whole Body
280[c]	6.0×10^4	9.1×10^4	7.0×10^3	5.7×10^6	8.6×10^6	6.7×10^5	6.0×10^7	9.0×10^7	7.0×10^6
100	2.1×10^4	3.1×10^4	2.3×10^3	2.0×10^6	2.9×10^6	2.2×10^5	2.1×10^7	3.1×10^7	2.3×10^6
10	2.1×10^3	3.1×10^3	2.3×10^2	2.0×10^5	2.9×10^5	2.2×10^4	2.1×10^6	3.1×10^6	2.3×10^5
5	1.1×10^3	1.5 x 103	1.2×10^2	1.0×10^5	1.5×10^5	1.1×10^4	1.1×10^6	1.5×10^6	1.1×10^5
3	6.4×10^2	9.2×10^2	6.9×10^1	6.0×10^4	8.7×10^4	6.5×10^3	6.3×10^5	9.2×10^5	6.9×10^4
2	4.3×10^2	6.2×10^2	4.6×10^1	4.0×10^4	5.8×10^4	4.4×10^3	4.2×10^5	6.1×10^5	4.6×10^4
1	2.1×10^2	3.1×10^2	2.3×10^1	2.0×10^4	2.9×10^4	2.2×10^3	2.1×10^5	3.1×10^5	2.3×10^4
0.1	2.1×10^1	3.1×10^1	2.3×10^1	2.0×10^3	2.9×10^3	2.2×10^2	2.1×10^4	3.1×10^4	2.3×10^3

[a]Dose commitment for lung is sum of doses to bronchial epithelium and pulmonary tissue; values for bone and whole body include inhalation and ingestion pathways. Dose commitments for the uncovered tailings include doses due to both particulates and radon from the tailings. Dose commitments for covered tailings are based on the assumption that there will be no particulate releases from covered tailings.

[b]Assuming 76 mill sites, each with 80 ha of tailings.

[c]Average exhalation rate assumed for uncovered tailings.

Table 9.13 Somatic Health Effects on Population of North America from Radon Releases from Mill Tailings

Exhalation Rate (pCi/m^2-s)	Premature Cancer Deaths: Annual Rate[a]	Cumulative Number: 2000-2100	Cumulative Number: 2000-3000
280[b]	6.0	560	5960
100	2.1	196	2050
10	0.21	20	205
5	0.103	9.8	103
3	0.062	5.9	62
2	0.041	3.9	41
1	0.021	2.0	21
0.1	0.002	0.2	2.1

[a]Assuming 76 mill sites, each with 80 ha of tailings.

[b]Average exhalation rate assumed for uncovered tailings. Base case values were derived from rounded values in Table 6.39.

radon than complete saturation of tailings with solution would be. For example, chemical surface stabilizers will be prone to imperfections and defects which will provide escape routes for the mobile radon gas.

The alternatives which will offer the greatest potential for providing solution cover are those alternatives involving slurry diposal and lining of impoundment bottoms with impermeable liners (Alternatives 2, 4, 5 and 6). Tailings areas with solution cover would increase for these alternatives by about 50% above the base case. On the other hand, increasing tailings solution works against the objective of reducing seepage to groundwater, and also is likely to create additional problems with regard to eventual reclamation and long term stability. While dewatering of tailings, such as is done in Alternative 3, may result in less attenuation of radon in the short term than the slurry disposal alternatives, it provides a potential significant benefit in terms of the groundwater protection and impoundment stability it provides. It may also make easier the matter of final tailings drying and covering. The approach which would best reconcile this conflict is phased reclamation of tailings areas. Alternative 5 is an example of how staged reclamation might be accomplished. This alternative is intended only to demonstrate the concept of staged reclamation. Impoundment shapes other than the continuous, linear trench assumed for this alternative would also permit staged reclamation. Construction of separate, unit cells for tailings disposal is, for example, being implemented in one case (see NUREG-0505, Sweetwater Uranium Project, Final Environmental Statement, December 1978). Other proposed below grade disposal schemes are described in Appendix T-3.

Another difference between alternative disposal programs with regard to emissions during operation will occur between above and below grade disposal alternatives. Tailings will be sheltered from the wind when they are disposed of below grade, whereas above grade they will be very susceptible to wind action.

9.3.8.4 Environmental Impacts of Obtaining Cover Materials

With the exception of Alternative 8, which involves disposal of tailings by backfilling underground mines, the nine tailings management plan alternatives described in Sections 8.4.2 through 8.4.10 all effect final reclamation by emplacement of a thick earthen cover over the disposed tailings. The environmental impacts arising from this operation differ over the various alternatives due to differences in the amounts of cover material required and the degree of availability of such material. The environmental impacts associated with procuring and placing such final reclamation covers, and differences in these impacts among the various alternatives, are assessed in this section. Monetary costs are addressed elsewhere, in Chapter 11 and Appendix K, and further assessed in Chapter 12.

9.3.8.4.1 Availability of Cover Material

In most of the alternatives, sufficient cover material will be readily available as it is provided in abundant quantity through the normal course of events. Alternatives 4 and 5 involve tailings disposal in specially excavated impoundments wherein the excavated materials provide sufficient reclamation cover. Alternatives 2, 3, and 7 make use of an abandoned open pit mine and cover material is provided by the vast quantities of overburden routinely removed in such operations. Very little earth fill material is required in Alternative 8 which makes use of vacant underground mine passageways to dispose of tailings solids.

Only Alternatives 1, 6, and 9, which implement above grade tailings disposal schemes, will possibly require that earthen cover materials be obtained by excavation of otherwise undisturbed areas. In the other alternatives, sufficient cover material is inherently provided by the associated excavations which provide adequate below grade storage volume. Even with Alternatives 1, 6, and 9, it is quite possible that some or all of the needed cover materials could be provided by the overburden or mine waste produced by nearby mining operations. (This situation is quite similar to that of a number of existing sites which have utilized above grade disposal and did not foresee the eventual need for substantial quantities of reclamation cover; these operators must either excavate undisturbed terrain or transfer overburden or mine waste from offsite locations if sufficient reclamation cover is to be provided.)

Offsite availability of cover material, if it is not available by onsite excavation or produced inherently by associated mining or milling operations, will be site and region dependent. Where open pit mining is prevalent, as in Wyoming and Colorado, overburden will be available but it may still be less expensive and more practicable to excavate and reclaim in undisturbed areas, depending primarily on the relative distances and environmental values involved. Even in places where open pit mining is unusual and natural availability of cover material is minimal, areas always exist where more than adequate quantities of cover material are available. For example, the Gulf Mt. Taylor Uranium Mill is located in an area of rugged terrain and arid climate (Grants, New Mexico) but plans on disposal of tailings in man-made trenches excavated to a depth of 50 ft (15 meters) or more. The staff's judgment is that cover material will always be available; differences will exist, however, with respect to whether or not mine overburden is available, the distance from which cover material must be brought, and, if special excavation is necessary, the depth to which natural soils may be excavated. In this regard it must be remembered that the material required need not be of high quality or suitable for other purposes, such as agricultural use. Almost any material will suffice, if available in sufficient quantity. It need only be free of excessive levels of radioactivity.

9.3.8.4.2 Environmental Impacts

As discussed above, only Alternatives 1, 6, and 9 would not benefit from the production of cover material by excavation of sufficient below grade storage volume to dispose of tailings. In these cases, cover materials would have to be obtained from other sources, and perhaps from offsite locations. The worst case, from the standpoint of environmental impacts, would be a situation wherein cover materials would have to be excavated offsite from otherwise undisturbed areas. This would be the case if there were no practicable source of mine waste or overburden available, and is conservatively assumed herein.

The environmental impacts that would result from offsite excavation of cover materials would be similar in kind and variety to those resulting from mill construction which are described in Chapter 6. The volumes of cover material required, assuming that all of it had to be excavated offsite, would be 2.4, 2.4, and 1.2 million cubic meters for Alternatives 1, 6, and 9, respectively. Thus, impacts for Alternative 9 could be expected to be about 50% of those for Alternatives 1 and 6, which are discussed below.

Air Quality. Excavation of cover material would proceed after an overlying layer of topsoil, probably about 0.5 m in thickness, had been stripped and set aside for later reclamation of the borrow area. A front-end loader or similar device would probably be used to excavate material and place it in trucks for transport to the tailings area. These operations would result in dusting problems and impacts similar in kind and magnitude to those evaluated in Section 6.2.1.1.

Also, vehicle emissions would pervade the excavation area during operations. Assuming that reclamation of the tailings area was to be achieved in a 2-yr period, 23 MT (25 ST) capacity trucks were to be used, and the excavated material had a density of 1.6 MT/m3, an average of about 230 truckloads per day would have to be delivered for a two-year period. Conservatively assuming a 10-mile (16-km) hauling distance, each truck could be expected to make about 12 round trips per 8-hr work day. Thus, about 20 trucks would be constantly in operation; departures from the excavation area would occur about every 2 minutes. With this spacing, vehicle exhausts would not be likely to have any significant localized effects. The fleet of trucks would travel a cumulative distance of about 4600 miles (7400 km) per day and total about 3.4 million miles over the entire 2-year period. At an average of 4 miles per gallon of fuel, about 1200 gallons would be burned per day and about 0.84 million gallons would be burned over the full 2-year period. Vehicle exhausts over the haul roads, with one vehicle passing each way every 2 minutes, would not be problematical. If the distance to the borrow area were less than the assumed 10 miles, fuel use and vehicle emissions would be proportionately reduced but the number of round trips per day, and the frequency of about 1 truck every 2 minutes, would be unchanged. The staff believes that suitable cover materials can likely be obtained at less than 10 miles.

It is likely that some haul road construction would be necessary. Where travel was over dirt roads and dusting was a problem, sprinkling by water trucks could be used.

Water Resources. Impacts to water resources would be as described in Sections 6.2.4.1.1 and 6.2.4.2.1 with regard to surface water and groundwater, respectively. Possible impacts would accrue from alteration of natural drainage patterns and erosion of surface materials. During excavation of the borrow area, temporary catch basins could be established where necessary to prevent the uncontrolled transport of eroded materials, as per normal construction practice.

Soil Resources. An estimated 2.4 million cubic meters of soil material would be removed from the borrow area for use as reclamation cover over disposed uranium tailings. Subsequently, the area would be recontoured as suitable to blend in with the surrounding terrain, topsoil originally removed and stored for this purpose would be replaced, and the entire area would be revegetated. Costs for these operations are included in the unit costs for cover material given in Appendix K; details concerning proper revegetation practices and requirements are given in Appendix N. After reclamation of the borrow area, including successful revegetation, the area could likely be returned to its former uses, assuming the altered topography was still suitable.

Biota. Impacts on biota would be similar to those stemming from construction of the model mill which are given in Sections 6.2.6.1.1 (terrestrial) and 6.2.6.2 (aquatic). Impacts to aquatic biota, unless streams providing habitat are re-routed, would be negligible. Impacts to terrestrial biota (see Table 6.5) are proportional to the amount of area disturbed. Information in 6.2.6.1.1 and Table 6.5 is based on a disturbed area of about 220 ha (550 acres).

If only an average depth of 1 meter of cover material could be obtained from the borrow area, then about 240 ha would have to be excavated to provide a 3-meter cover for the 80-ha tailings impoundment of Alternatives 1 and 6. In this case, impacts to terrestrial biota would be similar in magnitude to those described in Chapter 6 arising from construction of the model mill. However, the staff considers this to be a very conservative worst case estimate. Other areas where excavation to much greater depths is possible are likely to be available within a reasonable distance and impacts to terrestrial biota are, therefore, quite likely to be substantially less than those arising from model mill construction. For example, if an average depth of 5 meters of cover material could be obtained from the borrow area, only about 48 ha (not including haul roads) would need to be disturbed, only about 22% of the area disturbed by model mill construction.

During the excavation period (at least 2 years) the borrow area would be lost from productive use. Following successful revegetation to a natural condition, which could take a considerable time but would be temporary in any case, the land could be returned to normal use, probably grazing, agricultural, or forestry.

Community. A work crew of about 20 to 22 would be needed for 8 hours per day, seven days per week, to complete the required excavation and movement of cover material in two years. Allowing for a more normal 5-day work week and bad weather would extend this time requirement to about 3 years. Total wages at $10 per hour would amount to about $1.3 million. The weekly payroll would be a maximum of about $12 thousand, for a seven day per week year-round operation, or about $8 thousand for a more normal 5-day per week schedule with some allowance for time lost due to bad weather.

This would provide an impetus to the local economy, reduce unemployment, and ease the problems of loss of employment at the mill. Because the reclamation efforts would follow mill shutdown it is not likely that significant increases in facilities for community services such as schools, hospitals, housing, police and fire protection would be needed. Temporary increases in the need for such services might result, however, if employees were drawn from outside the local community. It is likely that some employees would be mill workers who had temporarily taken up other jobs or who had stayed on at the mill in order to assist with site decommissioning and decontamination. In this respect, employment due to the earthmoving operations necessary to provide final reclamation cover would provide a buffering effect during the transition from full mill employment to final termination of all operations. In any event, the number of employees involved is relatively small and any negative impacts should be minor.

It would be necessary for the borrow area to be selected so as to avoid significant losses of archeological, historical, esthetic, recreational and other cultural resources and this is assumed to be the case.

Radiological. No man-made radioactive materials would be involved in the earth-moving operations and none would be released or made more available by borrow pit excavation. However, some naturally present radon gas would be released as a result of the digging up and transporting of the large quantities of material involved. Conservatively assuming an average concentration of 3 pCi/g of Ra-226 in the excavated cover material, and assuming a total release of all radon emanated in such material for 3 years, a total of about 300 Ci of radon (Rn-222) would be released. Because the cover material would be on top of the tailings, radon released from the tailings would be reduced by about 4400 Ci per year for each year the cover remained in place.

9.3.8.4.3 Comparison of Alternatives

The impacts assessed and described above are those resulting from a potential worst case scenario wherein cover material must be obtained offsite, at a distance of about 10 miles (16 km), and the depth of cover material available in the borrow area is only 1 meter. Conditions actually occurring, as perhaps at existing sites where tailings disposal is above grade, could hardly be worse and are likely to be much improved, with respect to both distance and depth of material which can be excavated. Also, overburden from open pit mines may be available in ample quantity within reasonable distance. However, for the purposes of comparison of the various alternatives, the impacts described above are ascribed to Alternatives 1 and 6. Impacts for Alternative 9 would be half those for Alternatives 1 and 6.

In all the other alternatives, except for Alternative 8, cover material would be available onsite, having been produced by excavation of the cavity or cavities into which the tailings are placed. In these cases it is not necessary to perform new excavation work in undisturbed areas and impacts to the environment stemming from such excavations are avoided. Also, because the haul distance is greatly reduced by virtue of having the material onsite, dusting, vehicle exhausts, and fuel consumption are greatly reduced; although they will still occur, they will be much more localized. Personnel requirements are also greatly reduced and although this reduces costs to the mill operator, it may be a negative difference with respect to the economy of the local community. Among these alternatives, Alternative 5 is superior since it involves progressive reclamation and much of the cover material can be placed in final position directly upon excavation, i.e., with single-handling.

Of all the alternatives, Alternative 8 is the least burdensome with respect to providing final reclamation cover since so little material is required.

9.3.9 Accident Analyses

Accidents specific to the various tailings management alternatives, but distinct from those accidents previously discussed in Chapter 7 in connection with the base case, are evaluated in this section. Accidents associated exclusively with the milling operation are specifically excluded because such accidents are not affected by the various tailings management alternatives. The types of acccidents covered in this section include:

. Rupture of the tailings slurry pipeline.

. Failure or flooding of the tailings impoundment area system.

. Other--any accident which is uniquely associated with one of the alternatives, and, therefore, not covered in the discussion of the base case.

. Alternative 1. The potential for accidents and their resulting consequences generally would be the same for Alternative 1 as for the base case.

. Alternative 2. The principal potentials for accidents that could result in release of consequential amounts of radioactive material under Alternative 2 would be rupture of the tailings slurry pipeline and the return water pipeline. To account for the fact that all of the mines supplying ore to the mill, to which tailings would be returned in this alternative, may not be immediately adjacent to the mill, a 16 km (10 mile) distance between pit and mill is assumed for this alternative.

Based on the difference in pipeline length, the likelihood of failure of the tailings slurry pipeline associated with Alternative 2 would be about 55 times greater than the likelihood of failure of the pipeline from the mill to the tailings pond envisioned for the base case; thus the likelihood of release to the watercourse is 0.55 per plant-year. Since the quantity of slurry transported via pipeline in Alternative 2 would be equivalent to that of the base case, the estimated amount of liquids and solids released in the event of a pipeline failure would be the same (see analysis in Sec. 7.1.3.2).

The liquid in the return water line could contain some residual radioactivity. As a conservative estimate, the liquid is assumed to contain the concentration of radioisotopes given in Table 7.2 (actual activity should be considerably lower given the fact that the liquid clarifies considerably over time in the impoundment area and is most likely diluted with clean makeup water). The likelihood of rupture of the return line would be identical to that of the slurry pipeline. Since the capacity of the water return line would be 30% of that of the slurry pipeline, the average quantity of liquid released due to pipeline rupture would be proportionally reduced. Assuming all of the liquid eventually would empty into Reservoir I in the model region, and using a minimum value for the average volume of water retained by the reservoir, the staff has calculated that the concentration of radioisotopes present in the liquid released would be reduced by a factor of 3×10^4.

A comparison of the concentrations of radioisotopes in the tailings solution with maximum permissible concentrations (MPCs) given in Table 7.2 indicates the isotope Th-230 to be of primary concern. The concentration of Th-230 present in Reservoir I following the release would be more than an order of magnitude below the MPC for unrestricted areas.

A significant advantage from the point of view of accidents provided by below grade alternatives is elimination of the potential for tailings dam failure that can occur with above grade impoundments, such as that described in the base case.

. <u>Alternative 3</u>. In Alternative 3, the potential for significant accidental release of radioactive materials would be associated with embankment failure, or flooding of any evaporation pond used for natural drying of the tailings, in lieu of mechanical drying. This accident would be comparable to that evaluated for a similar event at the tailings pond for the base case.

. <u>Alternative 4</u>. The probability and consequences of rupture of the 16-km (10-mile) pipeline associated with Alternative 4 would be the same as for Alternative 2.

It is assumed that the pit dug for Alternative 4 would be sufficiently large to hold all of the mill tailings plus the standard covering. Since the bottom of the pit would be impermeable, there might be a flooding hazard should a large amount of water enter the pit; there is no way of quantifying the likelihood of such an event, but it is expected to be very small.

. <u>Alternative 5</u>. Since special conditions would not be required, excavation of the trench called for in Alternative 5 might proceed in the vicinity of the mill, and it is assumed that the tailings slurry pipeline would be the same length as that required in the base case. The likelihood and consequences of pipeline rupture would therefore be the same as described in Section 7.1.3. The dimensions of the trench are thought to be sufficient to prevent tailings slurry from overtopping the walls, provided the disposal operation is properly monitored and the point of discharge is continually moved along the length of the trench to prevent abnormally high discharge at a particular point that would cause obstruction of feed. Since the trench would be excavated in sections, temporary dikes would be set up to isolate the tailings slurry from areas of construction. Failure of these dikes is considered a trivial accident, since the material would be released to mill property.

. <u>Alternative 6.</u> While disposal in this alternative is above grade, siting features, such as the very small upstream catchment area, would greatly reduce the potential for impoundment failure due to natural events from that existing in the base case. The dam would be designed to withstand a probable maximum flood and would be able to withstand earthquakes which could occur at the site. In general, the impoundment would be designed to conservative geotechnical engineering standards. (See Appendix B for a discussion on dam construction.)

. <u>Alternative 7.</u> Potential accidents of consequence associated with Alternative 7 would include (1) rupture of the slurry pipeline from the mill to the disposal site, (2) a fire or explosion in the evaporator section of the fixation plant used if neutralized slimes are fixed in asphalt, (3) embankment failure or flooding of any evaporation pond for natural drying of slimes before fixation in cement or asphalt, and (4) rupture of any pipeline to the evaporation pond.

The main slurry pipeline from the mill to the disposal site would be about 16 km (10 miles) long; therefore the potential for and consequences of a pipeline rupture would be the same as for Alternative 2.

In the case of fixation with asphalt, the use of asphalt introduces the possibility of either fire or explosion in the evaporator section of the fixation plant [the flash point of the product known as asphalt/cement used in road construction is ~245°C (~475°F)]. Fires are rare in conventional asphalt plants, and no quantitative data are available concerning the likelihood of such an event in the present application. It is conservatively assumed that in the event of a major fire, as much as 1% of the material present in the evaporators would be dispersed. The evaporators are designed to process 600 MT (660 ST) per day of slimes, and it is assumed that about 150 MT (165 ST) of material would be in the evaporation section of the plant at the time of the fire. Therefore, 1500 kg (3300 lb) of slime solids with a total activity of roughly 2×10^{-3} µCi/g would be dispersed to the environment. The maximum individual 50-year dose commitments at the fence [500 m (1600 ft)] and the nearest residence [2000 m (6500 ft)] that would result from this accident are estimated to be 2.0 rem and 3.1×10^{-2} rem to the lung, respectively. This is a highly conservative estimate that assumes all material released is in the respirable size range, and does not account for the fact that the asphalt present in the evaporator mixture should impede the rate of release to the atmosphere.

In cases where mechanical drying of slimes is not practicable, Alternative 7 includes the option of a separate, lined evaporation pond. Though the drying area would be less than half the size of that required in the base case, the slimes fraction would contain about 85% of the radioactivity originally present in the tailings slurry, and, thus, the radiological consequences of an accident involving either embankment failure or flooding would be similar to those described for the base case.

The length of pipeline to the evaporation pond is assumed to be similar to that of the slurry pipeline from the mill to the tailings pond of the base case; therefore, the potential for rupture is the same.

One difference between Alternative 7 and the base case, however, is the amount of activity present in the liquid fraction of the tailings slurry. Under Alternative 7, tailings slurry would be neutralized with lime, which precipitates many of the active components. About 90% of the radium and possibly more than 90% of the thorium would be precipitated, when the slurry was neutralized. Thus, the activity in the liquid portion of the tailings slurry would be significantly reduced. The release of radioisotopes to surrounding waterways via dam failure or flooding therefore should be negligible in comparison to the base case.

The outstanding feature of Alternative 7 is the mitigation of the consequences of accidental releases, once the tailings solids have been fixed with either asphalt or cement. Rupture in the pipeline from the fixation plant to the open pit mine would pose a clean-up problem, but would offer no significant threat to the environment. The use of an open pit mine would essentially eliminate the potential for embankment failure or flooding inherent in the base case.

. Alternative 8. In Alternative 8, tailings would be dried, neutralized, and fixed in the same manner as in Alternative 7. The analysis of such accidents as pipeline rupture, fire in the fixation plant, and embankment failure or flooding of the temporary outdoor drying area is therefore identical to Alternative 7. The only difference between these two alternatives is that fixed tailings would be ultimately deposited in a depleted underground mine in Alternative 8, as opposed to the open pit mine of Alternative 7. Although the underground mine would intersect the water table in several locations, it is assumed that the fixed tailings would not be affected by contact with subsurface water.

. Alternative 9. Relative to accidents, Alternative 9 strongly resembles Alternative 6, and the same accident analysis applies. The radiological consequences of any accidents would be reduced by an order of magnitude, because the specific activity of the tailings would be lower by this factor.

9.4 LONG-TERM CONSIDERATIONS

9.4.1 Stability against Natural Forces

Because contaminants contained in the uranium tailings include long-lived radionuclides, the tailings will remain hazardous for many thousands of years and should be isolated from the biosphere. A systematic study was made to describe the kinds of naturally caused "failure" events occurring over long periods of time that could destroy the tailings isolation. Potential failures that could lead to dispersion of the tailings or the contained radionuclides up to 100,000 years into the future were evaluated in several different time frames.[21] The purpose of the investigation was to identify potential failure mechanisms and the associated natural processes to be considered in developing a tailings disposal program. For each potential failure mechanism described, specific siting and design features that should be taken into account or incorporated in the planning process were systematically identified.

The question of long-term performance of tailings isolation is complex. The factors affecting long-term performance are numerous and interrelated. The problem, therefore, is one which necessarily must be dealt with on a case-by-case basis, taking into account site-specific factors. Because detailed evaluation of long-term stability depends upon such highly variable and site-specific factors as topography and climate, in-depth evaluation (requiring knowledge of actual physical shapes, contours, dimensions, etc.) of the tailings disposal alternatives considered in this study is not possible. Instead, a general discussion of geological and climatic change is presented (Sec. 9.4.1.1), followed by a description of specific natural processes and failure mechanisms that could lead to degradation of the tailings isolation (Sec. 9.4.1.2). This discussion is presented to provide a basis for comparison and evaluation of tailings disposal programs. Also, in light of this discussion, specific design and siting features that can effectively reduce or eliminate the potential for long-term failure of tailings impoundments are described.

9.4.1.1 General Geological and Climatic Change

Predictions of future stability become more uncertain as the time frame considered increases. Beyond several thousand years, long-term geological processes and climatic change will determine the stability and isolation of the tailings. Although some major climatic and geological changes are certain to occur during the period that the tailings remain hazardous (hundreds of thousands of years), the magnitude and direction of change cannot be determined. An understanding of the nature and extent of such potential future events can be gained by briefly reviewing events of the past 100,000 years.

The geological and climatic events that dominated this period, from a geomorphic viewpoint (i.e., changes in the surface of the earth), were the advance and retreat of the Wisconsin-age continental ice sheet. During this time, much of the United States north of the Ohio River and north and east of the Missouri River was significantly affected by ice erosion and deposition. Elsewhere, alpine glaciers were active, and clear evidence of glacial modification of the landscape in the western mountains can be found as far south as the San Francisco Peaks, Flagstaff, Arizona.

The direct effects of glacial ice were great, but even more important were global changes of climate that brought about the ice ages. Significant changes of climate during the past 100,000 years have drastically changed the hydrological cycle and the erosional and depositional processes acting on the landforms. For example, large pluvial lakes occupied the closed basins of Utah, Nevada, and southern California. Throughout the world, river activity changed and reflected the altered runoff and sediment regime of the drainage basins. Furthermore, the vast quantities of water stored in the ice sheets caused a 90- to 120-m (300- to 400-ft) fall of sea level, which exposed the continental shelves and caused the major rivers to cut deeply into the sediment and bedrock. Erosion rates during that period were larger than those which are typical at the present time. Much of the topographic relief that exists in the present-day landscape was created at that time.

During the past 100,000 years, volcanic activity and faulting has had significant, if local, effects. For example, Sunset Crater near Flagstaff erupted in 1067 and, of course, Mt. St. Helens erupted in 1980. Other volcanic activity is continuing at the present time. Recent fault scarps in easily erodible sands and gravels in Nevada, California, and Utah indicate continued mountain building activity, and the 2-cm/yr migration of western California to the north along the San Andreas Fault is clear evidence of the instability of the earth's surface.

Precise releveling by the Coast and Geodetic Survey has revealed significant changes in the surface of the United States during the past few decades. Attempts to estimate rates of mountain building have indicated that uplift can occur at average rates on the order of 8 mm/yr (25 ft/1000 yrs). These rates could be much greater locally. In fact, uplift on the order of 300 m (900 ft) has occurred in the Hudson Bay region during the last 10,000 years. In that case, the uplift has resulted from the melting of the ice sheet and subsequent response of the earth's crust to the release of the tremendous load of ice.

Erosion and denudation is a continuing process. The rate of denudation is a direct function of climate, nature of the surface material, and topographic factors. Schumm[22] has indicated that average denudation rates in arid and semiarid climates will be on the order of 0.08 mm/yr (1ft/4000 yrs) and less in areas of higher precipitation. These rates were determined on the basis of sediment yield in rivers for watersheds of various sizes. Therefore, they are influenced by localized areas of more rapid erosion (e.g., gullies and stream channels). More stable areas within each watershed will exhibit lower denudation rates and areas of deposition (aggradation) will also exist.

Deposition is also occurring. Major sediment basins are the seas, lakes, and gulfs. Terrestrial deposition is occurring around the edges of mountains and in localized areas within the mountains. Windblown deposits of soil hundreds of meters deep may be seen in several areas. One very noticeable deposit is the Great Sand Dunes in the San Luis Valley in Colorado. That deposit is about 200 m (700 ft) deep and approximately 10,000 ha (25,000 acres) in area. Also, large deposits of windblown sand and silt are continuing to form from the front range of the Rocky Mountains across the Great Plains to the Midwest. Accumulation of tens of meters in time periods on the order of 100 years can occur in some localities. Pediments and alluvial fans near mountain ranges continue to build.

Climate is a very important driving force and determinant of the rate and direction of the geomorphic process. Predictions about future climates are integral to the evaluation of long-term stability of structures placed on the earth's surface. One scenario of future climates, advanced by Calder and based in large part on the Milankovitch theory,[23,24] has the earth heating up in the near future. This heating, due to the so-called "greenhouse effect," is expected to end after a few hundred years, and the world would proceed towards a new ice age. Leet and Judson do not take a position about the direction of climatic change.[25] They do concur that climates are changing and emphasize the profound effect this change, regardless of direction, will have on man's future.

In considering the matter of long-term tailings impoundment stability, it is useful to consider landforms which have been observed to have been stable over very long time periods. By doing this, those factors which enhance long-term stability for time periods in excess of several thousands of years can be identified. For example, research has indicated that there exist particular threshold values of slope beyond which erosional rates are essentially zero.[22] This, in turn, leads to the conclusion that gentle slopes are an essential element in achieving long-term stability.

The erosion potential of a landform surface will be a direct function of its height above the base level, where the base level is defined as the theoretical lowest level to which erosion could be expected to proceed at a particular location. Long-term local base levels are comprised of erosion-resistant geologic formations, sediment basins such as lakes or playa or other low-lying formations. Materials deposited below the base level elevation are below the active surface of and, therefore, are not subject to further erosion.

The surface material and condition also affect the stability of landforms. Resistant rock, such as is found in cap rocks of mesas, precludes erosion. Permeable and cohesive soils resist erosion by water. Clays, silts and fine sands are most susceptible to erosion. Gravel armor, common on pediment surfaces, desert pavements and other desert landforms, provides good resistance to erosion. The effectiveness of rock cover is illustrated by so-called "desert pavements" which have been known to form where coarse rock and gravel on the surface stabilize landforms for very long periods of time. For example, alluvial deposits in Death Valley have been stable for 20,000 years because of the armoring provided by such pavements. Fragments with irregular and rough surfaces interlock and are most resistant to wind erosion. Landforms above the local base level elevation which demonstrate stability are of low and gentle relief, expansive, have surfaces which are armored or otherwise protected, and occur in low rainfall climates or in high rainfall areas with good vegetation.

In arid or semiarid regions, wind erosion can be a significant factor in landform change. However, most surfaces will eventually become stable to wind erosion if slopes are gentle, if some vegetation is present, and if soil composition is such that coarse, non-erodible material can be concentrated and armor the surface as fine silts and sands are removed. For example, desert pavements are produced by deflation, that is, a weathering process in which fine, erodible particles are removed from the surface by wind and water erosion leading to the concentration and consolidation of larger, less erodible rock fragments on the surface.

9.4.1.2 Failure Mechanisms

Despite the uncertainty about very long-term geological and climatic processes, specific potential failure mechanisms that would cause disruption of tailings isolation can be identified.[21] The staff concludes that by taking these potential failures into account in siting and design, tailings impoundment systems can be developed to keep tailings isolated for very long periods of time. The best overall method for accomplishing this, as illustrated below, is the below-grade mode of disposal. The following briefly summarizes those failure mechanisms of major importance along with the protective siting and design measures that are applicable to each:

(a) <u>Gullying and Sheet Erosion</u>. Heavy rainfall directly on the tailings impoundment or runoff channeled into surface tailings impoundments from the upstream drainage areas could cause rapid erosion or gullying of the cover and embankment. Similarly, headward erosion and gully formation can proceed from downstream areas. As the erosion progresses, failure of the containment and release of the tailings can result. Sheet erosion is a continuous and persistent process that will not result in a sudden loss of tailings cover material or embankments. Gullying could be more rapid because of the localized nature of this process, which normally results from channeling of runoff for large areas to one or several areas of impoundment surfaces. Once initiated, gullying tends to become more severe with time because the presence of the gully itself accelerates the channeling process. Gullying is most likely to be initiated at the points of abrupt change in slope or contour, such as at the top edge of an embankment, and unless arrested will present a much greater threat than sheet erosion for disruption and dispersion of the tailings. Gullies formed in downstream areas can develop in an upstream direction and result in undercutting of the reclaimed impoundment.

The major factors affecting the erosion potential of an impoundment are the intensity and amount of rainfall and those factors which influence the velocity and amount of runoff, that is, erodibility of cover materials, type of surface protection, and topographic factors such as upstream drainage area and steepness and length of slopes. Equations have been developed to evaluate the sheet erosion potential for limited short-term applications; specifically, the Universal Soil Loss Equation[26] indicates the relative effect these factors have on erosion potential. It also provides insight into the interrelationship that exists between various factors affecting erosion and gullying and, therefore, despite its limitations, can provide some general guidance in development of stable tailings disposal programs.

The Universal Soil Loss Equation can be written in the form

$$\text{soils loss} = R \cdot K \cdot LS{\cdot}VM.$$

R is a climatic factor which is a measure of the energy and intensity of rainfall at a site. K is a factor related to the inherent erodibility of soils. It is dependent on such factors as particle size and distribution, porosity and organic content of soils. The R and K factors are inherent properties of a site and, therefore, cannot be controlled in impoundment design.

The latter two factors in the equation can be controlled to minimize erosion. LS is a topographic factor which accounts for the length and steepness of slopes. It points to the need to eliminate embankment slopes where practicable and, in any case, to minimize their steepness and length. The last factor (VM) is a stabilization factor which measures the effectiveness of vegetation or other surface stabilization techniques in erosion control. Given the very long timeframe of concern, this factor becomes particularly critical in developing a stable tailings containment. For an impoundment that will be subject to continuing conditions favorable to the growth of native vegetation, such a vegetative cover might provide satisfactory protection of impoundment surfaces. However, it is unlikely that a full and self-sustaining vegetative cover can be achieved when there is low rainfall or other adverse conditions, and in these cases erosion resistant rock would be necessary for adequate long-term surface protection. This is particularly true for slopes and other areas where the erosive force of runoff increases. It should be noted that a properly placed rock cover should not preclude revegetation. In fact, a favorable habitat for vegetation growth between individual pieces of rock can be created; eolian soil particles can collect between rocks, forming a favorable environment for invading plant species which provide additional erosion protection.[27]

Below-grade tailings impoundment systems are the least susceptible to this mechanism because the tailings are deposited below the local base level, that is, below the active surface of erosion. Similarly, below-grade impoundments are least susceptible to failure events such as gullying which can be initiated outside the tailings disposal area and which can migrate into the area, thus undercutting above-grade structures. When below-grade burial is not possible, siting is of the utmost importance to ensure that (1) runoff from tributary watersheds is minimized, and (2) failure events will not proceed into the impoundment from areas outside the site. In addition, embankment and cover slopes should be very gentle and have durable, long-term surface protection. Other design steps can be taken to minimize or eliminate erosion potential; for example, in some cases the reclaimed impoundment surface can be designed to cause deposition, that is, to intercept sediment in runoff flow resulting in a gain rather than a loss of cover material.

(b) <u>Wind Erosion</u> - The potential for wind erosion at a particular site may be high. If allowed to progress, wind erosion could remove cover material and expose tailings and disperse them over a wide area. "Blowouts" or wind-caused gullies can occur where aboveground embankments are used and could lead to extensive erosion of tailings. The wind soil loss is a function of climatic factors, erodibility of the soil, surface characteristics, vegetation cover, slope length, steepness of slope, and unsheltered distance. The Wind Soil Loss Equation,[28] while limited in the same manner as the Universal Soil Loss Equation, can be used to understand the relative effect these factors can have on wind erosion and blowouts. As indicated by this equation, the worst situation with respect to wind erosion involves: (a) loose, finely divided dry soils; (b) a smooth bare soil surface; (c) topographic features which do not provide wind breaks; and (d) long, steep exposed embankment slopes.

Tailings deposited in a below-grade impoundment would be the least susceptible to wind erosion because, by definition, they would be located below the active surface of erosion.

Wind erosion will be reduced if the impoundment surfaces are shielded by the surrounding topographic features. Gentle slopes reduce the resistance to winds and, therefore, erosion potential. Because only small soil particle sizes are susceptible to wind transport, rock cover can be applied to prevent wind erosion. Similarly, removal of the smaller soil particle sizes from the surface by wind deflation can stabilize the surface against wind erosion. Vegetation can prevent erosion of surface soils when climatic conditions will support a vegetative cover which is full and self-sustaining. However, as described above in the discussion on water erosion, vegetation will not likely be a significant erosion control mechanism in dry climates. In windy, dry climates, the potential for wind erosion will be very significant; it can be much more important than water erosion. The amount of wind erosion varies strongly with the climatic factor (precipitation and temperature) that determine the amount of moisture present in a soil. The same conditions that contribute to poor vegetative growth also increase the potential for wind erosion and, thus, rock hardening of exposed surfaces becomes essential in many cases. Also, in very windy climates, this is particularly important as the rate of erosion varies as the cube of wind speed. A 30 mph wind is 3 times more erosive than a 20 mph wind speed.

(c) Floods. Water diversion structures around surface impoundments will become clogged and be ineffective without ongoing maintenance. Over long-term periods, therefore, the entire catchment area upstream from an impoundment will contribute to potential flooding of the impoundment.

If there is a flood of a magnitude larger than that which a surface impoundment could withstand, major portions of the impoundment that are contacted by the flood would be subject to severe erosion. Under the worst conditions, the entire impoundment could conceivably be washed away, dispersing the tailings over a wide area. This is probably the most severe failure mechanism in terms of catastrophic, irrevocable failure and wide dispersion of tailings.

Prediction of the maximum possible flood is subjective because of uncertainties in the hydrological conditions that will contribute to the flood. Except where the upstream watershed is small, prediction of the maximum possible flood that could occur over a period of several hundred or a few thousand years is tenuous. For this reason, tailings disposal areas should be designed very conservatively to avoid flood damage. Therefore, even the determination of impoundment capacity required during the relatively short operational period is based on a Probable Maximum Flood (PMF) series which is defined in the NRC Regulatory Guide 3.11 as equivalent to 1.4 times the PMF followed by a 100-year storm, appropriately providing a strong measure of conservatism. Similarly, it is prudent in designing long-term surface erosion protection (determining the placement of riprap) for locations on the tailings impoundment where runoff might concentrate to consider probable maximum precipitation (PMP) events which produce peak flows. However, to minimize the potential for flood damage, impoundments should not have embankments that could come in contact with flood waters (again considering a PMF) and should be located at sites that have small tributary watersheds with a low potential for surface runoff. Furthermore, an overall factor of safety should be applied (to either the estimated PMF flow or resultant shear force which must be resisted by riprap) given the inherent uncertainties with PMF estimates and the long period concern.

As was the case for protection against failure due to water sheet erosion and gullying, below-grade impoundments are least susceptible to damage from flooding. In all cases siting must be such that damage to the reclaimed impoundment from flooding would not be possible.

(d) Earthquake. A major earthquake could lead to the release of tailings and radioactive materials by causing cracking or rupture of the cover or the embankment of an above-grade impoundment. Extensive failure of an embankment and liquefaction of the tailings could lead to dispersion of the tailings over large areas. A massive failure due to liquefaction, however, is only likely to occur while the tailings contain relatively large quantities of water. After the tailings dry and consolidate, liquefaction would not occur and failure of the impoundment would result in exposure of tailings. For tailings buried below-grade, there should be no adverse effect, that is, the most likely result would be further settlement of the tailings and cover. Also, where retention structures are designed conservatively (such as to withstand a 1,000 year earthquake under saturated tailings conditions as is done to meet the NRC licensing policy), the potential for loss of tailings from an impoundment during earthquake over the long term, after the tailings dry and the impoundment is contoured upon reclamation to provide gradual slopes, is virtually eliminated.

(e) Degradation of Radon Attenuation. The tailings impoundment cover functions not only to physically stabilize and isolate the tailings but also to reduce the radon flux emanating from the tailings to acceptable levels. The failure mechanisms above relate primarily to the former function. However, there are other, more subtle ways in which the cover can become less effective in accomplishing the latter function through loss of moisture, cracking, or penetration.

As described in Appendix P and Section 9.3.8, moisture in a soil is perhaps the most important factor upon which radon attenuation properties depend. With use of some materials, such as clays which are wetted to obtain improved handling and compaction characteristics, the radon flux could be greatly reduced with relatively thin layers. However, it is not likely that such cover materials will retain high moisture levels over long periods of time when they are near surface and subjected to climatic influences. The so-called zone of seasonal moisture fluctuation, that is the zone where soils are subject to climatic influence, is on the order of 10 feet deep or more. Moisture levels at the time of cover installation may be much greater than what is observed for undisturbed soils in this near surface zone. However, it is expected that moisture levels will eventually return to levels similar to those in soils in their undisturbed state. Natural moisture levels in undisturbed soils in arid and semiarid regions have been found to be on the order of 9 to 12% in clays and 6 to 9% in other soils. This can have a profound adverse influence on the effectiveness of clay, as it has been shown that the diffusion coefficient for radon can increase by two orders of magnitude with a 20% decrease in moisture content.[20]

Covers also become less effective through cracking. Clays, especially those with a high content of material from the smectic clay mineral group (see Section 8.3.3.3) tend to absorb relatively large quantities of water and swell, and are particularly susceptible to cracking upon dessication or when subject to wetting-drying and freeze-thaw cycling. As discussed above this cycling will certainly occur when these materials are used as tailings covers. Cracking of soils is also possible, and even probable in many cases, where tailings dry out and consolidate over time and differential settlement of the cover occurs. Cracks can render any cover ineffective with respect to radon attenuation. Cracking and the attendant loss in radon attenuating properties can also be expected for thin layers of artifical materials such as asphalt and synthetic membranes which are not expected to maintain their integrity over long time periods.

Finally, a cover might be physically penetrated by the roots of vegetation or by burrowing animals. Such open channels not only increase the exhalation of radon but also permit the infiltration of surface water into the cover, and can therefore lead to further losses in cover integrity as the result of freeze-thaw cycling.

For a cover to be adequate it must be of sufficient thickness to ensure it functions as required without relying on special materials or the maintenance of special conditions. That is, the design of the cover would not be only that which is adequate at or shortly after the time of installation but would consider long-term changes in the cover itself. Such a design would account for a decrease in soil moisture content, for cracking and for physical penetration by plant roots and burrowing animals.

9.4.1.3 Evaluation of Alternatives

Because of its location above-grade, the disposal structure in Alternative 1 exhibits the greatest potential for erosion by water and wind. With a sizable upstream drainage and without protection or shielding of the pile from wind action, a steady erosion of the pile would occur. Gullies and blowouts could progress relatively rapidly resulting in slow but steady dispersion of tailings within relatively short periods of time (several hundred to several thousand of years). The impoundment would also be particularly susceptible to dispersion of tailings if it were located in a flood pathway or subject to seismic activity. Thus, the tailings impoundment of Alternative 1 would deteriorate relatively rapidly without on-going maintenance.

Below-grade disposal is included in Alternatives 2, 3, 4, 5, 7 and 8. This class of disposal alternative provides isolation from all major erosive forces that could cause either sheet-type erosion or gullying because, in general, there are no embankments. Gullying potential is greatly reduced by the absence of embankments and corresponding abrupt changes in slope. The features of these alternatives minimize the potential for physical transport and dispersion due to earthquakes, since there are no embankments to fail, or due to floods, since they do not present an "obstacle" to flood waters. Unfavorable groundwater conditions, however, could preclude the use of below-grade disposal; for example, groundwater formations may be near enough to the surface to forestall the implementation of Alternatives 2 through 5. The below grade burial concept may also be difficult to apply in areas of irregular terrain where the depth of soil overlying bedrock is not sufficient to permit excavating a pit without blasting large amounts of rock, and suitable alternate sites are not available. Some excavation may be possible to reduce the size of above grade embankments required, but disposal of the entire tailings volume below the surface of all points in the surrounding terrain may be impracticable. When complete below-grade burial is not practicable, Alternative 6 is an above-ground disposal plan that provides protection reasonably equivalent to below-grade disposal by employing proper siting and design. Alternative 6 takes advantage of favorable topographic and geomorphologic features to provide long-term stability.

From the discussion of failure mechanisms in Section 9.4.1.2 it is apparent that the following tailing impoundment system features would ensure long-term stability:

(a) Upstream catchment areas are minimized so as to decrease the size of the maximum flood possible.

(b) Topographic features provide good wind protection.

(c) Embankment and cover slopes are relatively flat after final stabilization to minimize erosion potential and to provide conservative factors of safety to assure long-term stability. Reducing slope gradients reduces the velocity and amount, and thus the erosive force, of runoff on the slope. With regard to wind erosion, the flatter slope obviously is better because it presents a more streamlined profile. The broad objective would be to reduce slope gradients to those which would exist if tailings and cover material were completely below natural grade; this could lead, for example, to slopes of 10 horizontal to 1 vertical (10h:1v) or less. For sites with relatively steep terrain this may be impracticable because an excessive amount of fill would be required. In such cases, special attention would have to be given to the other factors which would reduce the erosion potential. (See Section 12.3.3.2 discussion on slopes. Also, see Appendix K-9 for discussion on how contouring could be achieved at existing sites.)

(d) A suitable slope protection scheme, such as revegetation or use of rock cover, is employed to reduce wind and water erosion to negligible levels. In order to avoid continuing maintenance, vegetation must provide full coverage and be self-sustaining. Where this is not likely to occur due to low rainfall or other adverse conditions, rock cover would have to be used. Properly applied, rock cover can provide an "armoring" of the soil cover (see Sec. 8.3.4.4). Large rock and cobble will shelter erodible soil fractions. Vegetation and rock cover both have the effect of holding water, reducing the velocities and amounts, and thus the erosive force of, runoff. Rock cover can also create a favorable habitat for vegetative growth between individual pieces of rock. Eolian soil particles can collect between rocks forming a favorable environment for native plant species.27

The final rock cover design must be such that displacement of rock particles by human and animal traffic or by natural processes is avoided, and undercutting and piping precluded. The following factors must be considered:

" shape, size, composition, and gradation of rock particles (excepting bedding material, average particle size must be at least cobble size or greater);

" rock cover thickness and zoning of particles by size; and

" steepness of underlying slopes.

Individual rock fragments must be dense, sound, and resistant to abrasion, and must be free from cracks, seams, and other defects that would tend to unduly increase their destruction by water and frost actions. Weak, friable, or laminated aggregate must not be used. Shale, rock laminated with shale, and cherts must not be used. (See Appendix B, Section 4.5 for description of a rock cover.)

In cases where top covers are very thick (on the order of 10 m or greater); impoundment slopes are very gentle (on the order of 10 h:1v or less); cover materials have inherently favorable erosion resistance characteristics; and there is negligible drainage catchment area upstream of the pile; and there is good wind protection as described in criteria (a) and (b)--it is likely no rock covering of slopes would be necessary.

Furthermore, impoundment surfaces would be contoured to avoid areas of concentrated surface runoff or abrupt or sharp changes in slope gradient. In addition to rock cover on slopes, areas toward which surface runoff might be directed would be well protected with substantial rock cover (rip rap) designed to withstand the maximum possible flood (probable maximum flood with factors of safety employed as discussed in 9.4.1.2(c)). In addition to providing for stability of the impoundment system itself, overall stability, erosion potential, and geomorphology of surrounding terrain must be such that there are no ongoing or potential processes, such as gully erosion, which would lead to impoundment instability.

(e) The impoundment would not be located near a potentially active fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand.

(f) Where possible, the impoundment should be designed to incorporate features which will promote deposition of sediment suspended in any runoff which flows into the impoundment area. If runoff flowing across the impoundment surface can be delayed, settling of suspended matter can occur. The objective of such a design feature would be to enhance thicknesses of cover.

With regard to slope protection, it is noted that a common method of slope erosion control used in mine reclamation, highway construction and agricultural application is terracing of slopes. For example, see references 26 through 30. Terraces create a break in slopes and impound runoff, which reduces the amount and velocity of runoff. However, in most situations, erosion over very long periods of time (thousands of years) is not of concern and maintenance of terraces is assumed. Terracing of slopes does not appear to be a good practice to adopt in mill tailings disposal, where the objective is to eliminate erosion of isolating cover and containment unless they can be designed to be erosion-resistant. Without maintenance, terraces formed by contouring earthen slopes may actually enhance gullying; impounded water will spill over at the lowest point in the terrace, and the gullying potential is increased at this point of concentrated runoff. The formation of this gully would then create a channel which would worsen over time. Reliance on other erosion control methods, such as providing flat slopes and high quality protective cover, appears to be more appropriate in resolving the slope protection problem unless the face of the terrace can be made erosion resistant. (A form of terracing has been incorporated into the design of at least one recent tailings impoundment described in Appendix T-3. It involves construction of a series of stepped cells "which are developed for tailings disposal and reclaimed sequentially. The overall size and steepness of retention structures are greatly reduced from those commonly used in the past for tailings disposal.)

Various cover types and cover thicknesses for Alternatives 1 through 6 were evaluated in Section 9.3.8 in terms of radon attenuation. It was indicated in that evaluation that use of layers of moist clay or artificial material might decrease the total thickness of normal soil overburden required to reduce radon emissions. However, adding earthen cover materials to reduce radon flux also enhances long-term stability and, when examined solely in terms of long-term stability and isolation, those alternatives which achieve radon reduction by use of normal soils as opposed to those that rely on special materials or the maintenance of special conditions are more desirable because of the greater overall reliability provided. The additional thickness reduces the potential for a decrease in cover effectiveness due to changes in the cover over time.

Alternatives 7 and 8 offer potential for immobilizing contaminants in tailings by fixation. However, there is great uncertainty about the long-term stability of the bonds between the fixing agents (asphalt and cement) and the tailings. If this is not a problem, placement of tailings in contact with groundwater allows deeper burial in both cases. Alternative 7, unlike other open pit disposal alternatives (Alternatives 2 and 3), would not involve back filling to above the water table and, hence, would permit greater cover thicknesses. In deep mine burial of tailings, Alternative 8, location at depths greater than 100 m (300 ft) below the surface would result in complete isolation of tailings from surface erosion effects. Leaching of fixed tailings could take place, if they were in direct contact with groundwater, but such leaching is expected to be at reduced rates (Sec. 9.3.4).

Tailings management schemes for Alternative 9 are similar to the other alternatives except that the radium and thorium content in the tailings would be less. The potential for failure of the impoundment would be the same as for other alternatives, although the magnitude of release of radioactive material would be reduced in proportion to the radioactivity of the tailings. The proposed 10-m (30-ft) disposal depth of Ra-226 and Th-230 concentrates would isolate them from surface erosion effects.

9.4.2 Land Use Controls

9.4.2.1 General

Isolation of the tailings should come primarily from physical barriers, such as earthen cover, provided by the alternatives being evaluated. However, in addition to potential degradation through exposure to natural forces, as discussed in Section 9.4.1, there remains the possibility of disruption of the tailings isolation as a result of human activity. The potential need for land use controls to supplement isolation of the tailings provided by overburden and cover materials is evaluated in this section. (See also Sec. 10.3, which discusses the matter of overall long-term site monitoring and control, taking into consideration both the evaluation of this section and that of the preceding section.)

There are several types of land use that could lead to unacceptable health risks following final tailings disposal. Three general types of land use scenarios are used to assess the need for supplementary land use controls in the case of each alternative:

- Type 1--Nearby Residence. This type of land use involves occupancy of structures very near or, in the worst case, on top of the site (but with no digging at the tailings disposal area). Inadequate isolation or cover of the tailings could lead to radioactive airborne emissions, particularly radon, which could present unacceptable health risks to persons living near the tailings disposal site.

- Type 2--Excavation and Intrusion Events. This type involves direct human intrusion at the tailings site. For example, a basement might be dug to build a structure at the disposal site; the tailings might be dug into for use in offsite construction projects (see Ch. 2 description of past incidents); or a well might be drilled into or through the tailings. These kinds of activities do not lend themselves to prediction; it is not possible to evaluate the likelihood of such events in quantitative terms. Exposures from such activities would, however, pose potentially unacceptable health risks. It is estimated that in an extreme worst-case situation, where a basement is dug into isolating cover material so that it contacted the tailings, continuous occupancy could lead to exposures of 30 rem per year from radon,[31] an order of magnitude greater than currently allowable exposure levels specified in 10 CFR 20.

  It must be stressed that even the worst-case intrusion at the tailings site would not result in immediate health effects. The level of radioactivity is low and potential health effects would result only after long and continuous exposure to the tailings. Because the tailings represent a chronic, as opposed to acute, health risk, it would not be essential that controls be continuous and so complete that no intrusion could possibly occur. Annual or semiannual site visits would be sufficiently frequent to cease any Type 2 activity before it continued long enough to present a real health threat.

- Type 3--Surface Use Accelerating Erosion. This type of land use scenario involves surface uses which could lead to, or accelerate, natural erosion processes that could result in eventual exposure of the tailings. For example, grazing or intensive recreation (such as use of off-road vehicles) on the disposal site might result in loss of vegetative cover established to ensure long-term stability of the tailings area; accelerated erosion of cover material might then occur. This type of land use is distinguished from the second type in that it would not in itself involve immediate, direct human exposure. Instead, it would lead to disruption of the tailings isolation (uncovering of the tailings) and virtual return to a situation where emissions from the tailings were uncontrolled, as in the base case. Radon release and blowing of tailings would then present a threat to public health.

9.4.2.2 Evaluation of Alternatives

In the following paragraphs, the alternatives are assessed in terms of the land use control each would require to avoid unacceptable public health risks. In particular, each of the alternatives is assessed relative to the three land use types described above.

Most mining and milling activity occurs in sparsely populated regions. The model region, which is representative of the western milling regions, has a density of less than three persons/km^2 (7/mi^2), which is an order of magnitude less than the national average. This sparse development results from the harsh climate and soil conditions existing in most mining areas. While recognizing that it is not possible to predict climatic and demographic patterns as far into the future as the tailings will remain hazardous, current conditions and associated very low pressures for land development will most likely continue for a reasonably long period. For this reason, any of the above land use types will tend to be "worst case" or conservative scenarios for evaluating disposal alternatives at most disposal sites.

9.4.2.2.1 Alternative 1--Active Care Mode

It would be essential that land use controls be applied in the case of Alternative 1. Although enough cover materal could be provided initially (as discussed in Sec. 9.3.8) to reduce risks to individuals living very near the tailings site to acceptable levels (Type 1 use), measures to ensure that the isolating cover remains intact under natural weathering and erosive forces are not provided. Surface land uses of any sort would be unacceptable, since they would surely accelerate the erosion processes which will be working in this active care mode.

9.4.2.2.2 Alternatives 2 through 6--Passive Monitoring Mode

It would be prudent to exercise land use controls for Alternatives 2 through 6, which represent a more passive mode of disposal.

As described in Section 9.3.8, cover material can be provided to reduce risks to levels which would permit living near or even on the pile (Type 1 use). However, excavation (Type 2 event), followed by prolonged exposure, would probably lead to excessive radiological doses. For this reason, some control of sites appears to be a prudent supplementary measure. Whether or not Type 3 surface land uses could be allowed would have to be determined on the basis of a number of site-specific factors and the degree of success experienced in the tailings disposal area. As more fully described in the discussion of decommissioning events presented in Chapter 14, during the period that reclamation was being carried out and vegetation was being established, surface uses would have to be excluded. While it would be prudent to have continued control of the site (by periodic monitoring) to assure that there was no intrusion, it might be possible to permit some selected uses of the land. This can be determined, however, only on a site-specific basis and only after an extended period of observation. Eventually it might be possible to allow unrestricted surface use. Because below-grade disposal would virtually eliminate exposure to weathering and erosional forces, productive uses of the tailings site surface are a strong possibility. For example, the tailings area could be used for light recreation, grazing or, perhaps, even crop production. Because disposal of tailings in open pits will in general make it easier to provide thicker covers than could be afforded in cases involving above grade or specially excavated pit disposal, the potential for surface land use is greatest for Alternatives 2 and 3.

Because, as discussed above, the Type 2 intrusion event will not result in an acute exposure resulting in immediate health effects, and the potential negative effects of an unacceptable Type 3 activity would occur relatively slowly, continuous site monitoring probably would not be required. A periodic visit to the site (e.g., annually) in addition to either land ownership or records control would provide reasonable assurance that the tailings remained undisturbed. This level of monitoring also would be sufficient to detect any significant degradation of the tailings disposal area which may be occurring as a result of exposure to natural weathering and erosional forces in time to remedy the situation (since such effects will be slow). (A more complete discussion of long-term monitoring activities is presented in Sec. 10.3.)

9.4.2.2.3 Alternatives 7 through 9--Potential Reduced Care Mode

These alternatives provide some additional isolation of tailings beyond that provided in the preceding modes of disposal. Each, again, provides sufficient isolation to permit Type 1 land use. However, except possibly in the case of Alternative 8, involving fixation of the tailings and disposal in a deep mine, it again would be prudent to exercise land use controls. Disposal in deep mines would provide sufficient isolation that risks under even the intrusion event would be so small as to be insignificant. Therefore, no land use controls would be necessary for this alternative.

Alternative 7 involves fixation of the slimes, which contain most of the radioactivity in the tailings. Being fixed in cement or asphalt, the slimes could not be dug into or removed from the site very easily (Type 2 event). Also, consequences of loss of cover material resulting from surface land uses (Type 3 event) would be reduced, since radon exhalation and blowing of radioactive particulates would be greatly reduced. Although the hazards are reduced, it would appear that unrestricted land use would not be prudent. As discussed in Section 9.4.1 the long-term stability of cement and asphalt binders is uncertain. Furthermore, the sands would not be fixed, and the radioactivity associated with them, although reduced, would present the same kind of risks presented by tailings in previous alternatives.

Alternative 9 involves two waste forms which must be considered: (1) the radium and thorium concentrates and (2) the mill tailings. With regard to concentrates, there are essentially no risks associated with Type 1 or 3 land use activities. Although the likelihood of the intrusion event is much less than that for near-surface burial alternatives, potential consequences are increased. It is doubtful, therefore, that land use controls (at least in the form of periodic monitoring) could be eliminated. Although the tailings resulting from the nitric acid leach process would contain substantially less radioactivity than do conventional tailings, and, hence, potential consequences would be reduced, residual levels of radioactivity would still be significantly greater than background levels; therefore, some type of land use control appears to be prudent.

9.5 DECOMMISSIONING ALTERNATIVES

9.5.1 Introduction

The alternative modes of decommissioning considered are (1) the decontamination, retention, and reuse of some or all of the buildings and equipment, and (2) the complete removal of all buildings, foundations, and equipment, with the restoration of the site to approximately its original state. In either case, contaminated ground areas would be decontaminated to levels which would permit complete and unrestricted access and use of the site. The abandonment of the mill and site without decontamination or dismantlement is not considered. These two alternatives were described in Section 8.5; the monetary costs associated with these alternatives are given in Section 11.3.

Details of the decommissioning problem will vary depending upon specific conditions at the mill being decommissioned; however, the staff believes that the two general alternatives evaluated in this document for the model mill span the range of actions expected to be necessary at actual mills. It is assumed for this analysis that no tailings material has been removed for use in offsite construction, and therefore no decontamination of offsite buildings will be necessary.

Table 9.14 presents recent guidance for decommissioning, decontamination and land cleanup. It characterizes the levels of residual contamination which would exist at the site following decommissioning. The site cleanup guidance is interim guidance recently issued by the U.S. Environmental Protection Agency (presented in full in Appendix J).

Table 9.14 Suggested Decontamination Criteria

I. SURFACES[a]	
Radionuclide	Acceptable Levels
U-238	5000 d/m[b] over 100 cm^2 200 d/m removable[c]
Th-230, Ra-226	100 d/m over 100 cm^2 20 d/m removable
II. SITE CLEANUP	
Radiation	EPA criteria[d]
Indoor Gamma	20 μR/hr, above background
Indoor Radon Daughters	0.015 WL, including background
Ra-226 in Soil	5 pCi/g, above background

[a]Proposed American National Standards Institute criteria of June 1974.

[b]"d/m" means disintegrations per minute.

[c]Activity on filter or soft absorbent material obtained on wiping surface.

[d]See Appendix J for full details.

9.5.2 Impacts from Equipment and Building Decontamination and Reuse

9.5.2.1 On Air Quality

Hydrocarbons, sulfur oxides, and other air pollutants would be emitted by heavy machinery used in excavation of ore pads and in other earth-moving activities. Lesser amounts of these pollutants would be released from smaller machinery used for washing, spraying, or other cleaning processes. These emissions would be temporary. Dust from earth-moving and cleaning procedures would reduce air quality and visibility near the area of activity, but these effects also would be temporary. At worst, the areas disturbed could be expected to suffer wind erosion at a rate of 4.5 kg/ha-hr during operations, and perhaps 1 to 2 kg/ha-hr until the new vegetation can stabilize the soil. Wetting, covering the topsoil with straw, or use of chemical soil binders will reduce fugitive dust emissions.

The impacts will vary regionally, depending upon the rapidity with which the disturbed area is revegetated. The impacts should be greatest in Wyoming, the Great Plains, and the dry Southern Rocky Mountains.

9.5.2.2 On Surface Water Quality

If the mill is close to a surface water body (e.g., stream or creek), runoff from the building washdown procedures might drain into these waters. In most cases, however, any runoff would be channeled toward the tailings impoundments, which are normally downgradient of the mill.

9.5.2.3 On Groundwater Quality

No impacts to groundwater quality are expected from surface activities associated with decontamination. However, if deep excavations were necessary for burial of contaminated concrete and ore-pad bases, some leaching of contaminants to groundwater might occur if rain were allowed to percolate into the burial site and if there were any connection to the groundwater aquifer. Decontamination refuse would most likely be disposed of within the tailings impoundment, before final reclamation.

9.5.2.4 On Soils

No impacts to soils are expected from decontamination of buildings or ore pads. However, if previously undisturbed soils were removed, either to use as cover material over decontaminated ore pads or when a pit was dug to bury contaminated concrete, the productivity of that soil would be reduced. (It is indicated in Sec. 8.5 that contaminated material would most likely be placed in the tailings pond; however, depending on the method and timing of final tailings stabilization and reclamation, the tailings pond might already have been covered at the time of decommissioning, thus necessitating the digging of a burial pit.)

9.5.2.5 Biota

No significant impacts to animals are expected from decontamination procedures. Deposition of dust on vegetation might reduce photosynthetic activity, until the first rain washed the dust away. The adverse effects of dust could be partially mitigated by sprinkling disturbed areas with water during activities that would generate dust (e.g., earth-moving operations). In any case, these effects would be temporary.

9.5.2.6 On the Community

The dust and noise generated by the decontamination procedures are expected to be a temporary annoyance to any residents remaining in the area after mill shutdown. Most milling operations are usually more than 8 km (5 miles) from permanent communities, and no effects of decommissioning activities would be expected at such distances.

Some of the operating force at the mill probably would move from the region, resulting in a minor impact (since the percentage change in population would be almost negligible) to those segments of the business community which furnish goods and services to mill workers and their families.

9.5.3 Impacts from Removal of Buildings and Equipment

Impacts to air, surface and groundwater, soils, biota, and the community would be quantitatively similar to those above; however, the magnitude of the impacts to soils and groundwater resulting from excavation and burial of the solid waste material, and eventual covering of the mill site, ore pads, and burial pit is expected to be greater. This is because a larger area must be covered. The availability of soil could be very limited. Reclamation of these sites would be subject to the same considerations discussed in Appendix N.

9.6 SUMMARY

The effects of employing alternatives for reducing airborne emissions during operation, for tailings management and disposal, and for mill building and site decommissioning have been evaluated in this chapter. The alternatives considered were described in Chapter 8.

9.6.1 Airborne Emissions during Operation

Airborne emissions can be controlled by available methods to levels which would ensure that 40 CFR 190 offsite dose limits are met at locations near the mill site. Analysis of the base case identified emissions from the tailings pile as the most significant potential contributor to offsite exposures. Several alternative levels of dusting control were evaluated (in combination with more efficient yellowcake drying and packaging ventilation scrubbers) and it was shown that a high degree of tailings pile dusting control (about 80%) is needed to meet 40 CFR 190 limits at a trailer location occupied 50% of the time 400 m (1300 ft) from the tailings edge. This level of control could be achieved by several means, including increased cover by tailings solution, by water spray, or by chemical binders; in any case, management attention will be required to assure that such dusting control is continuous and comprehensive.

Evaluations of overall radiation exposure risks indicate that well over 80% of such risks arise from radon releases from the tailings area; these releases need not be controlled to achieve compliance with 40 CFR 190. As indicated in Section 9.2.8, the implementation of a progressive reclamation scheme involving sequential cell impoundment construction, filling, and covering would reduce base case radon emissions by a total of about 74,000 Ci over the first 20-year period, thus averting about 0.6 health effects.

Although yellowcake emissions could be reduced to low levels and 40 CFR 190 limits could be met at locations near the mill with available stack-scrubbing devices, offsite doses could be further reduced by elimination of the dryer circuit. This could be done by shipment of moist yellowcake. In addition to environmental benefits, overall occupational radiation exposure risks could be reduced by about 29%. Economic penalties of this alternative are addressed in Chapter 11. The degree to which it could be implemented is constrained by limited capacity for processing moist yellowcake at uranium hexafluoride conversion plants. More complete evaluation of this option is provided in Chapter 12.

Wet, semiautogenous grinding could eliminate exposures from already low (base case) emissions from ore crushing and grinding operations. More significantly, however, worker radiation exposure risks could be reduced by about 19% by utilization of this process.

9.6.2 Tailings Management and Disposal

The tailings management and disposal programs described in Section 8.4 are evaluated in terms of the degree to which they mitigate the environmental impacts covered in Chapter 6, that is, impacts on air quality, water quality, soils, biota, etc. It is difficult to summarize and quantify the severity of these impacts and, conversely, the degree to which they can be avoided by the mitigative measures evaluated. However, the evaluations of this chapter and of Chapter 6 indicate that the extent of such impacts relates primarily to the following:

- Extent of airborne emissions (particulates and radon gas) from the mill and mill tailings pile,
- Extent of seepage of tailings solutions,
- With regard to the tailings, the long-term stability of mitigative measures employed to control airborne emissions.

Therefore, to simplify the matter of conducting a benefit-cost analysis of the alternatives in support of establishing requirements for mill tailings management and disposal, the range of concern can be narrowed to these areas; this is done in Chapter 12.

One attempt to mitigate the evaluation of alternatives in terms of the many specific environmental impacts which could occur involved ranking the nine tailings disposal programs in numerical fashion. This ranking is provided in Appendix L. The limitations of such a process are great: it requires that subjective judgments be made both about the extent of impacts and the relative importance of impact categories [that is, relative importance of impacts on soils, biota, vegetation, public health (radiological impacts), etc.]; it does not factor in costs, nor does it reflect the fact that, as discussed in Section 8.4, there are many other mill tailings disposal programs that could be developed in real situations. However, while such an evaluation is not conclusive or definitive, it does tend to support the correlation between the value or benefit of particular alternatives and the degree to which they address the concerns identified above.

Alternatives are sorted into several groups by this ranking, according to the degree and potential permanence of isolation provided and, hence, to the degree to which effects of airborne emissions and seepage are minimized.

The alternatives receiving highest ranking were alternatives involving fixation of tailings and burial in an open pit (Alternative 7) or in a deep mine (Alternative 8). The next grouping includes those tailings disposal schemes featuring burial below grade in specially excavated or available open pits (Alternatives 2-5). Above-grade alternatives (1 and 6) rank lower according to the degree to which they provide isolation from natural weathering and erosional forces which affect long-term stability of isolation.

9.6.3 Decommissioning

Alternative modes of decommissioning are discussed in Section 9.5, wherein it is concluded that the environmental impacts of the two alternatives are not vastly different and are, in any case, minimal and transient.

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10. MONITORING PROGRAMS

The monitoring program to be applied at uranium milling activities must be designed to address three distinct phases: preoperation, operation, and postoperation. Each phase is discussed below. The type and frequency of monitoring needed for a given mill is highly dependent on the characteristics of the individual site and therefore the programs described below may not be totally applicable to any particular site. As discussed more completely below, the level of postoperational monitoring that will be required at sites is speculative; it will depend upon the mode of tailings disposal and the long-term stability achieved. Therefore, instead of outlining specific details of a postoperational monitoring program, the discussion of post-operational monitoring is intended to characterize in a general fashion the nature and extent of monitoring activities that would be required for various tailings disposal modes. Detailed monitoring programs for the preoperational and operational phases of the model mill would be essentially the same as those described in Appendix V, which is a reproduction of U.S. NRC Regulatory Guide 4.14, "Radiological Effluent and Environmental Monitoring at Uranium Mills."

10.1 PREOPERATIONAL MONITORING PROGRAM

The preoperational monitoring program should be conducted for at least one full year prior to any major site construction. This program should be designed to provide complete baseline data on the site and its environs prior to development. These data are needed to:

- Assess impacts of the future milling operations. Since many of the potential impacts associated with uranium milling are the result of the release of naturally occurring materials (e.g., radionuclides, toxic and/or trace elements, suspended solids, particulates), a thorough understanding of the background levels (and variability over space and time) of these materials must be developed.

- Provide reference data against which to measure the effectiveness of the mill effluent control systems and procedures during normal operation or in the case of an unusual release.

- Provide reference data against which to measure compliance with applicable environmental standards during later operations.

- Provide a reference point for use in site decommissioning, e.g., to provide a definition for "successful decommissioning and reclamation."

The radiological aspects of a uranium milling operation are largely common for all mills, and the essential components of a preoperational radiological monitoring program are summarized in Table 1 of U.S. NRC Regulatory Guide 4.14, reproduced herein as Appendix V. A number of these components should be extended into the operational phase of the mill.

Specific air quality monitoring programs are normally developed and made conditions of permits issued by States under the Clean Air Act. This will involve sampling of major sources for SO_2, NO_x, hydrocarbons, and particulates. Ambient monitoring may be required as often as every six days at locations selected to provide a statistically significant measure of how air quality is being affected by mill emissions.

A program of groundwater quality monitoring should also be conducted in conjunction with the radiological preoperational monitoring program. It should include sampling and measurements of certain nonradiological constituents, such as those listed in Table 10.1. The list is based on EPA water quality criteria.[1] Nonradiological constituents should also be measured in the other elements of the preoperational monitoring program, as appropriate on a site-specific basis.

Other nonradiological elements of a complete preoperational monitoring program are so site-specific that development of a hypothetical program for the model mill at the model site would serve no purpose. Regulatory Guide 3.8,[2] which includes specification of material that should be provided in applicants' environmental reports, should be used as a guide in the development of preoperational monitoring efforts in the areas of land use, geology and mineral resources, surface water, soils, biota, and demography.

Because ore composition varies, it will be necessary to analyze samples of the ores that are expected to be supplied to the mill to determine which of the trace elements are likely to be encountered in the mill effluents and emissions. Specifically, analysis should be made for metallic trace elements listed in Table 10.1. Many of these trace elements will inhibit the growth of vegetation in low concentrations and may be toxic to both flora and fauna in moderate concentrations. Some of these elements are also subject to bioaccumulation once they enter the food chain; hence, it may be desirable to monitor the incremental contribution of these elements attributable to the mill releases. The nonradiological preoperational monitoring program paralleling the radiological monitoring program (excluding radon) should then be undertaken to determine the ambient background concentrations of these elements. To the extent that "indicator species" of chemicals can be identified, the operational monitoring effort can then be restricted to the indicator species. In this context, an "indicator species" is any chemical species which (a) occurs in reasonably high concentrations (compared to limits of detection) in the ore, (b) can be readily detected by state-of-the-art methods, and (c) behaves similarly to several other species in the ecosystem. Clearly the optimum indicator species would be the radionuclides when it can be shown that they meet the above criteria, because they are included in the radiological monitoring program.

Table 10.1 Constituents to be Measured in Groundwater Monitoring[a]

Alkalinity	Lead
Arsenic	Manganese
Barium	Mercury (inorganic)
Beryllium	NO_3
Boron	NO_2
Cadmium	pH
Chloride	Selenium
Chromium	SO_4
Conductivity	TDS
Copper	Zinc
Iron	

[a]From "Quality Criteria for Water," U.S. Environmental Protection Agency, EPA 440/a-76-0.23, July 1976.

10.2 OPERATIONAL MONITORING PROGRAM

The monitoring program conducted during the operational period contains the same basic elements as that conducted in the preoperational phase of the project, with increased emphasis on such factors as airborne particulates. The operational monitoring program should continue until the mill tailings are finally reclaimed and all site decontamination and decommissioning efforts are completed.

The operational monitoring program should be designed to provide the data necessary to:

- Demonstrate or confirm compliance with applicable standards and regulations (radiological, air quality, water quality, etc.),
- Evaluate adequacy and performance of containment control systems and procedures,
- Evaluate environmental impacts of operation and provide an early warning of potential impact prior to the creation of an irreversible situation,
- Evaluate long-term trends and the buildup of concentrations of materials of concern in the environment.

A radiological environmental monitoring program designed to meet these objectives is outlined in Table 2 of Regulatory Guide 4.14, contained in Appendix V of this document. In addition to the radionuclides listed there, nonradiological factors such as those listed in Table 10.1 should be analyzed at least semiannually. This analysis may be restricted to those factors which, based upon preoperational groundwater monitoring and/or other monitoring or studies, would provide effective indication of levels of contamination. With respect to groundwater monitoring, the indicator should be selected from among the more mobile chemical species to allow delineation of the extent of groundwater effects.

10.3 POSTOPERATIONAL MONITORING PROGRAM

There will be two distinct phases of monitoring following termination of mill operation: the first involves monitoring to determine compliance with decommissioning and reclamation requirements before termination of license, and the second involves potential ongoing, long-term site monitoring. Chapter 14 contains a more complete description of the likely sequence of decommissioning events.

No attempt is made to describe in detail what postoperational monitoring programs should consist of. They will vary greatly, depending upon the mode of tailings disposal. Site-specific factors will also influence the scope and level of monitoring that will be appropriate. In the following sections, postoperational monitoring is discussed in general terms to characterize the nature and extent of activity that will be required in the postoperational period.

10.3.1 Monitoring to Determine Compliance

It is not possible at this time to delineate details of the compliance monitoring program. However, in general, it will involve making direct and indirect measurements of surface contamination on mill structures that may be decontaminated for further use at the site. Surface and subsurface soil profile sampling will be required in combination with gamma dose-rate measurements of the site to determine compliance with land cleanup requirements applicable to portions of the site away from the tailings disposal area.

With regards to the tailings disposal and reclamation program, a combination of radon surface flux measurements, ambient measurements, and visual observations will be required to determine compliance. Radon concentrations in air are extremely variable because of the large number of factors that influence the rate at which the radon is released (temperature, pressure, wind speed, etc.). For this reason, determination of compliance with tailings disposal requirements will be accomplished by measurement of cover thicknesses, supplemented by surface flux and air concentration measurements. Mill operators will be required to commit to specific disposal plans that establish thicknesses and shape of cover. (See Chapter 12 for more detailed discussion regarding implementation of cover thickness requirements.) Radon emanation would be measured to verify that attenuation was reasonably close to that predicted in the initial establishment of thickness requirements. The groundwater portion of the operational monitoring program should be continued until applicable licenses are terminated. Also, because one of the major aspects of the tailings disposal program will be surface reclamation (for example, vegetation) to ensure long-term stability of the tailings cover, the period of monitoring to determine compliance may extend for a considerable period of time (5-20 years). (See the more complete discussion of the sequence of decommissioning events contained in Chapter 14.) An extended monitoring period might be required, because it would take about five years for vegetation to become firmly established. Furthermore, it will take several years to experience a sufficiently varied set of climatic conditions to make judgments about the potential long-term performance of such covering.

In addition to meeting requirements imposed by NRC, the reclamation program must satisfy state and federal regulations applicable to reclamation of land used for mining, milling, and related activities. A summary of pertinent State reclamation regulations, including their significant major provisions, is given in Appendix N.

10.3.2 Long-Term Monitoring

The level of site monitoring required over the long term will depend upon the mode of tailings disposal and degree of stability achieved. Isolation provided for in the tailings disposal program is designed to confine radon and particulate airborne emissions and to reduce seepage to groundwater so that most of the environment measurements of the operational monitoring program can be discontinued. The purposes of any long-term postoperational monitoring effort would be to:

(1) Confirm that the tailings disposal program was providing the degree of isolation expected under natural weathering and erosional forces, and

(2) Ensure that human activities at the site were not compromising the tailings isolation.

The primary means of isolating the tailings will continue to be physical barriers, such as the earthen cover featured in the disposal alternatives evaluated. Continued monitoring represents a prudent additional measure that could detect degradation of isolation in time to allow appropriate repair. The monitoring program, however, is not intended to replace physical barriers as the primary means of tailings isolation.

10.3.2.1 Active Care Mode

Steps are taken to isolate the tailings so that a detailed monitoring program would not be necessary. However, an extensive maintenance program would be required in the tailings disposal area. As stated above, the extent of such a program is speculative and will, in any event, vary depending upon the severity of erosion that occurs at a given site. The following points characterize the activities that would likely be required in order to monitor and maintain the tailings:

1. An extensive irrigation system would be required to ensure vegetative cover of the entire tailings area.

2. Sections of the pile that are especially susceptible to erosion and blowouts would require periodic repair. This would involve hauling in topsoil, regrading, and seeding.

3. Equipment (such as the irrigation system) and fencing would require maintenance and periodic replacement.

4. Personnel also would have to be hired to carry out the maintenance program. It is likely that such personnel could care for a number of sites in the same region.

Obviously, this type of active care program would require a substantial, ongoing commitment of resources. Illustrative costs for such a program and more specific discussion of potential tailings area maintenance scenarios are presented in Appendix R.

10.3.2.2 Passive Monitoring Mode

Alternatives 2 through 6 would not require active care to ensure that the tailings remain isolated, and therefore a very low-level monitoring effort is expected. It would likely be sufficient for inspectors to visit the site annually to perform a visual inspection to confirm that erosion was not taking place and that there was no disruption from human activities. This also might involve taking photographs of the site to provide a point of comparison from one year to the next and perhaps drawing samples from established monitoring wells to confirm that no ongoing contamination was occurring. The extent to which groundwater monitoring will be required can be judged based upon knowledge of site-specific geohydrologic conditions and experience gained during the operational monitoring program. It is expected in most cases, however, that what limited sampling is done can be accomplished without a significant increase in effort or expense beyond that which will be incurred in making visual inspections. On the other hand, it might be possible to avoid visits at each site by conducting aerial inspections covering many sites in an area at the same time. High resolution aerial photographs might allow careful monitoring of the sites.

As discussed in Section 9.4, because most erosional processes are relatively slow, and even the worst of human intrusion events would not result in immediate, acute health effects, annual inspections would probably be sufficient. Human intrusion or disruptive activities, although extremely unlikely, particularly if there are land use and ownership controls, could be halted before any health hazard could occur.

As stated in Section 9.4 it may be possible to permit productive uses of the tailings disposal site, such as grazing. Monitoring of the site might be necessary to ensure that such uses were not causing problems, such as loss of cover and accelerated erosion.

10.3.2.3 Potential Reduced Care Mode

Except in the case of Alternative 8, it probably would not be possible to reduce further the low level of monitoring conducted in the passive monitoring mode. Deep disposal in a mine, as provided for in Alternative 8, would obviate the need for any monitoring because of the degree of isolation provided.

References

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2. Regulatory Guide 3.8, "Preparation of Environmental Reports for Uranium Mills," Revision 1, U.S. Nuclear Regulatory Commission, September 1978.

11. MONETARY COSTS OF ALTERNATIVES

Estimates of monetary costs for the base case and most of the alternatives described in Chapter 8 are presented in this chapter. Costs are merely presented in this chapter; a final cost-benefit analysis of alternatives is presented and corresponding conclusions are stated in Chapter 12.

The accuracies of the cost estimates presented have inherent limitations. This is particularly true with regards to costs for mill tailings disposal because of the site-specific nature of the factors which affect costs. The costs are of the engineering type, estimated to be accurate to within about % 25%. Where costs of material are important, as in mill process alternatives, the staff used the most recent information available from published data on commodity prices. Cost information developed during mill licensing actions over the past few years and special studies on costs developed in support of this document, also were used in estimating the costs of the tailings disposal alternatives.[1,2] Estimations of economies due to scale are based on traditional engineering approaches to such projections.

The costs cited are in 1980 dollars with no escalation or discounting factors used for expenditures occurring in later years or over a project lifetime. Lifetime costs are taken as the sum of capital costs plus annual or periodic operating costs summed over the time period that the mill operates (15 years). A detailed list of the items included in capital and operating costs is given in Appendix K-8. Cost figures taken from earlier references are escalated to 1980 in proportion to construction price indexes for the respective years. Engineering costs are implicitly contained in the figures; however, no contingency costs, which would normally be about 15% to 20% of the quoted figures, are added.

A more detailed discussion of the unit prices used in the staff's estimates is given in Appendices K-4 and K-8, where ranges of costs are displayed, the factors affecting costs are reviewed, and a rationale for the staff's choice of unit costs is presented.

11.1 CONTROL ALTERNATIVES

Various methods for controlling airborne contaminants to levels below those assumed for the model mill are described in Section 8.1, and detailed cost estimates are presented in Appendix K-1. Capital, operating, and lifetime costs for those methods selected for purposes of illustrating the reductions of source term strengths are presented in Table 11.1.

Table 11.1 Costs of Selected Control Alternatives[a]

		Costs (thousands of dollars)		
Source	Control	Capital	Operating (per year)	Lifetime
Ore storage	Windbreak	17	-	17
	Water spray	9	1.5	32
Crushing and grinding	Bag filter	310	33.2	808
	Semi-autogenous[b]	375	907	13,980
Yellowcake dryer	High-energy Venturi	71	23.8	428
	Wet shipment[c]	-	-	-
Tailings pond	Sprinkler system	-	35.0	525

[a]The costs listed are estimated outlay costs, not incremental costs. The latter may be positive or negative, depending on the relative costs of the equipment being replaced. Brief discussions of incremental costs are given in pertinent sections of Appendix K.

[b]Costs (escalated to 1980 dollars) are estimated from unit operation costs given in "An Evaluation of the Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transporting Systems in the Western United States," Dames and Moore, prepared for Argonne National Laboratory, July 1977. Capital and operating costs are about $100,000 and $0.1/MT or less, respectively, than base case dry ore crushing and grinding operations; thus semi-autogenous grinding would result in lifetime costs which are about $1.34 million less than the base case ore sizing processes.

[c]Costs are difficult to estimate for this alternative. Capital costs would be incurred in purchasing containers for the shipment of wet cake, and operating costs would appear as shipping costs. The staff currently has no information on which to base estimates of these costs.

11.2 TAILINGS MANAGEMENT PROGRAMS

In this section the monetary costs of each of the tailings management and disposal alternatives and of the base case are summarized. More complete descriptions of alternative tailings management and disposal programs are provided in Chapter 8 and Appendix K. more specifically, details of the cost evaluations are contained in Appendix K-4.

The adopted costs for various unit operations are given in Table 11.2.

Table 11.2 Unit Costs Used in Evaluations[a]

Factor	Selected Value
Excavate, load, haul ($\leq$ 1 km), deposit	$1.20/m^3
Truck transport ($\geq$ 1 km)	$0.27/m^3-km
Spreading and compacting (cover & fill)[b]	$0.45/m^3
Spreading and controlled compacting (liner & dam)[b]	$1.25/m^3
Compacting soil already in place	$2600/ha
Installation of clay liner[b]	$2.55/m^3
Installation of cover material	$1.75/m^3
Installation of Hypalon liner (30 mil)	$6.90/m^2
Installation of PVC liner (30 mil)	$4.90/m^2
Resurfacing and revegetation	$5000/ha

[a]Only those costs common to many alternatives are listed. For specialized costs, see the appropriate alternative. For ranges of costs see Table K-4.1 in Appendix K-4.

[b]Installation of liner or dam and hence, the degree of compaction, must meet more stringent quality assurance and testing requirements than cover or fill materials.

11.2.1 Base Case

Under this case an initial basin would be formed by building low earthen embankments on the four sides of a square. Mill tailings would be slurried into the basin and as the basin filled, coarse fractions of the tailings (sands) would be used to raise and broaden the embankments. The embankments would be compacted on the outer side to provide strength. Costs are given in Table 11.3.

Table 11.3 Estimated Costs for Base Case and Alternative 1

Action	Year	Yearly Cost	Total Cost (1980 dollars)
Base Case			
Initial dam construction	0		190,000
Compaction	2-15	51,000	710,000
Total			900,000
Alternative 1			
Area preparation	0		980,000
Dam construction	0		3,050,000
Diversion structures	0		110,000
Cover (3m earth)	18		4,200,000
Reclamation	18		500,000
Total			8,800,000[a]

[a]Rounded off to nearest $100,000.

11.2.2 Alternative 1

Under this alternative the basic program is similar to that of the base case, but better practices are assumed. Specifically, the following sequence of operations was considered:

1. Removal of 0.6 m (2 ft) of surface soil from the 100-ha (250-acre) tailings pond site and compaction of the exposed area.

2. Construction of embankments from compacted overburden, with inclusion of necessary diversion ditches, dikes, and drains.

3. Temporary stabilization against dust and erosion by spraying water.

4. When tailings have dried sufficiently, physical isolation of tailings and reduction of radon exhalation by emplacement of the standard cover, 3 m of acceptable backfill material. (Costs for various covers and cover thicknesses are presented in Sec. 11.3.)

5. Coverage of the entire area with topsoil and revegetation.

The estimated costs of these operations are also summarized in Table 11.3.

11.2.3 Alternative 2

Deposition of untreated tailings in a mine pit lined with a low permeability clay or synthetic (hypalon) layer is proposed in Alternative 2. Two options are considered: (1) the lining would be installed before the pit was backfilled, i.e., below the water table, or (2) the liner would be installed over compacted backfill above the water table. In Option 1, overburden would be placed over the lining to a level above the water table. Although compaction of the overburden would not be necessary, the side of the pit would have to be prepared so that the emplaced liner would be stable. Three modes of sidewall treatment are discussed in Appendix K-4 and detailed estimates for costs of the 12 possible variations are given there and in Table 11.4 (see p. 11-4). Installation of the 6 m cover (see Sec. 11.3) and revegetation would complete the program. Since restoration of the mine would be required in any case, only the cost of emplacing the cover is assessed against the tailings management program.

11.2.4 Alternative 3

Under Alternative 3, an abandoned mine pit backfilled above the water table with a low permeability (clay or PVC) liner installed above the fill would be used for tailings disposal. Tailings would be dewatered either by a belt filter or an in situ system. In the case of belt filtering, the tailings would be dried sufficiently so that no appreciable drainage would occur after the tailings were deposited in the pit; however, a small amount of further in situ drying might be necessary before heavy machinery could be operated on the tailings. On cessation of operations, the tailings would be capped with a 6 m earthen cover, and the surface restored (see Sec. 11.3). After installation of the earthen cover, there would be no incremental costs for restoring because such costs are considered a basic part of mine operations. Costs for Alternative 3 are given in Table 11.5.

Table 11.5 Estimated Incremental Costs for Alternative 3
(thousands of 1980 dollars)

Action	Vacuum Belt	In Situ Dewatering
Preparation of Retention Basin	3,290	3,290
Filtration	6,380[a]	680
Evaporation[b]	4,470	4,470
Lining (clay/PVC)	1,070/2,060	1,070/2,060
Cover	2,700	2,700
Total costs (clay/PVC)	17,900/18,900	12,200/13,200

[a]Includes hauling of dewatered tailings to pit.

[b]Evaporation pond is 40 ha in area and Hypalon lined.

Table 11.4 Estimated Costs for Alternative 2 (thousands of 1980 dollars)

Feature	Option 1 Method A	Option 1 Method B	Option 1 Method C	Option 2 Method A	Option 2 Method B	Option 2 Method C
Compaction of pit bottom	1,480	1,480	1,370	2,690	3,730	3,310
Preparation of sidewalls	3,960	4,000	1,150	2,160	2,130	860
(Clay liner / Hypalon liner)[a]	1,330/3,590	1,330/3,590	1,020/2,760	1,350/3,660	1,810/4,900	1,380/3,730
Floating decant pump	100	100	100	100	100	100
Evaporation pond[b]	2,880	2,880	2,880	2,880	2,880	2,880
Emplacement of cover	1,460	1,460	1,030	1,460	1,460	1,260
Total costs (clay liner / Hypalon liner)[a]	11,200/10,500	11,300/10,500	7,600/6,300	10,600/10,000	12,100/12,200	9,800/9,200

[a]Where Hypalon is used to line the tailings area, no evaporation pond or decantation system is used; liquids in this case are assumed to evaporate directly from the tailings area.

[b]Evaporation pond is 27 ha in area and Hypalon lined.

11.2.5 Alternative 4

In Alternative 4, a naturally occurring low permeability shale or clay bed is assumed to be available and a tailings disposal pit would be dug into the bed. Untreated tailings slurry would be transferred to the pit by a pipeline and allowed to dry. On completion of operations, the bed would be covered with the standard cover (3 m of overburden) and the surface restored. All costs of covering and restoration are assessed against this alternative (Table 11.6), unlike Alternatives 2 and 3, where restoration costs are treated as mining costs.

Table 11.6 Estimated Cost for Alternative 4
(thousands of 1980 dollars)

Action	Year	Total Cost
Pit excavation	0	10,770
Evaporation[b]	0	2,980[a]
Cap (3 m earth)	20	2,400
Reclamation	20	400
TOTAL		16,600

[a]Includes $100,000 for decantation system.

[b]Evaporation pond is 27 ha in area and Hypalon lined.

11.2.6 Alternative 5

Under this alternative, the tailings impoundment is prepared in staged sections during operations, so that material excavated from one section can be used as cover material over a section previously filled with tailings. An impermeable bed would not be required and the trench would be lined. In excavating and lining the trench, an initial section sufficient for about five years' worth of tailings would be required. Later sections could be built as needed; however, temporary dikes would be required across the trench to isolate tailings water from construction areas. Sealing, backfilling, and restoration could follow about a year after a trench area was filled with tailings. Construction, filling of tailings, and restoration would move along the length of the trench in sequence. Costs for this alternative are presented in Table 11.7.

Table 11.7 Estimated Incremental Costs of Alternative 5
(thousands of 1980 dollars)

Action	Clay Liner	Plastic Liner
Preparation of Retention Basin	10,800	10,030
Liner[a]	3,060	8,250
Evaporation[b]	2,880	-
Cap	2,120	2,230
Reclamation	590	560
TOTAL	19,500	21,100

[a]Where Hypalon is used to line the tailings area, no evaporation pond is used; tailings liquids in this case are assumed to evaporate directly from the tailings area.

[b]Evaporation pond is 27 ha in area and Hypalon lined.

11.2.7 Alternative 6

The program of this alternative consists of construction of a dam, built to NRC specifications (see App. B), across a naturally occurring basin. The bottom would be compacted and lined and appropriate dikes and drains installed. Tailings would be emplaced as a wet slurry and allowed to dry; during this period, dry beaches would be stabilized against dusting and erosion by use of chemical agents. Tailings liquids would be pumped to an evaporation pond. After complete drying of the tailings, the standard cover would be installed and the tailings area reclaimed. The outer slope of the dam would be contoured to a slope of 10 horizontal to 1 vertical; rock cover would be emplaced over the outer slope. Costs for this program are listed in Table 11.8.

Table 11.8 Estimated Incremental Costs for Alternative 6 (thousands of 1980 dollars)

Action	Year	Yearly Cost	Total Cost
Area preparation[a]	0		620
Dam construction[a]	0		660
Liner[f] (clay/Hypalon)[a]	0		2,040/5,500
Evaporation[a,e]	0		2,980[c]
Chemical stabilization[b]	2-18	22	380
Cover[a]	20		4,200
Reclamation[a]	20		1,620
TOTAL[f] (clay/Hypalon)			12,500/13,000

[a]Capital cost.

[b]Operating cost.

[c]Includes $100,000 for decantation system.

[d]Includes recontouring of surface of, and rock cover over, outer slope (10 horizontal to 1 vertical) of dam.

[e]Evaporation pond is 27 ha in area and Hypalon lined.

[f]Where Hypalon is used to line the tailings area, no evaporation pond is used.

11.2.8 Alternative 7

Under the assumptions of Alternative 7, the tailings slurry (50% solids) would be transferred by pipeline to the edge of a depleted mine pit. At this point, the sands and slimes would be separated. The sands would be washed with clean water, partially dried, and deposited in the unlined mine pit. The slimes, along with aqueous mill wastes, would be neutralized with lime. The solids, including newly formed precipitates, would be separated from the water and partially dried. Optional methods of drying would be: use of thickeners and filters, thickeners, and fossil-fueled or electrically heated mechanical dryers, or a combination of a special tailings drying area (a sand filter termed a "dewatering filter bed") with a separate evaporation pond. When sufficiently dry, the slimes would be combined with Portland cement (1 part cement to 5 parts tailings) or asphalt (1.5 parts asphalt to 2 parts tailings) and deposited in the mine pit, where the slurry would harden. Both the fixed slimes and the washed sands are assumed to be sufficiently resistant to leaching that exposure to groundwater would be permissible. On completion of tailings operation, the tailings would be covered with the standard cover (see Sec. 11.3) and the surface restored.

Capital costs for Alternative 7 (and Alternative 8) are summarized in Table 11.9, and operating costs are given in Table 11.10; operating costs predominate.

11.2.9 Alternative 8

Alternative 8 differs from Alternative 7 in that an available deep mine rather than a surface mine would be used for tailings disposal. In terms of cost, the only difference between Alternatives 7 and 8 would be the cost of transporting the treated tailings from a treatment plant to a deposition point. It is assumed that in both cases the treatment plant would be adjacent to the depository and that the cement or asphalt slurry could be pumped to the deposition point. There would be small cost differences in the deposition slurry pipelines, depending on local conditions. Accordingly, the capital and operating costs of Alternative 8 are taken as equal to those of Alternative 7 (Tables 11.9 and 11.10), with the additional cost of the boreholes, which is estimated at about $1,880,000.

Table 11.9 Estimated Capital Costs of Alternatives 7 and 8[a] (thousands of 1980 dollars)

Equipment[b]	Evaporator Cement	Evaporator Asphalt	Bed Filter Cement	Bed Filter Asphalt
Sand washing and drying	210	210	210	210
Lime neutralization	2,270	2,270	2,270	2,270
Filtration	1,350	1,350	5,040	5,040
Evaporation				
Pond[c]	4,470	4,470	4,470	4,470
Fossil Fuel Evaporator	1,700	1,700	1,700	1,700
Fixation	1,400	5,150	1,400	5,150
TOTAL				
Pond	9,700	13,500	13,400	17,100
Evaporator	6,900	10,700	10,600	14,400

[a]Cost shown for Alternative 7. For Alternative 8, add $1,880,000 for well drilling to all options.

[b]Installed costs are cited.

[c]Evaporation pond is 40 ha in area and Hypalon lined.

11.2.10 Alternative 9

Under this alternative, it is assumed that the tailings would be released from a nitric acid mill. The tailings disposal program is that of Alternative 6 (dammed natural basin); however, a thinner cover (1.5 m earth) could be used to attain the same radon attenuation as for the standard cover, since much of the radium would be removed, and costs are estimated on this basis. In addition to the tailings, about 50 MT/day (55 ST/day) of dried nitric acid leachate (containing ~ 90% of the thorium and radium in the ore) would be produced. It is assumed that this material would be calcined, fixed in asphalt or cement, and buried in a special pit. These costs, as well as the incremental costs (above the sulfuric acid process) of the nitric acid process, are assessed against this alternative. All costs are given in Table 11.11.

11.2.11 Optimizing Tailings Management System Alternatives

It was noted in Section 8.4 that tailings management system alternatives 1 through 9 have been provided to illustrate how various system components might be combined to produce complete systems, and that a great number of potential systems are possible by slightly modifying and using the alternatives in combination or by modifying an alternative in a staged fashion. This is also true of the overall costs of those systems. As an example of how alternatives might be combined, a hypothetical system was described in which the tailings sands and slimes are separated as in Alternative 8, but with the sands being deposited as a slurry with cement in the deep mine while the slimes are deposited in specially excavated pits or trenches, such as those described in Alternatives 4 and 5, respectively. Such a modification would have several advantages. If one-half the total tailings were stored as sands in the deep mine, only one-half would be required to be managed in near-surface facilities which would significantly reduce the cost of the near surface facility or increase the total capacity of the system. The cemented backfilled sands would provide structural support to prevent mine subsidence and subsequent cross-connection of overlying aquifers and might make it easier to mine contiguous, marginal ore bodies at a future time.

Examples of alternatives that could be modified to include conducting operations in a staged fashion are Alternatives 4 and 6 (Note that trench disposal as described in Alternative 5 is representative of operations involving impoundment construction, filling, and reclamation activities conducted simultaneously). This has the primarily economic benefits of reduced initial capital investment and reduced financial risk and exposure throughout the operations and particularly at final decommissioning. It also results in reduced handling of materials and a reduced quantity of tailings exposed at any one time. The latter not only reduces the area from which blowing tailings sands would have to be controlled but might result in reduced liner requirements if the source of seepage is adequately limited in duration and extent. Finally, a staged tailings management system provides the opportunity to further optimize disposal operations as they progress, and increases confidence that unanticipated adverse impacts can be mitigated without resorting to extreme measures such as an indefinite complete shutdown of operations.

Table 11.10 Annual Operating Costs for Alternatives 7 and 8[a]
(thousands of 1980 dollars)

Cost	Evaporator & Disc		Pond & Bed		Evaporator & Bed		Pond & Disc	
	Cement	Asphalt	Cement	Asphalt	Cement	Asphalt	Cement	Asphalt
Salaries	290	290	190	190	250	250	230	230
Maintenance	200	260	130	190	150	210	180	250
Power	120	120	70	70	90	90	100	100
Fuel	4,840	5,400	--	560	4,840	5,400	--	560
Asphalt	-	5,300	--	5,300	-	5,300	--	5,300
Cement	2,450	-	2,450	--	2,450	--	2,450	--
Lime	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Total annual	8,890	12,340	3,830	7,270	8,770	12,220	3,960	7,420
15-year total	133,400	185,100	57,500	109,100	131,600	183,300	59,400	111,300
Capital costs[b]	6,900	10,700	13,400	17,100	10,600	14,400	9,700	13,500
TOTAL	140,300	195,800	70,900	126,200	142,200	197,700	69,100	124,800

[a]Costs shown for Alternative 7. For Alternative 8 add $1,880,000 as part of capital costs to all options.
[b]From Table 11.9.

Table 11.11 Estimated Costs for Alternative 9[a]
(thousands of 1980 dollars)

Action		Costs
Area preparation		620
Dam construction		660
Liner[d]		
Clay		2,040
Hypalon		5,500
Evaporation[b]		2,980[c]
Chemical stabilization (lifetime)		380
Leachate disposal pit		400
Fixation equipment		
Cement		160
Asphalt		120
Fixation operating costs (lifetime)		
Cement		2,420
Asphalt		5,890
Cover		2,100
Reclamation of tailings pond		400
Reclamation of leachate area		10
Totals		
	Asphalt	Cement
Hypalon[d]	16,000	12,600
Clay	15,500	12,100

[a]To obtain lifetime costs, the incremental costs ($81 million) of the nitric acid process over those of the sulfuric acid process must be added (see Table K-2.1).

[b]Evaporation pond is 27 ha in area and lined with Hypalon.

[c]Cost includes $100,00 for decantation system.

[d]Where Hypalon is used to line tailings pit, no evaporation pond is used.

In essence, it is not possible to generically specify the tailings management systems which are the best for a particular site. These can be developed and evaluated only after all the unique constraints on the project have been defined. The alternatives and options examined in detail in this document should be viewed as examples of basic systems that might be formed from the wide range of tailings management system components, and the costs provided here are considered reasonably representative of those which would actually be encountered.[8-8]

11.2.12 Summary

Comparative lifetime costs for each alternative, including options, are given in Table 11.12. The range of costs is quite large ($900,000 to $200,000,000); the lowest cost is associated with the base case, and the largest cost is for burial of the tailings in a mine after fixation with asphalt. The most costly specific item in the table is fuel used to evaporate tailings water in Alternatives 7 and 8. The costs of asphalt or cement for fixation are also very large, and if a special pit must be excavated, these costs too are very large. The costs of clay or synthetic liners are also significant. (See Ch. 12, in which is provided a final cost-benefit analysis of alternatives evaluated.)

Table 11.12. Lifetime Costs for Tailings Management Alternatives

Alternative No.	Option			Total, 10^6 (1980)	Tailings,[a] $/MT	Yellowcake[b] $/lb	Yellowcake[b] $/kg	Energy, mills/kWh	Largest Single Cost 10^6 (1980)	Largest Single Cost Item
	Base Case			0.9	0.11	0.05	0.11	0.002	0.90	Embankment
1				8.8	1.05	0.51	1.12	0.025	4.20	Cover
2	(1)	A	Clay Liner	11.2	1.33	0.65	1.43	0.032	3.96	Prep. of mine sidewalls
2	(1)	A	Hypalon Liner	10.5	1.25	0.61	1.34	0.030	3.96	Prep. of mine sidewalls
2	(1)	B	Clay Liner	11.3	1.35	0.66	1.45	0.033	4.00	Prep. of mine sidewalls
2	(1)	B	Hypalon Liner	10.5	1.25	0.61	0.34	0.030	4.00	Prep. of mine sidewalls
2	(1)	C	Clay Liner	7.6	0.90	0.44	1.98	0.022	2.88	Evap. pond
2	(1)	C	Hypalon Liner	6.3	0.75	0.37	0.81	0.018	2.76	Liner
2	(2)	A	Clay Liner	10.6	1.26	0.62	1.36	0.031	2.88	Evap. pond
2	(2)	A	Hypalon Liner	10.0	1.19	0.58	1.28	0.029	3.66	Liner
2	(2)	B	Clay Liner	12.1	1.44	0.70	1.54	0.035	3.73	Prep. of basin
2	(2)	B	Hypalon Liner	12.2	1.45	0.71	1.56	0.035	4.90	Liner
2	(2)	C	Clay Liner	9.8	1.17	0.57	1.25	0.028	3.31	Prep. of basin
2	(2)	C	Hypalon Liner	9.2	1.10	0.53	1.17	0.026	3.73	Liner
3	Belt-Filter		Clay Liner	17.9	2.13	1.04	2.29	0.052	6.38	Filtration
3	Belt-Filter		PVC Liner	18.9	2.25	1.10	2.42	0.055	6.38	Filtration
3	In Situ		Clay Liner	12.2	1.45	0.71	1.56	0.035	4.47	Evap. pond
3	In Situ		PVC Liner	13.2	1.57	0.77	1.69	0.038	4.47	Evap. pond
4			-	16.6	1.98	0.97	2.13	0.048	10.8	Prep. of basin
5			Clay Liner	19.5	2.32	1.13	2.49	0.056	10.8	Prep. of basin
5			Hypalon Liner	21.1	2.51	1.23	2.71	0.061	10.0	Prep. of basin
6			Clay Liner	12.5	1.49	0.73	1.61	0.036	4.20	Cover
6			Hypalon Liner	13.0	1.55	0.76	1.67	0.038	5.50	Liner
7	CEMENT	DISC	Fueled Evaporator	140.3	16.70	8.16	17.95	0.408	72.6	Fuel
7	CEMENT	DISC	Evaporation Pond	69.1	8.23	4.02	8.84	0.201	36.8	Cement
7	CEMENT	BED	Fueled Evaporator	142.2	16.93	8.27	18.19	0.413	72.6	Fuel
7	CEMENT	BED	Evaporation Pond	70.9	8.44	4.12	9.06	0.206	36.8	Cement
7	ASPHALT	DISC	Fueled Evaporator	195.8	23.31	11.38	25.04	0.569	81.0	Fuel
7	ASPHALT	DISC	Evaporation Pond	124.8	14.86	7.26	15.97	0.363	79.5	Asphalt
7	ASPHALT	BED	Fueled evaporator	197.7	23.54	11.49	25.28	0.574	81.0	Fuel
7	ASPHALT	BED	Evaporation pond	126.2	15.02	7.34	16.15	0.367	79.5	Asphalt
8	CEMENT	DISC	Fueled Evaporator	142.2	16.93	8.27	18.19	0.413	72.6	Fuel
8	CEMENT	DISC	Evaporation Pond	71.0	8.45	4.13	9.09	0.206	36.8	Cement
8	CEMENT	BED	Fueled Evaporator	144.1	17.15	8.38	18.44	0.419	72.6	Fuel
8	CEMENT	BED	Evaporation Pond	72.7	8.65	4.23	9.31	0.211	36.8	Cement
8	ASPHALT	DISC	Fueled Evaporator	197.7	23.54	11.49	25.28	0.574	81.0	Fuel
8	ASPHALT	DISC	Evaporation Pond	126.7	15.08	7.37	16.21	0.368	79.5	Asphalt
8	ASPHALT	BED	Fueled Evaporator	199.6	23.76	11.60	25.52	0.580	81.0	Fuel
8	ASPHALT	BED	Evaporation Pond	128.1	15.25	7.45	16.39	0.372	79.5	Asphalt
9			Clay Liner	93.2[c]	11.10	5.42	11.92	0.271	81.0	Process increment
9			Hypalon Liner	93.7[c]	11.15	5.45	11.99	0.272	81.0	Process increment

[a]Based on 5.6×10^5 MT/yr tailings generated for 15 years.

[b]Based on 520 MT/yr U_3O_8 produced for 15 years.

[c]Includes operating costs of cement fixation of leachate (2.4) and incremental lifetime operating costs of nitric acid process (81.0).

11.3 VARIABILITY IN COSTS OF TAILINGS ISOLATION COVER

Costs for covering tailings disposal areas are dependent on a number of site-specific factors, the principal ones being attenuation properties of the cover material, and hence the amount of cover material needed; availability of cover materials; area of the tailings pile; ore quality; and distribution of sands and slimes in the tailings disposal area. The effects of varying each of these factors on cost are illustrated below. A more complete analysis is presented in Appendix K-6.

11.3.1 Radon Attenuation Properties

The thicknesses required and costs of obtaining various degrees of attenuation, using typical soils described in Section 9.3.8, are shown graphically in Figure 11.1. For the costs presented in Figure 11.1 the staff assumed a unit cost of $1.75/m^3 to place cover material; this includes excavating, hauling, and compacting the material, and reclamation of borrow pits. If cover can be applied in a simpler manner, such as by "pushing" nearby dirt over tailings disposed of below grade, costs could be reduced, as shown by Alternative 5. Costs could be higher in a case where hauling would have to be done on very steep grades or where other site-specific factors would make the covering operation more difficult.

11.3.2 Availability and Unit Costs of Cover Material

The costs for cover material are assumed to be only those of excavating, hauling, depositing, and spreading. The soil material is assumed to be essentially "free." For common overburden and soils, it is reasonable to assume such materials can be found onsite. Soil that is available from any excavation of disposal pits is assumed to be stored and used for reclamation.

In the staff analysis of costs, overburden stripped during mining and returned to an open pit is considered a mining cost and as such is considered to be "free" in the context of tailings disposal. Such costs would be incurred regardless of requirements for mill tailings disposal, because many existing state and federal mine reclamation laws would require such operations.

11.3.3 Variation of Tailings Area and Ore Grade

For a given volume of tailings, the surface area to be covered would depend on depth of the tailings pile. It was estimated that if a common soil such as soil 3 were used, the costs of covering the model mill tailings, which would have a depth of about 8 m (26 ft) and an exposed area of 80 ha (200 acres), would be $4,500,000. If the thickness of the tailings were increased to 16 m (52 ft) and the area proportionately reduced, then the cost of the tailings covering would decrease to about $2,200,000. In a similar manner, tailings covering costs for the model mill would almost double if the tailings pile thickness were halved to 4 m (13 ft).

Varying ore grade from that assumed for the model mill would not necessarily change the total costs of tailings cover if the amount of product (U_3O_8) did not change. For example, decreasing ore grade would reduce exhalation of radon from the tailings because radium concentrations in the tailings would be less. Countering this effect, however, would be the proportionate increase in volume and surface areas of tailings that would occur in generating the same amount of product.

11.3.4 Distribution of Sand and Slime Fractions

The manner in which the sand and slime fractions are distributed in the tailings pile will affect the thickness of cover needed and, therefore, the costs. If tailings are deposited in such a fashion that slimes are layered below sands as opposed to even distribution of these fractions, as might be the case in Alternative 5, the reduction of thickness required to reach the proposed limit using soil 2 could be as much as about 1 m (3 ft) and, associated cost savings of about $1.4 million in application of cover material could be realized.

11.4 COSTS FOR ALTERNATIVES FOR DECOMMISSIONING OF MILL AND MILL SITE

The decommissioning alternatives considered are: (1) the retention and use of some or all of the buildings and equipment after decontamination, and (2) the complete removal of all buildings, foundations, and equipment, with the restoration of the site to its original state. The abandonment of the mill and site without decontamination and with or without fencing and guards is not considered a reasonable alternative. For Option 1, equipment could be removed from the buildings as desired and the buildings would then be available for general use. For Option 2, the buildings would be removed and uncontaminated foundations broken up and used as fill or riprap on steep or erodible slopes. Areas outside the buildings and not covered with equipment would be treated identically in the two options.

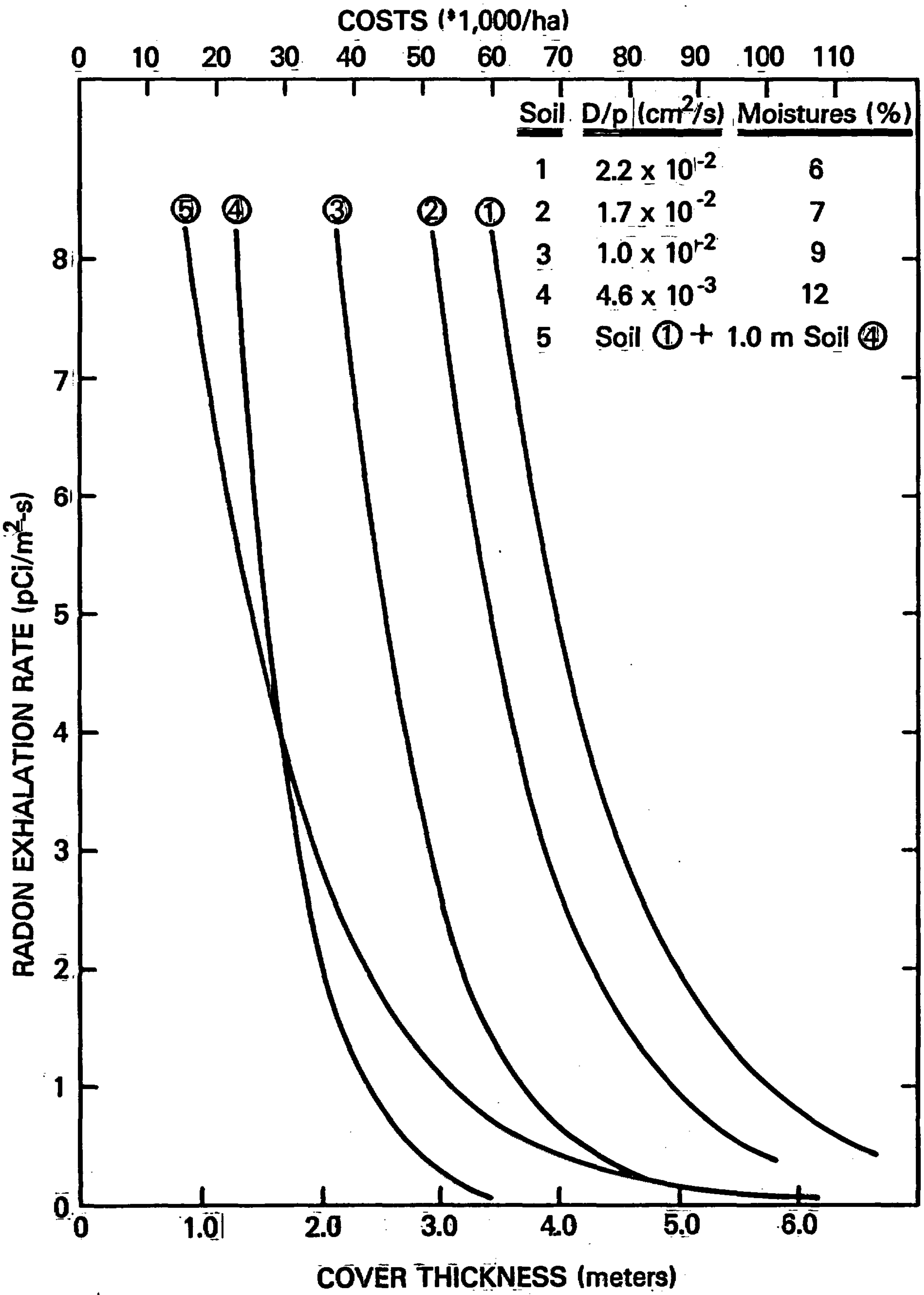

Fig. 11.1. Comparison of Cover Thicknesses and Costs for Radon Flux Attenuation by Use of Various Cover Types.

The potentially largest cost in decommissioning would be the cleanup of contaminated ground. Here it is assumed that the ore pad would be sufficiently contaminated so that excavation to a depth of about 1 m (3 ft) would be required. The area of windblown contamination depends on dust control measures and meteorological conditions at the mill. The staff has used the conservative assumption that 120 ha (300 acres) would have to be excavated to a depth of 0.15 m (6 inches). A more detailed discussion of decommissioning costs is presented in Appendix K-7.

In addition to decommissioning costs, engineering and contingency costs would be incurred. Based on a recent study,1 engineering costs would be about 6% and contingency costs would be about 15% of decommissioning costs. The costs are shown in Table 11.13 in 1980 dollars, and escalation must be added for future years if required. It will be noted that on the basis of the staff's assumptions, the costs of Options 1 and 2 are identical. In individual cases, the choice between these options would be made on the basis of other, nonmonetary, considerations.

Table 11.13. Summary of Cost Estimates for Decommissioning[a] (1980 dollars)

Expenditure	Cost
Mill and building decontamination, 12 man-years at $30,000 per man-year[b]	360,000
Machinery removal	No cost
Building removal	No cost
Restoration of heavily contaminated area, 82,000 cubic meters of dirt moved at $1.50/m³[c]	120,000
Restoration of lightly contaminated area, 120 hectares at $4750/ha[d]	570,000
Subtotal	1,050,000
Engineering, 6% of subtotal	63,000
Contingency, 15% of subtotal	157,000
TOTAL	1,270,000

[a]Since building and machinery removal are assumed to have no cost, the costs of Options 1 and 2 are identical. In individual cases, either may be preferred.

[b]Costs quoted are operator costs; that is, overhead is included.

[c]Area involved is 8 ha.

[d]Depth of excavation is 0.15 m.

References

1. "An Evaluation of the Cost Parameters for Hypothetical Uranium Milling Operations and Ore Transporting Systems in the Western United States," Dames and Moore report prepared for Argonne National Laboratory, July 1977.

2. "Costs of Alternative Mill Tailings Management Programs," (Update of Appendix K-4,) Stanley Consultants report prepared for Argonne National Laboratory, March 1980.

3. "Final Environmental Statement, Sweetwater Uranium Project, Minerals Exploration Company," NUREG-0505, U.S. Nuclear Regulatory Commission, Docket No. 40-8584, December 1978.

4. "Final Environmental Statement, Morton Ranch Uranium Mill, United Nuclear Corporation," NUREG-0532, U.S. Nuclear Regulatory Commission, Docket No. 40-8602, February 1979.

5. "Final Environmental Statement, White Mesa Uranium Project, Energy Fuels Nuclear, Inc." NUREG-0556, U.S. Nuclear Regulatory Commission, Docket 40-8681, May 1979.

6. "Environmental Assessment, Marquez Mill Facility, Bokum Resources Corporation," U.S Nuclear Regulatory Commission for New Mexico Environmental Improvement Division, Docket WM-25, February 1980.

7. "Report of the Tailings Management Evaluation of the Proposed Mt. Taylor Project [Gulf Mineral Resources Company]," U.S. Nuclear Regulatory Commission for New Mexico Environmental Improvement Division, Docket WM-26, May 16, 1980.

8. "Environmental Assessment, San Miguel Project, Pioneer-Uravan, Inc.," U.S. Nuclear Regulatory Commission for Colorado Department of Health, Docket WM-24. (In preparation).

12. PROPOSED REGULATORY ACTIONS

12.1 INTRODUCTION

On the basis of analyses of uranium milling operations up to the year 2000, presented in preceding chapters, the staff concludes that certain actions should be taken to ensure public health and safety and protection of the environment. Specific staff conclusions on technical requirements and needed institutional controls relating primarily to mill tailings management and disposal are presented here. A rationale for these requirements is also presented; this involves integrating facts and analyses presented primarily in previous chapters on environmental impacts (Chs. 6 and 9) and costs (Ch. 11) and, as such, constitutes a final benefit-cost evaluation of alternatives which have been considered.

This chapter identifies <u>what</u> regulatory requirements should be. The question of <u>how</u> these requirements and controls should be applied is taken up in Chapters 13 and 14. Chapter 13 deals with the regulatory framework for mill and mill tailings licensing and Chapter 14 addresses financial aspects of mill decommissioning and long-term tailings control. In some cases, the conclusions of this chapter can be implemented by regulations. Regulations are being promulgated by the Commission, simultaneously with the issuance of this document, incorporating the specific proposed requirements identified in Section 12.2 below and certain supporting financial arrangements delineated in Chapter 14. These regulation changes are essentially the same as those proposed in connection with the draft of this document (44 FR 50012). Some revisions have been made in light of public comments received, mostly to promote clarity.

12.2 REGULATORY REQUIREMENTS

Conclusions on what regulatory requirements need to be established cover both operation and decommissioning of the mill, as well as final tailings disposal (principally the latter since it poses the greatest potential long-term problem). These are essentially the technical and institutional criteria being established as new regulation. In Section 12.3, the benefit-cost rationale for each of the requirements is presented.

12.2.1 <u>Technical Siting and Design Requirements</u>

<u>Siting Criteria and Objectives</u>

1. In selecting among alternative tailings disposal sites or judging the adequacy of existing tailings sites, the following site features--which will primarily determine the extent to which a program meets the broad objective of isolating the tailings and associated contaminants from man and the environment during operations, and for thousands of years thereafter, without ongoing active maintenance shall--be considered:

   - remoteness from populated areas;
   - hydrologic and other natural conditions, as they contribute to continued immobilization and isolation of contaminants from usable groundwater sources, and
   - potential for minimizing erosion, disruption, and dispersion by natural forces over the long term.

   The site selection process shall be an optimization, to the maximum extent reasonably achievable, in terms of these features.

   In the selection of disposal sites, primary emphasis shall be given to isolation of tailings or wastes, a matter having long-term impacts, as opposed to consideration only of short-term convenience or benefits, such as minimization of transportation or land acquisition costs. While isolation of tailings will be a function of both site and engineering design, overriding consideration shall be given to siting features given the long-term nature of the tailings hazards.

Long-Term Stability of Tailings Isolation

2. The "prime option" for disposal of tailings is placement below grade, either in mines or specially excavated pits (that is, where the need for any specially constructed retention structure is eliminated). The evaluation of alternative sites and disposal methods performed by mill operators in support of their proposed tailings disposal program (provided in applicants' environmental reports) shall reflect serious consideration of this. In some instances, below-grade disposal may not be the most environmentally sound approach, such as might be the case if a high quality groundwater formation is relatively close to the surface or not very well isolated by overlying soils and rock. Also, geologic and topographic conditions might make full, below-grade burial impracticable; for example, bedrock may be sufficiently near the surface that blasting would be required to excavate a disposal pit at excessive cost, and more suitable alternate sites are not available. Where full below-grade burial is not practicable, the size of retention structures, and size and steepness of slopes of associated exposed embankments, shall be minimized by excavation to the maximum extent reasonably achievable or appropriate, given the geologic and hydrogeologic conditions at a site. In these cases, it must be demonstrated that an above-grade disposal program will provide reasonably equivalent isolation of the tailings from natural erosional forces.

3. The following site and design criteria shall be adhered to, whether tailings or wastes are disposed of above or below grade:

   a. Upstream rainfall catchment areas must be minimized to decrease erosion potential and the size of the maximum possible flood which could erode or wash out sections of the tailings disposal area.

   b. Topographic features should provide good wind protection.

   c. Embankment and cover slopes shall be relatively flat after final stabilization to minimize erosion potential and to provide conservative factors of safety assuring long-term stability. The broad objective should be to contour final slopes to grades which are as close as possible to those which would be provided if tailings were disposed of below grade; this could, for example, lead to slopes of about 10 horizontal to 1 vertical (10h:1v) or less steep. In general, slopes should not be steeper than about 5h:1v. Where steeper slopes are proposed, reasons why a slope less steep than 5h:1v would be impracticable should be provided, and compensating factors and conditions which make such slopes acceptable should be identified.

   d. A full self-sustaining vegetative cover shall be established, or rock cover employed, to reduce wind and water erosion to negligible levels.

   Where a full vegetative cover is not likely to be self-sustaining due to climatic or other conditions, such as in semiarid and arid regions, rock cover shall be employed on slopes of the impoundment system. The staff will consider relaxing this requirement for extremely gentle slopes, such as those which may exist on the top of the pile.

   The following factors shall be considered in establishing the final rock cover design, to avoid displacement of rock particles by human and animal traffic or by natural processes, and to preclude undercutting and piping:

   - shape, size, composition, and gradation of rock particles (excepting bedding material, average particle size shall be at least cobble size or greater);

   - rock cover thickness and zoning of particles by size; and

   - steepness of underlying slopes.

   Individual rock fragments shall be dense, sound, and resistant to abrasion, and shall be free from cracks, seams, and other defects that would tend to unduly increase their destruction by water and frost actions. Weak, friable, or laminated aggregate shall not be used. Shale, rock laminated with shale, and cherts shall not be used.

   Rock covering of slopes may not be required where top covers are very thick (on the order of 10m or greater); impoundment slopes are very gentle (on the order of 10 h:1v or less); bulk cover materials have inherently favorable erosion resistance characteristics; and, there is negligible drainage catchment area upstream of the pile, and good wind protection, as described in points a. and b. above.

   Furthermore, all impoundment surfaces shall be contoured to avoid areas of concentrated surface runoff, and abrupt or sharp changes in slope gradient. In addition to rock cover on slopes, areas toward which surface runoff might be directed shall be well protected with substantial rock cover (riprap). In addition to providing for stability of the impoundment system itself, overall stability, erosion potential, and geomorphology of surrounding terrain shall be evaluated to assure that there are no ongoing or potential processes, such as gully erosion, which would lead to impoundment instability.

e. The impoundment shall not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand. The term "maximum credible earthquake" means that earthquake which would cause the maximum vibratory ground motion, based upon an evaluation of earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material.

f. The impoundment, where feasible, should be designed to incorporate features which will promote deposition. For example, design features which promote deposition of sediment suspended in any runoff which flows into the impoundment area might be utilized; the object of such a design feature would be to enhance the thickness of cover over time.

4. Final disposal of tailings should be such that ongoing active maintenance is not necessary to preserve isolation.

Direct and Airborne Radioactive Emissions--Tailings Disposal Covering

5. Sufficient earth cover, but not less than three meters, shall be placed over tailings or wastes at the end of milling operations to result in a calculated reduction in surface exhalation of radon emanating from the tailings or wastes to less than two picocuries per square meter per second. In computing required tailings cover thicknesses, moisture in soils in excess of amounts found normally in similar soils in similar circumstances, shall not be considered. Direct gamma exposure from the tailings or wastes should be reduced to background levels. The effects of any thin plastic or other synthetic caps shall not be taken into account in determining the calculated radon exhalation level. If non-soil materials are proposed to reduce tailings covers to less than three meters, it must be demonstrated that such materials will not crack or degrade by differential settlement, weathering, or other mechanism, over long-term time intervals. Near-surface cover materials (i.e., within about the top three meters) shall not include mine waste or rock that contain elevated levels of radium; soils used for cover must be essentially the same, as far as radioactivity is concerned, as that of surrounding surface soils. This is to ensure that surface radon exhalation is not significantly above background because of the cover material.

Seepage of Toxic Materials

6. Steps shall be taken to reduce seepage of toxic materials into groundwater to the maximum extent reasonably achievable. Any seepage which does occur shall not result in degradation of existing groundwater supplies from their current or potential uses. The following shall be considered in order to accomplish this objective:

o installation of impermeable bottom liners. (Where synthetic liners are used, a leakage detection system shall be installed immediately below the liner to ensure major failures are detected if they occur.) Where clay liners are proposed or relatively thin in situ clay soils are to be relied upon for seepage control, tests shall be conducted with representative tailings solutions and clay materials to confirm that no significant deterioration of permeability or stability properties will occur with continuous exposure of clay to tailings solutions. Tests shall be run for a sufficient period of time to reveal any effects if they are going to occur (in some cases, deterioration has been observed to occur rather rapidly after about nine months of exposure).

o mill process designs which provide the maximum practicable recycle of solutions to reduce the net input of liquid to the tailings impoundment.

o dewatering of tailings by process devices and/or in situ drainage systems. (At new sites, tailings shall be dewatered by a drainage system installed at the bottom of the impoundment to lower the phreatic surface and reduce the driving head for seepage, unless tests show tailings are not amenable to such a system. Where in situ dewatering is to be conducted, the impoundment bottom shall be graded to assure that the drains are at a low point. The drains shall be protected by suitable filter materials to assure that drains remain free running. The drainage system shall also be adequately sized to assure good drainage.)

o neutralization to promote immobilization of toxic substances.

Where groundwater impacts are occurring at an existing site due to seepage, action shall be taken to alleviate conditions that lead to seepage and restore groundwater quality to its potential use before milling operations began, to the maximum extent practicable.

The specific method, or combination of methods, to be used must be worked out on a site-specific basis. Technical specifications shall be prepared to control installation of seepage control systems. A quality assurance, testing, and inspection program, which includes supervision by a qualified engineer or scientist, shall be established to assure the specifications are met.

While the primary method of protecting groundwater shall be isolation of tailings and tailings solutions, disposal involving contact with groundwater will be considered provided supporting tests and analyses are presented demonstrating that the proposed disposal and treatment methods will not degrade groundwater from current or potential uses.

In support of a tailings disposal system proposal, the applicant/operator shall supply information concerning the following:

- o The chemical and radioactive characteristics of the solutions.

- o The characteristics of the underlying soil and geologic formations particularly as they will control transport of contaminants and solutions. This shall include detailed information concerning extent, thickness, uniformity, shape, and orientation of underlying strata. Hydraulic conductivity of the various formations shall be determined.

  This information shall be gathered by borings and field survey methods taken within the proposed impoundment area and in surrounding areas where contaminants might migrate to usable groundwater. The information gathered on boreholes shall include both geologic and geophysical logs in sufficient number and degree of sophistication to allow determining significant discontinuities, fractures, and channeled deposits of high hydraulic conductivity. If field survey methods are used, they should be in addition to and calibrated with borehole logging. Hydrologic parameters such as permeability shall not be determined on the basis of laboratory analysis of samples alone; a sufficient amount of field testing (e.g., pump tests) shall be conducted to assure actual field properties are adequately understood. Testing shall be conducted to allow estimating chemisorption attenuation properties of underlying soil and rock.

- o Location, extent, quality, capacity and current uses of any groundwater at and near the site.

Furthermore, steps shall be taken during stockpiling of ore to minimize penetration of radionuclides into underlying soils; suitable methods include lining and/or compaction of ore storage areas.

<u>Emission Control--During Operation</u>

7. Milling operations shall be conducted so that all airborne effluent releases are reduced to as low as is reasonably achievable. The primary means of accomplishing this shall be by means of emission controls. Institutional controls, such as extending the site boundary and exclusion area, may be employed to ensure that offsite exposure limits are met, but only after all practicable measures have been taken to control emissions at the source. Notwithstanding the existence of individual dose standards, strict control of emissions is necessary to assure that population exposures are reduced to the maximum extent reasonably achievable and to minimize site contamination. The greatest potential sources of offsite radiation exposure (aside from radon exposure) are dusting from dry surfaces of the tailings disposal area not saturated or covered by tailings solution and emissions from yellowcake drying and packaging operations.

   Checks shall be made and logged hourly of all parameters (e.g., differential pressures and scrubber water flow rates) which determine the efficiency of yellowcake stack emission control equipment operation. It shall be determined whether or not conditions are within a range prescribed to ensure that the equipment is operating consistently near peak efficiency; corrective action shall be taken when performance is outside of prescribed ranges. Effluent control devices shall be operative at all times during drying and packaging operations and whenever air is exhausting from the yellowcake stack. Drying and packaging operations shall terminate when controls are inoperative. When checks indicate the equipment is not operating within the range prescribed for peak efficiency, actions shall be taken to restore parameters to the prescribed range. When this cannot be done without shutdown and repairs, drying and packaging operations shall cease as soon as practicable.

To control dusting from tailings, that portion not covered by standing liquids shall be wetted or chemically stabilized to prevent or minimize blowing and dusting, to the maximum extent reasonably achievable. This requirement may be relaxed if tailings are effectively sheltered from wind, such as may be the case where they are disposed of below grade and the tailings surface is not exposed to wind. Consideration shall be given in planning tailings disposal programs to methods which would allow phased covering and reclamation of tailings impoundments, since this will help in controlling particulate and radon emissions during operation. To control dusting from diffuse sources, such as tailings and ore pads where automatic controls do not apply, operators shall develop written operating procedures specifying the methods of control which will be utilized.

Nonproliferation of Disposal Sites

8. To avoid proliferation of small waste disposal sites and thereby reduce perpetual surveillance obligations, byproduct material from in situ extraction operations, such as residues from solution evaporation or contaminated control processes, and wastes from small remote aboveground extraction operations shall be disposed of at existing large mill tailings disposal sites, unless, considering the nature of the wastes, such as their volume and specific activity, and the costs and environmental impacts of transporting the wastes to a large disposal site, such offsite disposal is demonstrated to be impracticable, or the advantages of onsite burial clearly outweigh the benefits of reducing the perpetual surveillance obligations.

Decommissioning of Mill Buildings and Site

9. The mill buildings and site must be decontaminated to levels allowing unrestricted use of the site upon decommissioning, excluding the tailings disposal area as discussed in 12.2.2.6 below. Mill operators should meet requirements issued in the form of regulatory guidance concerning cleanup of contaminated surfaces and land.

12.2.2 Supplementary Institutional and Procedural Requirements

Decommissioning Plan, Environmental Review, and Public Participation

1. A plan for decommissioning of the mill buildings and site, and for disposing of the tailings, in accordance with requirements delineated above, must be proposed by applicants, and approved by appropriate agencies, before issuance or renewal of licenses. At active mills, such plans must be submitted within about nine months. This plan must be submitted in conjunction with an environmental report, and must address the expected impacts of milling decommissioning and tailings disposal; alternatives for mitigating these impacts shall be evaluated. Aspects of the decommissioning plan relating to structures and site cleanup must provide sufficient detail to make reasonable cost estimates and to assure that mill design and operations are planned in a manner that facilitates decommissioning efforts.

2. Prior to the licensing of a milling operation, documented environmental analysis, independent of the applicant's, should be prepared by the NRC or the Agreement State, treating significant impacts and alternatives considered, and issued for review and comment by the public and interested agencies. No major construction activity should be allowed before public availability of the final document.

3. Opportunity for public hearings should be provided in any mill or mill tailings licensing case.

4. While the complete tailings disposal and mill decommissioning plan may take some time to arrive at in approved form at active mills, the process of establishing an approved, complete plan must provide for immediate development and implementation of an interim program dealing with operational problems such, as the blowing of tailings, spreading of seepage-caused contamination, and the like, where these are occurring.

Financial Surety

5. Financial surety arrangements must be established to ensure the availability of sufficient funds for disposal and reclamation of the mill tailings and decommissioning the site and buildings in accord with the approved plan discussed in Section 12.2.2, item 1.

Preoperational and Operational Monitoring

6. At least one full year prior to any major site construction, a preoperational monitoring program shall be conducted to provide complete baseline data on a milling site and its environs. Throughout the construction and operation phase of the mill, an operational monitoring program shall be conducted to measure or evaluate compliance with applicable

standards and regulations; to evaluate performance of control systems and procedures; to evaluate environmental impacts of operation; and to detect potential long-term effects.

Daily inspections of tailings or waste retention systems shall be conducted and documented. Such inspections shall be conducted to be aware of any unusual conditions which, if not corrected, could lead to failure of the system and result in a release of tailings.

Long-Term Control

7. As a prudent measure of protection, continued control of tailings disposal sites should be exercised, including control of land use and periodic inspection. Such control should be provided through ownership and custody of disposal sites by a Government agency, following a determination that a licensee has satisfied decommissioning requirements and subsequent license termination.

12.3 BENEFIT-COST ANALYSIS AND RATIONALE FOR REGULATORY REQUIREMENTS

12.3.1 General

Incorporation of these regulatory requirements into the mill licensing programs of the NRC and the Agreement States will result in long-term isolation of tailings and site decommissioning in such a way that conditions at disposal sites will be very similar to those in the surrounding environs, and in a manner which will not necessitate ongoing, active maintenance to preserve these conditions. Emissions during operation will be sufficiently low to ensure compliance with established exposure limits. Furthermore, costs for implementing these requirements will be a very small fraction of the price of the mill product (yellowcake) and of the costs of generating electricity.*

The following discussion constitutes a final benefit-cost evaluation of alternatives utilizing information and analyses developed primarily in preceding chapters on potential public health and safety and environmental impacts and costs. In Chapters 6 and 9, a series of very specific impacts were considered; that is, impacts on air quality, water quality, soils, biota, etc. It is difficult to summarize and quantify the severity of these impacts and, conversely, the degree to which they can be avoided by the alternative mitigative measures evaluated. However, the evaluation of these potential impacts indicates that the extent to which they occur relates primarily to the following:

- extent of airborne emissions (particulates and radon gas) from the mill and mill tailings pile,
- extent of seepage of tailings solutions,
- the long-term stability of mitigative measures employed to control these airborne emissions and seepage.

Therefore, to simplify benefit-cost analysis of the alternatives in support of establishing requirements for mill tailings management and disposal, the range of concern can be narrowed to these areas. The following benefit-cost discussion focuses on the objectives of reducing airborne emissions and seepage, and assuring long-term stability (as do the regulatory requirements summarized in Section 12.2).

For clarity, the rationale presented in Section 12.3 treats each of these major objectives separately and in turn. It must be stressed from the beginning, however, that there is a strong interrelationship among them. Tradeoffs and balancing of competing factors are necessary in selecting specific methods and design details, particularly with regard to tailings disposal. In some instances, steps taken to satisfy one objective aid achieving another. For example, addition of cover material not only would reduce radon emissions, but also would enhance long-term stability and isolation of the tailings from both natural forces and human activity. On the other hand, there may be some competition among objectives. For example, placement of tailings below grade locates them nearer aquifers; in some locations, a near-surface groundwater formation may make below-grade burial a less than optimum mode of tailings disposal.

Table 12.1 presents costs for the alternative mill tailings disposal programs considered. These costs are broken down according to the major operations of which they are comprised; these operations correspond roughly to the major objectives (reducing airborne emissions and seepage and assuring long-term stability of controls). In the benefit-cost discussion that

*In this evaluation, the price of yellowcake (U_3O_8) is assumed to be \$66/kg (\$30/lb) and the cost of generating electricity is assumed to be 25 mils per kWhr.

follows (Sections 12.3.2, 12.3.3 ,12.3.4 and 12.3.5), an attempt is made using information from Table 12.1 and other cost data developed in Chapter 11, to identify incremental costs incurred in taking steps to satisfy each of the major objectives in turn. At the same time, however, the complex interrelationship which exists between objectives, and the kind of tradeoffs which must occur in real situations are illustrated. These interrelationships make it impossible to take a completely isolated view of each. For example, placing tailings below grade to meet long-term objectives may result in the need for lining much larger areas and, hence, in higher costs to achieve groundwater protection objectives than would be required with an above grade disposal scheme.

Because the optimal balance point of tradeoffs can be attained only by development of a tailings disposal program for a specific site, the requirements proposed above are stated largely as performance objectives. The staff believes methods exist to meet these objectives at reasonable costs, as summarized below.

12.3.2 Siting Criteria and Objectives

As illustrated in previous chapters and discussed more completely in Section 12.3.3.2, siting is of overriding importance in developing a tailings disposal program. For this reason, the staff considered it necessary to stress its importance explicitly in regulations and require that primary emphasis should be given to long-term hazards over short-term considerations.

Furthermore, the staff considers regulations being established must state explicitly the major factors which must be considered in selecting new tailings disposal sites and in judging the adequacy of existing sites. Site selection and evaluation must be a process of optimization in terms of these factors. Including this in the regulations is necessary so they realistically account for the site-specific and multidimensional nature of the tailings disposal problem, as discussed in Section 12.3.1, which requires that tradeoffs be made in performing this optimization. It is not appropriate to optimize on one objective without consideration of the others.

12.3.3 Long-Term Stability of Tailings Isolation

Alternatives representing varying levels of tailings isolation were evaluated in Chapters 8, 9 and 11. They can be grouped roughly into three categories, according to the degree of ongoing care required (see Sec. 8.4 and 10.3). The categories are:

- Active care mode--Alternative 1
- Passive monitoring mode--Alternatives 2 through 6
- Potential reduced care mode--Alternatives 7 through 9.

12.3.3.1 Active Care Mode

The active care mode is one in which steps are taken to control potential airborne emissions and seepage to groundwater, but continuous active care of the tailings disposal area would be required over the long-term. A situation where ongoing care, such as maintenance of vegetative cover, would be required because steps were not taken to reduce exposure to wind and water erosion is represented by Alternative 1.

The staff concludes that although Alternative 1 incorporates features which are an improvement over past practice, the alternative is unacceptable. It commits future generations to a prolonged obligation to care for wastes generated to produce benefits which those generations will receive only indirectly, if at all.

12.3.3.2 Passive Monitoring Mode

In Alternatives 2 through 6, tailings would be disposed of below grade, or in locations where they would be sheltered from natural weathering and erosional forces. Steps again would be taken to control airborne emissions and minimize impact on groundwater, but this mode is characterized by features which would eliminate the need for ongoing, active care to maintain integrity of the pile.

Three situations are examined. The first, represented by Alternatives 2 and 3, is one in which an open pit mine would be available for disposal of the tailings. The second, represented by Alternatives 4 and 5, is one in which a special pit would be dug because an open pit mine is not available. A third situation, Alternative 6, is difficult to depict in a generic manner. It would involve the operators taking advantage of natural characteristics, augmented by design features, to provide protection from natural forces for an above grade program that is reasonably equivalent to the protection provided by the below-grade schemes.

Below-grade burial is identified as the prime disposal option since it would virtually eliminate exposure to surface weathering and erosion processes which could disrupt the tailings (see

TABLE 12.1 COST SUMMARY FOR TAILINGS DISPOSAL PROGRAM ALTERNATIVES[1,2] (DOLLARS – THOUSANDS)

		BASE CASE	ACTIVE CARE MODE	PASSIVE MONITORING MODE						POTENTIAL REDUCED CARE MODE		
				Alt. 2 - Below Grade Burial in Open Pit Mine; Tailings in Slurry Form with Bottom and Sides Lined						Alt. 7/Alt. 8 - Fixation in Cement or Asphalt; Burial in Open Pit or Deep Mine		
Line	Operation	No Mitigating Measures	Alt. 1 - Tailings Slurry to Above Grade Impoundment; Compaction of Bottom	Opt. 1 Liner Below Fill	Opt. 2 Liner Above Fill	Alt. 3 - Below Grade Burial in Open Pit Mine; Tailings Dewatered and Bottom Only Lined	Alt. 4 - Below Grade in Specially Excavated Pit; Impermeable Subsoil Assumed	Alt. 5 - Below Grade in Specially Excavated Pit; Lined Sides and Bottom	Alt. 6 - Above Grade Burial; Siting and Design Features Assure Long-Term Stability	Cement	Asphalt	Alt. 9 - Nitric Acid Leaching; More Complete Removal of Radioactivity
1.	Preparation of Impoundment – Dam Construction (dc); Preparation of Mine Bottom or Side Wall (mp); Excavation of Pit (exc).	900 (dc)	4,100 (dc)	1,480(mp)	3,730[3]	3,290	10,770 (exc)	10,800/10,030 (exc)	1,280 (dc)	–	–	1,580[8] (dc, exc)
2.	Seepage Control – Liners (l); Decantation (d), Evaporation (e), and Filtration (f) Systems	–	–	8,310/7,690 (l, d, e)	6,920/7,130 (l, d, e)	6,220/7,210 (l, e, f)	2,980 (e)	5,940/8,250 (l,e)	5,020/5,500 (l)	–	–	5,020
3.	Airborne Emissions[4,5] Control (esp. Radon) – Tailings Cover; 3.3 m Soil and Clay Cover	–	4,700	1,460	1,460	2,700	2,800	2,710/2,790	6,200[5]	–	–	2,890
4.	Advance Treatment – Capital Equipment	–	–	–	–	–	–	–	–	6,930/13,390	10,680/17,140	49,000[7]
	Operating Expenses, Fuel Consumption Materials, etc; Total Lifetime Cost	–	–	–	–	–	–	–	–	133,370/57,470	185,120/109,050	34,600[7]
5.	Total Costs (Percentage Price of U_3O_8)[6]	900 (0.17%)	8,800 (1.7%)	11,300/10,500 (2.2/2.0%)	12,100/12,200 (2.3/2.4%)	12,200/13,200 (2.4/2.6%)	16,600 (3.2%)	19,400/21,100 (3.8/4.1%)	12,500/13,000 (2.4/2.5%)	140,300/70,900 (27.1/13.7%)	195,800/126,200 (38/24.5%)	93,100 (18%)

[1]Costs in this table are derived under the assumptions identified in Appendix K and Chapter 11 for the model mill processing 1,800 MT per day of ore and operating for a 15-year period. More complete cost summaries are provided in Tables 11.12 and K.4.2. Detailed costs for individual alternatives are presented in Tables 11.3 through 11.11 and in additional tables of Appendix K. All figures in this table are total lifetime costs in discounted 1980 dollars. Mill operating cost are not included. Letters in parentheses behind cost figures are intended to describe the precise nature of the operations included in the cost estimate; the legend for these notations is given in left hand column describing operations in general.

[2]Except for Alternatives 7 and 8, where two cost entries are shown separated by a slash (e.g., Alternative 2 total cost: 11,300/10,500), upper figure is for clay liner and lower figure is for a synthethic liner. Double entries under Alternatives 7 and 8 relate to whether an evaporator or dewatering filter bed (upper and lower figures respectively) are employed to remove moisture in preparation for fixation.

[3]Mine preparation costs for Alternative 2, Option 2 are incurred to support liner installation. These costs, therefore, are perhaps more appropriately associated with the objective of controlling seepage than with carrying out belowgrade tailings burial for long-term stability and isolation objectives. Special pit excavation costs identified in line 1 for Alternatives 4 and 5, however, relate almost exclusively to the long-term isolation objective.

[4]Costs for airborne emission control are those of applying soil and overburden cover. Variation in cover costs reflects differences in the earthwork operations which are associated with the overall disposal program. Section 12.3.4.5 addresses the matter of tailings cover costs more specifically. Also, see Appendix K.4 for additional discussion of unit cost assumptions.

[5]Alternative 6 includes costs for providing very gradual embankment slopes and rock covering of such slopes under item 3, Airborne Emission Control. This amounts to about \$1.2 million above top cover soil and revegitation costs. This cost is most appropriately related to the long-term isolation objective as it involves steps required in regulation (discussed in Section 12.2) concerning this objective.

[6]A price of yellowcake (U_3O_8) of \$30/lb is assumed.

[7]Capital and operating costs shown here are incremental costs for utilizing nitric acid leaching instead of conventional sulfuric acid leaching of ore (see Table K-2.1). Also, included are costs of fixing dried nitrate acid leachate containing the increased amounts of radium and thorium removed from the ore.

[8]Costs cover construction of dam for tailings and excavation of special pit for deep burial of dried nitrate acid leachate containing radium and thorium which has been removed from the ore.

Sec. 9.4.1). Costs associated with below-grade burial will vary with the availability of a suitable open mine pit. In any case, the staff considers these costs to be reasonable in view of the benefits provided by this mode of disposal.

In some cases, below-grade burial may not be feasible because of potential groundwater problems. The concept of below grade burial may also be difficult to apply in areas of irregular terrain where the depth of soil overlying bedrock is not sufficient to permit excavating a pit without blasting large amounts of rock. Some excavation may be possible in such a case to reduce the size of embankments required, but disposal of the entire tailings volume below the surface of all points in the surrounding terrain may be impracticable. Alternative 6 represents a scheme which, with the incorporation of the design and siting features delineated in Section 12.2.1.3, would provide protection virtually equivalent to below grade disposal.

Assuring long-term stability is a highly site-specific problem. For this reason, the staff has termed below-grade burial a "prime" option, as opposed to a generally applicable requirement. In developing tailings disposal programs, applicants must evaluate a range of siting and design alternatives and give first consideration to alternatives that involve below-grade disposal and to sites having a low potential for disruption. The most important factor in this connection is siting. Consistent with the first point under Section 12.2.1, primary emphasis must be given to long-term impacts of mill tailings, as opposed to consideration of short-term conveniences or benefits, such as minimization of transportation or land acquisition costs. Before it would be reasonable to accept above grade tailings disposal programs, a showing that serious attempts had been made to locate alternate sites, which do not suffer from the kind of limitations described above that prevent below-grade burial, would have to be made. In any event, if an above-grade scheme is proposed, then the applicant must justify the proposal by demonstrating that it will provide reasonably equivalent protection from natural weathering and erosional forces.

Section 9.4.1 describes the basis for the specific siting and design features which must be considered in developing tailings disposal programs, whether above or below grade, to assure meeting the requirement that no ongoing active maintenance is needed at disposal sites. In general, these steps are aimed at minimizing the potential for disruption by natural processes such as wind and water erosion, earthquake, and flooding. The requirements in this area have been developed to provide needed flexibility to deal with the matter on a site-specific basis. At the same time, however, the regulations are specific on matters of special concern, such as the need to provide rock cover in areas where climatic or other conditions make it unlikely that a self-sustaining and full vegetative cover can be established. Also, guidelines on steepness of final slopes are presented.

With regard to criteria on slopes, the staff considered not identifying a specific limit on final embankment slope. The problems with identifying a 5 horizontal to 1 vertical (5h:1v) grade as a minimum desirable slope are: on one hand, it may tend to discourage providing flatter slopes such as 10h:1v (or eliminating them altogether through below grade burial) which provide the strong measures of conservatism called for in this area of considerable uncertainty; on the other hand, slopes steeper than 5h:1v might be acceptable under certain conditions. With regard to the latter point, it should be noted that the erosion potential of a tailings disposal area is a complex function of a number of site-specific factors, including size of upstream drainage areas, length of slope, type of embankment cover, and steepness (as discussed in Section 9.4.1). The quality of embankment cover, in fact, can be more significant than slope angle. Just what would constitute an acceptable program can only be determined on a site-specific basis, with appropriate consideration being given to all of the factors which influence erosion. Furthermore, it might be impracticable to provide the specified sloping due to local topography, which may be steep enough (for example, 8h:1v) that excessive quantities of fill material would be required.

As discussed in Section 9.4.1, the long-term effects of wind and water erosion are uncertain. Notwithstanding the drawbacks of being specific about slope steepness, the staff considers identifying 5h:1v as a minimum desirable slope steepness to be prudent in view of these uncertainties. Being specific on maximum slope steepness provides assurance that a conservative approach will be taken on a very important factor influencing the erosion potential of the tailings isolation. Flexibility is provided in allowing for steeper slopes, where 5h:1v or less steep is not practicable, and where compensating siting and design features provide a conservative degree of erosion protection.

As previously stated, given the site-specific nature of the siting and design process and the significant of decisions which must be made on a case-by-case basis, it is essential that tailing disposal programs be developed and evaluated through the public process described in Section 12.2.2.

Total costs of Alternatives 2 and 3 involving disposal in existing open pits depend upon the specific method of mine sidewall preparation and bottom liner installation employed. As shown in Table 12.1, total costs range from about $10 to 12 million in Alternative 2, involving tailings disposal in slurry form, and from about $12 to 13 million in Alternative 3, where tailings are dewatered. These compare with total costs of about $9 million for the Active Care Mode of disposal represented by Alternative 1. It is difficult to establish an incremental cost which can be associated exclusively with the long-term stability objective. Disposal in an available open pit, undertaken primarily to meet long-term objectives, permits taking advantage of the earthwork already performed in the mining operations to provide tailings isolation. In cases where existing mine pits can be used, costs for impoundment construction and final covering can be less than those of an above grade program. (This can be seen by comparing Table 12.1 lines 1 and 3 costs for open pit disposal Alternatives 2 and 3, with similar costs for an above grade scheme, Alternative 1.) Costs savings in covering tailings in open pits are assumed here because mining laws in some states require that mine sites be returned to their previous or higher use. This requirement involves returning overburden stripped during mining operations to the open pits and a portion of the cover costs are, therefore, attributed to mining backfill requirements. On the other hand, opting for the below grade scheme may result in higher costs to meet the groundwater protection objectives than would be required in an above grade disposal program. Special mine bottom and sidewall preparation is likely required and areas requiring liners are increased. (This can be seen by comparing Table 12.1, lines 1 and 2 costs for Alternatives 2 and 3, with line 2 costs of Alternative 6.)

In the case where a special pit must be excavated to place tailings below grade (Alternatives 4 and 5), excavation costs can be tied almost exclusively with the long-term stability objective. These excavation costs would range from about $10 to 11 million, resulting in total costs which are approximately double those of Alternative 1. However, the incremental costs of digging the pits should not exceed about 2% of product price, nor result in an increase of more than about 0.1% in electricity costs.

The costs of the design measures being specified in the regulations (Section 12.2) which are intended to assure impoundment long-term stability will vary substantially from site to site. Also, there is no way to separately describe the benefits of each specific design measure to make a reasonable cost-effectiveness judgment about each. They are too interrelated to reasonably attempt discussion of their effects separately. Some sense of the cost of such measures can be gotten from the costs estimated for providing gradual slopes and rock cover protection of slopes in Alternative 6. The incremental costs of providing slopes which are 10h:1v, as opposed to 2.5h:1v as is assumed in the Active Care Mode (Alternative 1), and applying a hardened cover over the face of the 1000-m exposed embankment is about $1.2 million, or about 0.23 percent of the price of mill product.

It is not possible to generically discuss costs associated with the siting features delineated in Section 12.2 which are intended to assure long-term stability. These costs will be a complex function of transportation distances, topographic, hydrogeologic, and climatic factors and so on. It is not expected, however, that if consideration is given to the siting objectives and criteria from the inception of project planning, this will result in any significant incremental economic impact.

In summary, the incremental costs associated with long-term stability are considered to be reasonable, given the significant benefits associated with them (e.g., elimination of the need for continued active maintenance), and because they represent a very small fraction of the price of product or the cost of producing electricity.

12.3.3.3 Potential Reduced Care Mode

This mode is represented by a loose collection of alternatives (7, 8, and 9) that represent marked departures from current technology; in varying degree, they provide an added measure of isolation and protection above that provided by the previous modes. The staff concludes, however, that because of uncertainty about the incremental benefits provided by these alternatives, coupled with high costs and uncertainty about technological feasibility, the industry cannot reasonably be required to adopt alternatives under this mode.

The programs of Alternatives 7 and 8 involving fixation of the slimes portion of tailings in either cement or asphalt suffer from several drawbacks. First, fixation of tailings by cement or asphalt is not a commercially developed technology. There is also uncertainty as to the long-term stability of bonding between the tailings and the cement or asphalt. Furthermore, minimum costs for fixing the tailings would be about $70 million in the case of cement fixation, and over $125 million in the case of asphalt fixation (see Table 12.1). These costs exceed the upper range of costs for below-grade disposal alternatives featuring liners and covers by about $50 million to $100 million. These alternatives do provide an added measure of isolation for the tailings and contribute to more than just the long-term objective. But the costs for the incremental benefit do not appear to be warranted, especially in light of the technological uncertainties involved. It may be possible in some cases to economically dispose of certain fractions of tailings in a solid matrix form, where this would serve to meet other economic requirements of uranium mining and milling. For example, cemented, washed sands fractions might be used for roof support in underground mine stopes. Obviously, to the extent this can be done in a manner which preserves existing water quality, it effectively deals with long-term stability concerns.

Nitric acid leaching (Alt. 9) offers some potential for reduction of the radiological hazard of the tailings. Radium and thorium are removed from the ore during the same leaching process that removes the uranium. However, several problems remain. Laboratory studies to date indicate that residual radium and thorium concentrations in the tailings of a nitric acid leach process are still significantly above background concentrations. Therefore, isolation of the tailings in a manner similar to that provided for conventional tailings would still be required. Nitrates formed from the nitric acid leach process also pose a more severe environmental problem than anion species formed from conventional sulfuric or alkaline leach processes. Costs are high. The incremental lifetime costs of the nitric acid leach process (compared with conventional mill operation and tailings disposal costs of the most expensive passive monitoring mode alternative such as Alternative 5, see Table 12.1) would be nearly $70 million. Finally, there is still a problem of disposing of the radium and thorium concentrates (about 25 nCi/g each of Ra-226 and Th-230) from this process. In this study, these wastes are assumed to be solidified in a cement or asphalt matrix and buried 10 m (30 ft) below grade. They are, however, not unlike other alpha-emitting wastes from the fuel cycle, for which a final disposal mode is yet to be established.

12.3.3.4 Comparison with Disposal of Other Alpha-Emitting Wastes

On the basis that mill tailings contain alpha-emitting elements similar to those present in spent fuel and transuranic (TRU) wastes, some have raised the question of whether or not mill tailings should be disposed of with the same care as these other wastes. Actinides in spent fuel will accompany the high-level wastes being disposed of in the deep repository. Portions of TRU wastes may also be disposed of there.

Although the radioactivity in mill tailings is similar to the actinides present in spent fuel (i.e., long lived, alpha emitters), mill tailings are a completely different kind of waste than spent fuel. Actinides in the fuel are 20 million times more concentrated than are the alpha emitters in mill tailings. The radioactivity in mill tailings is dispersed in a sand matrix which makes them much more like the earth's crust, phosphate mine tailings, fertilizer and coal ash than spent fuel carrying actinides. Radium concentrations in uranium mill tailings are on the average only about 300 times those in common soil, and as little as 10 times those of some of the other materials mentioned. Exposure to the actinides in spent fuel, and the fission products which are bound up with them, would result in immediate and acute health effects; long and sustained exposure to mill tailings would be required before any perceivable health effects would occur. Mill tailings have many times the volume of spent fuel (they would be 10,000 times more voluminous). Therefore, not only would it be unnecessary, but it would also be impracticable to dispose of tailings in deep locations similar to spent fuel disposal.

It is difficult to compare disposal of mill tailings with TRU wastes. There is considerable uncertainty about the exact total volume and concentrations of TRU wastes. There is also variability in their form, as well as uncertainty about the method that will be used to dispose of them. Some of this waste may go to a deep repository. However, the concentrations involved would certainly be greater, and volumes less, than those of mill tailings for this to be necessary or practical.

Different methods of disposing of the actinides in spent fuel and those in TRU, and mill tailings are called for. This is not to say that great care should not be taken in tailings disposal. Disposal methods must reflect the long-lived nature of the hazards present. The staff considers that the alternatives falling under the Passive Monitoring Mode of disposal will provide the long-term isolation of tailings wastes that is needed.

12.3.4 Direct and Airborne Emissions--Tailings Disposal Covering

12.3.4.1 Overview

The regulations require that sufficient cover be placed over the tailings to reduce radon emissions to less than 2 pCi/m^2/sec above background rates, that direct gamma exposure be reduced to background levels, and that, as a minimum, the cover be no less than 3 meters. In developing these requirements, the staff examined several alternative levels of isolation. A wide range of tailings cover thicknesses was considered not only from the point of view of radon attenuation achieved, but also in terms of physical protection and isolation that will be provided over the long-term following final site decommissioning. The range includes requiring no radon reduction, to requiring virtual elimination of radon releases.

In addition to the proposed action, alternatives were considered for controlling radon as follows:

1. at much higher levels: for example, 10 to 100 pCi/m^2-sec, or no control at all,

2. at levels near but different from the proposed level: for example, 3 to 5 or 1 pCi/m^2-sec,

3. virtual elimination of the radon source.

Also considered was the alternative of requiring no minimum thickness of tailings cover.

The guiding principle used in selecting the required level of tailings isolation among the alternatives considered was that tailings disposal sites should be returned to conditions which are reasonably near those of surrounding environs upon completion of milling operations, and which will not require ongoing active maintenance to preserve these conditions. The proposed limit on radon flux of 2 pCi/m^2-sec assures that radon exhalation at these sites will be within the range of variability of natural flux rates. Beyond this, the proposed limit was selected in consideration of several additional perspectives, no one of which by itself leads conclusively to the proposed level of tailings cover control but which, taken together, support the proposed requirements as being reasonable and appropriate. This broad evaluation of the radon control issue (as well as the staff's evaluation of long-term tailings disposal in general) effectively addresses the major principles of the International Commission on Radiation Protection (ICRP) concerning the need to keep individual exposures within appropriate limits and to keep exposures as low as reasonably achievable, economic and social factors taken into account. The staff's conclusion is that requirements being established in the form of regulations are in conformance with these principles.

A brief overview of the perspectives evaluated is provided first, followed by more complete discussion of each (Sections 12.3.4.2 through 12.3.4.8). Also, the nature and extent of the uncertainties involved in underlying technical bases are discussed. Finally, the approach taken by the staff in weighing costs and benefits of alternative levels of isolating cover, in view of these and other uncertainties, such as those which exist in computational models, and with regard to potential effects far into the future, is discussed (Section 12.3.3.6).

1. Risk to Individuals - The specified radon attenuation level is one which would, in a worst case land use scenario of individuals occupying a structure on the tailings disposal area, result in exposures which are comparable to, but less than, limits specified by the U.S. Surgeon General for remedial actions at sites where uranium mill tailings were used for construction of homes and other inhabited structures.

2. Population Exposures - Population doses and health effects calculated for the United States, and parts of Canada and Mexico resulting from radon releases (under the proposed limit) from the total accumulation of tailings in year 2000 would be an indistinguishable fraction of effects resulting from releases from natural soils (about 0.002%) and several other technologically enhanced sources. Emphasis on this perspective might lead to a conclusion that much higher residual flux levels (for example, 10 pCi/m^2-sec) might be acceptable; it does not, however, point to any specific radon control level as being uniquely appropriate.

3. Total Costs - Costs to attain the required level of control would be reasonable. For cover with a common soil, resulting costs would be about 1% of the price of yellowcake (about $6 million at the model mill). Costs would vary depending upon many factors, such as type of soils, surface areas of tailings impoundment, etc., but in the worst case, cover costs should still be no more than about 1.5% of the price of yellowcake. Evaluation of factors which will vary from site to site indicates no undue economic burden will be suffered at any particular site.

4. Long Term Physical Isolation and Stability - In general, providing cover over the tailings provides physical isolation and protection of the tailings pile to assure stability over the long-term. In addition to reducing radon, the tailings cover provides a measure of protection against disruption of tailings by such things as erosion, root penetration, burrowing animals and human intrusion. Specifying a minimum thickness of cover assures that undue reliance is not placed on thin coverings, which, at least for a short time, may reduce radon flux to within the level specified.

12.3.4.2 Control of Radon to Background Levels

The required limit on radon flux was selected on the basis that it will assure exhalation rates directly over mill tailings disposal areas will be within the range of those occurring naturally from most soils.

The objective is that mill tailings sites be returned to a condition which would permit reasonable surface land uses, avoid the need for active maintenance, and minimize the degree of monitoring that is required at tailings disposal sites. This conservative approach is consistent with objectives proposed by the U.S. EPA in its proposed "Criteria for Radioactive Wastes" (43 FR 53262), November 15, 1978, and with the "Uranium Mill Tailings Radiation Control Act of 1978" (Section 161X; see Appendix Q). While the mill tailings legislation provides for government control through land ownership of final mill tailings disposal sites, the objective of isolating mill tailings in such a way as not to rely upon institutional controls requires that radon be controlled at the very low level required.

The rate at which radon is exhaled naturally from soils is variable. It will depend upon radium concentrations in, and radon attenuating properties of, a particular soil. On the basis of radon flux measurements made at several specific locations in western milling regions and summarized in Appendix O, the average exhalation rate appears to be about 0.65 pCi/m^2-sec. The range of variability can be determined from numerous measurements made of radium soil concentrations in western milling regions. While in limited, isolated areas, natural radon flux can be quite high (for example, it can be an order of magnitude or more greater than the average), analysis by the staff of available data indicates that radon flux varies according to a log-normal distribution, and that 99% of the time radon flux will not exceed 2.3 pCi/m^2-sec.

The level of 2 pCi/m^2-sec was selected over other comparable control levels (such as 1 or 3-5 pCi/m^2-sec) because this level appears best to meet the objective of reducing fluxes to levels which are within the range occurring naturally from almost all soils.

12.3.4.3 Risks to Individuals

Exposure to individuals living near a tailings pile resulting from the limit of 2 pCi/m^2-s, and alternative control levels, was computed in Section 9.3.8; results are presented in Table 12.2, Part I. In a worst case land use scenario, incremental radon exposure to an individual living on a tailings disposal area would be at about 0.004 working levels above background if radon is controlled at the proposed level. [A working level (WL) is a unit of aggregate air concentration of the short-lived daughters of radon. The technical definition of a unit WL concentration is presented in Appendix C, but using reasonable assumptions of dosimetry, continuous exposure to 0.01 WL for one year would result in about a 1200 mrem dose to the bronchial epithelium.] The 0.004 WL exposure is less than that specified by the Surgeon General for dwellings constructed on or with uranium mill tailings. The Surgeon General's guidelines specified that no remedial action was needed for homes with an inside exposure level of less than 0.01 WL above background. It should also be noted that the U.S. EPA has issued interim standards under the UMTRCA, for uranium mill tailings contamination cases, which limit exposures to 0.015 WL inclusive of background; background can be as high as 0.007 WL inside structures in western milling regions.

Slightly higher radon flux limits, such as 3-5 pCi/m^2-sec, would also result in exposures less than the Surgeon General limits. However, these levels would be above the upper range of average natural background flux rates. Furthermore, Surgeon General limits were developed for a remedial action situation where options were limited, as distinguished from the situation examined here where the same constraints do not present themselves. Part I of Table 12.2 presents exposures in terms of working level (WL) units, in order to compare them with Surgeon General limits. To assist in understanding the significance of these exposures, Part II of Table 12.2 presents risks to individuals from selected radon control levels in the more commonly used terms of mrem/yr and fraction of background risk.

The land use scenario evaluated here is a conservative one; it involves occupancy of a structure directly over the tailings. More conservative land use scenarios can be postulated, as described in Section 9.4. These might involve digging into the tailings, as could be postulated to occur if the basement of a house were constructed at some future time when "institutional controls" initially exercised at the site were no longer in existence. To provide protection in such a case, thicker covers than those needed to meet the selected flux limit would be required.

However, the staff considers that it is unreasonable to establish the limit based upon such scenarios, for several reasons. Such events are unlikely, or at least extremely uncertain. The staff does not consider it reasonable to set a universal limit based upon such an uncertain worst case "intrusion" scenario. The UMTRCA establishes an arrangement where sites are to be owned and controlled by government agencies. While recognizing that institutional controls could break down sometime during the period over which the tailings will remain hazardous, the staff does not consider that deciding the amount of tailings isolation which should be provided should be driven by such an indefinite scenario, particularly in light of the arrangements for long-term control and surveillance that have been established. It is also important to restate in this connection that no immediate and acute health effects will occur if there is intrusion. Furthermore, because of the speculative nature of this problem, it would be impossible to obtain agreement upon how far down a person would dig under such a scenario, and, therefore, how much additional conservatism should be factored into the proposed radon limit.

Less conservative scenarios can also be postulated, particularly in light of the long-term control arrangements which have been established. Exposures as close in as a fence post near the

Table 12.2

Exposures and Risks to Individuals on and Near Uranium Tailings from the Model Mill--Alternative Radon Control Levels[a]

I. Radon Daughter Concentration--Working Level above Background[b,c]

Radon Flux (pCi/m^2-sec)	Above Tailings[d]	Fence Post Near Edge of Disposal Area[e]	Ranch at 2.0 km
280	0.50	1.6×10^{-2}	2.3×10^{-3}
100	0.18	5.7×10^{-3}	8.2×10^{-4}
10	0.018	5.7×10^{-4}	8.2×10^{-5}
5	0.009	2.8×10^{-4}	4.1×10^{-5}
3	0.0054	1.7×10^{-4}	2.5×10^{-5}
2	0.0036	1.1×10^{-4}	1.6×10^{-5}
1	0.0018	5.7×10^{-5}	8.2×10^{-6}
0.1	0.00018	5.7×10^{-6}	8.2×10^{-7}

II. Estimated Doses and Risks in Comparison with Background Risks--Selected Radon Control Levels

	Above Tailings[d]		Fence Post Near Edge of Disposal Area[e]		Ranch at 2.0 km	
Radon Flux (pCi/m^2-sec)	Dose[f] (mrem/yr)	Risk[g] (% background)	Dose[f] (mrem/yr)	Risk[g] (% background)	Dose[f] (mrem/yr)	Risk[g] (% background)
280	62,000	9,000	1,990	280	280	39
100	22,000	3,200	710	100	100	14
10	2,200	320	71	10	10	1.4
2	450	64	14	2	2	0.3
0.1	22	3	0.7	0.1	0.1	0.01

[a]Cost for attaining various levels of control are given in Section 12.3.3.5, Table 12.4 and Figure 12.1.

[b]Tailings are assumed to be 80 ha in area. Working level values are derived from estimated outdoor radon concentrations, assuming that 1 pCi/l of radon is equivalent to 0.005 WL.

[c]These exposures compare with the following limits established by the Surgeon General in 1970 for remedial action cases involving use of tailings in construction of homes: 0.01 to 0.05 working levels. Below 0.01 WL, no remedial action was needed. Between 0.01 and 0.05 WL, judgment about needed remedial action was allowed, based upon cost and other factors. No exposures above 0.05 WL were allowed.

[d]Inside a structure (see Sec. 9.3.8.2 for assumptions).

[e]At fence post, about 100m downwind (ENE) from the edge of the tailings pile.

[f]Doses are to bronchial epithelium and are estimated by multiplying WL exposure levels by the following: 25 CWLM/yr/WL x 5 rem/CWLM. (CWLM denotes "cumulative working level months.")

[g]Risk is expressed as a percentage of background radon exposure risks. Background radon exposure results in a risk of about 50 chances in one million of dying prematurely from cancer from one year's exposure. As described in Section 4.12, background exposure to the lung is assumed to be about 700 mrem/yr in western milling regions.

edge of the pile would be about 1.1 x 10^{-4} WL above background levels (as illustrated in Table 12.2), which is a small fraction of any reasonable individual health protecton limit (1% of the Surgeon General's guidelines). However, the staff considers that with the uncertainties involved with regard to the models used to estimate exposures, the long-term performance of the tailings isolation, permanence of institutional controls, and given the broad goal of minimizing releases and population exposures to very low levels, some conservatism is appropriate.

12.3.4.4 Risks to Populations

Postoperational population doses and health effects from radon released from mills were also estimated in Section 9.3.8 (see Tables 9.12 and 9.13). These estimates indicated that there might be 6000 premature cancer deaths in the Continental North America over the next 1000 years because of radon released from all of the tailings generated in the United States through the year 2000 if the tailings piles were left uncovered. If the tailings piles were covered sufficiently to reduce the radon resulting from tailings to 2 pCi/m^2-s, then the estimated number of health effects would be reduced to about 40 cancer deaths over the time period 2000 to 3000. Since there is great uncertainty in calculating health effects for a period of a thousand years and even more uncertainty in going beyond a thousand years, estimates of cumulative impacts were truncated at 1000 years. For periods beyond 1000 years, risks have been expressed in terms of an annual number of health effects. The annual number of premature cancer deaths associated with radon releases from all tailings generated in North America until the year 2000, if the tailings are covered to the required flux limit, is about 0.04 premature deaths per year.

The required radon flux criterion will result in continued annual radon releases that are small in comparison to other sources of continuous releases of radon. In Table 12.3, the annual radon releases from all of the tailings generated in the United States due to complete operation of mills existing in 2000 are compared with natural and technologically enhanced sources of radon. This table is taken from a special investigation of natural and technologically enhanced radon sources conducted by Oak Ridge National Laboratory in support of this generic statement.[1]

The annual dose from radon releases from tailings accumulated to the year 2000, with sufficient soil covering to meet the required limit, will be about 0.002% of that due to background radon from soils, and about 0.02% of that due to background radon from evapotranspiration. The annual U.S. population dose to the bronchial epithelium from mill tailings (370 organ-rem, based on the U.S. 1978 population for comparison) will be only a small fraction of that from several other technologically enhanced sources. Higher population exposures will result from soil tillage (4.2 x 10^5 organ-rem), building interiors (2.2 x 10^7 organ-rem), and reclaimed land from phosphate mining (4.9 x 10^3 organ-rem).

This perspective by itself does not lead conclusively to a given level of radon control, since cumulative releases resulting from much higher levels, such as 10 or 100 pCi/m^2/sec, could be argued as being small fractions of natural releases. This perspective, however, does support the required radon control level as being reasonable from the point of view of cumulative exposure; it will result in minute (if not insignificant) increased levels of risk beyond those occurring from natural radon releases.

12.3.4.5 Variability in Costs of Radon Control

Costs for covering tailings disposal areas are dependent on a number of site-specific factors, the primary ones being attenuating properties of the cover material and hence, the amount of cover material needed; availability of cover materials; the nature of earthwork procedures involved in adding cover; area of the tailings pile; and ore quality. The effect of varying these factors on cost are examined in Chapter 11 and summarized here. The range of potential costs at a given site was examined to assure that no undue economic burdens would result at particular sites in implementing the proposed generally applicable limits. Based on this evaluation, the staff concludes that, while variability in costs may exist, no undue economic hardships will occur, as costs will represent a small fraction of product price (less than about 1.5% even in an unlikely worst case).

12.3.4.5.1 Radon Attenuation Properties

In this discussion, primary emphasis is given to the matter of radon attenuation and the required limit on radon flux of 2 pCi/m^2-s. Soil cover thicknesses needed to meet the limit are discussed without consideration of the minimum thickness requirement discussed more fully in Sec. 12.3.3.7, below.

Soil properties affecting radon attenuation are variable; transport of radon through soil will depend primarily upon residual moisture content. Therefore, cover thicknesses (and associated costs) needed to meet the required limit vary depending on soil type, as discussed in Sections 9.3.8 and 11.3. The required cover thicknesses and associated costs of a range of residual soil moisture contents have been evaluated for illustrative purposes. The attenuation

Table 12.3 Comparison of Continuous Releases of Radon from Uranium Mill Tailings with Other Continuous Radon Releases[a,b]

Source	Estimated Annual Release (Ci/yr)	Estimated Annual Population Dose (organ-rem to the bronchial epithelium)
Natural soils	1.2×10^8	1.6×10^7
Building interiors	2.8×10^4	2.2×10^7
Evapotranspiration[c]	8.8×10^6	1.2×10^6
Soil tillage	3.1×10^6	4.2×10^5
Fertilizer used (1900-1977)	4.8×10^4	6.9×10^3
Reclaimed land from phosphate mining	3.6×10^4	4.9×10^3
Postoperational releases[d] from tailings generated to year 2000	3.9×10^3	2.8×10^2

[a]Estimates of all radon releases except those from mill tailings are taken from an investigation of natural and technologically enhanced radon sources performed in support of this generic statement by Oak Ridge National Laboratory (See reference 1, NUREG/CR-0573). Population doses were derived from reference 1 using a dose conversion factor of 0.625 mrem/yr/pCi/m^3 (see Appendix G). Exposures to mill tailings in regions around mills is included; see Section 6.4.

[b]Population at risk is taken to be the United States 1978 population, for purposes of comparison. Predicted exposure and health effects for U.S. would be roughly 88% of the total for North America and 70% of the global total.

[c]Evapotranspiration is the collective release of water vapor from soil surfaces and vegetation.

[d]For purposes of comparison, this table presents exposures to bronchial epithelium from inhalation only, as opposed to total exposures from ingestion and inhalation as presented in Tables of Sections 6.4 and 9.3.8.

properties (a measure of which is a soil's "diffusion coefficient," a parameter used in equations for predicting radon attenuation) of the typical soils illustrate the range of attenuating properties expected of real soils. Figure 12.1 shows cover thicknesses and costs required to achieve various radon control levels. Costs for meeting the proposed level of radon flux for each of the soils combinations evaluated are presented in Table 12.4.

Specifically, Figure 12.1 shows the cost for covering the tailings with soils which would exhibit long-term moistures in the range of from about 6% to 10% by weight; soils 1, 2, and 3 fall in this range. As discussed in Section 9.4.1, this is a range within which most near-surface soils in milling regions can be relied upon to remain over very long periods of time and under varying climatic conditions. Soil 4 represents what might exist with soils such as clays, which will tend, primarily because of smaller particle size, to retain higher levels of moisture; the assumed moisture level is 12% by weight. Soils 1, 2, and 3 cover costs would range from about \$57,000 to 88,000 per hectare, or from \$4.6 to 7 million total at the model mill. These costs are about 0.9 to 1.4% of product price. Soil 4 illustrates the effectiveness of some soils, such as clays, in attenuating radon. Soil 4 (not considering factors which lead to the conclusion that there should be a minimum cover requirement, as discussed in Section 12.3.4.7) would alone reduce radon flux to prescribed levels with 2.2 m, if it were to maintain its properties undiminished over time. It might be possible to reduce total cover thickness in cases where the majority of available cover materials are like soil 1, but limited amounts of soil similar to soil 4 are also available. Soil 5 in Figure 12.1 illustrates this. It is a combination of 1 meter of soil 4, and soil 1 in varying thicknesses. The total thickness needed to meet 2 pCi/m^2-sec would be 3.3 meters for this combination, as compared to a thickness of 5.0 meters if soil 1 alone were used. Hence, appreciable cost savings could be realized by employing this combination.

12.3.4.5.2 Variability of Other Factors

The costs presented in Table 12.4 assume a unit cost of $1.75/m^3 to place cover material; this includes excavation, hauling and compacting the material. It also includes the costs of reclamation of the borrow pit. If cover can be applied in a simpler manner, such as by "pushing" dirt over tailings disposed of below grade from an adjacent stockpile, such as would be produced by pit excavation to begin with, costs could be reduced significantly. Also, planning covering operations in conjuction with other project earthmoving operations can appreciably reduce costs; using material from excavations as it is dug up, such as would occur in Alternatives 2, 3, 4, and 5, is an example. Costs could be higher in a case where hauling would have to be done on very steep grades, or other site-specific factors make the covering operation more difficult. The range of costs for covering tailings impoundments shown in Table 12.1 (line 3) illustrates how such unit cost variation will affect total cover cost. In any case, it is not expected that unit costs would cause total costs to be significantly greater than upper bound estimates described in 12.3.4.5.1 above.

For a given soil cover type and thickness, costs for tailings coverings will also vary with the area of the tailings pile and the ore grade. For a given volume of tailings, the surface area to be covered will depend on depth of the tailings pile. For example, the cost for tailings covering with soil 2 for the model mill is estimated to be $6,000,000, on the assumption that the tailings will have a specific activity of 280 pCi/g and an exposed area of 80 ha (200 acres). Increasing thickness of the tailings pile would reduce disposal area and decrease total cover costs. For example, if a pile thickness of 16 m (52 ft) instead of 8 m (26 ft) were assumed and soil 2 were used, costs would reduce from about $6,000,000 to $2,500,000. The 8-m pile thickness assumed is conservatively low, hence, costs presented in Section 12.3.4.5.1 are upper bound estimates in terms of the tailings area variable.

Varying ore grade from that assumed for the model mill is not expected to significantly change the total costs of tailings cover if the amount of product (U_3O_8) does not change. For example, decreasing ore grade would reduce exhalation of radon from the tailings, because radium concentrations in the tailings would be less. Countering this effect somewhat, however, would be the proportionate increase in volume and surface areas of tailings that would occur in generating the same amount of product.

In summary, reviewing the factors which will affect covering costs at a particular site, the staff concludes no unusual or excessive costs will be encountered owing to site-specific conditions. It is not likely that all of the factors discussed above will simultaneously combine in the adverse direction; the 1.5% fraction of product price is expected to be a reasonable upper bound of covering costs.

Table 12.4 Costs to Meet Proposed Radon Limit Using Various Soils[a]

Soil Type	Soil Thickness, meters	Cost,[b] $1000/ha	Cost at Model Mill,[c] $$10^6$	% Price[d] of U_3O_8
1	5.0	87.5	7.0	1.4
2	4.3	75.3	6.0	1.2
3	3.3	57.8	4.6	0.89
4	2.2	38.5	3.1	0.60
5[e]	3.4	59.5	4.8	0.92

[a]Values are presented to illustrate what is required to meet the radon control limit; when the requirement to provide a total cover thickness of 3 m is considered, the cost for Soil Type 4 is increased to $4.2 million.

[b]Cost of cover material is assumed to be $1.75 per m^3.

[c]Model mill tailings disposal area occupies 80 ha.

[d]The model mill produces 7,800 MT of U^3O^8 over a period of 15 years. If a price of $30/lb of U_3O_8 is assumed, then the model mill produces $5.2 x 10^8 of U_3O_8.

[e]Soil Type 5 is a combination of 1 meter of Soil 4 and the remaining thickness of Soil 1.

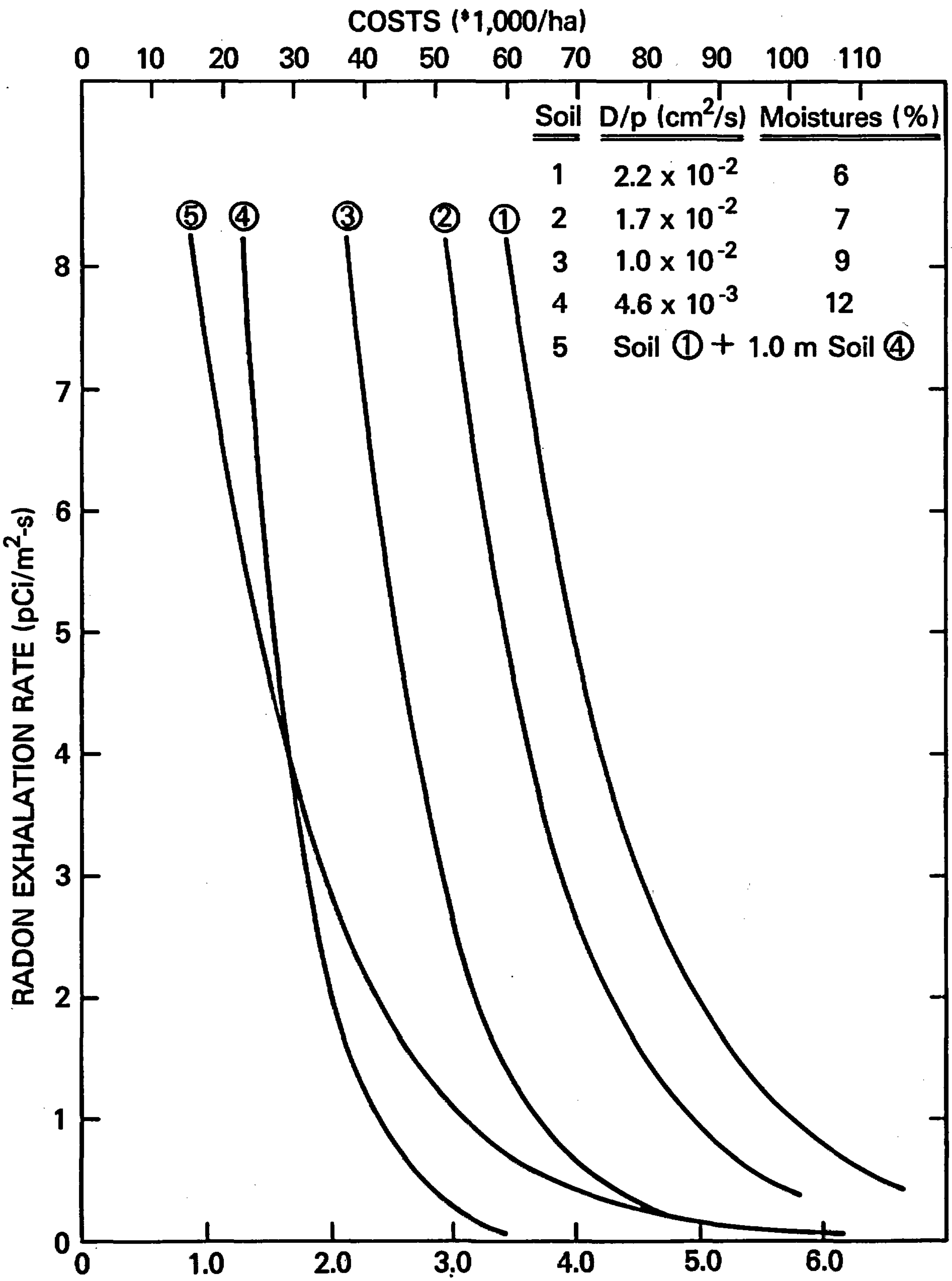

Fig. 12.1. Comparison of Cover Thicknesses and Costs for Radon Flux Attenuation by Use of Various Cover Types.

12.3.4.6 Incremental Cost-Benefit Optimization

The staff considered, but determined it would be impracticable and inappropriate, making a fully monetized, incremental cost-benefit optimization the basis for establishing limits on radon flux, given the complex, multi-dimensional and long-term nature of the mill tailings disposal problem. While such an optimization process appears to offer a "rational approach" to decision-making, it can be misleading if, as in this case, it grossly oversimplifies the problem. Furthermore, it can be quite arbitrary, given the highly subjective nature of some of the major factors and assumptions which must be decided upon to use it.

Appendix U contains a description and analysis of techniques which have been developed for carrying out such an optimization process. In general, the optimum level of radioactive emission control is that level where costs associated with providing any increased control to avert health effects are balanced against what is considered to be an appropriate monetary value for the health effects averted. To support such a process, the following basic factors must be established and there is either considerable uncertainty, or widely varying judgment, as to the appropriate value for each:

- The period of time over which health effects should be integrated;
- The economic or monetary value of averting health effects;
- Factors relating health effects to radioactive emission; that is, prediction of resulting health effects per unit of radioactivity release; and
- The costs of providing emission control and the effectiveness of such control in reducing emissions.

Using what the staff considers to be reasonable ranges of values for these factors, the derived optimum radon flux limit varies by several orders of magnitude, as shown in Appendix U. The results of these evaluations, with simplifying assumptions being made with regard to the last two factors detailed above, are presented in Table 12.5 for various final tailings cover flux levels. Total industry costs and cumulative health effects averted, and also associated incremental costs per averted health effect, are given. These incremental cost-benefit ratios are essentially derived from the slopes of the curves presented in Figure 12.1 (linear relationship with the slope).

Period of Integration

The period over which health effects should be integrated is highly subjective, and commenters on the draft of this document varied widely in their opinions on the matter. On one hand, 100 years was considered appropriate. On the other hand, a period of time which is commensurate with the long half-lives of the radon progenitors thorium-230 (80,000-year half-life) and uranium-238 (4.5×10^9-year half-life) was urged. Obviously, by selection of this parameter alone, the optimum radon control level can be made to come out either at a level of very little control or at a level of essentially complete control. For example, if one were to select a value of $1 million as the appropriate monetary value of averting a health effect, the optimum flux limit would be nearly 50 pCi/m^2-sec if 100 years of effects were considered, while virtual elimination of radon releases would be called for if effects over a 100,000-year period were considered.

Monetary Value of Health Effects

This factor also involves considerable subjectivity. What is the monetary worth of averting a health effect (premature loss of life by cancer)? Today? 1,000 or 10,000 years from now? Some indication of what society is willing to spend today to avert a health effect can be obtained by examining what society is spending to reduce risk from other life-threatening hazards. This ranges widely, however, depending upon many complex societal factors and perceptions--anywhere from as little as $20,000 to at least $10,000,000 per health effect saved and more has been spent on health protection. This range includes expenditures for such things as medical screening and care, automobile traffic safety, airline safety, radioactive- and nonradioactive-related emissions and activities. Expenditures for radioactivity-related risks are routinely much greater than for other societal risks. Picking the range of $10,000 to $10,000,000 for the value of averting a health effect and selecting a 1000-year integration period, the optimum flux level can vary from greater than 100 pCi/m^2-sec to virtual elimination of residual radon flux.

Health Effect Prediction

There is substantial uncertainty in the calculational models used to estimate the environmental transport of radon and its daughters, and resulting human exposure and potential health effects. When considering the long-term nature of the radon hazard, the very large uncertainties concerning such things as future population size and distribution, impacts of changes in climate (such as heating of the earth's surface and atmosphere, the greenhouse effect), and scientific advances (which could conceivably include a cure for lung cancer) make impracticable definitive health effect prediction. It is estimated that these uncertainties can cause variation in the optimum flux over several orders of magnitude.

Cost and Effectiveness of Control

The factor which will determine what the releases of radon will be over the long-term is not the initial thickness of radon attenuating cover placed over the tailings. It will be a complex function of chiefly climatic and topographic site-specific conditions and of those siting and design features which are built into a disposal program to account for these conditions. The siting and design features include such things as placing tailings below grade, flattening of slopes, minimizing of upstream drainage, providing cover erosion protection, and so on, which are intended to isolate the tailings containment from erosion and other disruptive processes. The cost for these factors will vary widely from site to site (Sec. 12.3.3). Also, there is no practicable way to correlate each of these steps with specific levels of long-term performance. What will be the incremental benefit (increase in containment effectiveness), over hundreds or thousands of years, of providing slopes that are 10h:1v as opposed to 2h:1v?--or of having rock cover over exposed slopes of embankment as opposed to vegetation alone? What will be the difference in erosion over hundreds or thousands of years, if there is an upstream drainage area of a square mile with a 1% grade at a site, as opposed to a few acres with a 5% grade?--or if there is a few more inches of net rainfall per year at one site than at another? These differences are significant in terms of actual future radon releases, but they are impossible to quantify.

This inability to correlate containment performance uniquely with costs is probably the most significant reason why it is not reasonable or realistic to adopt a strict incremental cost-benefit optimization.

The uncertainty associated with containment performance is vastly different from other radioactive environmental control or waste management cases where incremental cost-benefit analysis might, in some cases, be reasonably relied upon. Tailings impoundments constitute large, diffuse, and essentially permanent area sources as opposed to finite-term, point sources which are amenable to mechanical emission control equipment. The hazards in the tailings are very long-lived and the containment will need to be similarly durable. Therefore, there is very large uncertainty as to the long-term isolation performance, unlike what would be the case when controlling a stack emission for a short period of time. As opposed to being disposed of in deep geological formations, tailings are being disposed of near-surface, where conditions affecting performance are much more rapidly variable with time.

Also as discussed previously, there is a strong interrelationship among the various goals of tailings management. In some cases, there is competition among objectives. For example, in attempting to provide greater containment of radon and long-term stability by placing further tailings below grade, with increasingly thicker covers, tailings are being put closer to groundwater formations, making groundwater protection objectives more difficult to achieve. In other cases, working to achieve one objective also contributes toward attainment of another. For example, placing cover over a tailings pile not only reduces radon emissions and the associated impacts, but also provides some isolation from intrusion and reduces potential for tailings misuse. It is not possible to monetize these interrelated factors so as to assure that the cost-benefit optimization is a realistic one.

Conclusion

In view of this discussion, the staff has weighed alternative radon control levels in terms of how they would meet the simple objective of returning disposal sites to conditions which are reasonably near those of surrounding environs. Achievement of this simple objective assures that any resulting incremental impacts from radon, although continuing, will be similar in magnitude and kind to those occurring naturally. In conjunction with the required limit on radon flux, a conservative approach is taken with regard to the general mode of disposal. Below grade burial is identified as the prime disposal mode to assure that the effects of natural weathering and erosion processes which could disrupt the tailings isolation are eliminated or reduced to very low levels. A minimum cover thickness and other protection measures are also required by regulations to provide a measure of conservatism, with regard to long-term stability of tailings cover.

12.3.4.7 Minimum Cover Thickness

In evaluating all aspects of the matter of tailings impoundment long-term cover requirements, the staff has concluded that it is prudent to establish a minimum cover thickness requirement. This will avoid undue reliance on special materials or maintenance of special conditions, and will provide a reasonable minimum measure of physical isolation of the tailings.

The radon attenuation properties for various soil covers depicted in Figure 12.1 hold true for these soils under optimum conditions. The covers will lose their effectiveness if moisture is lost, cracks form, or the covers are penetrated in any manner. As described in Appendix P and Section 9.3.8, moisture in a soil is perhaps the most important factor upon which radon attenuation properties depend. With use of some materials, such as clays which are wetted to obtain optimum handling and compaction characteristics, radon flux can be attenuated to the prescribed flux limit with relatively thin layers. For a clay cover installed at the moisture content which is optimum for compaction (about 20% by weight or greater), this thickness could be as little as one meter or so. However, it is imprudent to count on these materials retaining such moisture levels over long periods of time when they are near-surface and subjected to climatic influences. The so-called zone of seasonal moisture fluctuation, that is, the zone where soils are subject to climatic influence, is on the order of 10 feet deep or more. Optimum compaction moisture levels are much greater than what is observed for clay-type materials in this near-surface zone. It is expected that, over time, moisture levels will return to levels like those in soils in their undisturbed state. The minimum cover thickness requirement precludes reliance on soils retaining moisture contents greater than what is commonly found in similar soils in similar locations (on the order of 9-12% for clays).

Also, specifying a minimum cover will minimize the effects of cracking of soils, which can occur in several ways. Clays, because they are plastic materials, will crack upon dessication or when subject to wetting-drying and freeze-thaw cycling. As discussed above, this cycling will certainly occur when these materials are used as tailings covers. Cracking of soils is also possible, and even probable in many cases, where tailings dry out and consolidate over time and differential settlement of cover occurs. As discussed in Section 9.4.1, cracking will lead to dramatic loss in radon attenuation properties. Synthetic cover materials are also not likely to remain intact and maintain initial radon attenuation properties under any reasonable long-term scenario, if applied in relatively thin layers; currently, such synthetic materials must be applied in relatively thin layers to be economically competitive.

Such a minimum thickness requirement will also reduce the likelihood and potentially disruptive effects of root penetration and provide protection from burrowing animals. Although it is necessary that human land uses be appropriately controlled at disposal sites, the objective is that continued beneficial use of the surface be possible; a minimum thickness requirement will enhance the probability of meeting such an objective. Also, while the overall tailings disposal program must effectively eliminate the potential for disruption by erosion or other natural phenomena, as described in Section 12.3.3.2, there are undeniable uncertainties about long-term cover performance. The minimum cover thickness provides a desirable margin of safety in the face of these uncertainties. Furthermore, it provides margins of safety which are desirable, given uncertainties about the upward migration of toxic salts from the tailings to the surface, which have been raised by recent research.

Deciding what should be a minimum cover thickness is a matter of judgment. The staff considers, however, a minimum cover thickness of 3 m (10 ft) to be a reasonable lower limit. Given moistures and other properties of soils commonly observed under normal conditions in the western milling regions, it is most likely that 3 m or more will be required, in most cases, to meet the radon flux limit. While materials such as a moist clay might reduce radon flux to prescribed levels in somewhat less than 3 meters (soil 4 in Figure 12.1, which represents a soil near the upper range of natural moisture contents, is needed in a 2.2 meter thickness), it is virtually certain they will not remain free of cracks or other defects over the long term. So from the point of view of radon attenuation alone, 3 meters appears to be a reasonable lower limit. Considering the other concerns described above, a thickness greater than the minimum needed to meet prescribed radon limits under optimum conditions appears very reasonable.

The staff considers that regulations on uranium mill tailings disposal should generally be in the form of performance objectives because of the many site-specific factors involved. However, regulations must explicitly address potential problems where they are known, and this is such a case. The staff considers it prudent to specify the minimum thickness, given the firm knowledge of the problems discussed above. The NRC, as well as other government agencies and industry, will continue to conduct research into tailings cover material technology. It is not beyond the realm of possibility that techniques could be found for economically resolving the concerns that lead to the minimum cover thickness requirement, under certain conditions which would make it reasonable to relax the requirement. However, the staff is aware of no current technology that would do this and cannot ignore the known problems discussed above upon the speculation that they might be resolved in the future.

12.3.4.8 Relationship to Interim Staff Criteria

The proposed limit on radon exhalation rate has been set as an allowable increment above background, as opposed to a multiple of background rates as was the case with interim criteria

Table 12.5 Incremental Costs and Health Effects for Various Radon Attenuation Levels - Operation of Uranium Milling Industry to year 2000[a]

Flux Limit (pCi/m^2-sec)	Total Industry Costs ($M)[b]	100 Years		1,000 Years		10,000 Years		100,000 Years	
		Cumulative Health Effects Averted	Cost per Health Effects Averted ($M)	Cumulative Health Effects Averted	Cost per Health Effects Averted ($M)	Cumulative Health Effects Averted	Cost per Health Effects Averted ($M)	Cumulative Health Effects Averted	Cost per Health Effects Averted ($M)
100	45.5	386	0.316	3860	0.0316	38,600	0.00316	386,000	0.000316
10	215	579	3.51	5790	0.351	57,900	0.0351	579,000	0.00351
3	306	594	11.7	5940	1.17	59,400	0.117	594,000	0.0117
2	336	596	17.6	5960	1.76	59,600	0.176	596,000	0.0176
1	388	598	35.1	5980	3.51	59,800	0.351	598,000	0.0351
0.1[d]	562	600	351	6000	35.1	60,000	3.51	600,000	0.351
0[e]									

[a]Population is assumed to remain constant at values expected for the year 2100. Population at risk is that of the continental North America. Exposures in Europe and Asia are roughly estimated to be about 25% of continental North American totals. No erosion of tailings disposal areas is assumed. Benefits associated with long-term isolation provided by soil cover are not included.

[b]Industry costs are projected for a tailings covering having properties of soil (3) depicted in Figure 12.1. A unit cost of soil of $1.75/$m^3$ is assumed. The accumulation of tailings due to full operation to end of life of mills in existence through the year 2000 is assumed, an area of 6080 ha.

[c]Somatic effects are predicted using the assumption of a linear, non-threshold dose-effect relationship; a risk estimator of 360 premature lung cancer deaths per million person-WLM is assumed (see Appendix G). A total of 6.0 premature cancers per year is estimated for the case with no control.

[d]By the theoretical method of calculating radon attenuation, an infinite cover thickness would be predicted. As a practical matter, the thickness predicted to be necessary to reduce flux to 0.1 pCi/m^2/sec (about 5.5 m would be needed for ore grades of 0.1% U_3O_8) would constitute virtual flux elimination. Resulting incremental fluxes would be well below the lowest practicable measurable level.

[e]It is assumed that if slimes were fixed, as described in Alternatives 7 and 8, and layered over tailings sands, that radon emanating from the tailings would not escape.

issued by the staff in 1977.[2] This means that an equal level of radon control will be required at each site, as opposed to effectively varying levels of control resulting from a limit specified as a multiple of a variable background rate.

The proposed level will result in an increment above background which is on the average about 2 times that specified in interim criteria, if average background flux levels are taken to be about 1 pCi/m^2-sec (see Section 12.3.3.2).

The interim staff tailings management criteria do not specify a minimum thickness of cover of the tailings. Nevertheless, tailings disposal plans developed in individual licensing cases to meet these criteria involve coverings that, in about half the cases, would meet the 3-m (10-ft) minimum and, in other cases, are sufficiently near the minimum that they can be modified readily to conform with the minimum thickness requirement.

12.3.4.9 Implementation of Proposed Radon Control Requirements

The required radon control level is expressed as a requirement to provide enough cover over the tailings to reduce radon flux originating from the tailings to less than 2 pCi/m^2-s on a calculated basis; essentially this will result in a 2 pCi/m^2-s flux rate increment over background rates because radioactivity occurring naturally in the overburden would be excluded in the calculations. The methods presently intended by the staff to be used in calculating required thicknesses, when reviewing proposed tailings disposal plans, are presented in Appendix P.

It is not possible at this time to delineate details of the compliance monitoring program that will be conducted at the time of mill decommissioning. However, it is likely that this will primarily involve confirming that final cover thicknesses and shapes are as specified in approved tailings disposal plans. Radon concentrations in air are extremely variable because of the large number of factors that influence the rate at which the radon is released (temperature, pressure, wind speed, etc.). For this reason, radon surface flux and air concen-tration measurements would be conducted only to supplement thickness measurements. These radon measurements would be used to confirm that attenuation of the radon by the cover materials was reasonably close to that predicted in initially determining required thicknesses (see Sections 10.3 and 14.1).

12.3.5 <u>Seepage of Toxic Materials</u>

Several specific methods for reducing the potential for groundwater contamination were explored in this study. However, because the factors that determine whether undesirable health effects from contaminated groundwater are likely to occur are highly site-specific, the staff does not consider it appropriate to require particular techniques to be used to meet this objective. Some of the factors which influence the concentration and movement of toxic materials are examined in Section 6.2.4, which presents the results of a study which considers the effect of variation in parameters, such as conductivity and dispersivity of subsoils and underlying strata, hydraulic gradients of underlying groundwater formations, ion-exchange and buffering capacity of subsoils, and amounts of precipitation and evaporation. Perhaps of more importance in some cases are factors such as discontinuities and zones of high hydraulic conductivity, such as fissures, fractures, sand lenses, acid-soluble calcareous materials, and so on, which would permit channelling of seepage contamination; experience has shown that, where they exist, these zones can be the controlling factor in underground migration of contaminants. Furthermore, sizes and locations of nearby drinking water supplies affect the extent to which contaminants entering such supplies would pose health risks. Specific methods employed to reduce or eliminate potential impacts of seepage from tailings impoundments must, therefore, be determined on a case-by-case basis with these site-specific factors taken into account.

As demonstrated in Sections 6.2.4 and 9.3.4, there are essentially two classes of contaminants in the tailings that are of concern when considering impacts on groundwater--those which ion-exchange or sorb onto the clays and soils underlying the site and those which do not. The radionuclides of concern tend to fall into the first category, and the staff concludes that these can, in most cases, be effectively contained by a combination of impoundment liners and natural underlying soils. The more difficult containment problems are believed to arise with regard to anion species, such as sulfates, and trace metals, such as selenium and arsenic, which will not ion-exchange or sorb in some instances.

The staff concludes that the most effective way to reduce potential groundwater contamination and associated health effects is to reduce the amount of moisture available to carry toxic contaminants away from the impoundments--that is to control seepage. The intent of seepage control is to preserve groundwater uses. The regulations explicitly state that any seepage which does occur shall not result in deterioration of existing groundwater supplies from their current or potential uses. This means, for example, that if groundwater quality of a potentially affected aquifer would meet applicable drinking water standards before milling operations, it should remain so after milling operations take place.

Several methods explored in this document could lead to seepage control, and these are identified in the regulations: reduction in the quantity of liquid wastes generated (for example, by recycling of water to the mill), use of low-permeability liners on the bottom and sides of the impoundment, and dewatering of tailings. Recycling of water to the mill process results in reduction in the amount of tailings solution to be disposed of and in a side benefit of reduced consumptive water use in milling areas, which are frequently water-scarce. Highly impermeable clay and synthetic liners drastically reduce the rate at which tailings solutions can seep from the disposal area and, hence, the rate at which toxic materials can escape to groundwater. As shown in Section 9.3.4, the effect of lining the tailings impoundment for the model mill is to reduce seepage to a small fraction (6%) of that occurring without a lining; while increased evaporation caused by liners is expected to produce a more mineralized or concentrated seep, the net effect is a significant positive one. In situ dewatering systems involving use of tailings underdrains are relatively inexpensive, as featured in Alternative 3, and can contribute to much more than just reducing seepage from impoundments. They also make the tailings a much more stable material mass. With dewatered tailings, it will be much easier to cover tailings, since problems of differential settlement and general instability of tailings with high moistures will be avoided. Dewatering tailings will also facilitate staged covering of tailings, the benefits of which are discussed in Section 12.3.7. Regulations, therefore, call for such dewatering at new mills except where tailings are not amenable to the process.

The determination of which of these methods, or what combination of them, will represent the optimum way to avoid groundwater problems must be done on a case-by-case basis. Determining what steps must be taken to control seepage requires a thorough understanding of site geologic and hydrologic conditions described above, which will control seepage movement; therefore, regulations establish explicitly the collection of such information as a requirement and identify the general characteristics of the data-collection program that is needed to assure information is complete and representative of actual conditions.

The total costs for various components of seepage control systems (that is, liners, evaporation ponds, and dewatering systems) are shown primarily in line 2 of Table 12.1. Variation in cost results from differences in amounts of surface areas needing lining, and required sizes of evaporation ponds. These in turn depend upon the kind of earthmoving operations that are carried out in developing impoundments, and climatic conditions which control evaporation rates. In real cases, these factors can all be considered, and the overall program designed to optimize both efficiency of the seepage control system and costs; it is not possible to depict the optimization process in this generic statement except only generally, as is done in the Appendix K and Chapter 11 descriptions of costs for alternatives. In any case, seepage control costs for the model mill, which range from about $5 million to $10 million (a range of about 1 to 2 percent of product price), are considered to adequately bound costs. The staff considers these expenditures to be reasonable, given the benefits derived from them.

Since milling is currently conducted in semiarid regions where evaporation rates are far in excess of rainfall rates, it is not expected that seepage will be a long-term problem. There is concern about providing good seepage control primarily during the operational period, when hundreds of tons of waste solutions are generated daily at an average mill. After the impoundments dry, there will be virtually no driving force for seepage. There is good reason to expect that there is, in general, little recharge of aquifers in interfluvial zones in the semiarid milling regions, if there is any at all (see Section 9.3.4.2.2).[4] It is for this reason that the staff considers use of synthetic liners, the likely long term stability of which is questionable at best, acceptable. Regulations call for neutralization to be considered in developing tailings disposal programs. However, given the expectations about long-term seepage and the extremely high cost of neutralization, as described in Appendix K-2, it is likely neutralization will not be appropriate for most situations in arid and semiarid areas. If milling were proposed to be conducted in areas of higher rainfall, neutralization would need to be given strong consideration.

While not described in earlier chapters, there are methods for rectifying existing groundwater problems which have occurred from uncontrolled seepage. Pumping from contaminated groundwater zones to evaporation ponds, for example, has been done in some cases. There may be some problems at existing mills of establishing baseline water quality levels. However, positive steps should be taken to clean up seepage contamination to pre-milling conditions, to the maximum extent practicable, given this and other valid constraints, which may present themselves on a site-specific basis.

Fixation of the tailings in either asphalt or cement (Alternatives 7 and 8) offers potential for more complete isolation of toxic materials than would be accomplished by use of the methods discussed above; however, as stated in Section 12.3.2, uncertainty about the value of this incremental benefit and high costs has lead the staff to conclude that this alternative should not be required of the industry.

Nitric acid leaching will remove radium and thorium from the tailings, but the nitrate ions present in this process pose greater potential health risks than do sulfates of the conventional leaching process. This potential negative incremental effect, combined with high costs and uncertainties discussed in Section 12.3.2, leads the staff to conclude that nitric acid leaching cannot be required on a generic basis.

12.3.6 Overall Tailings Disposal Program Costs

In the preceding sections, the costs and benefits of tailings disposal programs are discussed separately as they relate to three major objectives: assuring long-term stability, controlling airborne radioactive emissions (radon), and protecting groundwater. In each case, the staff has concluded, and states in these preceding sections, that costs for individual aspects of disposal programs are reasonable. The staff, however, also concludes that total costs of disposal programs comprised of the specific measures discussed above are reasonable, as shown by Table 12.1.

Alternatives 2 through 6 (which fall into the passive monitoring mode of disposal) feature measures which would accomplish each of the major objectives. They can be accomplished at total disposal program costs which are as low as about 2-2.5% of product price, and 0.2-0.25% of electricity generation costs, in cases involving above grade disposal (Alternative 6), or use of available open pit mines (Alternatives 2 and 3).

Where open pit mines are not available, it may be necessary to excavate a pit to ensure long-term stability; Alternatives 4 and 5 are examples. Alternative 4 could be accomplished for about $17 million. These costs are about one-third more than those for above grade disposal, largely, because of high pit excavation costs, but they still represent a small fraction of product price (at most, 3.2%).

In view of the potential significance of seepage, it is essential that liner material perform as expected in design, that seepage control systems be installed as called for by design and in a way which will not damage them, and that operational monitoring systems be installed to detect any failure. Tests must be conducted to assure liners being used will not degrade under exposure to acid solutions. Clay liners, in particular, are of potential concern when exposed to acid tailings solutions (see Section 9.3.4.2.1). Seepage control systems must be installed with quality assurance programs. After these systems are in place and tailings are piled on them, there is little that can be done to remedy any problems that might occur. Groundwater monitoring systems are discussed in Chapter 10. While predictions can be made about seepage control system performance, only a monitoring system can give direct indication of whether or not groundwater protection requirements are met. Also, it is important that seepage detection systems be installed directly beneath synthetic liners, in addition to the groundwater monitoring system, since the potential for and significance of a synthetic liner leak are greater than they are for a natural clay liner which tends to be self healing.

Alternative 5 illustrates a program of phased reclamation of tailings. The shape of the disposal trench would allow some sections to be covered and reclaimed while active deposition is occurring in other sections. Shapes other than the linear trench postulated in this Alternative might permit achieving the same objective more efficiently and at lower costs, or might be more suitable given site-specific topograhic features. One recent proposal, in fact, involves digging four square, below-grade cells.[8] (See Appendix T.3 for a description of several recent below grade tailings disposal programs.) In any case, with careful planning, such phased reclamation can be accomplished without encountering costs much larger, if larger at all, than cases where tailings are disposed of in a single impoundment area. There are also substantial benefits to the operator, in that costs are spread out over the project lifetime, as opposed to being concentrated at the critical beginning and end of operations. Sequenced operations also allow for readily making mid-course corrections on the basis of actual operation.

It should be noted that the cost estimates are based upon disposal operations being performed by an independent contractor. However, many mill operators are also engaged in mining activities and thus possess the equipment and expertise to perform their own earthwork. Hence, considerable savings, perhaps as much 50% of the quoted figures, could be efected, should the operator perform his own earthwork. On the other hand, contingency costs which would normally be about 15% to 20% of quoted figures, were not included. Also, a few indirect costs, such as taxes, interest, and insurance costs (as described in Appendix K-8), have not been included because of their highly variable nature; these costs could be as much as 30% of quoted figures. Therefore, considering both contingency costs and excluded indirect costs, total costs could be as much as about 50% more than quoted figures. Considering these additional costs, the staff still concludes that costs for meeting the requirements being established are reasonable, as stated in previous sections.

12.3.7 Emission Control - During Operation

Radioactive emissions during operations are limited by standards recently developed by the EPA (40 CFR 190), which limit annual dose commitments to offsite individuals to 25 mrem or less (to the whole body or any single organ, excluding doses from released radon). This limit is usually more restrictive than allowable exposures under the offsite concentration limits of 10 CFR 20. Offsite dose depends greatly on variable occupancy and dietary habits. Analysis of Section 9.2.8 indicates, in general, that emission control methods are available to ensure that 40 CFR 190 limits can be met at locations reasonably near the mill.

The provisions specified in point 7 of Section 12.3.2 identify control of dusting from the tailings pile and particulate emissions from yellowcake drying operations as being of primary concern in assuring that the 40 CFR 190 limit is met; as shown by Tables 6.2.8.1 and 9.2.8-1, these radioactive particulate emissions are the largest from the mill and thus, the largest contributors to offsite exposure (excluding radon). Blowing tailings can be substantially reduced if tailings areas are kept saturated or covered with tailings solution, or are otherwise kept wetted or chemically stablized. However, because these controls are not automatic, constant vigilance and management attention must be provided. For this reason, as part of its program for keeping emissions as low as reasonably achievable (ALARA) and implementing 40 CFR 190, the staff will require that operators prepare operating procedures specifying methods for controlling dusting from tailings piles.

The staff considers that tailings disposal programs which permit phased reclamation should be carefully and thoroughly examined in the mill planning stage because of the substantial advantages they provide in controlling emissions during operation. Radon emissions will be suppressed to the greatest extent when a water cover, or complete saturation of the upper tailings surfaces, is the control method employed. Chemical sprays and superficial wetting employed to control dusting from dried tailings surfaces are not expected to provide as efficient attenuation of radon as is provided by water cover, since these would produce only a thin surface film. Thin films would be effective in controlling dust, but small imperfections or penetrations which would likely be present in such films would provide escape routes for radon. Water cover could be achieved in cases where the tailings are disposed in a slurry. This, however, has potential negative aspects when viewed from the broad perspective required in developing a long-term tailings disposal program. For example, water cover provides a driving force for seepage to groundwater, creates additional problems of impoundment stability, and makes the problems of final covering of the tailings much more difficult and lengthy than if tailings are dewatered or dried prior to disposal. This conflict is resolved best by those tailings disposal schemes which involve staged covering and reclamation of tailings. Phased or progressive reclamation effectively minimizes the available tailings surface area for unattenuated radon exhalation. Although not addressed by the requirements of 40 CFR 190, radon emissions from tailings are the primary and dominant source of all offsite exposures and radiation risks.

Several methods for controlling yellowcake dryer and packaging area stack emissions exist. It is important that the stack control equipment be checked frequently, since significant stack releases can occur, if the equipment is not operating efficiently. Regulations being promulgated explicitly require this. Costs for any of the control methods are small in comparison to those of tailings disposal and product price (less than 0.1% of the price of yellowcake). Yellowcake emissions can be eliminated entirely if yellowcake is shipped from the mill as a slurry or moist cake. Also, eliminating the yellowcake dryer would reduce occupational exposure at mills; a decrease of about 29% in total worker radiation exposure risk is predicted. Despite these potential benefits, the staff does not consider that wet shipment can be required, because of the projected high cost of this shipment mode, and insufficient capacity at UF_6 conversion facilities to handle wet cake. In fact, the process at one conversion plant is a "dry" one and is incompatible with the wet yellowcake shipment option. Modifying the process would require a dryer at the receiving end and thus, in this case, would only involve transferring associated problems from one location to another. Also, this particular facility is already borderline with respect to 40 CFR 190 compliance and could not continue to operate if offsite exposures were increased by any significant degree.

As illustrated in the base case, emission from ore crushing and handling operations are relatively minor. Nevertheless, the wet, semi-autogenous ore grinding process offers significant advantages. It will virtually eliminate what ore crushing emissions do occur. More significantly, worker exposure risk is estimated to be reduced by 20% if this process is utilized. Total costs would be comparable to those of a mill featuring dry crushing, if not somewhat less. As a result, it is concluded that use of the semi-autogenous grinding process should be evaluated as a substitute for dry crushing operations, for each new mill operation.

In general, methods to control all of the mill sources evaluated in this study are employed in newer mills at the present time; it is inferred, therefore, that control can be accomplished by using available state-of-the-art technology at reasonable costs. Total lifetime costs for controlling mill emissions by various control alternatives are presented in Table 11.1.

Utilizing best available equipment, including semi-autogenous grinding, would result in total costs of about $1 million dollars. This would constitute a very small fraction of product price (about 0.1%).

Point 8 of Section 12.2.1 requires that exposure limits be met primarily by emission control, as opposed to extending exclusion areas. Uncontrolled emission will add to contamination of ground surfaces, both on and off the site, which will eventually have to be cleaned up at the completion of milling operations. Before beginning operations, mill operators will have to determine at what distance site boundaries should be established to ensure that offsite radioactivity concentration and individual dose limits are met. Because the transport of emissions offsite is dependent on variable, site-specific conditions, a generic requirement regarding the extent of exclusion areas is not appropriate. The determination will have to be made on the basis of predictive assessments of radiological impact, prior to the start of milling operations, and confirmed by actual measurements during the operational monitoring program discussed in Section 12.2.2, point 6.

Notwithstanding individual dose limits, strict emission control must be exercised to reduce population exposures to the maximum extent reasonably achievable and to avoid site contamination. This would mean, for example, that very strict design and management control of tailings areas would be required, even at a mill where there were no nearby residences, as sometimes occurs.

12.3.8 Isolation of Tailings

It is necessary to ensure that individuals near milling operations do not receive exposures greater than established limits, and to ensure that milling operations and tailings disposal not be carried out near towns. It is possible that individual limits could be met in such situations but that cumulative population exposure would be greater than that achievable if the mill were sited in remote areas. It is recognized that it is not possible to predict accurately what demographic patterns will be as far into the future as the tailings will remain hazardous. Nevertheless, the staff also considers that remote location of mills is desirable, because at least for the near future, this will reduce the potential for disruption of the tailings site by human activity, and intrusion after final disposal.

The objective of remote siting is easily met in most western mining and milling regions, because, as depicted for the model site, population densities in such regions are typically very low. Although the staff does not consider a strict numerical guideline to be appropriate, the general quality of remoteness must be duly optimized in the site selection process, in the context of similar and simultaneous optimization of other important siting considerations. This is as discussed in Section 12.3.2.

12.3.9 Decommissioning of Mill Buildings and Site

Cleanup of the mill site, and either dismantlement or decontamination of mill structures, to permit unrestricted use of the complete site (excluding the mill tailings disposal area) can be accomplished by use of simple and straightforward cleaning and excavation methods. Costs for these operations will be site-specific, but will be on the order of $1.3 million for situations comparable to the model mill. In view of these relatively small costs and the nature of the operation, a less complete decommissioning mode (any type of conditional or restricted use mode) would be unacceptable.

The U.S. EPA is establishing standards for cleanup of soils and open lands contaminated by uranium milling activities, to permit unrestricted land use; under provisions of the UMTRCA, the EPA has issued interim cleanup standards for inactive tailings sites (45 FR 27370) and will be proposing standards for active sites shortly. The interim EPA standards for inactive sites are presented in Appendix J. Decontamination of mill structures should be guided by Table 1 of Regulatory Guide 1.86, in which limits are specified for residual surface decontamination levels.

12.3.10 Decommissioning Plan, Environmental Review, and Public Participation

Decisions regarding proper disposal of mill tailings must be made prior to initiation of mill operations. In the model mill, tailings are produced at a rate of nearly three-quarter million tons per year. Nearly irrevocable commitments are made once milling operations have begun and several million tons of tailings have been generated. Therefore, it is essential that a tailings disposal plan be worked out, approved, and agreed to before a license is granted.

Similarly, to ensure that milling operations are conducted in such a manner that decontamination of the mill can be carried out effectively and without complication and so that the full costs of mill operation are identified prior to its beginning, a decommissioning plan for the mill building and site must be worked out, approved, and agreed to by the operator, before a license is granted.

As has been pointed out numerous times throughout this document (for example, see Section 12.3.1), the specific methods and engineering details of tailings disposal can only be worked out on a site-specific basis. Major siting decisions are made in each case. Given this, and because each mill tailings pile constitutes a low-level waste burial site containing very long-lived material, a comprehensive environmental review of each mill and tailings waste disposal operation must be conducted; it is also essential that this review be conducted so there is opportunity for full public scrutiny of the decisions being made. The most effective way to achieve this is for the NRC and the Agreement States regulating mills to conduct independent, documented assessments which are made available for review by the public and interested government agencies. Beyond this, so as to ensure maximum opportunity for public participation, there should be opportunity for public hearings in connection with each licensing case. For reasons stated above, and because the impacts of construction can be significant and long-lasting, no major construction activities should be allowed before the environmental review has taken place and has been documented, there has been opportunity for public review and comment, and the final document is issued.

It is also important that avoidable impacts which are occurring now at mills, such as from blowing of tailings, or possibly groundwater contamination, be dealt with immediately. At existing mills it may take as long as several years to complete the full process of developing and negotiating an approved final plan for ultimate disposal of tailings, since this will involve consideration of alternate sites and resolution of other tough questions which inevitably present themselves at active mills which have been operating for many years. Therefore, interim plans aimed at tackling existing immediate problems must be promptly developed and implemented by operators, well in advance of full resolution of all those questions involved in the final reclamation plan. The regulations being issued require this.

12.3.11 Long-Term Control

The primary means of isolating the mill tailings must be by physical barriers. Disposal must be by means which reasonably assure the tailings will remain isolated under natural forces without active care and maintenance and it is desirable that some reasonable and productive uses of the land be permissible. The staff considers, however, that as a supplementary measure, there should be continued monitoring and control of land uses at sites, except possibly where there is deep mine disposal, and no significant degradation of groundwater quality is likely to occur, to confirm that there is no disruption by either natural erosion or by human-related activities. It is prudent to have such monitoring and control for as long as it can be provided by human institutions. A more complete discussion of potential health risks under various land use scenarios is presented in Section 9.4.2.

As described in Section 10.3.3, ongoing monitoring would most likely consist of annual visits to the site. Ownership and custody by a government agency, as opposed to private individuals, is the most effective and reliable way to provide the supplementary long-term control proposed. Stability of any institution over a very long period of time (as long as the tailings will remain hazardous) is, in view of history, doubtful; however, government institutions can be expected to be much more long-lived and provide more continuity than will private institutions, businesses, or persons. Furthermore, in the unlikely event that remedial actions at disposal sites are required, only a government agency could be relied upon to have sufficient resources to adequately support proper action.

12.4 IMPLEMENTATION OF PROPOSED REQUIREMENTS AT EXISTING SITES

Because of the site-specific nature of the tailings disposal problem, the regulations are being cast primarily in the form of performance objectives. Most of the objectives for tailings disposal identified in Section 12.3 were developed primarily in consideration of what can be done in prospective milling operations. Objectives related to siting and groundwater protection may not be met with the same degree of conservatism at existing sites as will be possible at new sites. The staff considers that these objectives, however, should be satisfied to the maximum extent practicable at existing sites. Therefore, the regulations are written so as to clearly indicate those criteria which are applicable as minimum requirements at all sites. These include, for example, tailings cover surface stabilization and embankment slope requirements. Numerical requirements such as radon control limits are, in particular, applicable in all cases. Where groundwater contamination has occurred or is occurring at a mill, it is mandatory that the mill operator take prompt action to revise the practices that lead to this contamination and restore offsite areas already contaminated in a manner that is consistent with the preservation of potential water uses prior to existence of the mill.

The objectives that will be potentially most difficult to implement at existing sites are those regarding long-term stability, groundwater seepage, and location near populated areas. The existence of current mill tailings disposal operations with associated committed impacts place severe constraints on mill operation which do not exist before a mill is constructed. However, at each active milling site, evaluations should be conducted of current and planned tailings disposal operations to determine what specific practicable actions can be taken to meet each specific objective. The costs, environmental impacts and benefits of the following alternatives should be considered:

1. Continued use of existing tailings area,

2. Discontinued use of the existing area with newly generated tailings disposed of at a new location, preferably below grade, and

3. Disposal of all tailings at a new location, preferably below-grade; this would involve moving existing tailings from current above-grade locations to a new disposal location.

In addition to constraints on alternative tailings disposal methods resulting from existence of very large volumes at existing sites (nearly 30 million tons at one site), there will be a greater problem in paying for tailings disposal at these sites, because disposal costs were not incorporated into the price of the product as the tailings were being generated. Therefore, future operations at such sites may have to provide for disposal of both newly generated and existing tailings. Appendix K-9 discusses potential costs of meeting requirements at existing mills for 2 cases: (1) recontouring existing piles and stabilizing in place, where site conditions would permit this, and (2) moving tailings to a new suitable location (assumed to be 10 km away from the existing site) where a pit is excavated for disposal. Costs, for quantities of tailings similar to that produced at the model mill, are about $6 to $13 million and $20 to $25 million for cases (1) and (2), respectively. These costs are for the model mill which produces 8.4 million MT over a 15-year lifetime. While this quantity of tailings is less than that existing at many mills, the relative impact of these requirements can be obtained by considering costs in terms of mill revenues, that is, yellowcake price. Spread out over an assumed full lifetime of production at $30/lb yellowcake, these costs are 1.2 to 2.5% and 3.9 to 4.9% of product price, respectively, for cases (1) and (2). However, if it were assumed that these costs were to be borne by mill revenues during the later phases of mill life, these costs will be a larger fraction of product price.

Economic Impact at Existing Mills[a]

Period of Amortization	Case 1 Stabilize In Place (% U_3O_8 Price)	Case 2 Relocate Tailings (% U_3O_8 Price)
Full life	1.2-2.5	3.9-4.8
1/2 mill life	2.4-5.0	7.8-9.6
1/3 mill life	3.6-7.5	11.7-14.4

[a]This assumes ore grade of 0.1 percent U_3O_8 and a yellowcake price of $30/lb.

Case 1 represents what will be required, as a minimum, to meet the requirements of regulations being implemented. It can be seen that, where stabilization is carried out in place (in worst case cost conditions reflected by the upper end of the cost range) and it is financed by operations in the last phase of mill life, (for example, the last third of life) the economic impact can be appreciably greater than that of implementing full below-grade burial in special pits at new mills (Alternative 5). In any case, costs are considered reasonable. Where existing site conditions are clearly unacceptable from the point of view of long-term stability, that is, the recontouring, covering, and hardening of the tailings impoundment assumed for Case 1 will not assure stability, then relocation will be necessary and Case 2 applies. This situation might arise where tailings are located in the path of a major drainage, or are situated where earthquakes would most likely cause major disruption of the tailings pile. The economic impact in such cases could be significant; as much as 10% or more of product price will be required to cover costs, if financed by the last phase of mill operations (the last third of mill life, for example). In any case, hard decisions must be made at existing sites. This underscores the importance of performing the documented site-specific evaluations discussed above in Sections 12.3.9. and 12.3.10.

12.5 IMPLEMENTATION OF PROPOSED REQUIREMENTS TO HEAP LEACHING AND SMALL PROCESSING SITES

Methods for exploiting small or low-grade ore bodies located far from conventional milling facilities have been developed. The small size or low quality of these ore bodies is typically such that costs for transportation to large mill facilities make their processing otherwise uneconomical. Local processing of these ore bodies may involve either heap leaching of raw ore (App. B) or use of semiportable milling equipment. These activities would present the same kind of environmental problems that occur with conventional milling: releases of radon and radioactive particulates and seepage of tailings solutions. Therefore, the staff concludes that the same tailings management and disposal criteria proposed for conventional mills should be applied to such activities. This includes the solid aboveground wastes generated by in situ uranium recovery operations described in Appendix B.

While quantities and concentrations of emissions would be lower in the case of these small operations than occur with large mills, they present a unique problem. Exploitation of isolated ore bodies could increase significantly the inventory of sites which must be controlled over the long term. In view of this, the staff considered proposing general rules requiring the consolidation of tailings from such operations with other small operations, or with larger mills. It was concluded however, that this would be extremely difficult and, furthermore, unwarranted. By the very nature of these operations (in most cases involving low grade ore and, hence, small concentrations of radioactivity), the relative hazard of tailings produced will be much less than if there was consolidation at only a few sites. While general rules do not seem appropriate, the staff believes that consideration should be given to consolidation of such tailings on a case-by-case basis, where environmental benefits, costs and problems of long-term control can be fully examined and balanced.

12.6 UNCERTAINTY OF FUTURE EFFECTS

The staff has characterized the long-term impacts resulting from milling operations and tailings disposal. Specifically, potential health effects resulting from continuing incremental radon releases above background have been estimated for several different periods (100 years and 1000 years into the future) and beyond 1000 years as an annual rate. For control of radon at the specified limit, radon releases and resulting exposures are an extremely small fraction of natural releases, as indicated in Section 12.3.4.4.

As discussed in Section 9.4.1, the very long-term performance of tailings isolation (that is, several thousands of years into the future and beyond) will be governed by climatic and geological forces which cannot be predicted precisely. In Section 9.4.1.2, the staff has examined a full range of possible failure modes, not with the purpose of predicting in absolute or quantitative terms chances for or consequences of failure, but in order to provide a guide in siting and design of tailings disposal schemes. The pertinent question is: "What siting and design factors should be considered or taken into account in order to provide reasonable assurance of long-term isolation of tailings?"

A fundamental aspect of the tailings disposal requirements that the staff proposes be incorporated in regulatory programs is that disposal be carried out in such a fashion that exposure to natural weathering and erosional forces are eliminated or reduced, to the maximum extent reasonably achievable. The staff considers that proper design of tailings disposal programs (below-grade disposal being a prime design option) and careful siting of disposal impoundments (for example, to eliminate upstream drainage) can provide reasonable assurance that the tailings will remain isolated for very long periods of time (many thousands of years) and in some cases may even become more isolated over time. The basis for this position is presented in Section 9.4.1.

However, to account for uncertainties, particularly with regard to the very long-term (greater than several thousand years), examining the effects of a certain level of tailings isolation failure may be useful. Without postulating specific failure scenarios (methods and timing of failure), a "failure" of ten percent of the tailing isolation areas is arbitrarily assumed, to provide what the staff considers to be a very conservative perspective on the matter of potential health effects from radon release. Specifically, it is assumed that there is complete loss of cover from ten percent of all of the tailings accumulated through the year 2000. This would result in incremental releases which are about 0.05 percent of those resulting from natural radon releases (see Table 12.3). Therefore, consequences of such worst case situations are seen to be a very small fraction of those naturally occurring without milling.

As described in Section 9.4.1, erosion is expected to occur very slowly (on the order of a foot in tens of thousands of years) if it occurs at all, given the siting and design measures being required to reduce erosional potential and avoid other long-term failure mechanisms. Some have suggested, however, that tailings piles will eventually become uncovered and tailings widely dispersed. It has then been suggested that tailings will emit radon undiminished and expose populations for hundreds of thousands of years, until decay of its precursors is complete. Such "worst case" scenarios result in extremely large health impacts. Larger annual death rates than estimated for the uncovered base case in Chapter 6 are postulated, because tailings are assumed to become totally dispersed, and there is no self-shielding or attenuation of radon, as there is when tailings are in a pile form.

The staff considers such scenarios to be completely unrealistic, however. They are not reasonable upper bound scenarios of health impacts associated with tailings disposal. In addition to the fact that measures are being required to be taken to avoid such failures, these failure scenarios do not recognize that the same erosional processes which must be postulated to uncover and disperse the piles would also work to remove tailings from the earth's surface. Erosion will either cover tailings with other eroded materials, or eventually carry them into streams. In fact, it is just as reasonable to assume that the erosion which might uncover tailings piles will eventually uncover natural ore bodies. Viewed in this sense, it can be argued that mining and milling of uranium results in no significant net health impact above that occurring if mining was not conducted; mining only changes the point in time where the uranium and its daughters are brought to the earth's surface.

With regard to individual exposures from such "total" failures, no immediate and acute health effects would result. Long and sustained exposure to radioactivity in the tailings pile would be required to produce any significant chance of adverse effect. That is, remedial action could be taken in a time frame that would prevent any adverse health effects to maximally exposed individuals.

The staff considers that tailings disposal alternatives falling into the "passive monitoring mode" include a strong measure of conservatism in design and siting to assure long-term isolation and stability without perpetual active care. However, this analysis shows that the consequences of even several unlikely, reasonable "worst case" failures are small in comparison to those occurring from natural releases.

12.7 CONTINUED DEVELOPMENT OF TECHNOLOGY

The technical requirements for tailings disposal which are being incorporated into the Commission's regulations (Section 12.2) are not specific as to detailed methods of disposal. The past few years of mill licensing activity has involved development of new tailings management disposal practices and methods. In fact, many of the specific alternative disposal methods addressed in this study represent those which were developed by industry in working to meet staff interim licensing performance objectives which are very much like the requirements now being implemented. It is expected that continued NRC and Agreement State mill licensing experience, the experience of providing final reclamation of tailings at inactive tailings sites which will be taking place over the next few years, and general research conducted by various agencies (viz. NRC, EPA, and DOE) will result in development of improved methods of tailings management and disposal. For example, methods of treating tailings so they may be placed below grade in contact with groundwater, and at the same time preserve groundwater quality, are being examined by various researchers. Such a development would facilitate below-grade burial of tailings. Also, experience of inactive site remedial work and upcoming NRC studies are expected to provide more specific, additional information regarding surface stabilization of tailings disposal areas. The proposed requirements provide flexibility which will allow and, indeed, foster, continued improvement in methods and techniques of disposal. The staff plans to reexamine its tailings disposal criteria, after remedial action has been taken at several sites, to determine if any changes to the criteria or more specific guidance is appropriate in view of this experience.

12.8 CONCLUSIONS REGARDING NONRADIOLOGICAL ENVIRONMENTAL IMPACTS

The staff has drawn the following general conclusions regarding non-radiological environmental impacts not discussed previously in this chapter.

1. No changes appear warranted in the NRC regulatory program (beyond those identified above for tailings management and disposal) to control non-radiological impacts of milling operations. Mitigative measures can be taken on a case-by-case basis to assure that no unacceptable environmental impacts occur. Thorough environmental assessments in connection with each mill licensing action will provide an adequate mechanism for dealing with and resolving potential undesirable negative impacts. The Commission is currently preparing environmental impact statements in connection with mill licensing actions; Agreement States are required by UMTRCA to conduct environmental reviews and document them in a public process, as described in Section 12.2.2.

2. Because impacts tend to be localized, unacceptable accumulations of nonradiological impacts are not expected to occur, even in cases where there will be a concentration of mining and

milling activity. The cumulative effects that will potentially be most significant are socio-economic. In some situations, a regional approach toward mitigating impacts may be desirable. In this connection it is noted that, in response to potential rapid and major development of uranium resources in northwestern New Mexico, the U.S. Department of Interior has recently completed a study with the purpose of developing a regional base of information to aid in mitigating impacts likely to be of concern in that area, such as socio-economic impacts (San Juan Basin Regional Uranium Study[5]). In any case, the staff concludes that non-radiological impacts examined can be mitigated to acceptable levels on a case-by-case basis.

3. As discussed in Section 12.3.1, the extent to which the many types of non-radiological environmental impacts evaluated in this document occur will relate to the extent to which airborne emissions are controlled and seepage reduced. The requirements proposed for incorporation in regulations should assure that seepage and airborne emissions are controlled to a high degree. Therefore, nonradiological impacts which occur will not necessarily result in exceeding any existing environmental protection regulations of federal or state agencies, such as those covering air and water quality. For example, with control of airborne emissions, as required, there would be little problem of meeting federal air quality limits on suspended particulates, even in the worst case, by a multiple mill cluster. At a reference location analyzed in this statement one km downwind of the model mill, total concentrations including background (35 $\mu g/m^3$,) are much less than regulatory limits (e.g., in Wyoming the limit is 60 $\mu g/m^3$).

4. Most nonradiological environmental impacts will not be irrevocable or persistent. For example, following mill decommissioning, impacts on soils and biota which occur will disappear, albeit slowly in some cases; vegetation will be reestablished in disturbed areas, and wildlife habitats will be restored, following site reclamation.

REFERENCES

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13. REGULATORY PROGRAM FOR URANIUM MILLS AND MILL TAILINGS

13.1 INTRODUCTION

In Chapter 12, the staff discusses what actions should be taken to assure that uranium milling operations and mill tailings disposal are conducted in a safe and environmentally sound manner. Proposed actions are based on analysis of public health, and environmental and cost aspects of uranium milling, discussed in previous chapters. Chapter 12 identifies both technical requirements and institutional controls that the staff considers necessary.

The uranium milling industry and the mill tailings waste disposal problems are issues of national importance, involving very long-term and potentially widespread environmental impacts. Past management of uranium mill tailings has been poor. Misuse of the tailings has included construction with tailings material, and removal of the tailings to offsite locations. As stated in Chapter 2, there are currently 22 inactive uranium mill sites, where tailings wastes were not adequately dealt with, upon mill decommissioning. Clearly, assurances should be provided by regulatory programs that there will not be a recurrence of past practices at currently active and new mill sites. Therefore, this chapter deals primarily with the question of how technical and institutional requirements can or should be implemented.

In developing this document, it was decided that four major issues needed resolution. These issues are:

1. Are regulatory authorities adequate to provide control of mill tailings?

2. Under what conditions should Agreement States regulate uranium mills?

3. What should be the land ownership arrangements following tailings disposal, to accomplish the long-term control proposed in Chapter 12 by the staff?

4. How do the roles of NRC, EPA and DOE interrelate in the area of mill tailings regulation and management?

Since the Commission announced its intention to prepare a generic environmental impact statement on uranium milling[1] and published a proposed scope and outline,[2] there has been considerable activity bearing on these issues. This activity has included:

1. Passage of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA)[3] and amendments to UMTRCA[4] which authorize remedial actions at inactive mill tailings sites (discussed in Chapter 2), strengthen regulatory authorities relating to active mill operations and tailings generation, and provide for long-term control of tailings, and,

2. Development of a Commission policy to offer technical assistance to Agreement States, in conducting environmental assessments of proposed uranium mills.[5]

The discussion in this Chapter reflects how the recent legislation and Commission policy statement resolve the four major issues just identified.

13.2 REGULATORY AUTHORITIES

13.2.1 Limitations

In developing this generic environmental impact statement, the adequacy of existing regulatory authorities over uranium mill tailings was reexamined and judged to have some limitations. Under the existing regulatory framework, NRC did not control mill tailings directly as licensable material. As a result, the period following cessation of milling operations and prior to completion of the final disposal of the tailings represented a time period during which NRC's authorities were not clear.

Under its source material licensing authority, the Commission has conditioned mill licenses to require mill operators to make provisions for tailings management and control during the license term.

Existing Commission regulations state that source material includes "ores which contain by weight one twentieth of one percent (0.05 percent) or more of (i) uranium, (ii) thorium or (iii) any combination thereof."[6] The concentration of uranium and thorium in uranium mill tailings is less than this amount, and thus is insufficient to qualify the tailings as licensable source material under the regulations. Nonetheless, accumulation of tailings at a mill site constitutes an integral part of the milling activity regulated under the Atomic Energy Act.[7] As such, it was controlled by the Commission until termination of the mill license, notwithstanding the fact that the tailings do not contain more than 0.05 percent uranium. Thus, control over tailings has been linked to the source material license for a milling operation and not to the tailings themselves.

This authority was buttressed by NRC's responsibilities under the National Environmental Policy Act[8] (NEPA). Under NEPA,[8] NRC is required to review and evaluate any proposed action to determine what, if any, environmental impacts would occur. This law has provided a basis for control over tailings (the effects of which could extend beyond the period of active plant operations) for the purpose of environmental protection. Thus, NEPA strengthened the authority of the Commission to impose license conditions for environmental purposes, for periods after cessation of source material processing.

Notwithstanding this, however, NRC's enforcement authorities were not clear following cessation of active milling operations. NRC clearly had full regulatory authority to impose and enforce license conditions related to tailings management and disposal, as long as the source material license was in effect. However, once milling operations ceased and all licensable source material was removed, it was not clear that NRC could refuse to terminate the source material license. This was so because such a termination would eliminate the basis for control over the unlicensable tailings materials.

13.2.2 Effect of Legislation

Recognizing these limitations, the U.S. Congress enacted the UMTRCA[3] which amends the Atomic Energy Act of 1954[7] and creates a new category of licensable material. The definition of the term "byproduct material" is expanded to include "the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content" (Section 201).[3]

Therefore, as a result of this legislation, NRC's regulatory authority clearly continues upon cessation of milling operations and removal of licensable source material, extending at least until tailings are finally disposed of according to Commission regulations. Tailings have become controllable directly as licensable material. The UMTRCA[3] also contains requirements for the long-term control of tailings. This is elaborated on further in Sections 13.4 and 14.3.

13.3 AGREEMENT STATE PROGRAMS

The Commission stated, in publishing the scope and outline of this Generic Environmental Impact Statement, that uranium milling operations in Agreement States would be evaluated. (As indicated in Section 3.4.3, nearly 60 percent of "probable" uranium resources are located in Agreement States.) Furthermore, the Commission stated that the interrelationship between NRC and Agreement State regulatory programs would be evaluated. Within the context of the development of this document, and in connection with a lawsuit brought against the NRC and the State of New Mexico over licensing environmental review procedures in that State,[9] the Commission has conducted policy reviews focusing on the manner in which Agreement States regulate uranium mills. Specifically, the arrangement whereby Agreement States have regulated, under programs compatible with NRC's program, was evaluated, and some important differences in regulatory programs were identified.

13.3.1 Existing Arrangements - NRC Policy Review

Section 274 of the Atomic Energy Act of 1954, as amended, provides a mechanism whereby the NRC may transfer to the States certain regulatory authority over specified nuclear materials, when (1) a State desires to assume this authority, (2) the Governor certifies that the State has an adequate regulatory program, and (3) the Commission finds that the State's program is compatible with that of the NRC and is adequate to protect the public health and safety.[7] Section 274(g)[7] directs the Commission to cooperate with the States to assure that State and Commission programs for radiation protection will be coordinated and compatible.

Each agreement entered into with a State recognizes the importance of maintaining compatible programs and of providing for reciprocal recognition of licenses. Each agreement contains an article pledging the use of best efforts on the part of the Commission and the States to achieve coordinated and compatible programs. Of the 26 Agreement States, four of these States are currently licensing uranium milling activity within their borders: Colorado, New Mexico, Texas, and Washington.

Notwithstanding this arrangement, one area where there were differences between NRC and State programs was that involving environmental reviews of proposed licensing actions. In response to this situation, NRC conducted a policy evaluation aimed specifically at the matter of environmental reviews in Agreement States. This policy review included a workshop sponsored by NRC in November 1977,[10] to discuss primarily the matter of environmental reviews, to compare State practices with NRC practices and to assess the attitudes of the States regarding NRC reassertion of regulatory authority over uranium mills.

The NRC conducts an environmental review, in connection with each proposed major uranium mill licensing action, culminating in the preparation of an environmental statement that is circulated for public review and comment. Although the Agreement States were conducting environmental reviews of proposed mill licensing actions, preparation of an independent, documented environmental report was generally not a part of their regulatory programs. Although the States generally viewed such environmental reviews as beneficial, they indicated at the Workshop[10] that extensive studies were beyond their financial or manpower resources and might unduly delay the licensing process. With respect to NRC's reassertion of regulatory authority over uranium mills, all Agreement States at the November 1977 Workshop indicated that they emphatically wished to retain licensing authority and vigorously opposed the idea of giving it up.[10]

The Commission concluded, in light of this information, and its own experience in licensing mills, that the licensing process in Agreement States would benefit from preparation of an independent environmental assessment similar to that conducted by NRC in non-Agreement States. In a policy statement[5] the Commission indicated that such an assessment need not be identical in scope to those prepared for mills licensed by NRC; however, the assessment should treat the most important environmental aspects of milling operations: tailings waste management and disposal, siting, and radiological assessment.

Therefore, as part of its comprehensive program to strengthen public health and safety regulation of uranium mills, the Commission decided to offer technical assistance to Agreement States, on a temporary, trial basis, to assist them in assessing the environmental impacts of their uranium mill licensing.[5] Under this arrangement, the Commission is in the process of assisting the States of Colorado, New Mexico, and Washington in the preparation of environmental assessments associated with several recent uranium mill licensing actions. As previously indicated, this technical assistance program is an interim measure to aid the Agreement States in upgrading their regulatory programs. This program is in the process of being phased out and will be discontinued when the new requirements for Agreement State licensing become fully effective in 1981. NRC staff is preparing revised criteria to be used in evaluating the effectiveness of Agreement State programs at the time of the amended agreement review in November 1981 (when the new requirements become fully effective) and in all subsequent reviews.

13.3.2 Legislation

The matter of Agreement State regulatory programs discussed below is now covered by the UMTRCA[3] which specifies that when States license an activity involving mill tailings, that has a significant impact on the human environment, they must prepare a written independent analysis of the impact of such license on the environment, including any activities conducted pursuant thereto. This analysis, which must be available to the public before any licensing action is taken, shall include --

"(i) an assessment of the radiological and nonradiological impacts to the public health of the activities to be conducted pursuant to such license;

"(ii) an assessment of any impact on any waterway and groundwater resulting from such activities;

"(iii) consideration of alternatives, including alternative sites and engineering methods, to the activities to be conducted pursuant to such license; and

"(iv) consideration of the long-term impacts, including decommissioning, decontamination, and reclamation impacts, associated with activities to be conducted pursuant to such license, including the management of any byproduct material" (Section 204).[3]

Beyond this, the UMTRCA provides that the States are required to regulate tailings in accord with standards that are, to the extent practicable, equivalent or more stringent than standards promulgated by the Commission and the Administrator of the Environmental Protection Agency (Section 204).[3] Thus, the Act represents a departure from the preexisting Agreement State requirements that Agreement State regulatory programs must be "compatible" with those of NRC. The new legislation demonstrates that on such a matter of national importance as mill tailings waste disposal (that involves long-term and potentially widespread environmental impacts), the Congress has concluded that a uniform national approach to solving the tailings waste disposal problem is warranted.

Under the new arrangement, the Agreement State role in licensing mills will continue to be a substantive one, because, as discussed in Chapter 12, the potential environmental impacts of uranium mills and mill tailings are highly site-specific. There remains, therefore, a need for a comprehensive Agreement State review of each licensing case to assure that the criteria specified in NRC regulations (i.e., national standards) are met. The Commission's policy statement on Technical Assistance for Agreement States[5] has in some cases facilitated the issuance of environmental reviews, while the States developed the capability to prepare such reports on their own. In addition, Section 207 of the UMTRCA[3] authorized $500,000 in grants to Agreement States, to aid in development of State regulatory programs to implement its provisions.

13.4 LONG-TERM CONTROL AND CUSTODY OF DISPOSAL SITES

Land ownership of disposal sites is mixed; tailings are currently located on Federal, State and privately-owned lands. Prior to enactment of UMTRCA[3] there were no requirements pertaining to site ownership.

As stated in Chapter 12, the staff concludes that in most cases it would be desirable for tailings disposal sites to be owned and controlled by a governmental body. Briefly, disposal must be by means that reasonably assure the tailings will remain isolated under natural forces without active care and maintenance. The staff, however, has concluded that as a prudent added measure, there should be some continued monitoring and control of land uses at the site, to confirm that there is no disruption by either natural erosion or by human or animal activities. Ownership and custody by a government agency, as opposed to private individuals, appears to be the most effective way to provide this supplementary long-term control, since government institutions will probably be much more long-lived and provide more continuity than private institutions.

The UMTRCA[3] includes provisions that are consistent with the conclusions that there should be government ownership of tailings disposal sites. Specifically, the Act states that "The Commission shall require by rule, regulation or order that prior to the termination of any license . . . title to the land, including any interests therein, (other than land owned by the United States, or by a State,) which is used for the disposal of . . . " tailings " . . . shall be transferred to (a) the United States, or (b) the State in which such land is located, at the option of such State, unless the Commission determines prior to such termination, that transfer of title to such land and such byproduct material is not necessary or desirable to protect the public health, safety, or welfare or to minimize or eliminate danger to life or property."[3] The Act further provides that Indian lands are not subject to these ownership arrangements, but the custodian must enter into an agreement with NRC to allow monitoring and maintenance by the U.S.[3]

The legislation further specifically states that if transfer to the United States of title to such byproduct material and such land is required, the Secretary of Energy, or such Federal agency designated by the President, shall, following the Commission's determination of compliance, assume title and custody of such byproduct material and land. Further, if transfer to a State of title to such byproduct material is required, such State shall, following the Commission's determination of compliance, assume title and custody of such byproduct material and land. In any event, the ultimate custodian "shall maintain such material and land in such manner as will protect the public health, safety, and the environment," (Section 202a) pursuant to a license issued by the Commission.[3] The UMTRCA states that for those licenses in effect on November 8, 1981 (the effective date of Section 202), the Commission shall take into account the status of the ownership of such lands and the ability of the licensee to transfer title.

As indicated above, the Commission has concluded that in most cases it would be desirable for tailings disposal sites to be controlled by a governmental body. However, transfer of an unencumbered fee estate may be difficult to achieve since land ownership can be a complex matter, particularly in western states where it is not uncommon for surface rights, mineral rights (including oil and gas), and water rights to be conveyed as separate interests. The staff is concerned that if complete and total transfer is required, land ownership considerations (i.e., the difficulty in assembling title to all interests) may significantly impact the selection of sites. If the ability to obtain title to land became a driving force in the site selection process, this would be wholly inconsistent with the fundamental conclusion of this document; that physical isolation as opposed to institutional arrangements must be the primary means of long-term control.

However, in addition to concluding that physical site characteristics conducive to long-term stability are of overriding importance, the staff considers that in most cases government control of the surface rights is necessary 1) to control land uses at the disposal site which could lead to disruption of the tailings and 2) in general, to assure ongoing surveillance is performed. Government control is also considered prudent so that in the unlikely event that remedial action at a disposal site is required, a government agency, because it is probably the only institution which would have sufficient resources, would be available to support proper action. However, transfer of certain subsurface rights may be of less importance in providing the necessary control.

Thus, although applicants/operators must make a serious effort to acquire all interests in the land, it is considered necessary to maintain sufficient flexibility to permit the Commission to determine that surface ownership, by itself, of a site with characteristics conducive to long-term stability may be sufficient. In addition, the Commission would require appropriate notice in the public land records that the land is being used for tailings disposal and, thus, would be subject to an NRC license prohibiting the disturbance of the tailings in the exercise of any other interest in the real property.

From a public health and safety point of view, the staff considers there to be essentially no distinction between necessary land ownership requirements for licenses issued before or after November 8, 1981. As discussed in Section 12.3.11, the staff has concluded that surface ownership is necessary to assure ongoing surveillance, except possibly in the case of deep mine disposal. Thus, although UMTRCA directs the Commission to specifically consider the status of land ownership at existing facilities, the staff does not consider it reasonable to expect that any licensee or site owner would be willing to accept the onerous obligation associated with a perpetual NRC license, which would be required if land ownership is not transferred. Given these circumstances, the staff does not expect there will be a situation where waiver of surface land ownership transfer requirements is appropriate.

13.5 RELATIONSHIP BETWEEN NRC AND OTHER FEDERAL AGENCIES

In addition to the NRC, two other Federal agencies have strong roles in the area of uranium mill operations and mill tailings disposal--the Environmental Protection Agency (EPA) and the Department of Energy (DOE). Other agencies, such as the Department of Transportation, the Department of Interior (Bureau of Land Management and Bureau of Indian Affairs), Department of Agriculture, U.S. Forest Service, and the Council on Environmental Quality may become involved in a more limited way in milling operations and mill tailings disposal. However, this section describes the roles and authorities of EPA and DOE only, since these are most prominent among Federal agencies. These roles are discussed to provide a complete picture of the regulation of uranium mills and mill tailings.

13.5.1 Environmental Protection Agency

13.5.1.1 Mill Tailings Control Act

The EPA has several authorities that could potentially be used to control aspects of uranium milling operations and tailings disposal. However, the most prominent of these are authorities delineated in the UMTRCA.[3] Under Section 206 of this Act,[3] a new Section 275 is added to the Atomic Energy Act, granting EPA the authority to establish standards of "general application" covering radiological and nonradiological hazards from mill tailings located at active mill sites. EPA's responsibilities for inactive sites are similar to its duties for active milling sites. EPA was directed to develop these active site standards within 18 months of enactment of this legislation. Although they have fallen somewhat behind on this schedule, EPA intends to issue these standards as soon as possible. NRC is responsible for enforcement of these standards. Thus, EPA will establish general standards that are not specific to engineering methods and techniques. According to the UMTRCA,[3] NRC will address alternative methods and techniques required to meet the EPA standards in promulgating regulations and in licensing mills and tailings.

13.5.1.1.1 Timing of NRC Regulations

The staff proposed regulations which specifically address the matters of uranium mill operations, mill decommissioning, and tailings disposal. These proposed rule changes were issued in August 1979. Thus, NRC rule changes were proposed before EPA issued standards under Section 275 of the Atomic Energy Act, as amended.[7] Although the NRC could have delayed developing regulations until EPA issued its standards, this would have left unfinished the program to develop this document and associated rule changes that NRC has been working on for over three years.

The potential problem with having continued NRC work in this area without delay is that the standards developed by EPA could be different than requirements of NRC regulations. Differences, if they do occur, are expected to be small, because:

1. Requirements that the staff proposed are consistent with draft criteria for radioactive waste management developed by the EPA.

2. EPA has been consulted in the preparation of this document and in the development of the NRC regulations. In fact, EPA concurrence is required by the UMTRCA[3] for NRC regulations concerning tailings. The Act further requires that EPA consult with both DOE and NRC before issuing its standards.

3. Lastly, this approach is consistent with work plans for addressing the matter of mill tailings management and disposal developed by the Interagency Review Group on Waste Management.[11]

Furthermore, under Sections 81 and 84 of the Atomic Energy Act, as amended, the Commission is under an immediate duty to insure that the management of uranium mill tailings is carried out in a manner that will protect the public health and safety and the environment.

13.5.2 Other EPA Authorities

In addition to the authorities just described, EPA has several additional authorities that relate to uranium mill tailings: (1) authority to prepare Federal guidance as delineated in the Atomic Energy Act[7] and given to EPA as a part of Reorganization Plan Number 3 of 1970 (42 U.S.C. 2021(h));[12] (2) authorities under the provisions of the Resource Conservation and Recovery Act (RCRA);[13] (3) authorities under the Clean Air Act;[14] (4) authorities under the Federal Water Quality Control Act;[15] (5) authorities under the Safe Drinking Water Act;[16] (6) authorities under the Toxic Substances Control Act;[17] and (7) authority to set generally applicable environmental standards as authorized by the Atomic Energy Act[7] and transferred to EPA in Reorganization Plan Number 3 (42 U.S.C. 2021).[12]

Under its authority to recommend guidance for Federal agencies on radiation matters (42 U.S.C. 2021(h)), the EPA has developed general criteria to guide Federal agency decisions concerning radiological waste management. The mill tailings management and disposal requirements of Chapter 12 are consistent with these criteria. The UMTRCA[3] references preexisting authorities of RCRA,[13] the Clean Air Act[14] and Water Quality Act.[15] Under RCRA,[13] the EPA could potentially have regulated the generation and disposal of uranium mill tailings as a hazardous material. But control of these materials under the Atomic Energy Act[7] (provided by the UMTRCA) removes them from jurisdiction of RCRA[13] (Public Law 94-580, Section 1004 (27)). The UMTRCA[3] does, however, require consistency, to the maximum extent practicable with the requirements of RCRA.[13] With regard to the Clean Air Act[14] and the Federal Water Quality Control Act,[15] the UMTRCA[3] states that nothing in the Act shall affect the EPA authorities emanating from these other statutes. The precise manner in which EPA will apply authorities under these statutes to the matter of uranium milling has not been defined.

Under the authority to set generally applicable environmental standards (42 U.S.C. 2201), the EPA has established limits on exposures to members of the general public from the uranium fuel cycle (42 FR 2860, January 13, 1977). These standards (40 CFR 190) become effective at uranium mills on December 1, 1980, and limit individual exposures to 25 mrem per year, excluding exposures from radon. The 40 CFR 190 limits do not apply to waste management, so they will not be effective after the time that mill tailings are finally disposed of (i.e., when the tailings site is reclaimed).

13.5.3 Department of Energy

The UMTRCA assigns DOE the primary responsibility for carrying out remedial actions at inactive mill tailings sites. DOE will be responsible, in conjunction with the States involved, for selecting specific remedial actions that will meet general standards set by EPA as just described. NRC will be required to concur in important aspects of the inactive sites program such as remedial actions proposed by DOE.[3]

DOE is assigned a major role in the long-term control of tailings disposal sites. The UMTRCA specifies that DOE (or such other agency as designated by the President) shall assume custody of inactive sites that are ultimately owned by the Federal Government. Through a license, or by rule or order, the NRC may, as necessary, require DOE to perform certain monitoring or maintenance or emergency measures to protect public health and safety (Section 202a).[3]

Therefore, through its responsibilities under the UMTRCA[3] DOE assumes a lead role in developing and actually implementing methods and techniques for cleanup of inactive mill sites and disposal of mill tailings. Such activity, together with research that DOE will be undertaking on stabilization methods, will be a proving ground for tailings disposal methods. DOE, thus, assumes a lead role in the development of technology applicable to tailings disposal at all sites.

References

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3. The Uranium Mill Tailings Radiation Control Act of 1978, Pub. L. No. 95-604, (92 Stat. 3021) (1978).
4. The Surface Transportation Assistance Act, Pub. L. No.96-106 (93 Stat. 796) (1979).
5. Nuclear Regulatory Commission, "Assessment of Environmental Impacts of Uranium Mills in Agreement States," 43 Fed. Reg. 17879 (1978).
6. 10 CFR 40.4(h) (1978).
7. 42 U.S.C. 2011 et seq. (Suppl. V 1975).
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11. "Report to the President by the Interagency Review Group on Nuclear Waste Management" (Draft), p. 79, Oct. 1978.
12. "Title 3--Energy Reorganization Plan #3 of 1970," 35 Fed. Reg. 15623 (1970).
13. 42 U.S.C. 3251 et seq., 6901 et seq. (Suppl. V 1975).
14. 42 U.S.C. 1857 et seq., 7401 et seq. (Suppl. V 1975).
15. 33 U.S.C. 1151 et seq. (Suppl. V 1975).
16. 42 U.S.C. 300F (1974).
17. 15 U.S.C. 2601 (1976).

14. FINANCIAL ASPECTS OF URANIUM MILL DECOMMISSIONING AND TAILINGS MANAGEMENT

14.1 INTRODUCTION

This Chapter addresses the matter of financing decommissioning activities at a uranium mill and any long-term monitoring or care that may be required at mill and mill tailings sites after decommissioning. These two fundamentally different concepts of "short-term" financial surety and "long-term" or "perpetual care" funding are treated separately in this discussion.

Short-term financial surety refers to arrangements intended to ensure that the mill operator undertakes the required decommissioning activities. These activities would include decontamination of the mill site and structures, as well as tailings reclamation, according to license requirements and applicable regulations. The current policy of the Commission and some Agreement States requires mill operators to provide such financial surety arrangements. The purpose of this discussion is to evaluate various financial surety mechanisms, recommend which ones are adequate, and propose what changes in regulations should be made to put them into effect.

Long-term funding refers to the financing of any ongoing care and monitoring that may be required at mill tailings sites after termination of the mill operator's decommissioning responsibilities and license. The question here is whether a special fund or funds should be established to pay for any future care costs from revenues of active milling operations, rather than covering such costs by such means as appropriations from general governmental funds.

These issues have been addressed in previous studies including the Task Force Report on Bonding and Perpetual Care of Licensed Nuclear Facilities, written by the Conference of Radiation Control Program Directors,[1] and the Policy Recommendations on Financing Stabilization, Perpetual Surveillance and Maintenance of Uranium Mill Tailings, prepared by the Western Interstate Nuclear Board.[2]

14.1.1 Summary of Decommissioning and Post-Decommissioning Activities

To provide some background to this discussion, events pertinent to decommissioning (from initial licensing, through completion of milling operations, to the post-decommissioning period) are briefly described. The precise activities that will take place during the mill decommissioning phase and in the long-term will be dependent upon the procedural requirements specified in regulatory guidance yet to be developed. Therefore, this discussion cannot be a definitive statement of what will occur in the decommissioning and post-decommissioning periods. The purpose of this discussion is to characterize, approximately, the nature and extent of activities required during these periods, to enhance the understanding of what future costs should be planned for and to provide a basis for analyzing the short- and long-term funding issues.

Figure 14.1 depicts in schematic fashion, the major licensing events and relevant time periods involved in discussing decommissioning. The following discussion more completely describes these events.*

1. Initial Licensing - Decommissioning of the mill site and reclamation of the tailings disposal area must be addressed before the mill begins operation. It is unsound to proceed with operations without first analyzing how those operations will affect the problem of final cleanup. This is especially true for sites where the number of tailings disposal options is limited <u>after</u> several million tons of tailings are generated.

   Thus, a major part of the licensing process involves evaluating options for tailings disposal and committing the applicant to a specific plan, before granting a license. At this time, it is also necessary to obtain from the mill operator financial assurance that the approved decommissioning plan will be carried out. That is, provisions for short-term financial surety arrangements must be agreed upon at this time, and become conditions of the license. After a proposed milling operation is reviewed and decomissioning and reclamation approved, a consolidated source and byproduct license will be issued covering both milling operations and tailings disposal.

*Circled numbers relate to events described by Figure 14.1.

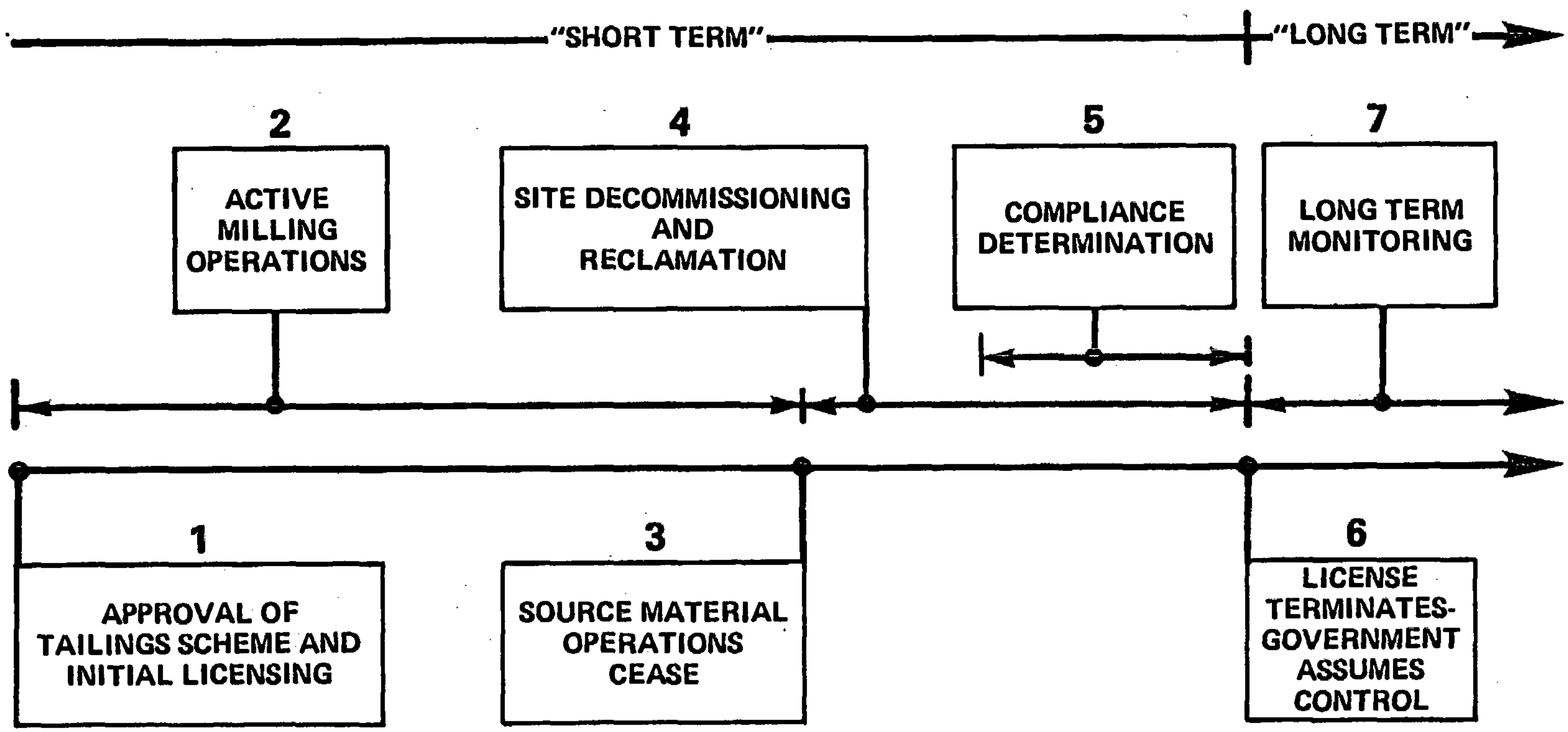

Figure 14.1 Time Line of Decommissioning Activities

Note: This drawing is intended to illustrate relationships qualitatively; this drawing is not to scale and proportions may vary from case to case.

2. 3. Mill Operation - Milling operation proceeds according to license conditions and regulations, including those ensuring future compliance with decommissioning plans, once operations terminate. Operations terminate when it is no longer economically viable to continue.

Some of the costly aspects of the tailings disposal program will be carried out before or during milling operations. For instance, lining of the tailings disposal area, to prevent seepage, will obviously have to occur before milling operations begin. If a special below-grade pit is dug (such as is featured in disposal program Alternatives 4 and 5), these excavation costs will be incurred before milling operations begin. In some instances (as indicated for Alternative 5), partial reclamation of tailings disposal areas may begin before the end of mill operations. Portions of the tailings area may be covered and revegetated, while other portions of the impoundment area are in active use.

4. Site Decommissioning and Final Tailings Reclamation--This will involve the operator decontaminating mill structures and site, permitting the tailings to dry out, and reclaiming the tailings disposal area or completing the reclamation begun during milling operation. Specific decommissioning and reclamation activities will vary from site to site and, as a consequence, the time needed to complete this activity will vary. In any event, the time period is expected to span several years, primarily to allow time for the tailings to dry sufficiently to permit the use of heavy earth-moving equipment on them. The period of drying will vary, depending on site-specific circumstances, but could last as long as ten years.

5. Compliance Determination--This period will overlap with the previous one. NRC and/or State regulatory officials will review information provided by the applicant and make independent measurements and observations in order to determine that the decommissioning activity performed by the applicant meets the terms of the license and applicable regulations. The "Uranium Mill Tailings Radiation Control Act of 1978" (UMTRCA)[3] establishes an oversight role for NRC for long-term control of all sites. Specifically, the NRC is required to determine compliance with tailings disposal requirements (Section 204(f)), and retain a continuing role of overseeing the agency having custody of the sites (Section 202(a) of UMTRCA).

Government inspectors will be onsite during this period to ensure that the thickness and shape of cover material placed on the tailings disposal area for isolation and radon attenuation is as specified in the approved tailings plan. (Also, see Section 10.3 for description of monitoring activities during this period.) In most cases, however, where revegetation is an important aspect of the reclamation scheme, there will have to be an "extended" period of observation, to determine that, in fact, vegetation is establishing itself as planned. This extended period will also be necessary to ensure that there are no "unexpected" problems with the tailings disposal scheme, such as excessive erosion in one section of the tailings area during heavy rains, or problems in "drying out" of the tailings impoundment. In the case of "unexpected problems," the applicant will be called upon to modify or correct problem areas. This would extend the time table of his reclamation efforts. The duration of this period will vary. It could be as long as 5 to 20 years, depending upon site-specific conditions.

During this period fencing of the site might be necessary to ensure that there could not be grazing or other land uses at the site, before the natural vegetation cover establishes itself.

6. License Terminates, Government Assumes Control--When site reclamation is complete, and observation indicates that reclamation is working out as was anticipated, and license conditions applicable to decommissioning have been met as demonstrated by a final survey, the mill operator will be released from his responsibilities at the site. His source material, byproduct material, or any other licenses under the Atomic Energy Act will be terminated by the NRC or the Agreement State. State agencies charged with carrying out general mining and milling reclamation laws are expected to evaluate the effectiveness of reclamation efforts, to determine compliance with these laws.

As noted in Chapter 13, the Congress, in the UMTRCA[3] has authorized government ownership of tailings sites. This Act contains a provision that title to the land shall be transferred to the United States or the State in which such land is located, at the option of such State. Therefore, at this time, the responsible agency would assume custody of the site. In the case of Federal ownership this will be the Department of Energy (unless otherwise decided by the President).

7. Long-Term Monitoring--Although the basic criterion for tailings disposal is that the disposal method not depend on perpetual human care and maintenance, as concluded in

Chapter 12, it would in most cases be desirable for tailings sites to be owned by a government agency. This prudent, added measure of control required under the UMTRCA,[3] will, for as long as it can be provided, prevent land uses that might contribute to the degradation of overburden cover isolating the tailings, or that would lead to direct human exposure.

The UMTRCA provides that the Commission may, pursuant to a license, or by rule or order, require the custodian of such property or material to undertake such monitoring and maintenance as is determined necessary to protect the public health and safety.[3] It is expected that surveillance of sites will consist primarily of periodic visual inspections of the site. A more complete description of potential surveillance activities is presented in Section 10.3. (Alternate surveillance activities are described in Appendix R). The major government monitoring activity will be carried out by DOE. NRC's oversight role is expected to involve a very small effort in comparison with DOE's effort. That is, NRC's role will be to establish what monitoring should be done, and will not be one which duplicates actual DOE inspection activities.

14.2 SHORT-TERM FINANCIAL ASSURANCE

The purpose of short-term financial sureties is to provide assurances that the mill operator will be around, or that a sufficient sum of the mill operator's money will be around, to perform tailings site reclamation. To appreciate the impact of this requirement, it is necessary to first put the nature of the costs and the technical aspects of mill decommissioning into some sort of perspective.

Reclaiming a uranium mill tailings site will basically be a dirt-moving operation, not unlike reclamation activities which are conducted at many mining sites (including non-uranium mine sites). These operations will be very different from the decommissioning of other types of fuel cycle facilities. The level of radioactivity (specific activity) associated with uranium mill tailings is much lower than the level associated with reactors or reprocessing plants. Reactors or reprocessing plants involve a high level of radioactivity and will require more elaborate or sophisticated decontamination procedures and safety precautions. Furthermore, as indicated in Chapter 11, costs associated with final stabilization of the mill tailings disposal area and site cleanup will be about $5,000,000. By comparison, the estimated cost range for decommissioning a nuclear power reactor or reprocessing plant is $50,000,000 to $60,000,000.[4] Therefore, the nature of final reclamation activities at mill tailings sites will be more like other mining reclamation activities than decommissioning of other nuclear fuel cycle facilities.

This section on short-term financial assurances attempts to define some of the surety mechanisms that are available, discussing the major distinguishing features of each. In addition, there is a general discussion of the relative merits of each surety mechanism, that is, the advantages and disadvantages of each mechanism as it would be applied in the specific situation of insuring the performance of mill decommissioning and mill tailings reclamation. Finally, a staff position on acceptable financial surety arrangements is stated and provisions incorporated in the regulation are described.

Since the primary purpose of this section is the evaluation of various surety concepts, it is written in general language. For instance, the roles of specific government agencies are not discussed, since these roles can vary among NRC regulated States and Agreement States. However, following evaluation of various surety concepts, Section 14.2.5 presents a separate discussion on implementation, where specific agency roles are described.

14.2.1 Short-Term Financial Alternatives for Assuring Tailings Pile Management

There are a wide variety of financial assurance schemes that could be investigated; however, the financial surety mechanisms considered most feasible are:

- surety bonds purchased by a mill operator from a surety company
- cash deposits to a State or Federal agency
- certificates of deposit
- deposits of securities to a State or Federal agency
- secured interests in mill operator's assets
- letters or lines of credit from a financial institution
- self-insurance by the mill operator

Alternatives involving the taxing authority of the State or Federal Government for development of a fund are not considered desirable for short-term financing and, hence, are not evaluated. A tax or fee would entail significantly greater administrative costs than the alternatives listed above. More importantly, the primary responsibility for decommissioning and reclaiming sites lies with the mill operator; paying a tax to a government agency will tend to create a situation where this responsibility is transferred from the mill operator to the government agency. Under all the alternatives just listed, the State and/or the Federal Government would oversee the establishment of assurances, but would not be heavily burdened by their administrative or fund disbursement responsibilities. The alternatives presented are those that would be expected to entail the least amount of administrative cost for assuring that reclamation and decommissioning are carried out by the mill operator, according to the approved plan. These alternatives are all described in a special report[5] on financial sureties and long-term care funding prepared for Argonne National Laboratory, in support of this generic statement. All these surety methods are either presently being used or provision has been made for their use, in the uranium milling States. The following discussion reflects broad experience with these mechanisms.

14.2.2 Criteria and Practical Considerations

The following is a brief discussion of the criteria that were considered in the evaluation of the various surety mechanisms. The primary factor that was considered was the degree to which each method would protect the disposal site from becoming a public liability. The alternatives were also evaluated from several other points of view, related primarily to administration of the financial surety, to provide a more complete characterization of what the various mechanisms would entail. In addition, the discussfon of these administrative factors identifies aspects of the mechanisms that must receive special attention or be taken account of in any regulation. These criteria include:

- Level of difficulty in obtaining funds in case of default.
- Amount of administrative time and expense required to implement and monitor the surety.
- Problems of asset valuation engendered by the surety.
- Cost of surety mechanism or loss of productive use of corporate assets was also considered since this may lead to economic inefficiencies which are ultimately passed on to the consumer.

14.2.3 Description of Alternatives and Their Applicability

14.2.3.1 Surety Bonds

Surety bonds are presently the most extensively used method for providing assurance that reclamation plans will be carried out.

A surety bond is simply a method of providing a cosigner on an obligation. The surety company takes on a possible liability for a profit. As with insurance, a premium is paid to the surety company by the insured or bonded entity (in this case the mill operator). If the bonded mill operator were to default on this obligation to carry out reclamation and decommissioning activities, the bonding company must provide the guaranteed funds to the holder of the bond (the regulatory or other suitable government agency) to have the work done, or else arrange to implement the reclamation plan itself. On the other hand, upon successful completion of reclamation activities by the mill operator, the bonding arrangement can be terminated and the bonding company released from its obligation. The assurance provided by a bond, that funds will be available on default, is no better than the ability of the surety company to pay the obligation. Therefore, NRC will only accept a surety bond from a company listed in the Department of Treasury circular #570, "Surety Companies Acceptable on Federal Bonds" (published annually) and only for an amount which is within the company's single policy limitation as identified. Surety performance bonds covering mill tailings site reclamation are generally open-ended arrangements; that is, they remain in effect until the reclamation program has been completed and approved.* The bonds can be reviewed annually and adjusted through riders to account for inflation, in addition to other variables that may affect reclamation costs, such as anticipated changes in the volume of tailings to be generated.

Surety companies are generally regulated by State laws designed to ensure that the surety company is solvent and has assets of at least a minimum amount. Also, this State regulation of sureties involves assessment of financial management practices, including examination of whether the sureties are diversified in their lines of credit. The review conducted by the Treasury Department prior to issuance of circular #570 and policing of surety companies by some State agency give the regulatory agency concerned with reclamation additional assurance that the surety will be able to pay on default. According to the special report[5] prepared in support of this evaluation, in some cases defaults on surety bonds wind up in court. Thus, they may be more of a

*Caution should be exercised to ensure that these performance bonds are in fact open ended or provide an equivalent high level of assurance as an open ended arrangement would.

problem to collect on than certificates of deposit, which generally don't become involved in such litigation. However, staff investigation has shown that collection records on these forfeitures in the coal industry have been very good.

Some background information is necessary to develop some appreciation for the costs of obtaining such a surety bond. The intent of this computation is only to give an order-of-magnitude estimate of the out-of-pocket costs incurred by the mill operator, in addition to the actual costs for performing reclamation at a typical mill. The active lifetime of the typical plant assumed in this study is fifteen years. During this period, the plant would process 9.2 million tons of ore and produce 9,600 tons of yellowcake. Assuming that the surety bond would be obtained in the mill's first year of operation and continue through five years after the active plant lifetime, the bond would be an out-of-pocket cost item for a total of 20 years. (In some cases the bond may have to continue for longer than five years after operations cease to allow for drying of the tailings. In other cases the reclamation may be an integral part of operations, where very little or no drying time is necessary, and once operations cease and the mill is decommissioned, the bond could be terminated.) If the level of assurance required thoughout this period is three million dollars, at a cost of $12.50 per $1,000 per year, the out-of-pocket cost for each of the 20 years, in 1980 dollars, is $37,500 or $750,000 total for 20 years. The cost per ton of ore processed would be eight cents per ton. The cost per pound of yellowcake would be four cents per pound. Compared to current and expected prices of yellowcake, an increase of four cents per pound, in 1980 dollars, appears to be a modest cost to bear for the financial assurances of site decommissioning and reclamation of the tailings site. Because the costs of site decommissioning and reclamation are expected to inflate in accord with general economic inflation, a periodic review of the adequacy of funds is necessary.

The major advantages of the surety bonding mechanism are:

1. Administrative costs associated with a bond, exclusive of costs related to forfeitures, would be minimal. A document sent to the regulatory agency from the surety and filed with the operator's application and some assurance that the surety is properly certified by the agency licensing sureties, would be all the effort necessary to implement the bonding mechanism. Amendments to the amount of the bond would also involve minimal correspondence with the surety. Bonding companies thoroughly screen the credit record of the companies that they bond, so the agency does not have to become involved in checking an operator's financial condition.

2. A simple rider to an existing bond, or the purchase of a new bond, is all that would be required to adjust the amount of the bond, if this is necessary.

3. No problem of asset valuation exists in this alternative. That is, the responsible agency doesn't have to continually keep track of the value of the surety, as would be necessary with a deposit of securities discussed below.

4. For a mill operator, the total bond amount can be carried as a contingent liability that will not impair his liquidity, in that the liability does not have to be reflected in the balance sheets. Thus, very few assets are lost to more productive uses during the active mill lifetime, as would be the case with cash or security deposits.

The major disadvantages of bonding are:

1. Obtaining funds from the surety upon default may be more difficult than under some other alternatives;

2. The operator incurs out-of-pocket expenses for the bond, in addition to the costs of reclamation. For a $3-million surety bond at $12.50/yr./$1000, the cost for the typical mill is about eight cents per ton of ore milled, if the full bond amount was carried for five years after operations cease. These costs would be incurred over and above those costs associated with performing reclamation activities.

14.2.3.2 Cash Deposits

A cash deposit is another method of assuring reclamation whereby an amount equal to or greater than the estimated cost of reclamation is deposited into a special account. Use of the funds in this account is restricted to covering the cost of site reclamation. If the mill operator defaults, the state or federal government could withdraw the funds from the special account and arrange to have the decommissioning and reclamation performed. Assuming that the mill operator does not default, the government agency would withdraw the money as the mill operator performs the reclamation, thus, primary responsibility for site clean-up remains with the mill operator.

Some of the advantages of this method include:

1. There is no difficulty in obtaining funds in case of default by the operator since the special deposit account is controlled by the government agency.

2. No problem of asset valuation exists in this alternative.

Some disadvantages of this method are:

1. While cash is in the account, there is a loss of productive use of corporate assets that could be used in productive investments for the mill operator. At least in the case of the federal government, no interest could be paid on funds in the special deposit account. This could potentially lead to an increase in consumer costs.

14.2.3.3 Certificate of Deposit (CD)

Generally, certificates of deposit may be issued by any bank. Cash or securities are deposited by the mill operator with the bank and a certificate of deposit is issued, made payable to a government agency. Only the government agency can cash the certificate. It can be cashed if the mill operator fails to perform decommissioning and reclamation activities according to the approved plan, and used to have these activities performed. On the other hand, if the mill operator satisfactorily decommissions the mill and reclaims the tailings site, the government agency will cash the certificate of deposit and return it to the mill operator. Therefore, the certificate of deposit surety mechanism is effectively very much the same as cash deposits.

Some advantages of this method are:

1. There is minimal difficulty in obtaining funds in case of default by the operator, since the certificate is held by the government agency.

2. No problem of asset valuation exists under this method.

3. The additional cost to the mill operator, above the actual amount of the certificate, that is, the fee for purchasing the certificate of deposit, is small.

Some disadvantages of this method are:

1. More effort is needed to adjust the amount of the fund than is required under some other alternatives. (A new certificate of deposit must be purchased.)

2. Certificates of deposit result in a large amount of corporate assets being unavailable for the conduct and development of business. The interest rate on these deposits would, in most cases, be significantly less than the percent profit earned by the corporation. As with cash deposits, this could potentially lead to increased consumer costs.

14.2.3.4 Deposits of Securities

Theoretically, the securities referred to here could be of several different kinds including: long-term U.S. bonds; municipal bonds; or corporate securities. Under this method, securities with a value greater than the actual estimated reclamation cost usually would have to be required. In any case, bonds generally would be discounted from their market value, to ensure that the cash value is sufficient if and when the mill operator defaults on reclamation.

Some of the advantages of this method include:

1. There is little difficulty in obtaining the funds if the operator defaults, as the government agency already has the necessary funds.

2. The mill operator incurs no out-of-pocket expenses (such as annual premium for a surety bond).

Some disadvantages associated with this method are:

1. Unless a trust administrator is used, the responsible government agency must play a more active role under this method than under most other alternatives. It must hold the funds, distribute dividends from the securities to the mill operator, determine security values, and exchange securities for other securities, as the mill operator desires or as the market demand changes.

2. The values of the securities will fluctuate as market demand changes, thus causing additional administrative time to be spent to ensure that the proper amount is maintained in the fund.

3. Some difficulty is expected in adjusting the amount in the account. This involves contacts with the mill operator for additional securities, and fund administration time.

4. There is a loss of productive use of corporate assets. Securities lose their liquidity, and although exchanges of securities are possible, the regulatory agency must approve the securities used. Investments which might be acceptable for security deposits generally do not earn as much as other investments might.

14.2.3.5 Secured Interests

A secured interest is an interest in personal property or fixtures of the mill operator that gives to the holder of the interest, rights to possession of the property, to ensure payment of an obligation. A secured interest running to a government agency gives that government agency the right, in the event of default by a mill operator, to take possession of the assets it has an interest in and sell them in satisfaction of the claim. Such an agreement is legally established through formal documents. In most cases where a secured interest has been properly created, the holder of the interests has priority over these assets if the mill operator goes bankrupt. The secured assets may be repossessed by the secured interest holder, and proceeds from the sale of the assets are not required to be shared with other creditors in bankruptcy proceedings. Generally, secured interests are governed by Article 9 of the Uniform Commercial Code,[6] which has been enacted in all States except Louisiana, with only a few local variations.

Some of the advantages of this method are:

1. No out-of-pocket expenses are incurred by the mill operator. The only costs involved would be those associated with drawing up the required documents.

2. There is no loss of productive use of corporate assets. The collateral which is used as the secured interest can stay with the mill operator for use in his operations.

Disadvantages of this method are:

1. A significant amount of time may be necessary to administer this procedure. In addition to the man-hours that may be needed in case of default, it may take a substantial amount of time to establish a security interest by completing all the necessary paperwork and inspecting the collateral that is used as the secured interest. Time may also be necessary to periodically check the assets used for collateral to ensure that they haven't been sold or depreciated substantially. When assets of the mill operator are used as collateral, there is an additional problem of valuation of the assets. It is often difficult to place a value on assets such as equipment.

2. When it becomes necessary to adjust the amount of the fund, additional assets must be added to or withdrawn from the agreement. Again, this involves the problem of valuation of assets.

3. Significant difficulty may exist in obtaining the fund on default. In fact, it is likely that a lawsuit will result.

4. Under the secured interest alternative, the government may have difficulty disposing of the secured assets.

14.2.3.6 Irrevocable Letters of Credit

Irrevocable letters of credit are another short-term alternative to ensure decommissioning and reclamation of mill and tailings sites. Traditionally, letters of credit have been primarily used in international trade. However, they are beginning to be used more in domestic transactions. In using this method, the mill operator would apply to a bank for the issuance of a letter of credit that commits the bank to pay the beneficiary, the government, when the letter of credit comes due.

Open-ended letters of credit are traditionally not written. However, the staff considers that the same level of assurance provided by an open-ended surety mechanism can be obtained with an automatically renewed, irrevocable letter of credit. If the letter of credit were written for a specified period of time (e.g., one year) it would have to state that the bank agreed to automatically renew the letter of credit upon expiration unless the bank notified the beneficiary (the regulatory agency) and the principal (the licensee) some reasonable period of time (e.g., 90 days) prior to the renewal date of their intention not to renew. In such a situation the surety requirement still exists and the licensee would be required to submit an acceptable replacement surety within a brief period of time so as to allow at least 60 days for the regulatory agency to collect.

Proof of forfeiture must not be necessary to collect the surety so that in the event that the licensee could not provide an acceptable replacement surety within the required time, the surety should be automatically collected prior to its expiration. The conditions described above would have to be clearly stated on any surety instrument which is not open-ended, and must be agreed to by all parties. Such an arrangement demands efficient procedures for collecting the surety so that bureaucratic red tape will not prevent the beneficiary (the regulatory agency) from collecting in the required time frame. Procedures to initiate collection would have to be automatic and nondiscretionary for this to provide the needed level of protection.

For a mill operator to obtain a letter of credit, he must apply to a bank or financial institution that will issue one. Not all banks will issue a letter of credit. The mill operator will often be required to give the bank some type of security interest in his property. In the alternative, he may need to supply capital to the bank to ensure that he will not default.

For a three million dollar letter of credit at a bank that charges a fee of 1.5 percent of the face value of the letter of credit per year, the cost for the typical mill would be about seven cents per ton of ore milled, in 1980 dollars, if the lifetime of the mill and the duration of the letter of credit are the same.

Some of the advantages of this method include:

1. This method requires only a minimal amount of time, on the part of the government agency, to administer. The letter of credit is filed with the operator's license. A check of the bank's financial status may also be desirable.

2. There is no valuation of assets problem for the government agency. The agency simply receives the letter of credit for the amount required.

Disadvantages of this method include:

1. Some difficulty exists in adjusting the amount of the surety. This would require the issuance of a new letter of credit from the bank.

2. Some out-of-pocket expenses, associated with obtaining the letter of credit, are incurred.

3. This alternative may require that the mill operator provide some sort of collateral to the bank, resulting in the loss of assets for more productive uses.

14.2.3.7 Self-Insurance by the Mill Operator

As used in this analysis, self-insurance means an arrangement whereby the operator agrees to perform the reclamation and can show financial stability over the long term. In effect, it is an alternative involving no additional assurance other than the operator's legal obligation to perform decommissioning, which is required as a condition of the license. The legal obligation will exist regardless of any separate contract, whereby the operator agrees to perform decommissioning.

Some of the advantages of this alternative are:

- No adjustments in amount of surety would be necessary.
- No valuation problem exists.
- No loss of productive use of working capital.

Some disadvantages are:

In case of default, the government agency would have to obtain a legal judgment based on its contract with the mill operator, and would have to execute its judgment, if the operator has assets out of which the judgment can be satisfied. Although this approach is favorable to mill corporations and perhaps credible when a large, diverse corporation is involved, it provides no additional assurance beyond regulations requiring mill decommissioning and reclamation of tailings. (See Chapter 13 for more complete discussion of current regulatory authorities following mill operation and prior to decommissioning.)

14.2.4 Conclusions and Staff Recommendations

There are a number of surety mechanisms that the staff considers will provide adequate public protection against mill operator default prior to performance of reclamation. The alternatives that the staff finds acceptable on a generic basis are the surety bonds, cash deposits, certificates of deposit, deposits of government securities and irrevocable letters of credit. These alternatives were all found to be acceptable because without incurring a great administrative burden, each mechanism can be structured in such a way that a high degree of assurance that the site will not become a public liability is provided. Although the administrative burdens associated with the various mechanisms that the staff has approved do vary to a certain extent, this variance is not expected to be significant. Approving a range of satisfactory alternatives allows the mill operator a measure of flexibility in selecting the mechanism that best suits his needs. In addition, this range allows the use of a combination of surety mechanisms. For instance, a mill operator planning to perform staged reclamation may wish to obtain a surety bond at the time of initial licensing, when assets are generally more limited. Then, once milling operations begin and income is being generated, the mill operator could begin making deposits to an escrow account. When the escrow account reaches a point where the amount is sufficient to cover the costs of reclaiming the maximum amount of tailings exposed at any one time, the bond can be dropped.

While the other financial assurance mechanisms discussed above may be acceptable in certain cases, with the exception of self insurance, they do not appear acceptable on a generic basis. It is the judgment of the staff that the drawbacks of the other surety mechanisms makes them unacceptable; for example, the administrative burden associated with monitoring a secured interest surety, in addition to the potential difficulty associated with obtaining and then disposing of the secured assets, makes this mechanism unacceptable on a generic basis. Plans for alternative surety methods would have to be evaluated on a case-by-case basis. However, the staff has determined that since the self-insurance option provides no additional assurance, this mechanism will not be considered in satisfaction of the surety requirement.

The UMTRCA[3] states that provisions for financial surety should be incorporated into regulations. Specifically, the staff proposes that the regulation:

1. require that a surety be provided;

2. require that the amount of the surety be equal to the cost estimates in the approved plan for site decommissioning and tailings disposal, cost estimates should be based on contractor costs to perform these activities; therefore, they should include equipment, labor, profit, etc. The amount of the surety should also include the long-term funding charge since this will not be paid to the ultimate custodian until termination of the license.

3. allow flexibility regarding the specific surety mechanism employed, stating that:

   - cash deposits
   - surety bonds
   - certificates of deposit
   - deposits of government securities, and
   - irrevocable letters of credit

   would be acceptable on a generic basis, and other surety mechanisms would be evaluated on a case-by-case basis, for acceptability.

4. stipulate those factors that must be considered in setting up the surety arrangement:

   - Inflation;

   - Term of the mechanism (i.e., the term of the surety must be open-ended--it must remain in effect until the regulatory agency releases it, on satisfactory completion of decommissioning and reclamation; or provide an equivalent level of assurance), and

   - Adjustment provision that requires a periodic review of surety adequacy. The amount of the surety should be adjusted to recognize any increases or decreases resulting from inflation, changes in engineering plans, activities performed and any other conditions affecting costs. This will yield a surety that is at least sufficient at all times to cover the costs of decommissioning and reclamation of the areas that are expected to be disturbed, before the next license renewal. This provision will provide an incentive to design systems involving staged reclamation, whereby costs for the surety mechanism are reduced. Since financial risk and exposure during the critical site decommissioning period, when the mill is shut down and no longer producing revenue, are dramatically reduced, the required amount of surety coverage and associated costs are also minimized.

14.2.5 Implementation of Short-Term Financial Assurance Proposal

It has been the policy of the staff to require mill operators to provide financial surety arrangements before licensing. However, as indicated in Chapter 13, the UMTRCA[3] clearly authorizes the Commission to issue such financial assurance requirements. In addition, the Act[3] states that the Commission shall take into account financial arrangements required by other agencies, so as to avoid unnecessary duplication and expense.

With respect to NRC licensing cases, implementation of this financial assurance requirement can occur in several different ways. The NRC can directly administer the surety arrangements, or else State agencies can administer the financial assurances, where this is convenient. For example, in the situation where a State agency handles the surety arrangements for related mining activities, it has not proven to be that difficult for them to handle the surety arrangements covering the mill and mill tailings site decommissioning and reclamation also, since this is only a relatively small addition to the necessary mine reclamation. In fact, this is the current situation in several States.

Regarding the implementation of the financial assurance requirement in the Agreement States, much of the legal framework required of States to implement assurances for stabilization and reclamation of tailings piles is in place or is forthcoming in Colorado, New Mexico, Texas and Washington. All the Agreement States that have active mills have the authority to require mill operators to obtain one of the financial sureties discussed in this chapter.

Colorado allows surety bonds, cash deposits and government securities. Certificates of deposit, and letters of credit are not specifically mentioned in the Rules and Regulations of the Colorado Mined Land Reclamation Board (5/77 Rules 1-7);[7] however, the authority seems broad enough for the Board to accept these surety mechanisms also.

New Mexico's Radiation Protection Act[8] gives the Environmental Improvement Board authority to promulgate regulations requiring the posting of a surety to ensure compliance with regulations and license conditions.

The Texas Surface Mining and Reclamation Act[9] allows surety bonds, cash deposits and some negotiable securities.

The State of Washington's Department of Health and Social Services Regulation[10] does not specifically mention a surety requirement; however, authority exists to place conditions on licenses, including a surety requirement.

On the basis of this, the current regulatory framework in the Agreement States appears to be compatible with the staff proposals just delineated concerning financial surety arrangements.

14.3 LONG-TERM FUNDING

As stated in Chapter 12, the staff concludes that tailings should be disposed of so that no ongoing active care of disposal sites be required. Furthermore, the staff has concluded that mill structures and sites should be decommissioned to allow unrestricted use of portions of the site away from the tailings disposal area. As additionally stated in Chapter 12, the staff has concluded that it would be prudent to continue monitoring and exercising land use controls at most disposal sites. Such controls, for as long as they could be provided, would constitute an added measure of protection to that provided by physical containment barriers. The purpose of this monitoring activity would be to confirm that the site was not disrupted by natural erosion or by human or animal activities. The nature of the situation at these sites would, therefore, be a passive one. No active maintenance would be required and costs at individual sites are, therefore, expected to be relatively small (on the order of about two thousand five hundred dollars per year - 1978 dollars - as described below).

As indicated in Chapter 13, the UMTRCA[3] specifies arrangements that assure that such long-term control is possible. Specifically, the Act requires that mill tailings disposal sites be transferred to the United States or the State in which such land is located, at the option of such State, except where the Commission determines that government ownership is not "necessary or desirable to protect the public health, safety, or welfare or to minimize or eliminate danger to life or property"[3] (Section 202a). The Act further requires, in any case, that a license be in effect and empowers the Commission to require the custodian to undertake such control measures, as may be necessary (Section 202a).

Although costs on an individual site basis are expected to be small, overall monitoring costs could be appreciable. Therefore, the question of how such long-term costs should be provided is pertinent. The UMTRCA states that "if the Commission determines that any long-term maintenance and monitoring is necessary, the licensee.. . . will make available such . . . financial arrangements as may be necessary . . . ."[3] (Section 203). The Act[3] further states that the Commission shall take into account financial arrangements required by other agencies, so as to avoid unnecessary duplication and expense.

This section presents the staff proposed position on the question of funding for long-term monitoring of tailings disposal sites.

14.3.1 Staff Proposal

The staff proposes the following with regard to the issue of long-term funding:

1. Funds should be provided by each mill operator to cover the costs of long-term monitoring.

2. A one time charge (adjusted by the change in the Consumer Price Index to be equivalent to $250,000 in 1978 dollars) per site should be levied on mill operators, before termination of a license. The charge would be paid to the Federal government unless the State in which a mill is located chooses to have this responsibility. In any event, the sum for long-term monitoring should be paid to whichever governmental body is going to be the ultimate custodian of the site.

   If the long-term monitoring charge is paid to the Federal Government, it should be deposited in the general treasury funds of the United States, as opposed to a special earmarked fund that might be established. In the situation where a State opts to have custody of a site, it will also be responsible for fund management. Therefore, if a State wishes to deposit long-term surveillance funds in an earmarked account, rather than seek an annual or bi-annual appropriation from the State legislature for this purpose, they would be free to do so.

3. If monitoring requirements at a particular site are determined, on the basis of a site specific evaluation, to be significantly greater than those assumed here (e.g., if it is determined that fencing is appropriate), variance in funding requirements should be arranged.

The staff believes that this position is reasonable because it conforms in general principle with the notion that the waste generator should pay all costs for waste disposal, including any long-term costs incurred. Based on what the staff expects will be needed in terms of the long-term monitoring at most tailings disposal sites, the proposed arrangement is a fair, simple, and efficient one.

More complicated schemes involving such things as earmarking of funds and sliding scales for charges levied on operators, are unwarranted and inappropriate, given the uncertainty that exists over long-term stability of institutions, and other factors, such as long-term performance of interest and inflation rates. The proposed arrangement is a simple one, and as such, is adequate to handle the kind of uncertainties involved. The following discusses, in more detail, aspects of the long-term funding issue that were considered by the staff, and alternatives to the aforementioned proposal that were evaluated.

14.3.2 Assumptions

Establishing requirements for funding to cover the costs of long-term monitoring of the mill tailings sites depends on the assumptions that are made primarily with respect to: (1) the nature and extent of effort required for site control; and (2) the balance between interest and inflation rates over the long-term. Briefly, the primary assumptions on which the staff proposal is based are:

1. Disposal methods will be those that do not depend on active care and maintenance, after license termination. As a result, ongoing costs will be relatively small. The equivalent of two thousand five hundred 1978 dollars per mill site per year will be required for long-term monitoring.

2. The average real rate of return on invested money will be one percent.

14.3.3 Level of Monitoring Activity and Costs

As described in Section 10.3, it is expected that monitoring at tailings disposal sites will involve annual visits to confirm that isolation provided by the tailings disposal program is performing as anticipated and to ensure that the tailings are not being disturbed by human activity. Such visits might involve taking photographs of the site to permit the following of trends in site conditions from year to year. No active care or remedial actions such as irrigation of vegetation, hauling of fill to the site, regrading, seeding or the like are expected to be required. There will be no replacement of fencing which may be left at the site or maintenance of any onsite facilities or equipment. There will also be no sampling or airborne environmental measurements at the sites. Some groundwater monitoring might be performed by inspectors using portable groundwater sampling equipment.

Virtually the only cost item for long-term monitoring, therefore, is expected to be the time and effort of government inspectors who will visit the sites--their time in travel, making inspections, and preparing for and following up on inspections. (See Appendix R for a more complete discussion of this and alternate monitoring scenarios that correspond to what might be required if active care of sites is necessary.)

There will obviously be some variation in monitoring costs from one site to another. The fact that no mill tailings sites have actually been reclaimed results in uncertainty about the precise nature of monitoring that will be required. The scenario described above for monitoring is based on the staff's current best estimate of what will be required. As stated previously, the staff considers that, with the uncertainties involved, it is prudent to establish long-term funding arrangements using a conservative estimate. Therefore, the staff has selected $2,500, the upper bound of a range ($1,250 to $2,500) of estimated annual costs, per site to account for such uncertainties.

There are several additional monitoring and site control activities, not described in the above monitoring scenario, that might, under some conditions, be prudent to perform. The staff considers that these activities are sufficiently unlikely or low in cost, to make the above estimates of costs reasonably conservative and, therefore, appropriate for establishing long-term funding requirements. In rare cases, it may be decided at a later time that site control and monitoring requirements at a particular site will be significantly greater than those assumed above. In such cases, a variance in funding requirements can be arranged if the level of expected activity is judged to be sufficiently different than that assumed here. The following discusses more fully these potential additional activities and why the staff proposed funding scheme is appropriate. (For additional discussion of alternate monitoring scenarios and associated cost estimates refer to Appendix R.)

As discussed above, it may be prudent in some cases for inspectors to sample a few groundwater monitoring wells during their inspection and analyze for an indicator element such as radium-226. The preoperational, operational and compliance determination monitoring programs will be extensive, both from the point of view of what is done and the period of time covered (15-30 years). These programs will be sufficient, therefore, to determine if there are any potential groundwater problems at a site. If problems are identified and remedial action is considered necessary, this will be determined before a license is terminated, and the operator will be available to take action. Therefore, any sampling over the long-term would have the purpose of confirming that there are no problems occurring and, as such, will be very limited.

In some rare cases, it may be necessary to visit a site more frequently than annually. For example, if there were a period of very severe weather (e.g., heavy rainfall and flooding, a tornado or an earthquake near a site), a special inspection might be required. However, the staff considers that such visits would be very infrequent and that the degree of conservatism in the staff estimate is sufficient to account for them.

In some rare cases, site observation during the operational, reclamation and compliance determination periods might indicate that a site may either require continued fencing or some degree of active care. This is most likely to occur, if at all, at currently active sites where operations began prior to the establishment of the proposed staff requirements for tailings disposal. If this occurs, the expected level of care could be estimated on the basis of site specific conditions and a fee different than that recommended here could be levied on the mill operator to cover the expected additional ongoing effort. This would be worked out in the process of terminating a license and would have to be based on a benefit-cost assessment of the options for taking steps to eliminate the need for such active care similar to that described in Section 12.4. The regulations on long-term funding, therefore, should provide for such an unlikely contingency, allowing for charges greater than the equivalent of $250,000 in 1978 dollars to be levied if extenuating circumstances warrant this.

Despite the fact that such a special case might arise, the staff considers that a funding level should be set now, as opposed to taking a "wait and see" approach at each site. Estimates of what will be required in the future, in the way of site monitoring, will always be speculative. The staff believes the estimates made here to be reasonable, if somewhat on the conservative side. Fixing a fund amount now establishes a basis for planning by mill operators and assures that the full costs of operation including waste disposal are understood prior to the beginning of these operations. Further, establishing a fund amount now will tend to assure that there is uniform and equitable treatment of mill operators; variances from the fund amount will occur only where monitoring of site control activities are significantly different than those assumed here. Finally, this approach will tend to discourage adoption of a view that contribution to a "long-term care" fund might be substituted for development of isolation schemes which will eliminate the need for active care. In some limited situations, a degree of surveillance beyond that postulated here might be required. If this is needed, cost estimates must be made on the basis of site specific conditions. (For illustrative alternate scenarios, see Appendix R.)

14.3.4 Interest and Inflation Rates

The staff proposal involves an arrangement whereby funds paid to the Federal Government are paid to the general treasury, as opposed to an earmarked "perpetual" fund. Under this arrangement, no attempt would actually be made to keep track of the funds, as they are paid by operators, using them only for monitoring of mill tailings disposal sites, as would be done with an earmarked fund. The theory of an earmarked, perpetual fund is that funds would be accumulated in a special account and invested so that expenses for monitoring could be covered by the net annual yield, taking into account inflation rates and interest. The present worth of the fund would remain fixed in perpetuity. The staff rejected the concept of a Federally managed perpetual fund on the basis that it is unrealistic. Once milling operations cease, its value would depend solely on interest and inflation rates that fluctuate markedly. Although the perpetual fund arrangement is not opted for, the only reasonable way to determine what would be a fair charge on mill operators for future monitoring is to hypothesize that such a fund will exist. That is, the problem is determining how much should be paid by each operator, so that if a special fund were set up and invested, it would annually yield sufficient funds to pay the costs of inspection. The intent is to set up an arrangement which is equivalent to an earmarked "perpetual" fund, but avoids its management load.

The rate of inflation over a very long time period cannot be predicted. However, as the rate of inflation increases, it is reasonable to expect that interest rates will also increase, since investors will seek investments that assure that principal plus compounded interest will at least maintain the buying power of the original invested principal. The real rate of interest is the return on the principal over and above the rate of inflation, i.e., the increase in the real value of the principal. As is stated in a report prepared by the Kentucky Legislative Research Commission on Nuclear Waste Disposal,[11] conceptually, the interest rate earned on any investment includes a real component and an inflation component. "The real rate of interest is a reward for foregoing present consumption and for bearing the risk that the investment may be defaulted. The inflation component theoretically adjusts for losses in purchasing power of the investment caused by inflation."[11]

As a guide to choosing a real rate of interest for determining what charge should be levied on mill operators, the staff reviewed past performance of interest and inflation rates. The staff considers that the long-term government bond interest rate is an appropriate rate to assume in this situation. Government bonds, being conservative investments, bear a lower rate of interest than most investments. Table 14.1 shows how the interest rate and inflation have performed since 1951. Long-term government bond rates and the consumer price index, a measure of inflation, are compared. The relationship between the rates has fluctuated significantly but the average real interest rate has averaged very near one percent (0.96 percent) since 1951. Accordingly, the staff has decided to use one percent as the real rate of return in the calculations.

As the Kentucky report points out, "the data indicate an upward trend in both interest and inflation rates during the past quarter century . . . "[11] In addition, there has been significant variation in the real rate of interest from year to year. If the period 1953-1973, which was not characterized by extreme inflation, is examined, it can be seen that the real interest rate averaged 1.82 percent. However, the period 1973-1979 was characaterized by high inflation, and when these figures are added into the calculations, the real interest rate drops to about one percent.

Since the conservatively estimated average annual long-term monitoring cost is about $2,500, assuming an average one percent real rate of return, a $250,000 deposit (1978 dollars) per site would be necessary to cover the costs for long-term monitoring activities.

14.3.5 Options Based on Different Assumptions

Based on the requirement that tailings be disposed of such that no active care be necessary over the long term, the staff has proposed an arrangement whereby charges for funding of long term monitoring be a fixed amount from site to site as long as this requirement is satisfied. This is appropriate since, without a need for active maintenance, costs will be independent of the size of the tailings pile.

Several other options, stemming from different assumptions, were evaluated by the staff, with respect to the long-term funding issue.

No Fund

The alternative of having no long-term fund at all was among those options considered by the staff. Because costs associated with the passive monitoring mode are expected to be relatively

Table 14.1 Interest Rates, Inflation Rates and Real Interest Rates*

Year	Long-Term Govt. Bond Rates (1+r)	Change in Consumer Price Index (1+i)	Imputed Real Interest Rates (1+I)
1951	1.0257	1.079	.9506
1952	1.0268	1.022	1.0047
1953	1.0294	1.008	1.0212
1954	1.0255	1.005	1.0204
1955	1.0284	.996	1.0325
1956	1.0308	1.015	1.0156
1957	1.0347	1.036	.9987
1958	1.0343	1.027	1.0071
1959	1.0407	1.008	1.0324
1960	1.0401	1.016	1.0237
1961	1.0390	1.010	1.0287
1962	1.0395	1.011	1.0282
1963	1.0400	1.012	1.0277
1964	1.0415	1.013	1.0281
1965	1.0421	1.017	1.0247
1966	1.0466	1.029	1.0171
1967	1.0485	1.029	1.0190
1968	1.0525	1.042	1.0101
1969	1.0610	1.054	1.0066
1970	1.0659	1.059	1.0065
1971	1.0574	1.043	1.0138
1972	1.0563	1.033	1.0226
1973	1.0630	1.062	1.0009
1974	1.0699	1.110	.9639
1975	1.0698	1.091	.9806
1976	1.0678	1.058	1.0093
1977	1.0706	1.065	1.0053
1978	1.0789	1.077	1.0018
1979	1.0874	1.113	.9770
MEAN: 1951-79	1.0488	1.0393	1.0096
MEAN: 1953-73	1.0437	.976	1.0184

*SOURCES: U.S. Bureau of the Census, Historical Statistics of the United States, Colonial Times to 1970, Bicentennial Edition, Part 2 (U.S. Government Printing Office, Washington, D.C.), p. 1003,[12] September 1975. Board of Governors of the Federal Reserve System, Federal Reserve Bulletin, March 1975, p. A-30, June 1977, p. A-27.[13] U.S. Department of Labor, Bureau of Labor Statistics, Monthly Labor Review, February 1975, p. 117; February 1977, p. 117.[14]

small, and certain administrative costs associated with maintaining the fund are inherent, the no-fund option demanded some consideration. The uncertainties about the various aspects of the long-term funding question (that is, interest and inflation rates, stability of institutions, actual level of monitoring needed) and the inevitability of incurring administrative burdens, may lead one to question whether establishing a fund would be appropriate to cover what the staff considers will be a relatively small cost. However, it is not possible to quantify precisely what the administrative burden of a fund will be or to place a value on the uncertainties, in order to weigh these factors against the benefit of establishing a fund. Therefore, the staff has concluded that the notion that the waste generator should pay the full care costs should be the guiding principle on this issue. A governmental body will ultimately own the tailings sites. Thus, if no long-term fund were established, the taxpayers would be footing the full bill for monitoring the sites. This would not be fair. The staff believes that the recommended arrangement resolves this concern, yet at the same time is a very economical and simple solution.

Levy on Product

If one makes the assumption that some active care will be necessary following tailings reclamation, alternate funding schemes appear to be logical. For example, in the situation where active care over the long term is necessary, the size of the tailings pile becomes a critical factor. The size of the pile would directly impact the amount of care and associated care costs required; i.e., the bigger the tailings pile, the more maintenance that will be required. Under these circumstances, it would seem logical to have some sort of levy imposed per pound of yellowcake produced, or per ton of tailings generated. Obviously, this would result in a fund that would correlate with the size of the pile, thus producing a more equitable situation under the assumed circumstances. It should be noted that this type of fund has been created for a few low-level waste burial grounds, one in Kentucky[11] and one in South Carolina.[15] At these sites, due to the nature of the material involved, it is assumed that some active level of care over the long term will be required. New Mexico instituted a similar type of fund as an interim measure for mill tailings, until NRC adopts regulations governing continued care activities. They are requiring mill operators to deposit ten cents a pound, up to $1,000,000.[8]

Insurance Fund

It has also been suggested that funds be established to cover the costs of any unexpected extensive monitoring or remedial actions that may be required. This would essentially be an "insurance fund." Due to its very nature, setting the amount of such a fund would be very speculative. This approach would be more appropriate at existing sites where options for tailings disposal are more limited (see Section 12.4) and where uncertainties about long-term monitoring efforts are greater than at new sites. It was at least in part to provide such insurance that New Mexico insituted the long-term funding program described above. The staff proposed program recognizes the need for flexibility to increase funding amounts above the minimum in certain cases primarily those involving existing mills, where it is expected that more surveillance effort than assumed in establishing the minimum might be required or where uncertainties are large enough to make increased funding prudent.

Negotiable Fee

Another long-term funding alternative would be to establish a funding requirement, but leave the charge negotiable. Under this type of program, site specific features could be evaluated against a set of criteria and an appropriate long-term funding amount could be chosen on an individual basis. Although estimates of what will be required in the future will always be speculative, the staff believes that a minimum level of site monitoring will be necessary. Furthermore, establishing a fund amount now rather than taking a "wait and see" approach at each site establishes a basis for planning by mill operators and provides for uniform treatment of mill operators.

Total Fund Amount

Besides changing the structural aspects of the long-term fund (that is, tax or levy versus fixed charge, or earmarked fund as opposed to deposits to the general treasury), different assumptions concerning the anticipated level of long-term monitoring and, thus, the appropriate amount of the fund, can be made.

For illustrative purposes, Table 14.2 shows the appropriate funding amounts if other assumptions concerning annual monitoring costs and real interest rates are made. It describes the appropriate level of funds for several annual monitoring amounts at the real interest rates of one, two, and three percent.

Table 14.2 Total Fund Amount to Cover Long-Term Monitoring

		Annual Monitoring Amount			
		$1,000	$2,500	$5,000	$30,000
Real Interest Rate Percent	1	$100,000	$250,000	$500,000	$3,000,000
	2	$30,000	$125,000	$250,000	$1,500,000
	3	$33,300	$83,300	$166,700	$1,000,000

14.3.6 Implementation of Staff Long-Term Funding Proposal

As previously stated, the UMTRCA[3] requires government ownership of the mill tailings sites by either the Federal Government or the States, at the States' option, unless the Commission determines, before such termination, that transfer of title to such land and such byproduct material is not necessary or desirable to protect the public health, safety, or welfare or to minimize or eliminate danger to life or property.

Since the question of ultimate site custody may not be decided until termination of the mill operator's license, the staff has concluded that the simplest arrangement for the collection of monies to cover the costs of long-term monitoring is for the charge to be paid, upon termination of the license, to the governmental agency that will be the ultimate custodian of the site. The amount of the long-term fund will be included in the surety mechanism from the time of initial licensing until termination of the license.

The staff considered proposing a requirement that payments be made on an installment basis. A problem with such a requirement stems from the fact that the decision as to who would have ultimate site custody might not be resolved until termination of the license. Potential collection schemes that would resolve this problem included:

1. The Federal Government could collect the monies for long-term monitoring in all cases, and transfer funds to a State if the State opts to have custody of the disposal site; or

2. The States could collect the monies for long-term monitoring in all cases and transfer the funds to the Federal Government if they opt to transfer title of the disposal site; or

3. The Federal Government could collect funds from those operators regulated by NRC; and the Agreement States could collect funds from operators whom they regulate. Under this arrangement, fund tranfers would be necessary if an Agreement State chose to turn a disposal site over to the Federal Government, or if a non-Agreement State chose to hold title to the land.

The staff concluded, however, that such schemes were unwarranted and offered no benefit over the proposed arrangement. The proposed collecton method is adequate and, furthermore, more attractive because it will be simpler and more efficient than the schemes just described.

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9. Texas State Legislature, Texas Surface Mining and Reclamation Act, Jan. 21, 1975.

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15. Clemson University, Department of Agriculture Economics and Rural Sociology, South Carolina Agricultural Experiment Station, "Agricultural Economics and Rural Sociology Report--Economic Analysis of Funding Arrangements for Maintenance, Surveillance, and Contingency Costs Associated With Burial of Low-Level Radioactive Waste in South Carolina," Dec. 1974.

15. SUMMARY OF ENVIRONMENTAL IMPACTS, PRODUCTIVITY AND RESOURCE COMMITMENTS

15.1 INTRODUCTION

Various potential adverse environmental impacts resulting from conventional milling of uranium ores are discussed in earlier sections of this statement. Environmental impacts for a base case featuring a low-level of environmental control are presented in Section 6.2. Environmental impacts from a cluster of mills are presented in Section 6.3. The cumulative radiological impacts for the U.S. uranium milling industry (1979-2000), with no control of airborne emissions, are evaluated in Section 6.4. The environmental impacts evaluated for the base case industry in Chapter 6 are based on nuclear energy growth projections contained in Chapter 3, and the characteristics of the model region and the model mill described in Chapters 4 and 5, respectively.

Alternatives for mitigating environmental impacts from operating mills and disposed tailings are described in Chapter 8. Chapter 9 evaluates the impacts from these alternatives, and Chapter 11 estimates the costs for implementing these alternatives. A final benefit-cost evaluation of alternatives considered is presented in Chapter 12. Based on this, regulatory actions for mitigating environmental impacts from operation of mills and tailings disposal are proposed in Section 12.2. These requirements are briefly summarized below.

1. <u>Mill Operations</u>

   - Milling operations shall be conducted so that radiation protection limits applicable to offsite individuals as specified in 10 CFR 20 and 40 CFR 190 are met. The primary means of accomplishing this should be by means of emission control. Institutional controls, such as extending the site boundary and exclusion area, may be employed to ensure that offsite exposure limits are met, but only after efforts have been taken to control emissions at the source to the maximum extent reasonably achievable.

2. <u>Tailings Disposal</u>

   - Airborne emissions (primarily radon) from the tailings will be reduced to background levels. Specifically, radon emissions from tailings will be reduced to a 2 $pCi/m^2/sec$ increment above background flux rates which will assure that resulting total flux rates above tailings piles will be within the variations in flux which naturally occur.

   - Seepage of toxic materials will be eliminated or minimized to the maximum extent reasonably achievable.

   - Potential disruption and misuse of tailings leading to unsafe direct human exposure will be minimized through isolation of tailings with thick earthen covers. A minimum of three meters cover is specified.

   - The need for continuation of active care of sites to redress natural weathering processes will be reduced to very low levels or eliminated by disposal preferably below-grade or in above grade locations which provide nearly equal protection from erosion forces. Long-term monitoring of sites will be minimal and is recommended primarily as a prudent and conservative measure supplementing the physical isolation provided.

This chapter summarizes: (1) the cumulative unavoidable adverse impacts from future milling (Sec. 15.2); (2) the relation between short-term usage of man's environment and long-term productivity (Sec. 15.3); and (3) the irreversible and irretrievable commitment of resources from the U.S. milling industry (Sec. 15.4). In this discussion, it is assumed that the proposed regulatory actions delineated in Chapter 12 will be implemented for future milling operations. Cumulative impacts are based on a future industry of about 55 operating conventional uranium mills by the year 2000.

15.2 CUMULATIVE UNAVOIDABLE ADVERSE IMPACTS FOR FUTURE URANIUM MILLING INDUSTRY

The cumulative environmental impacts of the conventional uranium milling industry over the time period 1979 to 2000 are summarized in Table 15.1. Since the conventional uranium milling

Table 15.1 Summary of Integrated Unavoidable Impacts of Conventional Uranium Milling Industry Through the Year 2000[a]

	Estimated Value	Estimated Range
Production (MT U_3O_8 x 10^3)	440	410-490
Number of Operating Model Mills in Year 2000	55	47-69
Number of Model Mill Years of Operation	840	780-940
Natural Resource Use		
Land Temporarily Disturbed by Milling (ha x 10^3)	23	20-29
Tailings Disposal Land Permanently Committed to Restricted Use (ha x 10^3)	6.1	3.4-7.6
Land Temporarily Disturbed - Mining (ha x 10^3)	6.6	5.6-8.2
Water Lost to Evaporation (m^3 x 10^8)[b]	5.5	3.1-6.9
Effluents		
Tailings Solids Generated (MT x 10^8)	4.7	4.0-5.9
Dusts Released (MT x 10^3)[c]	330	180-410
Fumes (MT)	22	20-25
Gases (SO_x, NO_x) (MT x 10^3)	8.3	7.7-9.3
Radon - Mills (1979-2000) (Ci x 10^6)[d]	5.3	3.0-6.6
Radon - Mines (1979-2000) (Ci x 10^6)	6.2	5.3-7.7
Persistent Radon Releases from Tailings (KCi/yr)	3.9	1.6-4.9
Radiological Impacts		
<u>Milling</u>		
Health Effects - 1979 to 3000 (premature deaths)	92	38-120
Life-Shortening - 1979 to 3000 (years lost)	1750	720-2200
Persistent Health Effects - Beyond 3000 (premature deaths/yr)	0.043	0.018-0.054
<u>Milling Occupational</u>		
Health Effects - 1979 to 2000 (premature deaths)	32	30-36
Life Shortening - 1979 to 2000 (years lost)	610	570-680
<u>Mining</u>		
Health Effects - 1979 to 2000 (premature deaths)	56	48-70
Life-Shortening - 1979 to 2000 (years lost)	1060	910-1300

[a]Estimated values and ranges of impacts presented here are based primarily on information provided in Chapters 3,5,6,9, and 12 and Appendix S. Ranges are based on the types and magnitudes of uncertainties as described and assessed in Appendix S. Uncertainties in health effect conversion factors are not included; as described in Appendix G-7, this would extend the ranges for health effect estimates by about a factor of 2 in either direction. The average life-shortening per health effect is taken to be 19 years (see Appendix G-7).

[b]An additional 20-50% of this amount would be lost due to mining operations. This is counter-balanced by the fact that some evaporation of soil moisture would occur anyway; this evaporative loss would roughly equal precipitation intercepted by tailings areas, which amounts to 42% of the evaporation losses shown.

[c]Only dust losses during mill operation are shown. Tailings dust losses during assumed 5-yr pre-reclamation drying periods would add 50 thousand MT during 1979-2000.

[d]The estimate shown is conservative in that the effects of radon attenuation by interim stabilization or reclamation are not included; this overestimates total radon releases by approximately 10% for the 1979-2000 period.

industry is expected to supply nearly 80% of the U_3O_8 requirements over this time period, Table 15.1 approximates the impacts for the entire industry. In general, impacts from the nonconventional industry per MT of U_3O_8 expected to be less than impacts from the conventional industry per MT of U_3O_8. Estimates of cumulative radon release and land use impacts resulting from operation of the industry to the year 2000 are dependent on several key parameters. These include projections of nuclear power growth, uranium fuel enrichment policies, average ore grades processed, surface area and shapes of tailings impoundments and unit radon flux factors. To simplify analysis, the staff selected and used throughout the document single values for each of these key parameters. However, in stating cumulative impacts (Table 15-1), the staff has presented ranges to characterize the degree of uncertainty that exists. The basis for ranges is given in Appendix S.

While the effects of uranium mining are not within the specified scope of this statement, an attempt is made in the following discussion to indicate how mining impacts would compare with those from milling alone.

15.2.1 Physical Impacts

15.2.1.1 Land

Site preparation for construction and operation of 76 1800 MT/day mills with ancillary structures to process uranium ore requires the temporary disturbance of about 23,000 ha of land. The area permanently committed to tailings disposal would be about 6100 ha (with a range of about 3400 to 7600 ha). Although land where tailings have been disposed will be controlled, the land might be available for some productive uses. In cases where tailings are disposed of in deep mines, no land use control would be necessary, and the permanent commitment of land would be reduced accordingly. It is speculative as to how much of the tailings generated will be disposed of in this fashion, and so the staff estimate conservatively ignores this factor.

The land area disturbed by mining of ore to feed the conventional mills depends primarily on the amount of ore produced by open pit mining. It has been estimated that 0.03 ha of land is temporarily disturbed per metric ton of U_3O_8 produced.[1] Assuming that 50% of future conventional uranium needs will be mined from open pit mines, the total area temporarily disturbed by open pit uranium mining will be about 6600 ha. Since there is virtually no direct surface land disturbance by underground mining and because operators seek to minimize the quantity of waste rock that is brought to the surface, the area disturbed by underground mines would be negligible compared with the area disturbed by open pit mines.

15.2.1.2 Water

The water consumed in milling operations is usually lost from the area in which the operations occur. In general, the water used in milling originates in the dewatering of the mine pits and is discharged to the atmosphere via evaporative processes. The quantity of water lost by evaporation varies with the capacity of the mill and the amount of water recycled. In Section 9.3.4.2 it was estimated that the model mill would lose 6.60×10^5 m^3/yr due to evaporation. For the amount of milling that will take place between now and the year 2000 (840 model mill years) the cumulative amount of water lost from the milling regions by evaporation is about 5.5×10^8 m^3, assuming mills use good conservation practices.

Water resource impacts also occur as a result of mine dewatering operations. Aquifers are usually intercepted during mine excavation and the inflow of water must be pumped from the mine. The amounts of water returning to the groundwater via seepage or streamflow and that lost by evaporation are functions of mining practices and can be expected to vary widely. One study indicated that the amount of water pumped from underground mines may range from 1.10×10^3 to 1.6×10^4 MT/day.[2] In another study[3] in which the impacts of both mining and milling operations were assessed, it was estimated that the amount of mine water which would evaporate would be between 20-50% of that which is expected to evaporate from the mill tailings pond. The effect of this removal on aquifers is problematical, depending largely on aquifer characteristics and recharge rates. At best, the temporary adverse impact resulting from disruption of aquifers in the disturbed areas of mining cannot be avoided, and lowering of water levels in local wells will occur. At worst, in areas of concentrated mineral extraction, the net export of water from the aquifers could be sufficient to result in some lowering of water tables.

Some minor local deterioration of water quality may occur as a result of infiltration of rainfall and snowmelt in reclaimed areas, thereby leaching fill materials of salts that subsequently enter surface and subsurface drainages. In a worst case situation, the seepage might reach groundwater, thus contaminating potential sources of drinking water. Additionally, removal of protective vegetative cover and other soil disturbances will temporarily cause increased water erosion during construction and mining activities.

15.2.1.3 Air

During construction activities there will be some transient smoke and dust in the air near the site, creating a slight short-term nuisance to observers and, perhaps, nearby residents.

During operation, small quantities of fugitive dust and chemical effluents will be present in the air, but the resulting impact on air quality is expected to be minor since these impacts are estimated to be much less than applicable air quality standards. Mining operations will also introduce contaminants into the local air; however, unavoidable impacts upon the air quality of the region will be slight.

15.2.2 Biotic Impacts

During construction of the mill complex the terrestrial biotic community will be disturbed. Small burrowing animals and insects will be destroyed and a permanent loss of forage supporting larger animals will occur. Operational and postoperational impacts are considered to be negligible.

The impacts of mining operations are similar to those of mill construction in proportion to the areas involved.

15.2.3 Radiological Impacts

It is the staff's opinion that radiological effects will be minimal if the tailings are properly controlled during operation and if the postoperational disposal of tailings is carried out in an approved manner (Sec. 12.2.1). During operation, these measures should assure that the EPA limits (40 CFR 190) on maximum individual exposure of 25 mrem/yr will be met. The greatest radiological impact associated with active milling operations occurs as a result of radon released from tailings impoundments. The extent to which this will be controlled will be dependent on tailings management practices which are difficult to project (see Secs. 9.2.8 and 12.3.6). Risks to the average individual in a milling region, even where there is concentrated uranium development, will be small fractions of what will be faced due to exposures to natural background. In a case involving operation of 12 1800 MT/day mills in a 50 mile region (the assumed worst possible concentration of milling in year 2000), lifetime risks to the average individual in the region from milling would be about 0.015% of natural cancer risks. Persistent continental North American population health effects, 0.04 premature deaths/yr, would be about five orders of magnitude below those from natural background radon, and much less than those from a number of other technologically enhanced sources of radon (Sec. 12.3.3).

Occupational health effects due to radiation exposures (1979-2000) at mills may result in a total of 32 premature deaths; this is equivalent to about a 20% increase in risk of cancer among occupationally exposed mill workers over a career of 47 years.

15.2.4 Social-Economic Impacts

From a broad perspective, the socioeconomic impacts of uranium mining and milling are minor. On a local scale the normal costs of mineral exploitation will occur; however, there are compensating benefits resulting from local expenditures by the operations and the disbursement of the payroll monies. Negative socioeconomic impacts in the case of an isolated mill are expected to be relatively minor. Cumulative impacts could occur where multiple mills are located in a region. In areas of concentrated milling activity, social, economic and political structures could change rapidly with little time allowed for adjustments. Consequently, stress could be experienced at the family, neighborhood, and community levels. Impacts during the operational period could include rapid population growth accompanied by increased housing and service demands, etc. Impacts during the post-operational period could include population decrease followed by decreased demand for services and facilities and increases in unemployment and underemployment.

15.3 RELATIONSHIPS BETWEEN LOCAL SHORT-TERM USE OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

15.3.1 Scope

The National Environmental Policy Act (NEPA) mandates specific consideration of the long-term effects on economic productivity of a proposed Federal action, and of alternative "short-term uses of man's environment." Within the context of this statement, the staff has interpreted this to mean that the use of land to produce uranium should be balanced against other uses of the land, and that the long-term consequences of these uses should be evaluated. Short-term is taken to mean the period of construction and operation, and long-term to mean the period after decommissioning.

The economic productivity of the mining and milling sites, while they are being used to produce uranium, will be very large when compared with the productivity from grazing or other likely uses of these sites. The principal effects of uranium production that are inimical to long-term productivity are the consumption of depletable resources and the cost of decommissioning, including satisfactory reclamation of the tailings disposal area. The overall conclusion of the staff with respect to the issue of long-term productivity is that, under the condition that tailings disposal sites be returned to conditions near those of surrounding environs, the positive benefits outweigh the negative aspects of uranium production.

15.3.2 Enhancement of Productivity

The production of uranium has a beneficial effect on the economy of the region in which it takes place, lasting throughout the period of production. The economic activity generated by mining and milling efforts will foster growth in different aspects of the economy. The cumulative amount of U_3O_8 expected to be generated by conventional milling (440,000 MT) over the time period 1979 to 2000 is estimated to be worth about $\$29 \times 10^9$ at a constant price of \$30/lb. The annual production of U_3O_8 from the model mill (520 MT) is estimated to be worth about $\$34 \times 10^6$.

15.3.3 Uses Adverse to Productivity

The local effects of mining and milling uranium include prohibition of the use of the occupied land for agricultural or other purposes. The net evaporation of groundwater should normally have a small impact on the short- or long-term productivity of the region, but there may be special circumstances under which the impact may be more severe. For example, in some areas where concentrated uranium development in conjunction with other heavy mining activity occurs, evaporative losses could result in temporary lowering of water wells tapping aquifers.

15.3.4 Decommissioning and Reclamation

The strength of the conclusions reached above are dependent, to some degree, on the effectiveness of the decommissioning and reclamation programs in allowing future productive uses of the land formerly occupied by mining and milling operations. This question has been discussed from various viewpoints in foregoing sections. The primary basis upon which the proposed mill tailings disposal and site decommissioning requirements are based (Sec. 12.3) is the desire to return sites to conditions which are reasonably near those of surrounding environs so that long-term productive uses are not necessarily excluded to obtain short-term benefits (see Sec. 10.3). There appears to be no obstacle in returning most lands to unlimited use after operations cease, except that uses of land directly above and in the immediate vicinity of tailings disposal areas may have to be prohibited. However, in some cases, this land may be returned to grazing activity, the most likely alternative use in most areas where uranium is produced.

15.4 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

15.4.1 Scope

Irreversible commitments generally concern changes set in motion by the proposed action which at some later time could not be altered to restore the present order of environmental resources. Irretrievable commitments generally involve the use or consumption of resources that are neither renewable nor recoverable for subsequent use. Within the context of this statement, these commitments have been illustrated by considering those involved in the construction and operation of U.S. uranium mills over the time period 1979 to 2000. Irreversible and irretrievable resource commitments are summarized in Table 15.2.

15.4.2 Commitments Considered

The types of resources of concern in uranium production can be identified as (1) material resources and (2) nonmaterial resources, including a range of beneficial uses of the environment. Resources that may be irreversibly committed by the operation are (1) construction materials that cannot be recovered and recycled (Sec. 15.4.3.1), (2) materials consumed or reduced to unrecoverable forms of waste (Sec. 15.4.3.2), (3) the atmosphere and water bodies used for disposal of waste effluents, to the extent that other beneficial uses are curtailed (Sec. 15.4.4), and (4) land areas rendered unfit for other uses (Sec. 15.4.5).

15.4.3 Material Resources

15.4.3.1 Materials of Construction

The quantities of the principal materials required for construction of the mill are listed in Table 15.2. In addition to the materials included in Table 15.2, small quantities of

Table 15.2 Irreversible and Irretrievable Commitment of Resources Used in Construction and Operation of U.S. Uranium Mills Over the Time Period 1979 to 2000

Construction[a]	
Concrete (m^3)	3.1×10^5 - 4.2×10^5
Steel (MT)	7.7×10^4 - 8.8×10^4
Copper and Aluminum (MT)	2.2×10^3 - 2.8×10^3
Wood (MT)	7.2×10^2 - 1.0×10^3
Plastics (MT)	7.2×10^2 - 1.0×10^3
Operation[b]	
Sulfuric Acid (MT)	2.1×10^7
Sodium Chlorate (MT)	6.6×10^5
Ammonia (MT)	5.2×10^5
Iron (MT)	1.2×10^5
Organic Substances (MT)	2.4×10^5

[a]Construction estimates are based on the construction of 53 model mills (1800 MT/day), in addition to the 23 model mill equivalents now operating. Most of the materials used in constructing these mills, with the exception of concrete, could be salvaged by decontamination.

[b]Operation estimates are based on processing 4.7×10^8 MT of ore in order to produce 440,000 MT of U_3O_8, and the quantities of additives for the acid-leach process in Table 5.2.

various other materials (e.g., asbestos, chromium, manganese, zinc) are committed. Most of the materials used in construction could be recovered when the mill is decommissioned and dismantled, but all of the concrete and a small fraction of the other items may be irretrievable commitments. In addition, a considerable amount of energy in the form of electricity and combustible fuels (e.g., gasoline) would be required in the construction of the mill, and in powering trucks, automobiles, etc.

15.4.3.2 Irreplaceable Components and Consumable Materials

Sulfuric acid is the principal material irretrievably consumed in mill operation. The quantities of this acid, and of the other major items, consumed during the 1979-2000 period are given in Table 15.2.

15.4.4 Air and Water Resources

The expected releases of chemical and radioactive materials have been discussed in preceding sections. During and after milling operations, both air and water resources are used to bear these discharges. There is, therefore, a commitment of these resources for this purpose. These commitments, however, are neither irreversible nor irretrievable although they may extend for some period of time after operations cease, as may be the case with groundwater impacts.

15.4.5 Land Resources

Based on the projections for the growth of nuclear power, about 23,000 ha of land would have been temporarily disturbed by milling activity at 76 sites by the year 2000. After this period, most of the area could be used for other purposes, assuming proper decommissioning. A certain amount of land would also be temporarily committed to mining operations (about 6600 ha), roadways, etc.; all of this land resource should be available for other uses after these operations cease.

The area of land permanently committed to tailings disposal would be about 6100 ha (a range of about 3400 to 7600 ha is estimated). Although uses of land where tailings have been disposed will be restricted, the land might be available for some productive uses. In cases where tailings are disposed of in deep mines, there would be no commitment of surface land use. The amount of tailings which will be disposed in this fashion is speculative; to the extent it occurs, it will reduce the estimate of cumulative land committed.

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The Final Generic Environmental Impact Statement (GEIS) on Uranium Milling focuses primarily upon the matter of mill tailings disposal. It evaluates both the costs and benefits of alternative tailings disposal modes and draws conclusions about criteria which should be incorporated into regulations. Both institutional and technical controls are evaluated. Health impacts considered were both short and long term. Restatement and resolution of all public comments received on the draft (GEIS) are presented. There are three volumes: Volume I is the main text and Volumes II and III are supporting appendices.

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