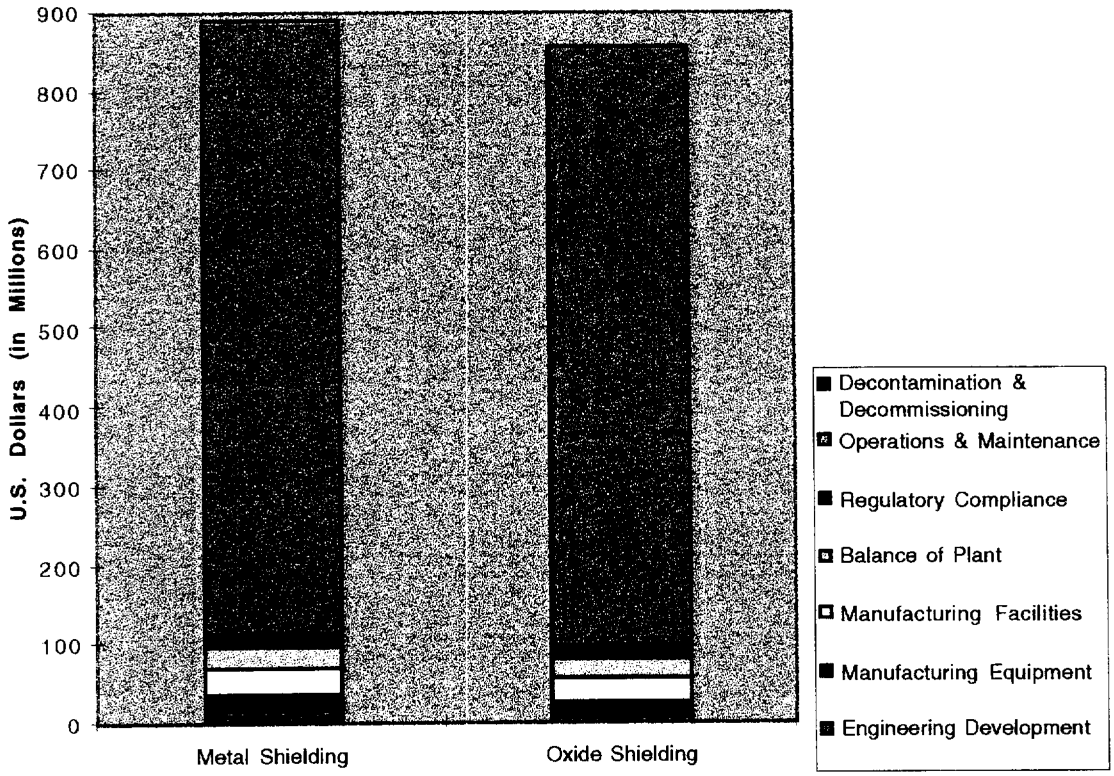
Figure 4.5 Total Costs of Manufacture of Metal and Oxide Shielding Options



4.4 Long-term Storage

Storage of depleted uranium is predicated on its use at some later date. In the engineering analysis, storage options are defined by the type of storage facility, and suboptions are defined by the chemical form in which the depleted uranium is stored. The types of storage facilities analyzed are (1) buildings, (2) below ground vaults, and (3) a mined cavity. The three chemical forms analyzed are (1) UF_6, (2) U_3O_8, and (3) UO_2, with corresponding assumed bulk densities of 4.6 gram per cubic centimeter (g/cc), 3.0 g/cc, and 9.0 g/cc at ambient temperature.[3] The area required to store depleted uranium depends on the uranium content in the storage form, the bulk density of the compound stored, the type of storage containers used, and the configuration of the storage containers. UF_6 would be stored in Type 48 cylinders, while U_3O_8 and UO_2 would be stored in 55- and 30-gallon drums, respectively. Total storage area requirements are greatest for U_3O_8 and least for UO_2, based on the preconceptual designs in the *Engineering Analysis Report.*

The storage cost was evaluated by combining the costs of technology development, equipment, facilities, balance of plant, regulatory compliance, and operations and maintenance. Facility costs include costs for the storage facilities (i.e., buildings, vaults, or a mined cavity), the receiving warehouse and repackaging building, and the cylinder washing building for the UF_6 storage options. Balance of plant costs include site improvements and utilities, the site support buildings such as the administration building and the workshop, and mobile yard equipment. Costs for site improvements and utilities are based on preliminary estimates for site clearing, grubbing, and mass earthwork, as well as other information provided in the *Engineering Analysis Report.* Operations and maintenance costs are based on emplacement over 20 years followed by surveillance and monitoring until 2040. Surveillance and monitoring will likely continue beyond 2040, but this is the period assumed for purposes of analysis.

There is considerable variation and uncertainty in costs associated with excavation and maintenance for the mined cavity. Available data from the Yucca Mountain and Waste Isolation Pilot Plant (WIPP) projects were used for estimating these costs.

Table 4.11 provides a summary of the costs of the various long-term storage options considered. It is evident from Table 4.11 that the lowest-cost storage option for UF_6, U_3O_8, and UO_2 is above ground (buildings), while the highest-cost storage option is a mined cavity. Significantly greater operations and maintenance (materials) and facility costs are estimated for the mined cavity than for the building or vault options. Storage in the oxide forms differs from storage as depleted UF_6 in six key areas:

- Lesser weight rating of the depleted uranium handling equipment due to the lower storage container weight (the weight rating is higher for UO_2 than for U_3O_8)
- Different equipment used for cylinder repackaging than for drum repackaging (e.g., autoclaves versus hoppers and vibrating platforms)
- Greater number of storage buildings required for storing U_3O_8, fewer for storing UO_2
- Larger site required for storing U_3O_8, smaller for storing UO_2
- Absence of a cylinder cleaning building
- Higher material and staffing requirements for storing U_3O_8, lower for storing UO_2

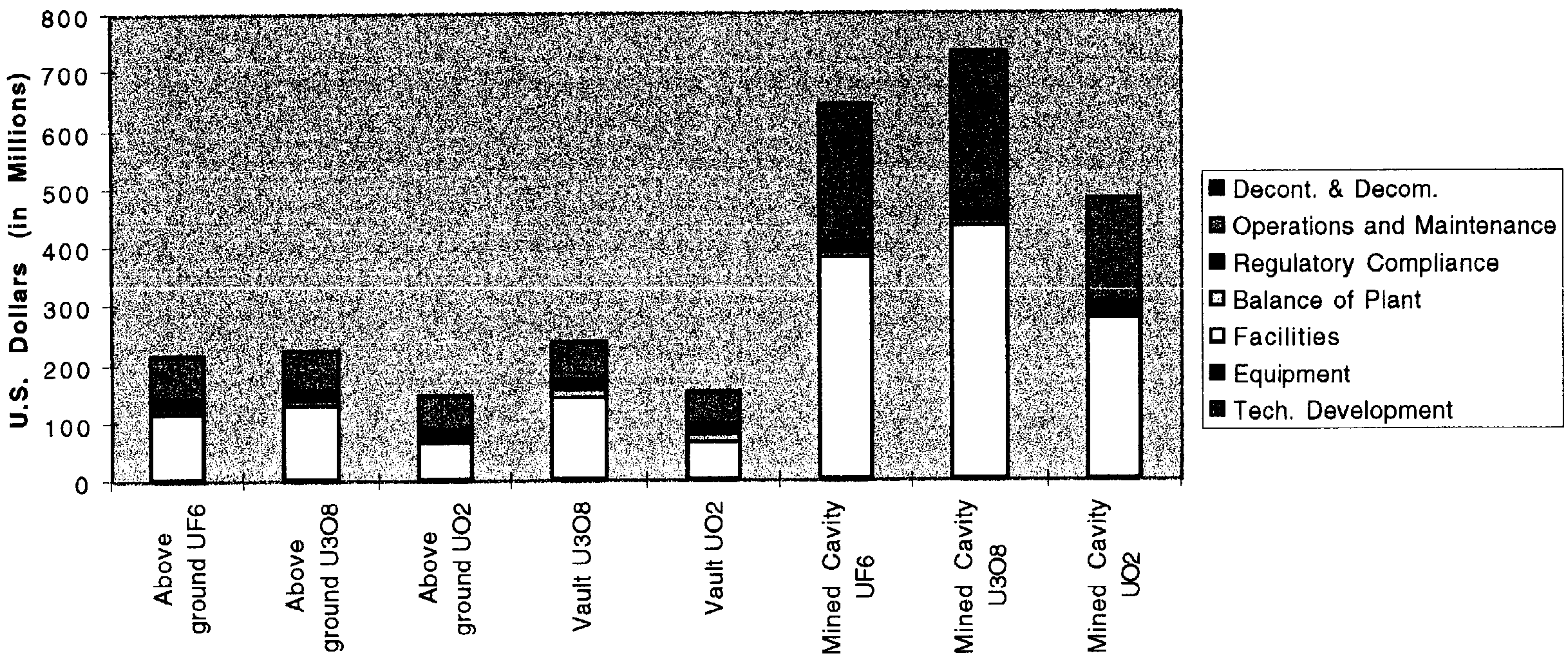
[3] The density of depleted UF_6 decreases dramatically when it is heated to a maximum working cylinder temperature of 250°F. Cylinders are filled so that they are about 62% full at ambient temperature.

Figure 4.6 compares the long-term storage costs for all options considered. For above ground storage (buildings), the facilities cost accounts for 52%, 57%, and 43% of the total storage cost for UF_6 , U_3O_8, and UO_2, respectively, while the operations and maintenance cost accounts for 32%, 29%, and 37% of the total storage cost. For the mined cavity option, the facilities cost accounts for 58%, 59%, and 57% of the total storage cost for UF_6, U_3O_8, and UO_2, respectively, while the operations and maintenance cost accounts for 36%, 36%, and 37% of the total storage cost. In all cases, facilities costs are dominant, making up nearly half of total costs.

Table 4.11 Cost Breakdown (in Millions of Dollars) for Long-term Storage Options

	Aboveground (Buildings)			Vault		Mined Cavity		
	UF_6	U_3O_8	UO_2	U_3O_8	UO_2	UF_6	U_3O_8	UO_2
Tech. Development	0.82	0.82	0.82	1.64	1.64	3.28	3.28	3.28
Equipment								
Engineering	0.95	0.42	0.38	0.24	0.23	0.47	0.30	0.30
Fabrication	1.39	1.01	0.94	0.68	0.65	1.33	0.93	0.90
Installation	2.68	0.79	0.71	0.36	0.34	0.68	0.36	0.38
Certification & Test	0.07	0.05	0.05	0.03	0.03	0.07	0.05	0.04
Subtotal	5.09	2.27	2.08	1.31	1.25	2.55	1.64	1.62
Facilities								
Engineering	21.30	24.30	11.91	26.17	12.59	71.18	81.50	51.77
Construction	77.45	88.37	43.32	95.17	45.79	258.82	296.38	188.27
Proj. Management	14.13	16.13	7.91	17.37	8.36	47.24	54.09	34.36
Subtotal	112.88	128.80	63.14	138.71	66.74	377.24	431.97	274.40
Balance of Plant								
Engineering	1.58	1.62	1.34	2.72	1.93	1.20	1.43	1.13
Construction	5.74	5.91	4.88	9.89	7.01	4.37	5.21	4.12
Proj. Management	1.05	1.08	0.89	1.80	1.28	0.80	0.95	0.75
Subtotal	8.37	8.61	7.11	14.41	10.22	6.37	7.59	6.00
Regulatory Compliance	18.61	18.61	18.61	18.61	18.61	18.61	18.61	18.61
Operations and Maintenance								
Material	19.41	12.37	8.05	10.38	6.46	185.26	211.38	128.53
Utilities	2.12	2.41	1.63	1.98	1.36	1.78	1.99	1.47
Labor	47.03	50.83	45.02	49.80	45.97	49.08	54.48	48.90
Waste Management & Disposal	0.15	0.27	0.13	0.27	0.13	0.08	0.27	0.13
Subtotal	68.71	65.88	54.83	62.43	53.92	236.20	268.12	179.03
Decont. & Decom.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	214.48	224.99	146.59	237.11	152.38	644.25	731.21	482.94

Figure 4.6 Total Costs for Long-term Storage Options



4.5 Disposal

Disposal options and suboptions are defined by the type of disposal facility and the nature of the waste form. The engineering analysis considered three disposal facility options: (1) engineered trench, (2) below ground vault, and (3) mined cavity. Each option was evaluated for the same four waste form suboptions: (1) grouted (cemented) U_3O_8, (2) grouted UO_2, (3) bulk (i.e., not grouted) U_3O_8, and (4) bulk UO_2. The area required to dispose of the depleted uranium depends on the uranium content in the disposal form, the bulk density of the compound stored, the type of storage containers used, and the configuration of the storage containers. Both grouted and bulk U_3O_8 would be disposed of in 55-gallon drums; grouted and bulk UO_2 would be disposed of in 30-gallon drums. The following list ranks the four waste forms from least to greatest number of disposal containers and disposal area required: (1) bulk UO_2, (2) grouted UO_2, (3) bulk U_3O_8, and (4) grouted U_3O_8.

The disposal cost was evaluated by combining the costs of technology development, equipment, facilities, balance of plant, regulatory compliance, operations and maintenance, and decontamination and decommissioning. Facility costs include costs for the disposal facilities (i.e., trenches, vaults, or mined cavity) and waste form preparation facilities (i.e., the cementing building and the curing building for grouted waste form preparation). Balance of plant costs include site improvements and utilities and the site support buildings such as the administration building, the product receiving warehouse, and the supply and shipping warehouse. Costs for site improvements and utilities are based on preliminary estimates for site clearing, grubbing, and mass earthwork, as well as other information provided in the *Engineering Analysis Report*. Operations and maintenance costs include the labor, utilities, materials, and waste management costs necessary to operate the waste form facility for 20 years. Emplacement and closure and surveillance and maintenance costs are incurred over the same 20-year period. All operations of the waste form and disposal facilities would be completed in 2029.

As with the option for storage in a mined cavity, there is considerable variation and uncertainty in costs associated with excavation and maintenance for disposal in a mined cavity. Available data from the Yucca Mountain and WIPP projects were used for estimating these costs.

Disposal costs for bulk oxides vary from storage costs for the same oxides in vaults or a mined cavity due to the differences listed below. Most of these differences are the result of providing accessibility in order to allow the surveillance and maintenance necessary for storage options.

- A waste form preparation facility is needed for disposal options, but not for storage options.
- Disposal vaults are covered with concrete and earth, while storage vaults are not.
- Disposal vaults are smaller and contain interior concrete walls.
- Disposal drifts are shorter, narrower, and shallower than storage drifts because access for inspections after emplacement is unnecessary. Access to drifts is by shafts for storage facilities and by ramp for disposal facilities.
- Drums are packed more tightly into disposal facilities than in storage facilities.
- Disposal facilities are not monitored for 20 years after emplacement as storage facilities are.
- Regulatory compliance costs for disposal options are more than double the regulatory compliance costs for the long-term storage options.

Table 4.12 provides a summary of the costs of the various disposal options considered. Waste form preparation costs are given first, followed by disposal facility costs and total costs. It is evident from Table 4.12 that the lowest-cost disposal option is disposal as bulk UO_2 in an engineered trench, while the highest-cost disposal option is disposal as grouted U_3O_8 in a mined cavity. Mined cavity disposal may be desirable, however, due to environmental impact considerations since this option provides the greatest isolation of the waste form. Additional discussion may be found in Section 6.13 of the *Engineering Analysis Report.*

Figure 4.7 compares the disposal costs for all options considered. It is noted that disposal costs (exclusive of waste form preparation costs) vary directly with the number of disposal containers and the disposal area required for each waste form and are, from least to greatest within each facility type: (1) bulk UO_2, (2) grouted UO_2, (3) bulk U_3O_8, and (4) grouted U_3O_8. When the preparation costs are added, the order shifts and disposal of bulk U_3O_8 has a lower cost than disposal of grouted UO_2 because the waste form preparation costs associated with the bulk U_3O_8 are about one-third of those associated with grouted UO_2 .

For a given waste form (e.g., bulk U_3O_8 or grouted UO_2), preparation costs are constant, regardless of the type of disposal facility (e.g., engineered trench), except for the technology development cost. For a given type of disposal facility, waste form preparation costs vary in the same manner as disposal facility costs, with bulk UO_2 having the least cost and grouted U_3O_8 having the greatest cost. Preparation costs are higher than other cost elements for all trench disposal options, making up about one-half the total costs for bulk disposal forms and three-fourths the total cost for grouted waste forms. Facility costs dominate total costs for the more complex waste disposal facilities.

For purposes of this analysis, regulatory compliance costs were assumed to be constant, regardless of facility or waste form. Accordingly, regulatory compliance is a significant factor at the lower end of the spectrum, making up 34% of total disposal costs for bulk UO_2 in an engineered trench. Compliance costs make up only about 3% of total costs for the highest-cost option, grouted U_3O_8 in a mined cavity.

Table 4.12 Cost Breakdown (in Millions of Dollars) for Disposal Options

Preparation	U_3O_8 Bulk			U_3O_8 Grouted			UO_2 Bulk			UO_2 Grouted		
	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity
Technology Development	6.56	6.56	8.20	8.20	8.20	9.84	6.56	6.56	8.20	8.20	8.20	9.84
Process Equipment												
Engineering	0.00	0.00	0.00	5.61	5.61	5.61	0.00	0.00	0.00	4.32	4.32	4.32
Fabrication	0.00	0.00	0.00	16.78	16.78	16.78	0.00	0.00	0.00	12.98	12.98	12.98
Installation	0.00	0.00	0.00	4.65	4.65	4.65	0.00	0.00	0.00	3.53	3.53	3.53
Certification and Test	0.00	0.00	0.00	0.60	0.60	0.60	0.00	0.00	0.00	0.46	0.46	0.46
Subtotal	0.00	0.00	0.00	27.64	27.64	27.64	0.00	0.00	0.00	21.29	21.29	21.29
Process Facilities												
Engineering	0.00	0.00	0.00	6.27	6.27	6.27	0.00	0.00	0.00	3.71	3.71	3.71
Construction	0.00	0.00	0.00	17.39	17.39	17.39	0.00	0.00	0.00	10.28	10.28	10.28
Project Management	0.00	0.00	0.00	4.01	4.01	4.01	0.00	0.00	0.00	2.37	2.37	2.37
Subtotal	0.00	0.00	0.00	27.67	27.67	27.67	0.00	0.00	0.00	16.36	16.36	16.36
Balance of Plant												
Engineering	6.01	6.01	6.01	10.90	10.90	10.90	3.63	3.63	3.63	7.68	7.68	7.68
Construction	16.56	16.56	16.56	30.05	30.05	30.05	9.99	9.99	9.99	21.17	21.17	21.17
Project Management	3.86	3.86	3.86	7.00	7.00	7.00	2.33	2.33	2.33	4.93	4.93	4.93
Subtotal	26.43	26.43	26.43	47.95	47.95	47.95	15.95	15.95	15.95	33.78	33.78	33.78
Regulatory Compliance	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Operation & Maintenance												
Materials	0.14	0.14	0.14	122.86	122.86	122.86	0.08	0.08	0.08	13.26	13.26	13.26
Utilities & Consumables	3.51	3.51	3.51	6.04	6.04	6.04	1.95	1.95	1.95	3.32	3.32	3.32
Labor	28.41	28.41	28.41	75.60	75.60	75.60	28.36	28.36	28.36	70.87	70.87	70.87
Waste Management	1.17	1.17	1.17	1.98	1.98	1.98	0.72	0.72	0.72	1.19	1.19	1.19
Subtotal	33.23	33.23	33.23	206.48	206.48	206.48	31.11	31.11	31.11	88.64	88.64	88.64
Decont. & Decom.	0.60	0.60	0.60	1.83	1.83	1.83	0.38	0.38	0.38	1.26	1.26	1.26
Total Preparation Cost	68.84	68.84	70.48	321.79	321.79	323.43	56.02	56.02	57.66	171.55	171.55	173.19

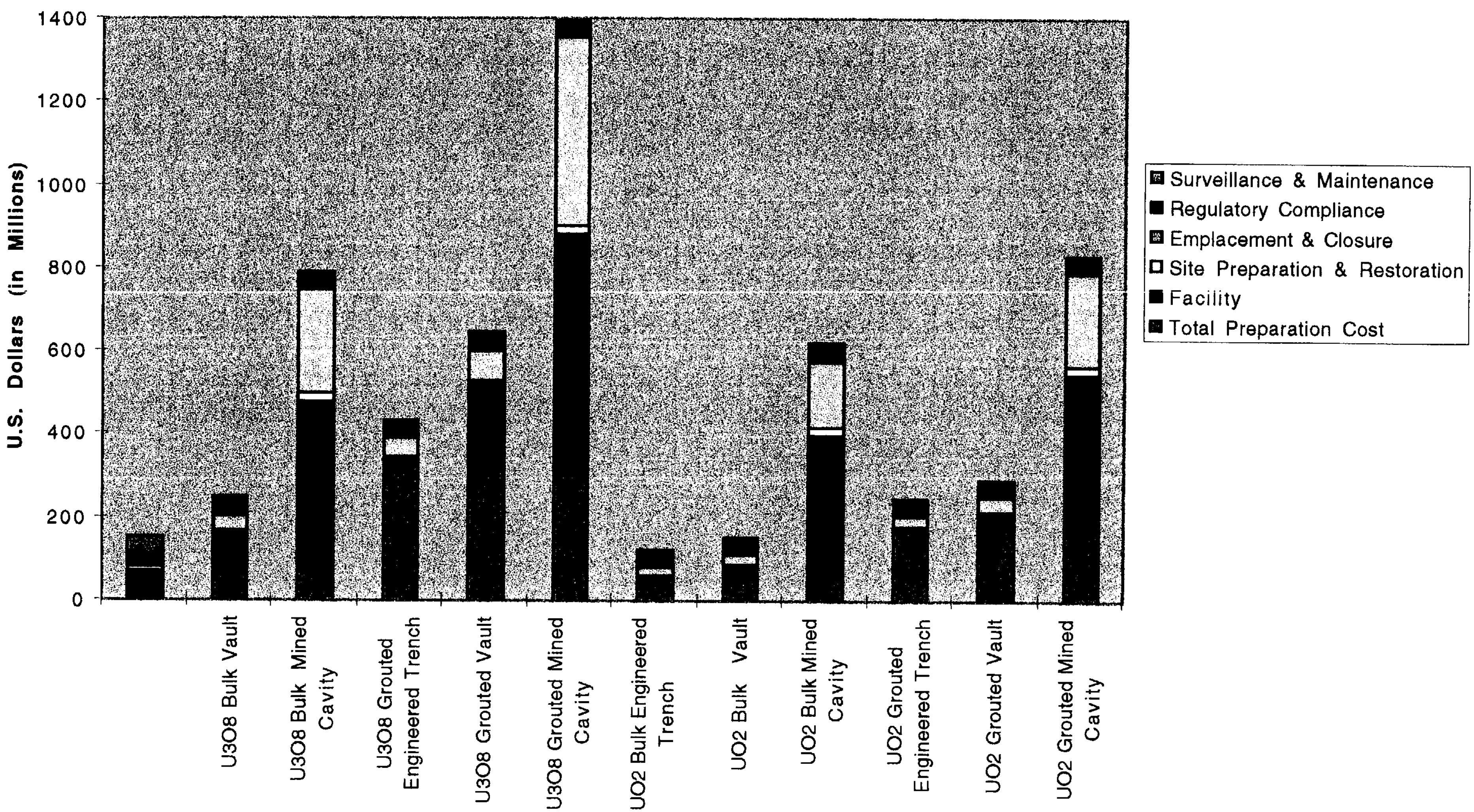
[Table 4.12 is continued on the next page]

Table 4.12 Cost Breakdown (in Millions of Dollars) for Disposal Options (Continued)

	U_3O_8 Bulk			U_3O_8 Grouted			UO_2 Bulk			UO_2 Grouted		
	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity
Facility												
Engineering	3.73	29.33	87.05	7.12	61.85	119.05	1.86	8.42	72.16	2.50	12.81	79.56
Construction	7.20	56.62	271.44	13.73	119.41	371.21	3.59	16.25	225.01	4.82	24.73	248.07
Project Management	1.29	10.13	50.53	2.46	21.37	69.11	0.64	2.91	41.89	0.86	4.43	46.18
Subtotal	12.22	96.08	409.02	23.31	202.63	559.37	6.09	27.58	339.06	8.18	41.97	373.81
Site Prep & Restoration												
Engineering	0.17	0.32	3.62	0.27	0.55	3.78	0.11	0.14	3.55	0.13	0.17	3.59
Construction	0.61	1.15	13.18	0.97	1.99	13.75	0.40	0.49	12.91	0.47	0.63	13.05
Project Management	0.11	0.21	2.41	0.18	0.36	2.51	0.07	0.09	2.36	0.09	0.12	2.38
Subtotal	0.89	1.68	19.21	1.42	2.90	20.04	0.58	0.72	18.82	0.69	0.92	19.02
Emplacement & Closure												
Materials	1.40	2.15	28.49	2.45	3.17	47.31	0.85	0.79	24.76	1.05	1.50	35.06
Equipment	3.63	3.84	183.46	5.16	5.24	357.60	2.33	2.23	103.23	2.44	2.76	143.39
Labor	25.58	33.21	36.93	35.82	66.26	44.80	14.43	23.71	33.30	18.55	30.06	43.28
Subtotal	30.61	39.20	248.88	43.43	74.67	449.71	17.61	26.73	161.29	22.04	34.32	221.73
Regulatory Compliance	40.35	40.35	40.35	40.35	40.35	40.35	40.35	40.35	40.35	40.35	40.35	40.35
Surveillance & Maintenance												
Materials	0.79	1.36	0.58	1.03	2.76	0.75	0.67	0.44	0.42	0.71	0.63	0.58
Labor	1.50	1.50	1.63	1.50	1.50	1.63	1.50	1.50	1.63	1.50	1.50	1.63
Subtotal	2.29	2.86	2.21	2.53	4.26	2.38	2.17	1.94	2.05	2.21	2.13	2.21
Total Facility Cost	86.36	180.17	719.67	111.04	324.81	1,071.85	66.80	97.32	561.57	73.47	119.69	657.12

	U_3O_8 Bulk			U_3O_8 Grouted			UO_2 Bulk			UO_2 Grouted		
	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity	Engineered Trench	Vault	Mined Cavity
GRAND TOTAL	155.20	249.01	790.15	432.83	646.60	1,395.28	122.82	153.34	619.23	245.02	291.24	830.31

Figure 4.7 Total Costs for Disposal Options



4.6 Continued Storage at Current Sites

Storage of depleted UF_6 in the current cylinders and yards would continue for several years under all alternatives. For all alternatives except the No Action alternative, storage as depleted UF_6 in the current yards would continue from 1999 to 2029, with the amount of depleted UF_6 in storage decreasing by 5% per year beginning in 2009 until it is gone by 2029. Under the No Action alternative, storage as depleted UF_6 in the current yards would continue from 1999 to 2040, without reduction of the amount of depleted UF_6 in storage.

The continued storage cost was evaluated by combining the costs of equipment, cylinder placement, facilities, and surveillance and maintenance. Equipment costs include the costs of capital equipment required to store the depleted UF_6 cylinders in yards. Cylinder placement costs include estimates of the cost of stacking and restacking cylinders in the storage yards, including the newly constructed or modified yards. Facilities costs include estimates for constructing new storage yards at the three existing facilities. Cylinder placement and facilities costs occur in the first six years and are therefore identical for the action and No Action alternatives.

Surveillance and maintenance costs include repainting, management of substandard cylinders (including breach repair and transfer of contents), general cylinder maintenance (including valve/plug replacement and paint touch-up), general yard and equipment maintenance, cylinder inspections, data tracking, systems planning and execution, conduct of operations, and engineering development. These costs decline for the action alternatives until they are zero by the year 2029 when all the cylinders are gone. Surveillance and maintenance costs continue at a steady rate for the entire time period under the No Action alternative and are therefore higher. There are no decontamination and decommissioning costs for the No Action alternative because storage of the depleted UF_6 cylinders is assumed to continue indefinitely.

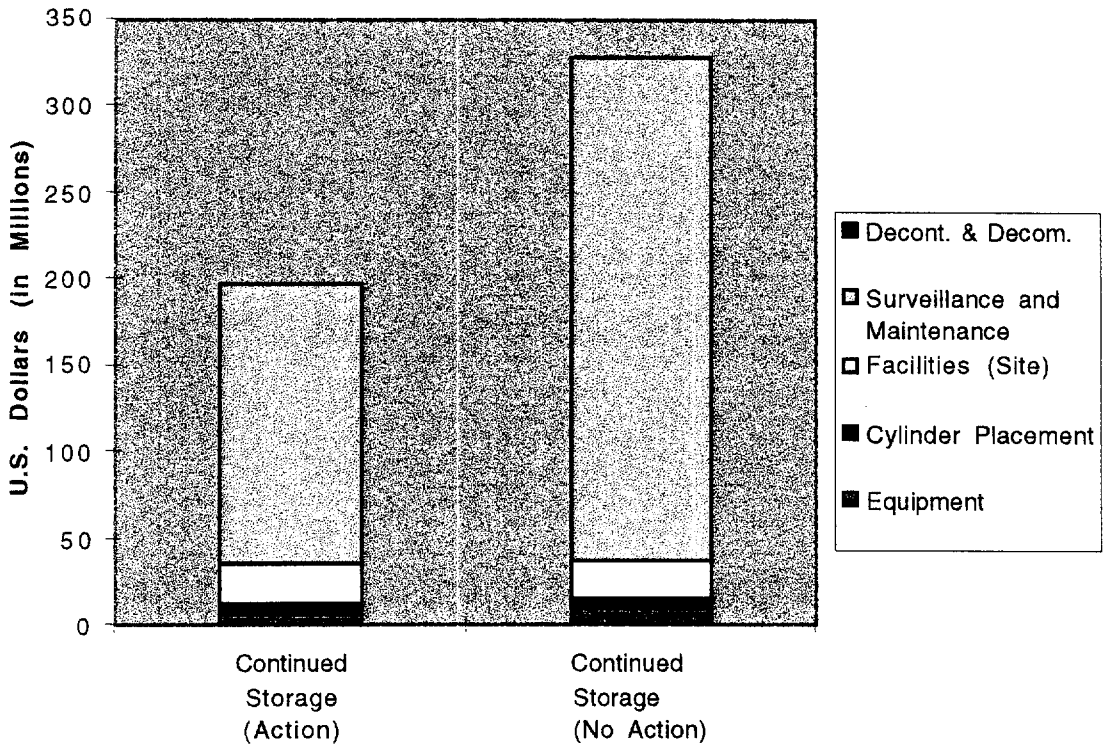
Unlike the other cost estimates, which are based on data contained in the *Engineering Analysis Report*, this cost estimate was derived from the Fiscal Year 1997 Baseline Plan for the sites and information provided by Lockheed Martin Energy Systems.

Table 4.13 and Figure 4.8 show the cost of continued storage for all alternatives. The first column gives the cost of continued storage for all alternatives other than the No Action alternative. The second column gives the No Action costs. Surveillance and maintenance account for more than 80% of the total cost for both.

Table 4.13 Cost Breakdown (in Millions of Dollars) for Continued Storage at Current Sites

	Continued Storage (Action)	Continued Storage (No Action)
Equipment	6.60	9.31
Cylinder Placement		
Materials	0.31	0.40
Utilities	0.00	0.00
Labor	6.89	6.89
Waste Management & Disposal	0.00	0.00
Subtotal	7.20	7.29
Facilities (Site)		
Engineering	3.89	3.89
Construction	14.71	14.71
Proj. Management	2.99	2.99
Subtotal	21.59	21.59
Surveillance and Maintenance		
Material	37.82	74.78
Utilities	1.78	3.93
Labor	118.63	204.98
Waste Management & Disposal	3.03	5.13
Subtotal	161.26	288.82
Decont. & Decom.	0.00	0.00
TOTAL	196.65	327.01

Figure 4.8 Total Costs for Continued Storage at Current Sites



5. COST ESTIMATION OF MANAGEMENT STRATEGIES

Six long-term management strategy alternatives are being considered. These strategies, which are described in Section 2.2, are listed below. The conversion options associated with each alternative are also identified.

- No action alternative
- Long-term storage as UF_6 in buildings or a mined cavity
- Long-term storage as oxide in buildings, vaults, or a mined cavity
  - U_3O_8 Defluorination with AHF production
  - U_3O_8 Defluorination with HF neutralization
  - UO_2 Gelation
- Use as uranium dioxide in DUCRETE™ for shielding applications
  - UO_2 Dry process with AHF production
  - UO_2 Dry process with HF neutralization
  - UO_2 Gelation
- Use as Metal for shielding applications
  - Batch metallothermic reduction
  - Continuous metallothermic reduction
- Disposal
  - U_3O_8 Defluorination with AHF production
  - U_3O_8 Defluorination with HF neutralization
  - UO_2 Gelation

The total cost for each management strategy is reported twice in this section by considering the lowest- and highest-cost options within each category included in a management strategy alternative. First, a low-cost scenario was considered that assumes (1) shipping is done by rail; (2) nonconforming cylinders are placed in a cylinder overcontainer in preparation for shipment; (3) storage of UF_6, U_3O_8, and UO_2 is carried out in a building; and (4) disposal of U_3O_8 and UO_2 is in the bulk form in an engineered trench. Second, a high-cost scenario was considered that assumes (1) shipping is done by truck; (2) depleted UF_6 in nonconforming cylinders is transferred to new or conforming cylinders which meet the DOT requirement; (3) storage of UF_6, U_3O_8, and UO_2 is carried out in a mined cavity; and (4) disposal of U_3O_8 and UO_2 is in the grouted form in a mined cavity. By selecting the lowest- and highest-cost options within each category, a range of costs for implementing each management strategy alternative is developed. For the remainder of this report, the low-cost scenario is addressed unless otherwise specified.

The costs of the alternatives, for both low- and high-cost scenarios, are summarized in Tables 5.1 and 5.2. As in the preceding sections of this report, the discount rate used is

7% p.a. Table 5.1 represents the lower-cost range for all the alternative strategies, while Table 5.2 represents the higher-cost range. Table 5.1 indicates that the lowest-cost management strategy is the No Action alternative and the second lowest-cost alternative is long-term storage of depleted UF_6. Unlike the other alternatives, these do not involve conversion to another chemical form. Table 5.1 also indicates that the highest-cost alternative management strategy is use as DUCRETE™ if the UO_2 conversion is by the gelation process; however, the cost of use as DUCRETE™ falls significantly if conversion is by a dry process. Additionally, taking credit for the cask can further reduce the cost of this alternative (refer to Section 6.1.3).

Table 5.2 indicates that disposal in a mined cavity as grouted U_3O_8 using the defluorination with HF neutralization conversion option is the most costly alternative using the high-cost scenarios. It is noted that the No Action alternative is still the lowest-cost alternative and long-term storage of depleted UF_6 is still the second lowest-cost alternative. The No Action alternative is unique in that the low- and the high-cost scenarios are equal since it is simply continued storage of depleted UF_6 in the existing yards, and options for preparation for shipment, transportation, and conversion do not apply.

Figures 5.1 and 5.2 compare the total costs of each alternative management strategy for both the low- and high-cost scenarios. Figures 5.3 to 5.28 present the percentage of cost attributed to each option category (continued storage, transportation, conversion, use, long-term storage, and disposal) for each alternative strategy for both the low- and high-cost scenarios.

Table 5.1 Cost Breakdown (in Millions of Dollars) for the Low-Cost Alternative Management Strategies

DUF_6 Alternatives	Continued Storage	Transportation	Conversion	Use	Long-term Storage	Disposal	TOTAL
No Action	327						327
DUF_6 Long Term Storage	197	172			214		583
Long-Term Storage as Oxide (U_3O_8 Defluorination w/AHF Prod.)	197	191	267		225		880
Long-Term Storage as Oxide (U_3O_8 Defluorination. w/HF Neutralization.)	197	191	325		225		938
Long-Term Storage as Oxide (UO_2 Gelation)	197	191	821		147		1,356
Use as Oxide (UO_2 Dry Process w/AHF Prod.)	197	200	347	856			1,600
Use as Oxide (UO_2 Dry Process w/HF Neutralization)	197	200	395	856			1,648
Use as Oxide (UO_2 Gelation)	197	201	821	856			2,075
Use as Metal (Batch Met. Reduction)	197	202	665	889			1,953
Use as Metal (Cont. Met. Reduction)	197	202	492	889			1,780
Disposal (U_3O_8 Defluorination. w/AHF Prod.)	197	191	267			155	810
Disposal (U_3O_8 Defluorination. w/HF Neutralization.)	197	191	325			155	868
Disposal (UO_2 Gelation)	197	191	821			123	1,332

Figure 5.1 Comparison of Total Costs of Alternative Management Strategies (Low-Cost Scenarios)

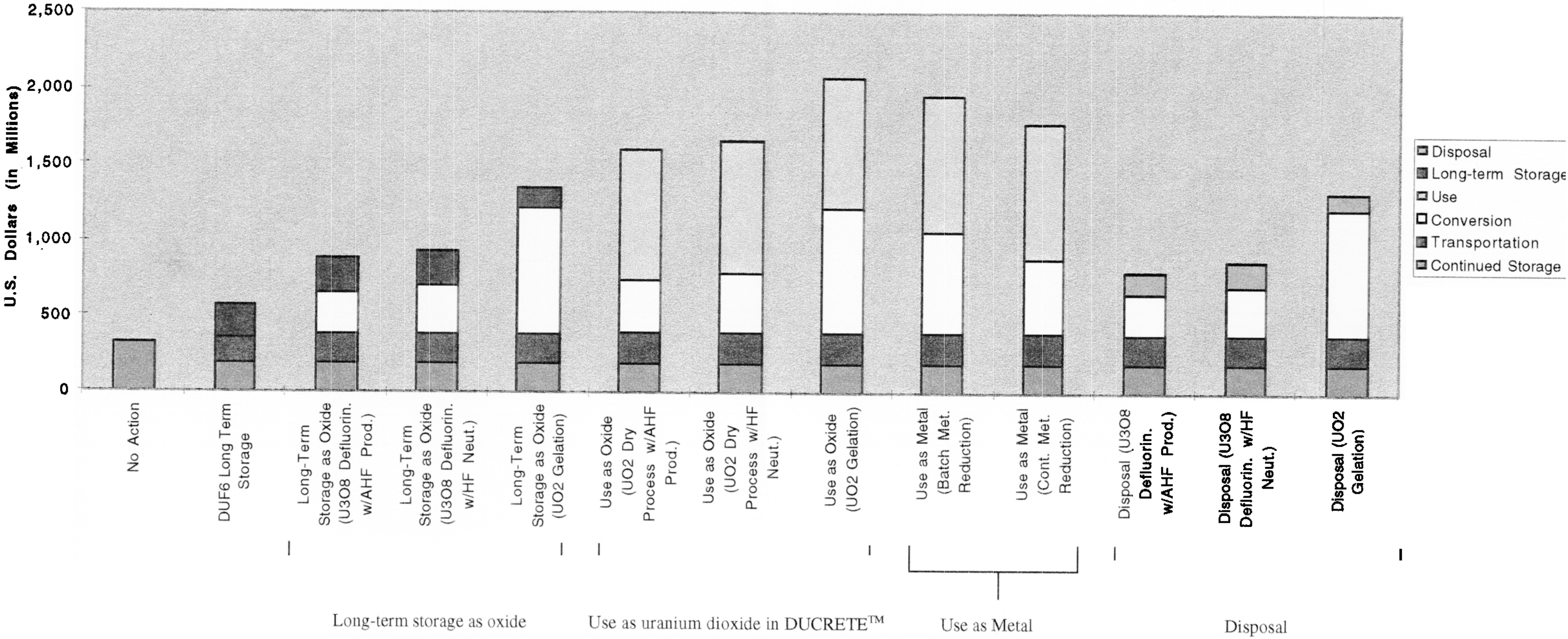


Table 5.2 Cost Breakdown (in Millions of Dollars) for the High-Cost Alternative Management Strategies

DUF_6 Alternatives	Continued Storage	Transportation	Conversion	Use	Long-term Storage	Disposal	TOTAL
No Action	327						327
DUF_6 Long Term Storage	197	677			644		1,518
Long-Term Storage as Oxide (U_3O_8 Defluorination. w/AHF Prod.)	197	702	267		731		1,897
Long-Term Storage as Oxide (U_3O_8 Defluorination. w/HF Neutralization.)	197	702	325		731		1,955
Long-Term Storage as Oxide (UO_2 Gelation)	197	702	821		483		2,203
Use as Oxide (UO_2 Dry Process w/AHF Prod.)	197	712	347	856			2,112
Use as Oxide (UO_2 Dry Process w/HF Neutralization.)	197	712	395	856			2,160
Use as Oxide (UO_2 Gelation)	197	711	821	856			2,585
Use as Metal (Batch Met. Reduction)	197	712	665	889			2,463
Use as Metal (Cont. Met. Reduction)	197	712	492	889			2,290
Disposal (U_3O_8 Defluorination. w/AHF Prod.)	197	702	267			1,395	2,561
Disposal (U_3O_8 Defluorination. w/HF Neutralization.)	197	702	325			1,395	2,619
Disposal (UO_2 Gelation)	197	702	821			830	2,550

Figure 5.2 Comparison of Total Costs of Alternative Management Strategies (High-Cost Scenarios)

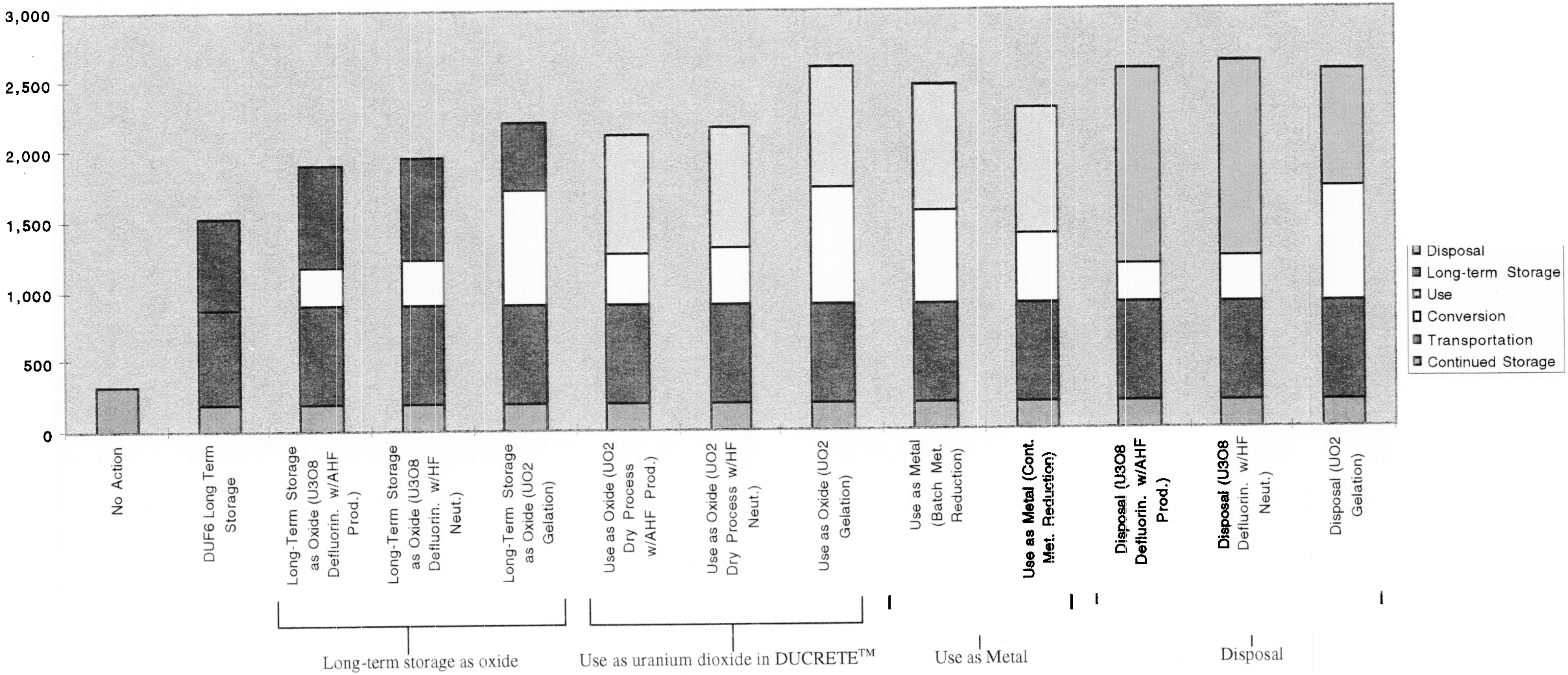


Figure 5.3 Low-Cost Breakdown for No Action ($327 Million)

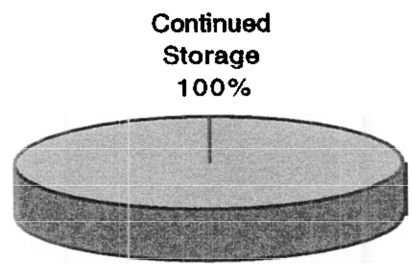


Figure 5.4 High-Cost Breakdown for No Action ($327 Million)

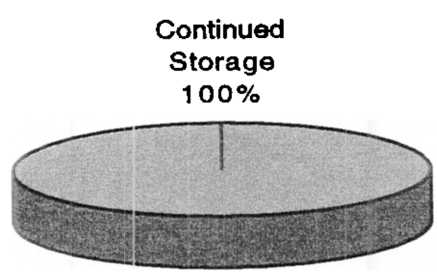


Figure 5.5 Low-Cost Breakdown for Long-Term Storage as DUF_6 ($583 Million)

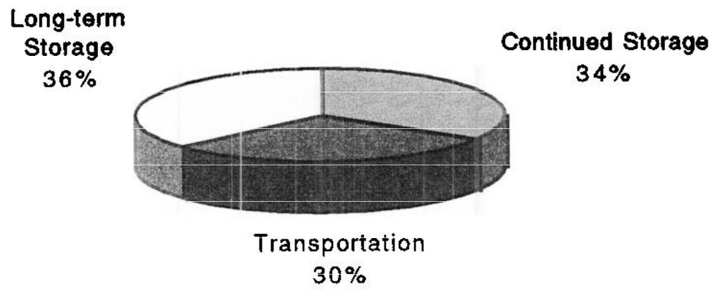


Figure 5.6 High-Cost Breakdown for Long-Term Storage as DUF_6 ($1518 Million)

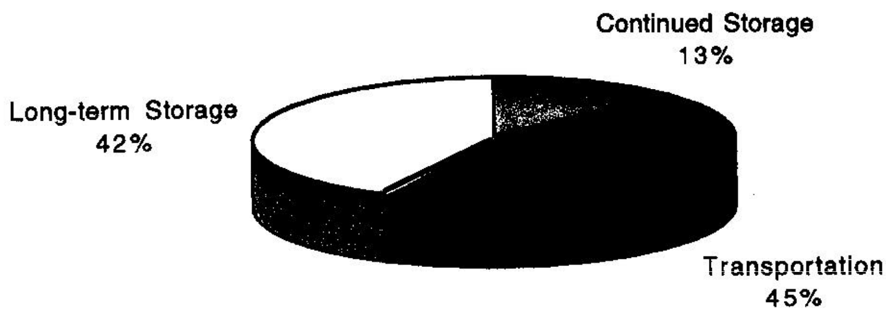


Figure 5.7 Low-Cost Breakdown for Long-Term Storage as Oxide - U_3O_8 Defluorination w/AHF Production ($880 Million)

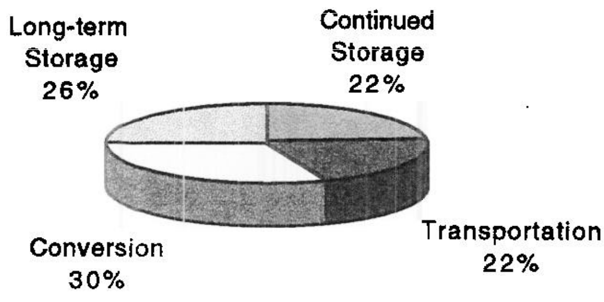


Figure 5.8 High-Cost Breakdown for Long-Term Storage as Oxide - U_3O_8 Defluorination w/AHF Production ($1897 Million)

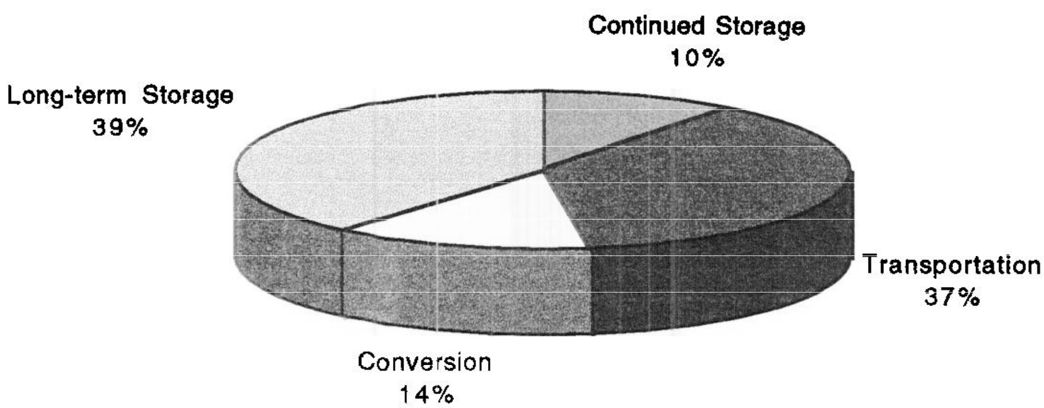


Figure 5.9 Low-Cost Breakdown for Long-Term Storage as Oxide - U_3O_8 Defluorination w/HF Neutralization ($938 Million)

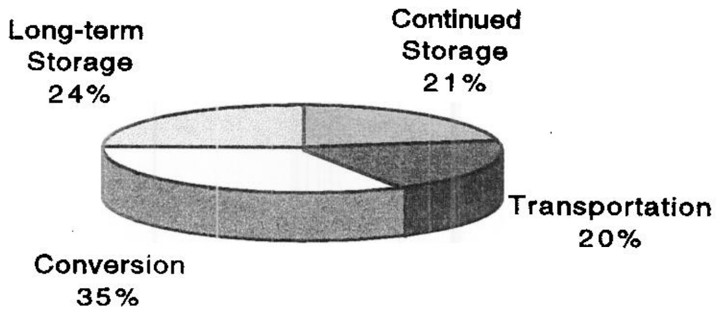


Figure 5.10 High-Cost Breakdown for Long-Term Storage as Oxide - U_3O_8 Defluorination w/HF Neutralization ($1955 Million)

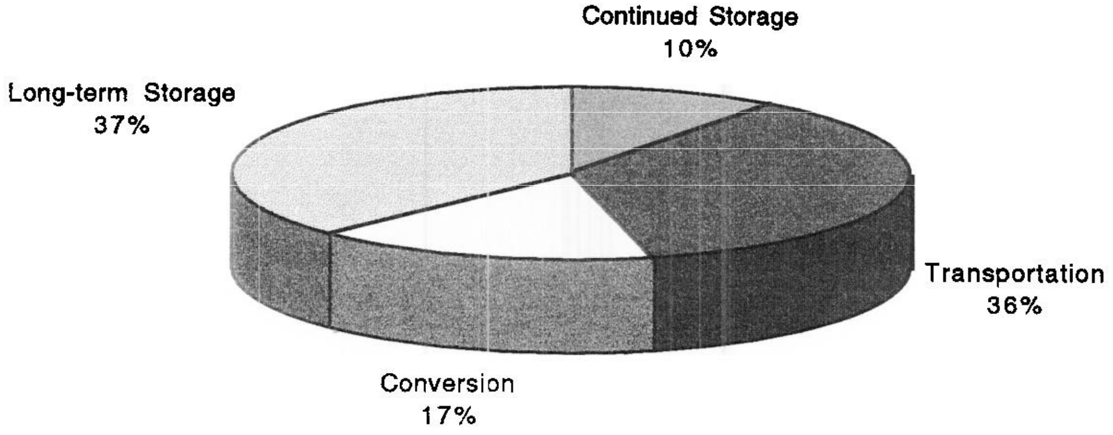


Figure 5.11 Low-Cost Breakdown for Long-Term Storage as Oxide - UO_2 Gelation ($1,356 Million)

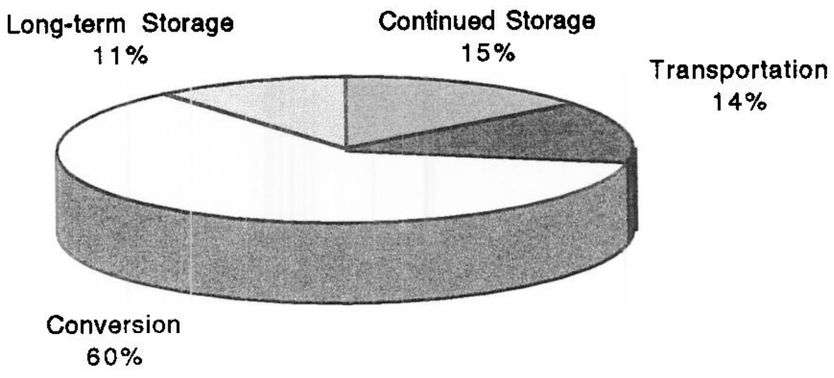


Figure 5.12 High-Cost Breakdown for Long-Term Storage as Oxide - UO_2 Gelation ($2,203 Million)

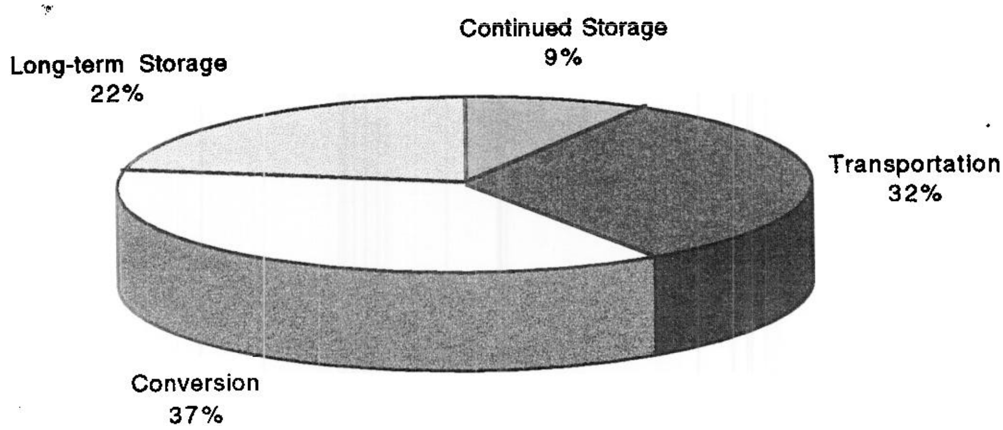


Figure 5.13 Low-Cost Breakdown for Use as Oxide - UO_2 Dry Process w/AHF Production ($1,600 Million)

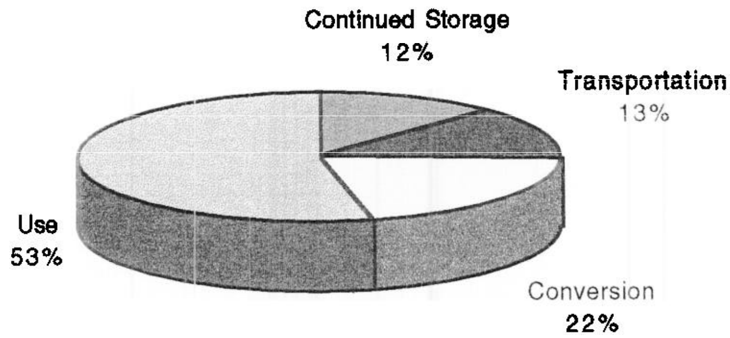


Figure 5.14 High-Cost Breakdown for Use as Oxide - UO_2 Dry Process w/AHF Production ($2,112 Million)

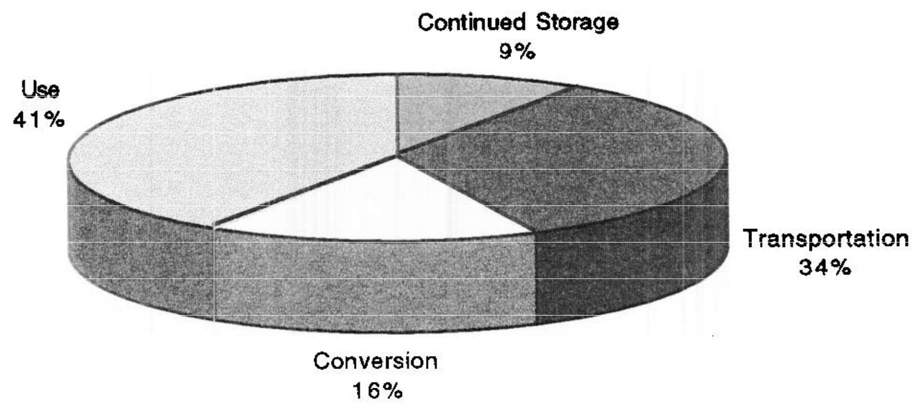


Figure 5.15 Low-Cost Breakdown for Use as Oxide - UO_2 Dry Process w/HF Neutralization ($1,648 Million)

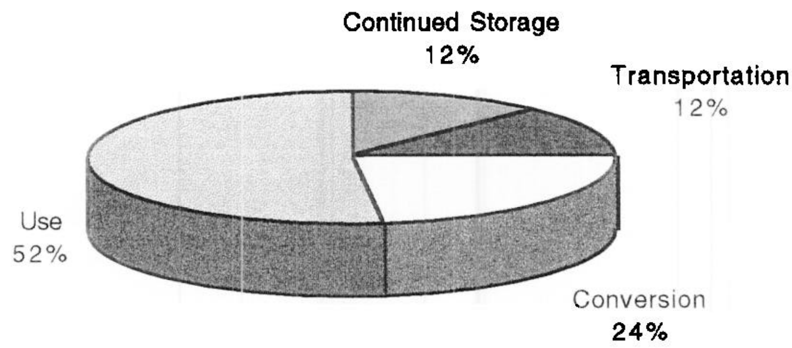


Figure 5.16 High-Cost Breakdown for Use as Oxide - UO_2 Dry Process w/HF Neutralization ($2,160 Million)

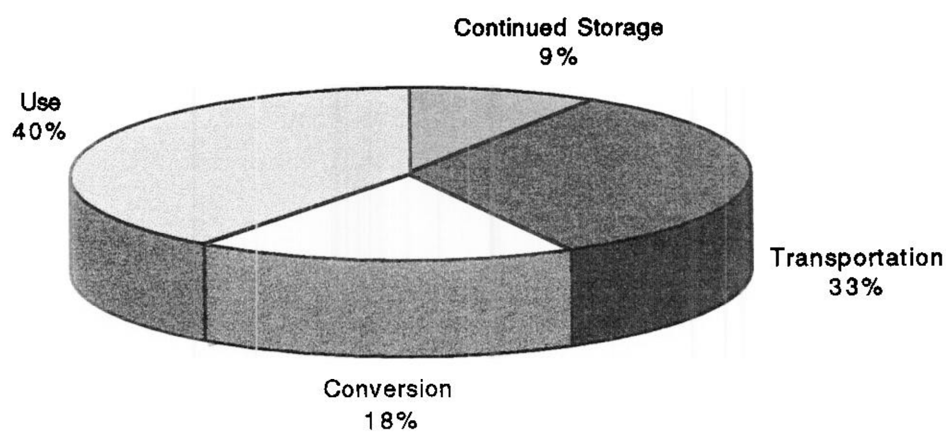


Figure 5.17 Low-Cost Breakdown for Use as Oxide - UO_2 Gelation ($2,075 Million)

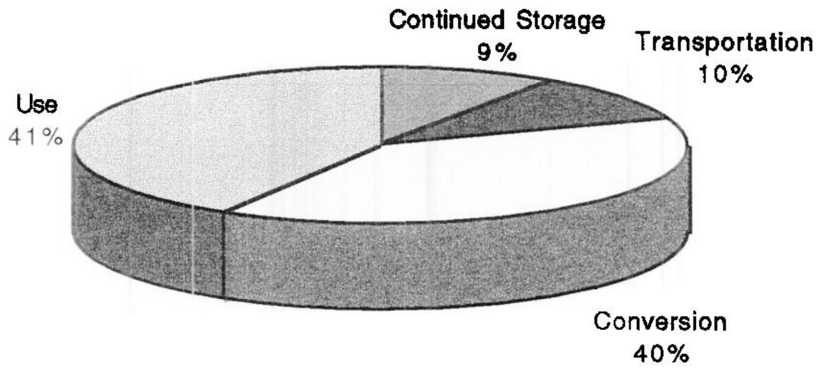


Figure 5.18 High-Cost Breakdown for Use as Oxide - UO_2 Gelation ($2,585 Million)

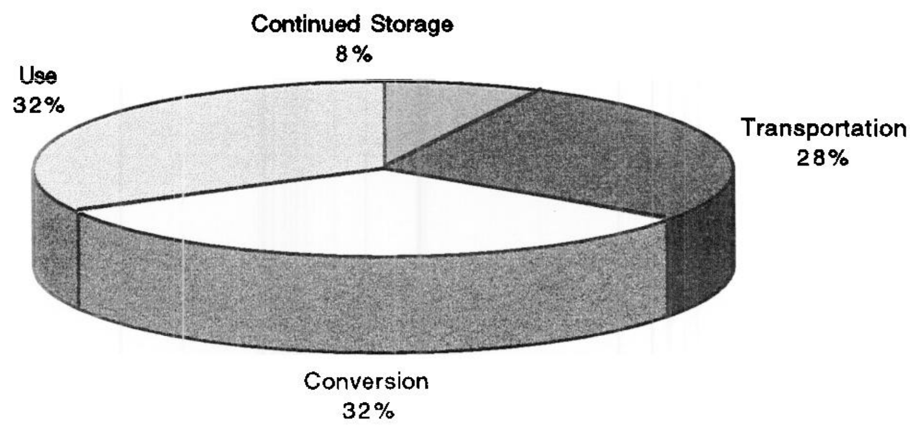


Figure 5.19 Low-Cost Breakdown for Use as Metal - Batch Metallothermic Reduction ($1,953 Million)

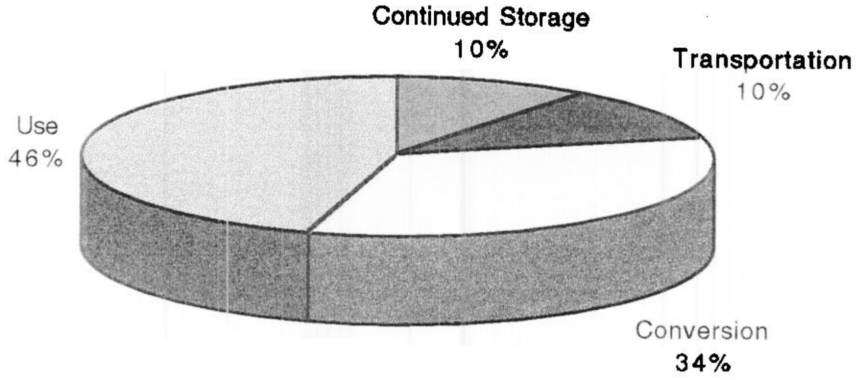


Figure 5.20 High-Cost Breakdown for Use as Metal - Batch Metallothermic Reduction ($2,463 Million)

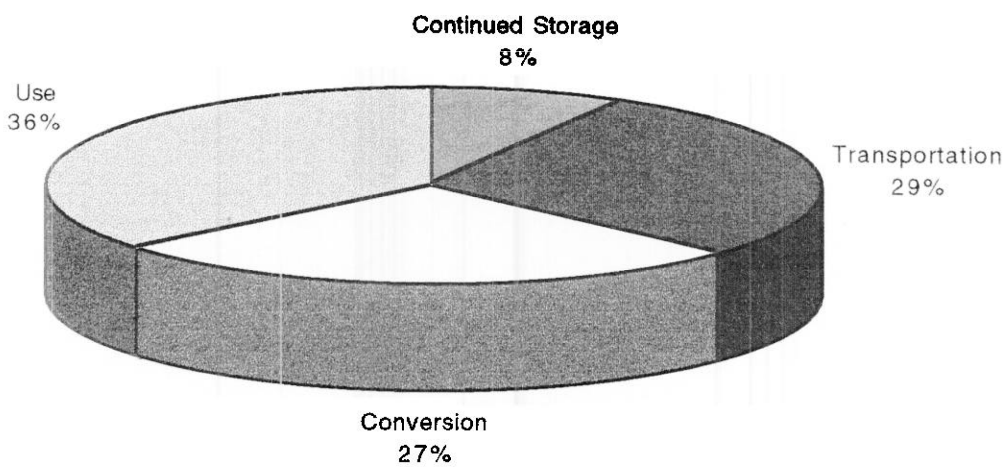


Figure 5.21 Low-Cost Breakdown for Use as Metal - Continuous Metallothermic Reduction ($1,780 Million)

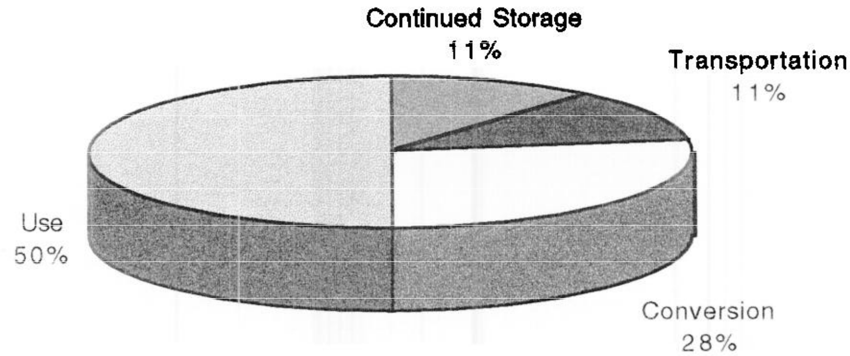


Figure 5.22 High-Cost Breakdown for Use as Metal - Continuous Metallothermic Reduction ($2,290 Million)

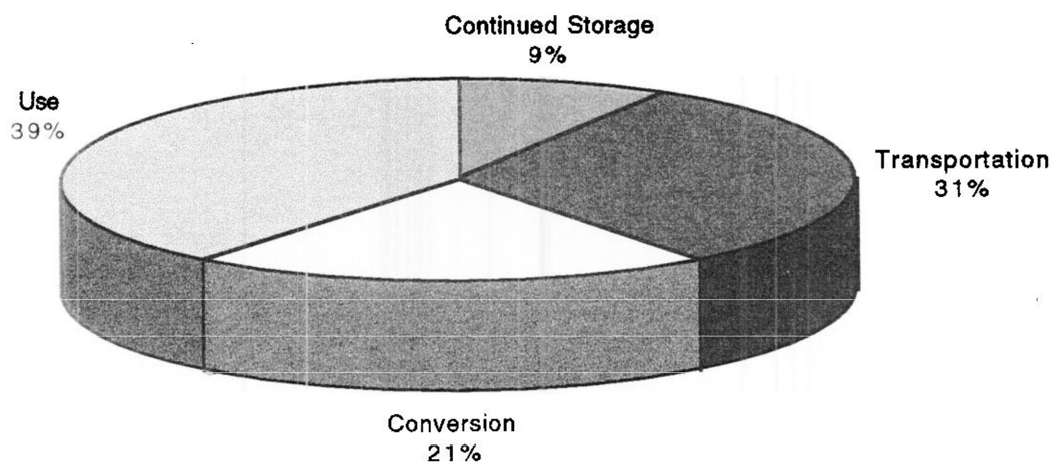


Figure 5.23 Low-Cost Breakdown for Disposal as Oxide - U_3O_8 Defluorination w/AHF Production ($810 Million)

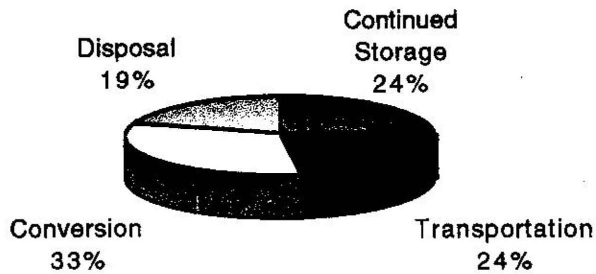


Figure 5.24 High-Cost Breakdown for Disposal as Oxide - U_3O_8 Defluorination w/AHF Production ($2,561 Million)

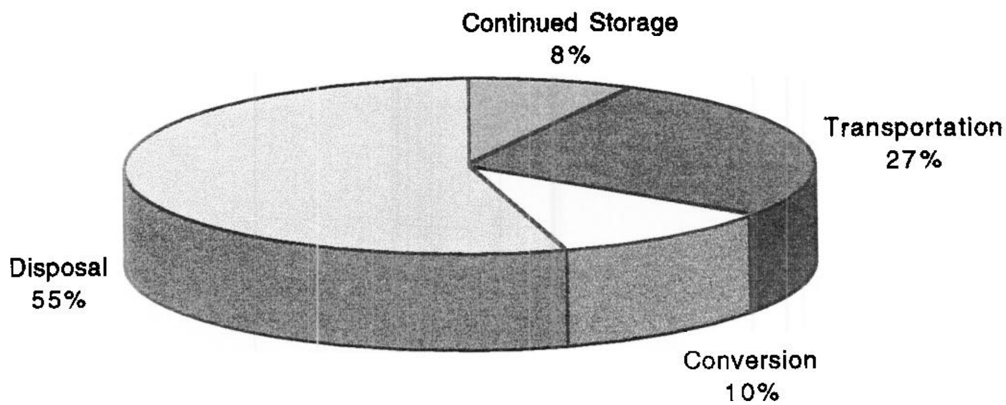


Figure 5.25 Low-Cost Breakdown for Disposal as Oxide - U_3O_8 Defluorination w/HF Neutralization ($868 Million)

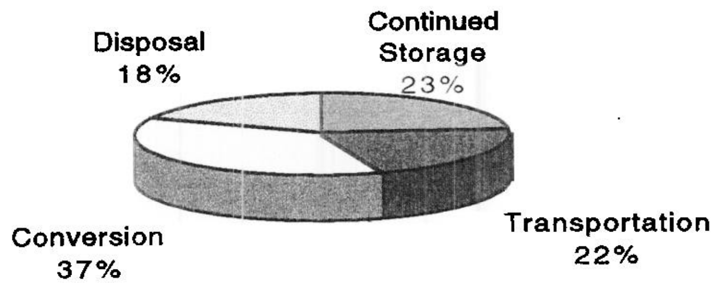


Figure 5.26 High-Cost Breakdown for Disposal as Oxide - U_3O_8 Defluorination w/HF Neutralization ($2,619 Million)

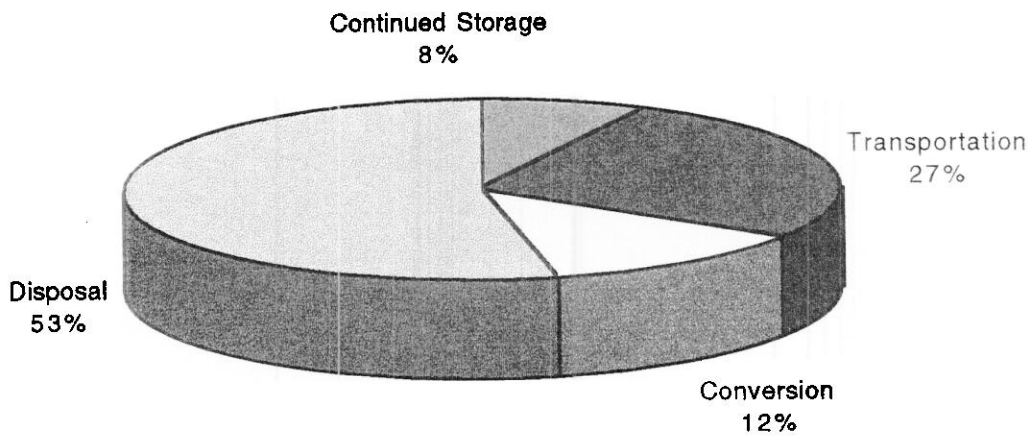


Figure 5.27 Low-Cost Breakdown for Disposal as Oxide - UO_2 Gelation ($1,332 Million)

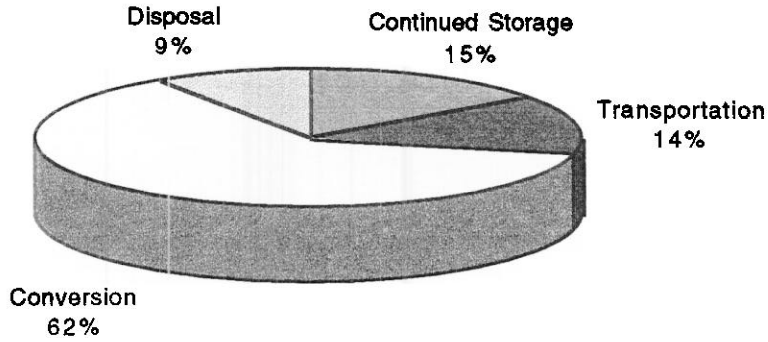
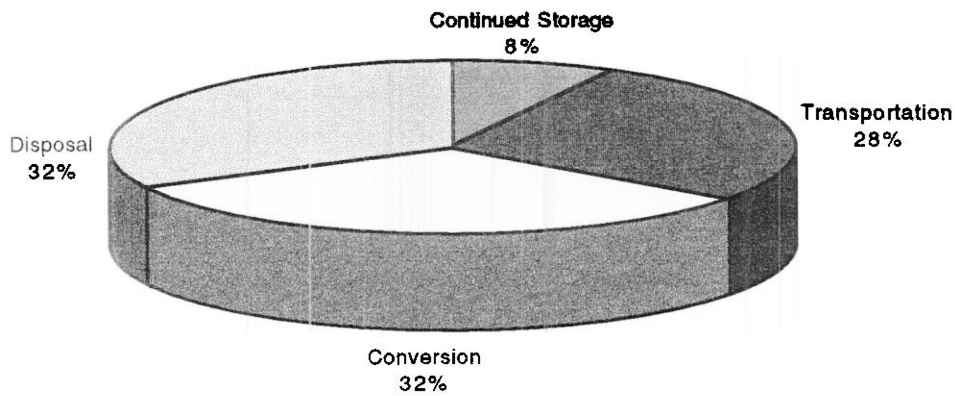


Figure 5.28 High-Cost Breakdown for Disposal as Oxide - UO_2 Gelation ($2,550 Million)



6. ANALYSIS OF SENSITIVITIES, RISKS, AND VULNERABILITIES

In addition to the reference cases treated in Chapters 4 and 5, there are sensitivity cases, performance risks, and vulnerabilities that need to be considered because they can make the cost outcome substantially different from that found for the reference cases. Sensitivity analyses were performed in accordance with OMB Circular No. A-94 guidance to determine how sensitive the costs of the alternative strategies were to changes in assumptions for various input parameters. The results are presented in Section 6.1.

In Section 6.2, Performance Risk, uncertainties in facility operating conditions and their potential cost impacts are discussed. For purposes of this discussion, performance risks are defined as failures of equipment and systems to perform up to the levels specified by their designers and causing them to operate below design specifications or to require additional process equipment in order to meet product quality requirements.

Process vulnerabilities to changes in the external environment in which the facility operates are the focus of Section 6.3. The facility may exactly meet its design goals, for example, but may not be allowed to dispose of a major processing waste as planned. Cost impacts due to external regulations affecting the use of major by-products or the disposal of large waste streams are discussed in Section 6.3.

Performance risks and vulnerabilities are alike in that they result from insufficient information being available to the facility designers. They differ in that performance risks can be reduced to as low a level as desired by early expenditures on developing and demonstrating the technology and the equipment. Vulnerabilities, since they result from changes in the legal and regulatory environment, cannot be controlled by the process designer or facility operator.

6.1 Sensitivity Analyses

Sensitivity to variations in discount rate, transportation distance, shielding cask values, product density, and facility throughput are presented in this section.

6.1.1 Effect of Discount Rate

All costs were estimated in first-quarter 1996 dollars and discounted to the start of the project according to OMB guidance:

> constant-dollar benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent. This rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years.

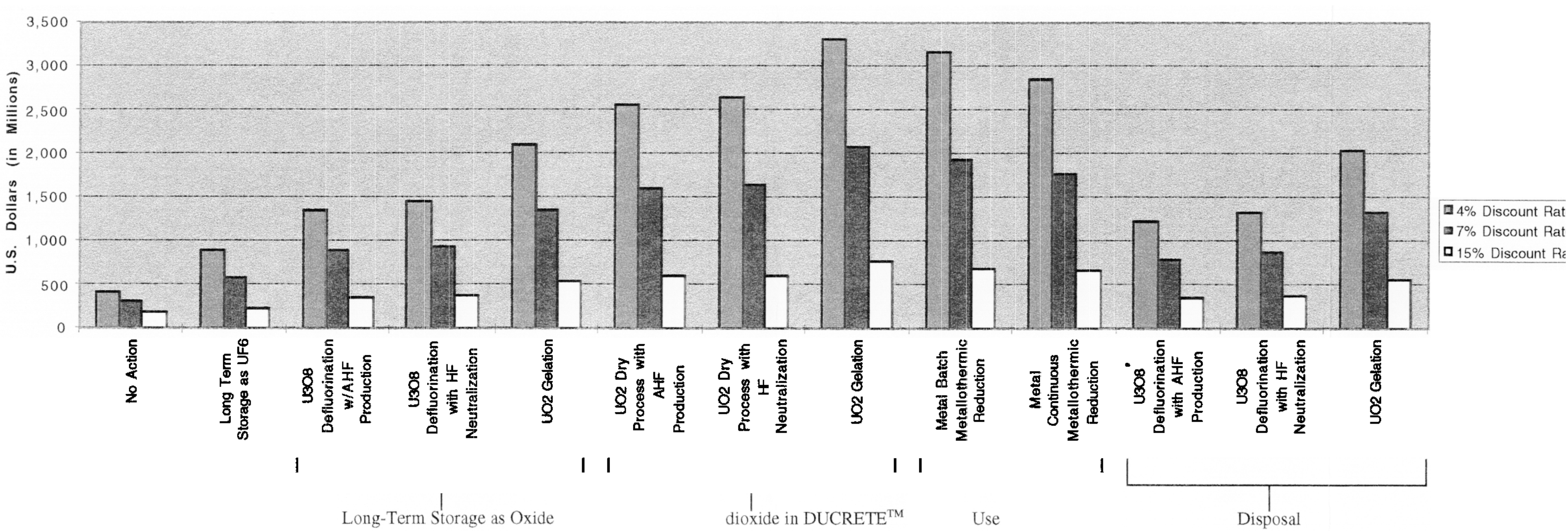
However, 7% may be too high if the long-term management of depleted UF_6 is viewed as an "internal" government investment that takes the form of decreased federal costs. Conversely, it may be too low if the management of the depleted UF_6 is privatized and private industry views the financial return as riskier than normal. Therefore, the effects on the present value of discount rates as low as 4% and as high as 15% were analyzed and the results summarized in Table 6.1 and Figure 6.1 (the low-cost scenario is addressed, as described in Chapter 5). Examination of Table 6.1 and Figure 6.1 shows that the ranking of strategies according to their cumulative discounted net costs is essentially unaffected by the choice of discount rates used for sensitivity analysis.

Table 6.1 Cost Breakdown (in Millions of Dollars) Based on Discount Rate

Strategy	Discount Rate 4.00%	7.00% *	15.00%
No Action	432	327	193
Long Term Storage as UF_6	903	583	241
Long-Term Storage as Oxide			
U_3O_8 Defluorination w/AHF Production	1,357	880	365
U_3O_8 Defluorination with HF Neutralization	1,462	938	378
UO_2 Gelation	2,099	1,356	554
Use as DUCRETE™			
UO_2 Dry Process with AHF Production	2,553	1,600	598
UO_2 Dry Process with HF Neutralization	2,643	1,648	607
UO_2 Gelation	3,309	2,075	775
Use as Metal			
Metal Batch Metallothermic Reduction	3,154	1,953	705
Metal Continuous Metallothermic Reduction	2,850	1,780	661
Disposal			
U_3O_8 Defluorination with AHF Production	1,221	810	357
U_3O_8 Defluorination with HF Neutralization	1,327	869	370
UO_2 Gelation	2,043	1,332	558

* Values in this column are for the reference case; they were taken from Table 5.1

Figure 6.1 Total Costs for Given Rates



6.1.2 Effect of Transportation Distances

The *Cost Analysis Report* and the draft PEIS assume a transportation distance of 1000 km whenever facilities are not collocated. The actual transportation distance may be more or less. In order to provide insights into the impacts of different transportation distances, the transportation cost components of the alternative management strategies for different distances are presented in Table 6.2 and Figure 6.2. All values presented in this table reflect the rail and overcontainer options.

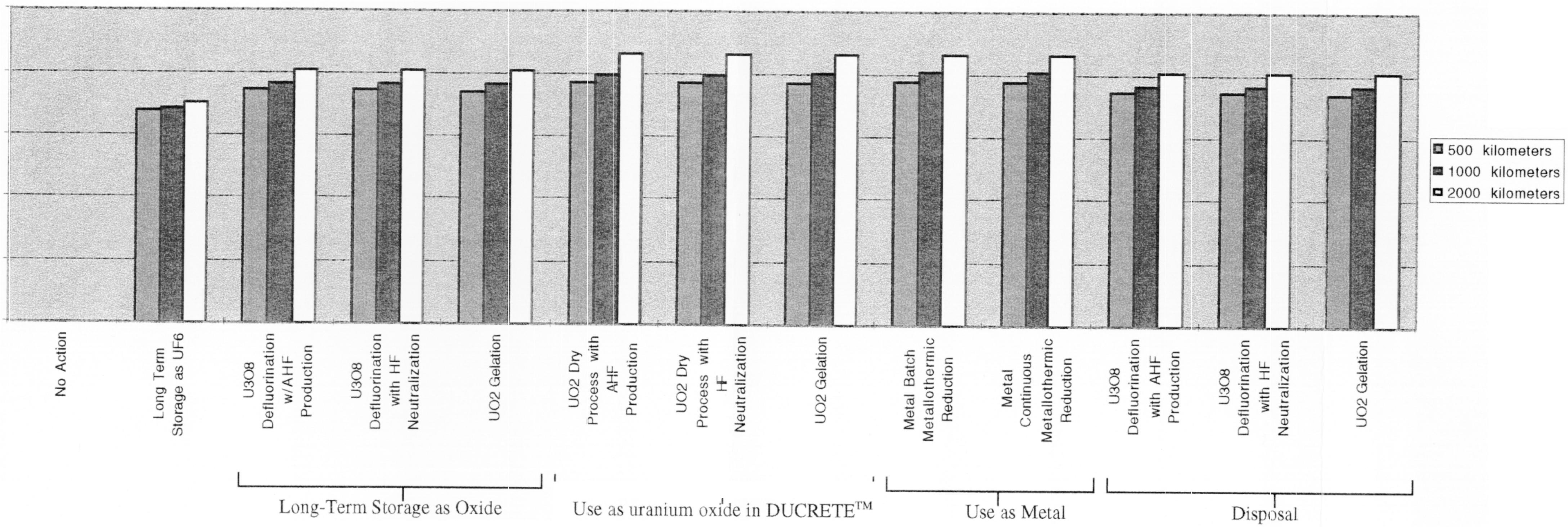
The loading, shipping, and unloading costs represent less than one quarter of the transportation costs. Changing the shipping distance does not change the ranking of strategies by cost. Distance affects only the shipping component of transportation costs, which will vary linearly with the distance between facilities. Total transportation costs are therefore relatively insensitive to distances between facilities. There is significant flexibility, therefore, in choosing off-site locations for conversion, manufacturing, storage, and disposal facilities. On-site locations, which would eliminate transportation costs, would require additional consideration. These cases would require site-specific analysis of distinctly sized facilities. The cost savings from avoiding transportation could readily be exceeded by the costs incurred from deploying multiple facilities.

Table 6.2 Transportation Cost Breakdown (in Millions of Dollars) based on Distance Between Facilities using Rail and Overcontainer Options

Strategy	Distance Between Facilities (in kilometers)		
	500	1000 *	2,000
No Action	0	0	0
Long Term Storage as UF_6	169	172	177
Long-Term Storage as Oxide			
U_3O_8 Defluorination w/AHF Production	186	191	202
U_3O_8 Defluorination with HF Neutralization	186	191	202
UO_2 Gelation	186	191	202
Use as DUCRETE™			
UO_2 Dry Process with AHF Production	193	200	215
UO_2 Dry Process with HF Neutralization	193	200	215
UO_2 Gelation	193	201	216
Use as metal			
Metal Batch Metallothermic Reduction	195	202	217
Metal Continuous Metallothermic Reduction	195	202	217
Disposal			
U_3O_8 Defluorination with AHF Production	186	191	202
U_3O_8 Defluorination with HF Neutralization	186	191	202
UO_2 Gelation	186	191	202

* Values in this column are for the reference case; they were taken from Table 4.6.

Figure 6.2 Total Transportation Costs for Given Distances between Facilities (Rail and Overcontainer Options)



6.1.3 Effect of Shielding Cask Values

As described in Section 2.1.5, the *Engineering Analysis Report* and the draft PEIS consider two alternatives involving the manufacture and use of depleted uranium for shielding: uranium dioxide (DUCRETE™) and uranium metal. The first option involves the manufacture of DUCRETE™ casks for dry storage of spent nuclear fuel disposal. The second involves the use of depleted uranium metal in the manufacture of annular shields for a multipurpose unit system for the storage, transportation, and disposal of spent nuclear fuel. The cost of these options was presented in Section 4.3 without taking any credit for the cask.

Both the *Cost Analysis Report* and the *Engineering Analysis Report* were based on the assumption that the demand for casks would match the supply, working off the inventory over 20 years. Based upon a throughput of 28,000 MT of depleted UF_6 per year, 480 DUCRETE™ and 453 depleted uranium metal casks would be produced annually. This approach is supported by the literature:

> The total quantity of DU metal needed for fabrication of 9500 containers is approximately 437,000 MTU. This total demand for DU metal exceeds the current DOE-owned inventory. . . (Herztler and Nishimoto, pp 33-34).

and

> Placing all of the U.S. spent fuel (about 86,000 metric tons) in DUCRETE casks would require about 9,500 casks and use most of the current DOE depleted uranium inventory (Powell, p. 2).

If depleted uranium or DUCRETE™ were manufactured into shielding casks for the storage of spent nuclear fuel, some price could be charged to the power reactor operator for such casks. This charge would off-set a portion of the costs incurred by management strategies for using depleted UF_6 whose end product is a cask. The revenue to the depleted UF_6 management enterprise from this charge should be taken into account, just as revenues from by-product AHF or CaF_2 sales are folded into the present-value evaluations presented in Chapters 4 and 5.

Casks made from depleted uranium metal or DUCRETE™ may have benefits to reactor operators that would make them more attractive to use (and thus command a higher price) than conventional concrete casks. These benefits might include potential reductions in transportation costs and cask handling operations. For example, a DUCRETE™ cask could be loaded directly in the spent nuclear fuel pool, whereas the current plan is to use a separate transfer cask because a conventional concrete cask is too large to fit into the storage pool. Additionally, it is possible that the depleted uranium cask could eventually be disposed with the spent fuel at the repository. However, these added benefits are speculative at the present time. The focus of this section is to make an initial assessment of the off-setting revenues resulting from cask production. This estimate will then be used in the life-cycle cost analysis for strategies leading to manufactured depleted uranium metal or DUCRETE™ casks to test the sensitivity of life-cycle costs to the cask value.

The economic differences between a DUCRETE™ spent nuclear fuel storage cask and a conventional concrete storage cask are summarized in the report, *Comparative Economics for DUCRETE Spent Fuel Storage Cask Handling, Transportation, and Capital Requirements*. The conventional concrete cask system considered in the report is the NRC-licensed Sierra Nuclear Corporation Ventilated Storage Cask, with an estimated cost for materials of about $200,000, excluding such elements as engineering design and project management (Powell 1995).

Another NRC-licensed concrete cask is the Vector Fuels Division's NUHOMS concrete horizontal storage module. In the *Depleted Uranium Concrete Container Feasibility Study* (Haeslig 1994), the estimated cost for the concrete module of this storage system is $150,000. It is noted that an inner metal multipurpose canister system is needed to contain the spent nuclear fuel stored in any of the dry concrete storage systems. Similar economic data for the multipurpose unit system were not discovered. Accordingly, a sensitivity analysis assuming a cask credit of $150,000 and $200,000 per cask for both the DUCRETE™ and metal shielding applications was conducted.

As shown in Table 6.3, a cask credit of $150,000 and $200,000 per cask would reduce the life-cycle costs of the shielding options by about 40-60%. The cost of complete management strategy alternatives is presented in Chapter 5 of this *Cost Analysis Report.* These costs range from about $1,600 to $2,600 million (7% p.a. discount rate) for the shielding alternative without the cask credit. Total management strategy alternative costs would be reduced about $370-$550 million (7% p.a. discount rate) or 14-34% with the assumed cask credit.

Table 6.3 Sensitivity Analysis for Depleted Uranium Shielding Applications - Cask Credit

	DUCRETE™ Shielding Applications	Metal Shielding Applications
Number of casks manufactured		
per year	480	453
total, in 20 year project	9,600	9,060
Annual credit from sale of casks (millions)		
@ $0.15 million/shield	$72.00	$67.95
@ $0.2 million/shield	$96.00	$90.60
Cumulative present value credit from sale of casks (millions)		
@ $0.15 million/shield	$362.39	$342.00
@ $0.2 million/shield	$483.18	$456.00
Cumulative present value of shielding option (millions)		
With no credit for sale of casks (reference case)*	$856.30	$889.30
With credit of $0.15 million/cask	$493.91	$547.30
With credit of $0.20 million/cask	$373.12	$433.30

* Values in this row are for the reference case; they were taken from Table 4.10.

6.1.4 Effect of Density on UO_2 Storage and Disposal Options

The costs for the UO_2 storage and disposal options (Chapter 4) and their associated strategies (Chapter 5) are based on the gelation process for the conversion of UF_6 to dense

UO_2. The gelation process produces small spheres with a higher bulk density than the conventional UO_2 process, which produces pellets. This leads to a reduction in storage and disposal volume requirements, and therefore the gelation process minimizes the costs for the storage and disposal options involving the oxide. However, the gelation process is substantially more expensive than conversion to UO_2 pellets or U_3O_8 powder. Because the higher conversion cost of the gelation process does not off-set its lower storage and disposal option costs, the storage and disposal strategies based on U_3O_8 have a significantly lower cost (Chapter 5).

Bottom-up storage and disposal costs were not determined for UO_2 pellets, which have a bulk density and a conversion cost between that for U_3O_8 powder and that for UO_2 produced by the gelation process. An approximate scaling analysis was used to estimate the storage and disposal option costs for ungrouted UO_2 pellets. Within the estimating uncertainties, no significant differences were found in the strategy costs for storage and disposal of ungrouted UO_2 pellets and ungrouted U_3O_8 powder. Thus, storage and disposal of UO_2 pellets as a variation on the long-term management strategies for storage and disposal as an oxide are suitably contained within the options analyzed.

6.1.5 Effect of Facility Throughput

A period of 20 years was assumed to disposition the entire depleted uranium stockpile (about 560,000 MT UF_6 in 46,422 cylinders). This corresponds to an annual throughput rate of 28,000 MT of UF_6 or about 19,000 MT of uranium. Each option was evaluated at this rate, assuming that a single alternative would be selected. It is possible, however, that a hybrid of alternatives will be implemented. The need for parametric analysis of other options being considered for the long-term management of depleted UF_6 was determined after the end of the scoping period for the PEIS (March 25, 1996). The following options were selected for parametric analyses:

- Conversion to U_3O_8: defluorination with anhydrous hydrogen fluoride (AHF)
- Conversion to UO_2: ceramic UO_2 with AHF
- Conversion to uranium metal by continuous metallothermic reduction
- Manufacture and use as shielding (DUCRETE™ and metal)
- Storage in buildings as UO_2 and UF_6
- Disposal in a mined cavity as bulk U_3O_8

Key engineering and cost data elements for facilities that are sized for 50% and 25% of the reference capacity case (28,000 MT/year of depleted UF_6) were evaluated. These smaller facilities are assumed to be deployed on the same schedule as the reference facility and operate at throughputs of 14,000 MT/year and 7,000 MT/year, respectively, for 20 years. A summary of the results of these analyses is presented in Tables 6.4 to 6.11, and Figures 6.3 to 6.6. A discount rate of 7% p.a. is assumed.

As shown by these tables, reducing the throughput does not result in a corresponding cost reduction of the same magnitude. This is expected, on the basis of economy of scale considerations; however, the magnitude of this effect depends strongly on the specific option. For the conversion options, the present-value cost drops about 16%, on average, when the throughput is halved from the reference capacity. For the storage options, the equivalent reduction is about 34% on average. This significant difference reflects the greater modularity of the storage facility designs. These studies of throughput variations show that hybrid alternatives would likely have a higher total cost than a single alternative. For example, a hybrid which involves converting the depleted UF_6 to UO_2 and using half in DUCRETE™ shielding applications and storing half would have a higher cost over the time frame considered than storing it all as oxide. Likewise, the cost could also be significantly higher for an alternative involving multiple sites for the same module. For example, the increase in conversion costs from converting the depleted UF_6 to UO_2 at two sites may not be off-set by the decrease in avoided transportation costs.

Table 6.4 Parametric Analysis of Conversion to U_3O_8: Defluorination w/AHF (in Millions of Dollars)

	25%	50%	100% *
Tech. Development	9.84	9.84	9.84
Process Equipment			
Engineering	3.26	3.64	4.74
Fabrications	7.96	8.88	11.91
Installation	3.78	4.21	5.19
Certification & Test	0.35	0.39	0.52
Subtotal	15.35	17.12	22.36
Process Facilities			
Engineering	6.88	8.29	10.16
Construction	20.01	24.12	29.56
Proj. Management	4.48	5.40	6.61
Subtotal	31.37	37.81	46.33
Balance of Plant			
Engineering	4.22	4.96	6.40
Construction	12.28	14.44	18.63
Proj. Management	2.75	3.23	4.17
Subtotal	19.25	22.63	29.20
Regulatory Compliance	22.70	22.70	22.70
Operations and Maintenance			
Material	29.85	37.79	52.71
Utilities	11.73	12.12	12.83
Labor	123.09	127.16	134.68
Waste Management & Disposal	4.35	6.92	11.86
By-product Revenue	-19.33	-38.66	-77.32
Subtotal	149.69	145.33	134.76
Decont. & Decom.	1.18	1.39	1.76
TOTAL	249.38	256.82	266.95

* Values in this column are for the reference case; they were taken from Table 4.8

Table 6.5 Parametric Analysis of Conversion to UO_2: Ceramic UO_2 w/AHF (in Millions of Dollars)

	25%	50%	100% *
Tech. Development	13.94	13.94	13.94
Process Equipment			
Engineering	5.50	6.26	7.74
Fabrications	13.10	15.05	18.96
Installation	6.70	7.47	8.91
Certification & Test	0.57	0.66	0.83
Subtotal	25.87	29.44	36.44
Process Facilities			
Engineering	9.83	12.52	14.91
Construction	28.61	36.44	43.39
Proj. Management	6.40	8.15	9.71
Subtotal	44.84	57.11	68.01
Balance of Plant			
Engineering	5.10	6.18	7.76
Construction	14.85	17.97	22.57
Proj. Management	2.71	3.28	4.12
Subtotal	22.66	27.43	34.45
Regulatory Compliance	22.70	22.70	22.70
Operations and Maintenance			
Material	38.85	49.67	66.12
Utilities	13.45	13.84	14.55
Labor	141.13	145.20	152.72
Waste Management & Disposal	4.81	7.01	12.47
By-product Revenue	-19.33	-38.65	-77.31
Subtotal	178.91	177.07	168.55
Decont. & Decom.	1.69	2.06	2.51
TOTAL	310.61	329.75	346.60

* Values in this column are for the reference case; they were taken from Table 4.8

Table 6.6 Parametric Analysis of Conversion to Metal by Continuous Metallothermic Reduction (in Millions of Dollars)

	25%	50%	100% *
Tech. Development	20.50	20.50	20.50
Process Equipment			
Engineering	4.72	5.55	6.52
Fabrications	10.63	12.75	15.22
Installation	6.29	7.19	8.20
Certification & Test	0.46	0.56	0.66
Subtotal	22.10	26.05	30.60
Process Facilities			
Engineering	11.59	13.47	16.09
Construction	33.70	39.18	46.82
Proj. Management	7.54	8.77	10.47
Subtotal	52.83	61.42	73.38
Balance of Plant			
Engineering	5.32	6.39	8.22
Construction	15.48	18.59	23.91
Proj. Management	3.46	4.16	5.35
Subtotal	24.26	29.14	37.48
Regulatory Compliance	22.70	22.70	22.70
Operations and Maintenance			
Material	70.74	108.86	171.76
Utilities	12.00	12.39	13.30
Labor	125.91	129.98	139.57
Waste Management & Disposal	3.25	4.30	6.14
By-product Revenue	-6.53	-13.05	-26.11
Subtotal	211.90	255.53	330.77
Decont. & Decom.	1.78	2.09	2.54
TOTAL	349.54	404.38	491.86

* Values in this column are for the reference case; they were taken from Table 4.8

Figure 6.3 Parametric Analysis of Conversion Options

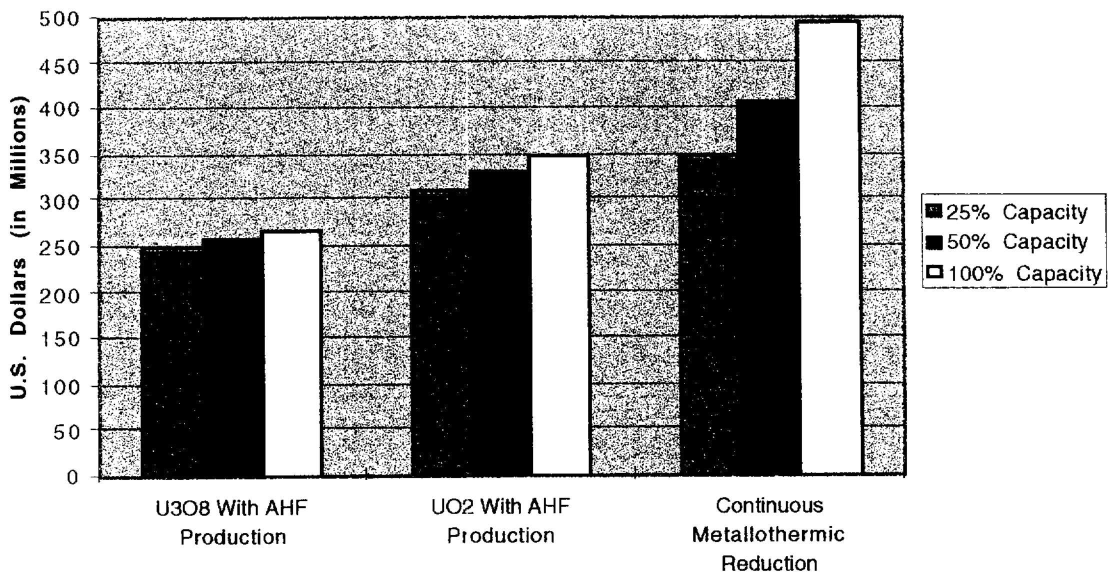


Table 6.7 Parametric Analysis of Manufacture and Use as Metal Shielding (in Millions of Dollars)

	25%	50%	100% *
Engineering Development	16.40	16.40	16.40
Manufacturing Equipment			
Engineering	2.47	3.14	4.11
Fabrication	6.93	8.80	11.55
Installation	1.94	2.45	3.19
Certification and Test	0.33	0.39	0.51
Subtotal	11.67	14.78	19.36
Manufacturing Facilities			
Engineering	5.43	6.41	7.64
Construction	15.81	18.68	22.26
Project Management	3.54	4.18	4.99
Subtotal	24.78	29.27	34.89
Balance of Plant			
Engineering	5.81	5.88	5.95
Construction	16.89	17.10	17.31
Project Management	3.79	3.83	3.88
Subtotal	26.49	26.81	27.14
Regulatory Compliance	17.43	17.43	17.43
Operations & Maintenance			
Materials	93.97	166.49	311.49
Utilities	30.71	36.11	42.30
Labor	301.37	354.37	415.13
Waste Management	1.29	1.96	3.70
Cask Credit	0.00	0.00	0.00
Subtotal	427.34	558.93	772.62
Decontamination & Decommissioning	1.13	1.27	1.46
TOTAL	525.24	664.89	889.30

* Values in this column are for the reference case; they were taken from Table 4.10

Table 6.8 Parametric Analysis of Manufacture and Use as Oxide Shielding (in Millions of Dollars)

	25%	50%	100% *
Engineering Development	6.56	6.56	6.56
Manufacturing Equipment			
Engineering	2.41	3.05	3.94
Fabrication	6.76	8.56	11.06
Installation	1.89	2.38	3.06
Certification and Test	0.32	0.38	0.49
Subtotal	11.38	14.37	18.55
Manufacturing Facilities			
Engineering	5.05	5.79	6.87
Construction	14.72	16.86	20.02
Project Management	3.30	3.78	4.49
Subtotal	23.07	26.43	31.38
Balance of Plant			
Engineering	4.83	4.88	4.94
Construction	14.06	14.21	14.36
Project Management	3.15	3.18	3.22
Subtotal	22.04	22.27	22.52
Regulatory Compliance	17.43	17.43	17.43
Operations & Maintenance			
Materials	88.41	157.59	296.05
Utilities	30.49	31.35	42.41
Labor	299.19	307.60	416.18
Waste Management	1.37	2.08	3.92
Cask Credit	0.00	0.00	0.00
Subtotal	419.46	498.62	758.56
Decontamination & Decommissioning	1.01	1.13	1.30
TOTAL	500.95	586.81	856.30

* Values in this column are for the reference case; they were taken from Table 4.10

Figure 6.4 Parametric Analysis of Use Options

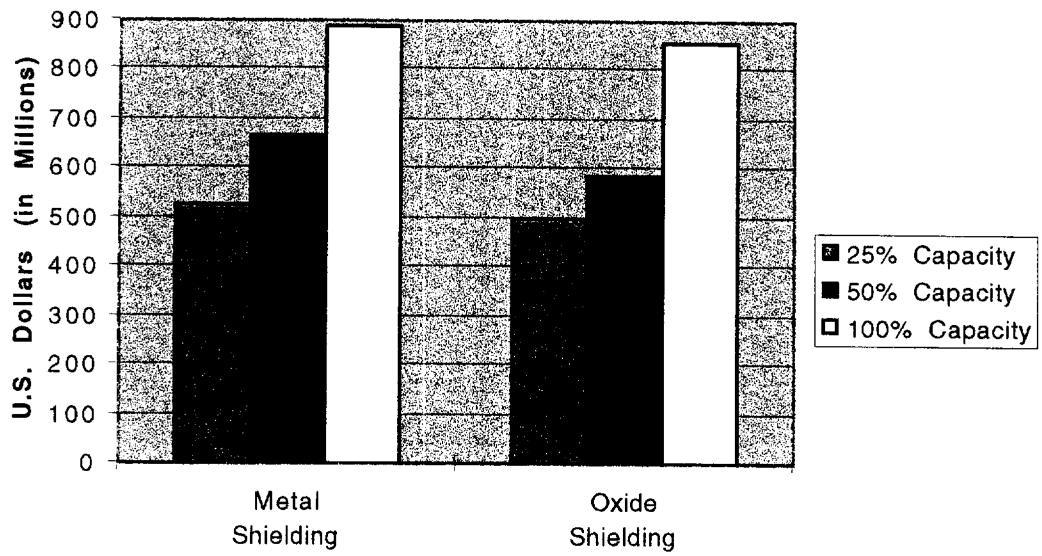


Table 6.9 Parametric Analysis of Storage in Buildings as UF_6 (in Millions of Dollars)

	25%	50%	100% *
Technology Development	0.82	0.82	0.82
Equipment			
Engineering	0.42	0.59	0.95
Fabrications	0.62	0.87	1.39
Installation	1.20	1.67	2.68
Certification & Test	0.03	0.04	0.07
Subtotal	2.27	3.17	5.09
Facilities			
Engineering	6.47	11.03	21.30
Construction	23.54	40.10	77.45
Proj. Management	4.30	7.32	14.13
Subtotal	34.31	58.45	112.88
Balance of Plant			
Engineering	1.00	1.26	1.58
Construction	3.65	4.59	5.74
Proj. Management	0.67	0.84	1.05
Subtotal	5.32	6.69	8.37
Regulatory Compliance	18.61	18.61	18.61
Operations and Maintenance			
Material	8.80	12.00	19.41
Utilities	0.90	1.33	2.12
Labor	24.46	31.88	47.03
Waste Management & Disposal	0.15	0.15	0.15
Subtotal	34.31	45.36	68.71
Decont. & Decom.	0.00	0.00	0.00
TOTAL	95.64	133.10	214.48

* Values in this column are for the reference case; they were taken from Table 4.11

Table 6.10 Parametric Analysis of Storage in Buildings as UO_2 (in Millions of Dollars)

	25%	50%	100% *
Technology Development	0.82	0.82	0.82
Equipment			
Engineering	0.27	0.30	0.38
Fabrications	0.65	0.73	0.94
Installation	0.49	0.55	0.71
Certification & Test	0.03	0.04	0.05
Subtotal	1.44	1.62	2.08
Facilities			
Engineering	4.57	7.04	11.91
Construction	16.62	25.61	43.32
Proj. Management	3.03	4.67	7.91
Subtotal	24.22	37.32	63.14
Balance of Plant			
Engineering	1.04	1.19	1.34
Construction	3.78	4.33	4.88
Proj. Management	0.69	0.79	0.89
Subtotal	5.51	6.31	7.11
Regulatory Compliance	18.61	18.61	18.61
Operations and Maintenance			
Material	5.35	6.15	8.05
Utilities	1.12	1.23	1.63
Labor	22.83	29.85	45.02
Waste Management & Disposal	0.13	0.13	0.13
Subtotal	29.43	37.36	54.83
Decont. & Decom.	0.00	0.00	0.00
TOTAL	80.03	102.04	146.59

* Values in this column are for the reference case; they were taken from Table 4.11

Figure 6.5 Parametric Analysis of Storage Options

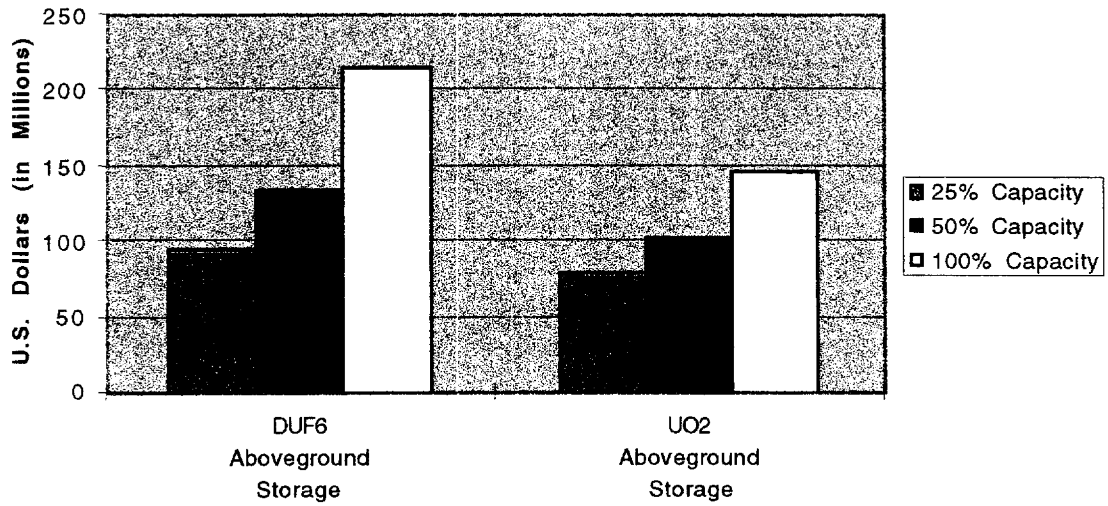


Table 6.11 Parametric Analysis of Disposal in a Mined Cavity as Bulk U_3O_8 (in Millions of Dollars)

Preparation	25%	50%	100% *
Technology Development	8.20	8.20	8.20
Equipment			
Engineering	0.00	0.00	0.00
Fabrications	0.00	0.00	0.00
Installation	0.00	0.00	0.00
Certification & Test	0.00	0.00	0.00
Subtotal	0.00	0.00	0.00
Facilities			
Engineering	0.00	0.00	0.00
Construction	0.00	0.00	0.00
Proj. Management	0.00	0.00	0.00
Subtotal	0.00	0.00	0.00
Balance of Plant			
Engineering	3.11	4.19	6.01
Construction	8.58	11.55	16.56
Proj. Management	2.00	2.69	3.86
Subtotal	13.69	18.43	26.43
Regulatory Compliance	2.02	2.02	2.02
Operations and Maintenance			
Material	0.07	0.10	0.14
Utilities	1.69	2.41	3.51
Labor	15.98	21.38	28.41
Waste Management & Disposal	0.54	0.74	1.17
Subtotal	18.28	24.63	33.23
Decont. & Decom.	0.37	0.46	0.60
Total Preparation Cost	42.56	53.74	70.48

* Values in this column are for the reference case; they were taken from Table 4.12

[Table 6.11 is continued on the next page.]

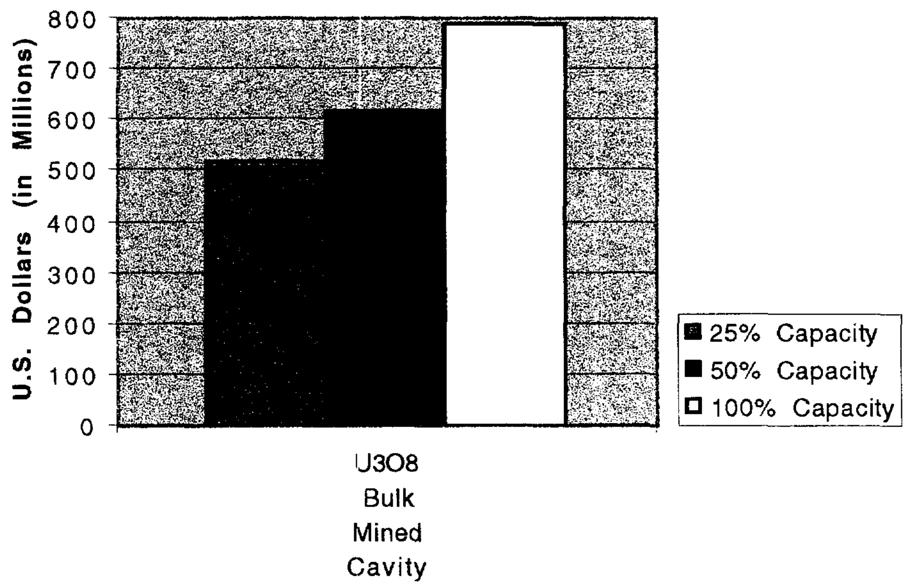
Table 6.11 Parametric Analysis of Disposal in a Mined Cavity as Bulk U_3O_8 (Continued)

	25%	50%	100% *
Facility			
Engineering	66.74	74.17	87.05
Construction	208.11	231.28	271.44
Project Management	38.74	43.06	50.53
Subtotal	313.59	348.51	409.02
Site Preparation & Restoration			
Engineering	3.46	3.54	3.62
Construction	12.57	12.88	13.18
Project Management	2.29	2.35	2.41
Subtotal	18.32	18.77	19.21
Emplacement & Closure			
Emplacement	12.44	18.12	28.49
Emplacement Support	63.03	103.16	183.46
Closure	26.78	29.67	36.93
Subtotal	102.25	150.95	248.88
Regulatory Compliance	40.35	40.35	40.35
Surveillance & Maintenance			
Materials	0.58	0.58	0.58
Labor	1.63	1.63	1.63
Subtotal	2.21	2.21	2.21
Total Facility Cost	476.72	560.79	719.67

	25%	50%	100%
GRAND TOTAL	519.28	614.53	790.15

* Values in this column are for the reference case; they were taken from Table 4.12.

Figure 6.6 Parametric Analysis of Disposal Options



6.2 Performance Risk

The cost effects due to uncertainties in the number of nonconforming cylinders and process and facility design are presented in this section.

6.2.1 Number of Nonconforming Cylinders

The number of depleted UF_6 cylinders that will not meet transportation requirements over the shipping time frame is uncertain. Changes in the number of such cylinders impact the costs of preparing the cylinders for off-site shipment. The preliminary estimate of the number of nonconforming cylinders is 19,200 at Paducah; 5,200 at Portsmouth; and 4,683 (the entire inventory) at K-25. The uncertainty in the number of nonconforming cylinders ranges from a low of one-half of these preliminary estimates to a high of all cylinders. It is anticipated that the range of uncertainty will change over time as estimates of the numbers of overpressured, overfilled, and substandard cylinders are refined and as cylinder conditions and regulatory requirements change.

	Reference		Low		High	
	Number of Non-Conforming Cylinders	Number of Conforming Cylinders	Number of Non-Conforming Cylinders	Number of Conforming Cylinders	Number of Non-Conforming Cylinders	Number of Conforming Cylinders
Portsmouth	5200	8188	2600	10788	13388	0
Paducah	19200	9151	9600	18751	28351	0
K-25	4683	0	2342	2341	4683	0
Total	29083	17339	14542	31880	46422	0

In order to analyze the impact of this uncertainty, the engineering analysis developed preconceptual designs for transfer facilities to handle three different throughput rates. The low-capacity case was 320 cylinders per year; the reference case was 960 cylinders per year; and the high-capacity case was 1,600 cylinders per year. The largest facility would be capable of transferring all the cylinders at Paducah, the site with the most cylinders (28,351). The smallest facility would be appropriate for transferring all the cylinders at K-25 (4,683) or all the projected nonconforming cylinders at Portsmouth (5,200) in fewer than 20 years. The cost of each of these three throughput rates was evaluated and used to interpolate or extrapolate costs for the low, reference, and high numbers of nonconforming cylinders.

Costs for preparing cylinders for shipment are, of necessity, site-specific. Based upon the cases analyzed above and the assumptions made concerning the number of nonconforming cylinders, the present value (7% p.a. discount rate) of the total costs for preparing the cylinders for shipment is presented in Tables 6.12, 6.13, and 6.14. The cost of preparing conforming cylinders for shipment is presented in Table 6.12. Tables 6.13 and 6.14 present the costs of the two options for preparing nonconforming cylinders for shipment, the cylinder overcontainer option and the transfer facility option. Since labor costs dominate the preparation for conforming cylinders (Table 6.12) and the overcontainer option (Table 6.13), for initial purposes all other costs for the low and high cases (where applicable) were equated to the reference values. The total cost for each option is the sum of the cost for preparing conforming cylinders for shipment and the cost of preparing nonconforming cylinders for shipment. For the overcontainer option, there is a slight variation in labor costs and costs for the overcontainers (which are reusable). For the transfer facility option, a transfer facility sized according to the number of nonconforming cylinders is needed at each site.

There is a significant difference between the cost of preparing cylinders for shipment using the overcontainer and preparing them for shipment using the transfer facility. Total costs using the overcontainer for problem cylinders range from about $147 million (low-cost column in Table 6.12 plus low-cost column in Table 6.13) for 14,542 nonconforming and 31,880 conforming cylinders to about $171 million (high-cost column in Table 6.13) if all 46,422 cylinders were nonconforming. The number of nonconforming cylinders has a greater dollar impact on the transfer facility option, where total costs range from $609 million (low-cost column in Table 6.12 plus low-cost column in Table 6.14) to $706 million (high-cost column in Table 6.14). Clearly, what is most significant from a cost perspective is which option is chosen—the overcontainer or the transfer facility.

Table 6.12 Cost Breakdown (in Millions of Dollars) for Preparing Conforming Cylinders

	Reference	Low	High
Inspection and retrieval equipment			
Engineering	0.17	0.17	0.00
Fabrication	1.39	1.39	0.00
Certification	0.07	0.07	0.00
Subtotal	1.63	1.63	0.00
Handling fixtures			
Engineering	0.06	0.06	0.00
Fabrication	0.47	0.47	0.00
Certification	0.02	0.02	0.00
Subtotal	0.55	0.55	0.00
Shipping fixtures			
Engineering	0.02	0.02	0.00
Fabrication	0.16	0.16	0.00
Certification	0.01	0.01	0.00
Subtotal	0.19	0.19	0.00
Facilities			
Engineering	0.00	0.00	0.00
Construction	0.00	0.00	0.00
Project management	0.00	0.00	0.00
Subtotal	0.00	0.00	0.00
Regulatory compliance	1.13	1.13	0.00
Operations and maintenance			
Materials	1.64	1.64	0.00
Utilities	0.01	0.01	0.00
Labor	44.27	81.35	0.00
Waste management and disposal	0.19	0.19	0.00
Subtotal	46.11	83.19	0.00
Decontamination & decommissioning	0.00	0.00	0.00
TOTAL	49.61	86.69	0.00

Table 6.13 Cost Breakdown (in Millions of Dollars) for Preparing Nonconforming Cylinders - Overcontainer Option

	Reference	Low	High
Engineering Technology	0.82	0.82	0.82
Inspection and retrieval equipment			
Engineering	0.23	0.23	0.23
Fabrication	1.93	1.93	1.93
Certification	0.09	0.09	0.09
Subtotal	2.25	2.25	2.25
Overcontainers			
Engineering	0.54	0.28	0.86
Fabrication	2.39	1.22	3.80
Certification	0.15	0.08	0.24
Subtotal	3.08	1.58	4.90
Handling fixtures			
Engineering	0.06	0.06	0.06
Fabrication	0.47	0.47	0.47
Certification	0.02	0.02	0.02
Subtotal	0.55	0.55	0.55
Shipping fixtures			
Engineering	0.03	0.03	0.03
Fabrication	0.24	0.24	0.24
Certification	0.01	0.01	0.01
Subtotal	0.28	0.28	0.28
Facilities			
Engineering	0.00	0.00	0.00
Construction	0.00	0.00	0.00
Project management	0.00	0.00	0.00
Subtotal	0.00	0.00	0.00
Regulatory compliance	1.13	1.13	1.13
Operations and maintenance			
Materials	6.60	5.88	7.47
Utilities	0.03	0.03	0.03
Labor	96.03	48.02	153.36
Waste Management & Disposal	0.33	0.33	0.33
Subtotal	102.99	54.26	161.19
Decontamination & decommissioning	0.00	0.00	0.00
TOTAL	111.10	60.87	171.12

Table 6.14 Cost Breakdown (in Millions of Dollars) for Preparing Nonconforming Cylinders - Transfer Facility Option

	Reference	Low	High
Engineering Development	2.46	2.46	2.46
Process Equipment			
Engineering	3.70	2.20	5.49
Fabrications	8.01	4.61	12.08
Installation	5.24	3.27	7.59
Certification & Test	0.35	0.20	0.53
Subtotal	17.30	10.28	25.69
Process Facilities			
Engineering	16.86	13.76	20.55
Construction	49.04	40.03	59.79
Proj. Management	10.97	8.96	13.38
Subtotal	76.87	62.75	93.72
Balance of Plant			
Engineering	12.46	10.72	14.55
Construction	36.26	31.18	42.32
Proj. Management	8.11	6.98	9.47
Subtotal	56.83	48.88	66.34
Regulatory Compliance	56.20	56.20	56.20
Operations and Maintenance			
Material	82.78	58.75	111.46
Utilities	28.17	25.46	31.41
Labor	278.51	251.68	310.53
Waste Management & Disposal	4.70	4.17	5.33
Subtotal	394.16	340.06	458.73
Decont. & Decom.	2.71	2.19	3.33
TOTAL	606.53	522.82	706.47

6.2.2 Process and Facility Uncertainties

Uncertainties in facility and process scope cover those factors that are usually beyond the contractor's or the architect/engineer's control or outside the scope of the original design, schedule, and cost estimate. The project owner (e.g., DOE) must have funds available to cover the cost effects of these factors, or allocate the process development and demonstration time and funds up front to reduce these uncertainties.

Cost impacts were estimated for various equipment additions and enhancements to address potential performance risks. It was assumed that equipment additions would mitigate possible throughput deficiencies or product/by-product quality issues. The reader is referred to Chapter 3 of the *Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride*, Rev. 2.

For the transfer facility and selected conversion facilities, the potential increase in the process equipment costs and the resulting increase in the associated process facility costs were estimated. Table 6.15 lists the facility cases addressed, summarizes the equipment sensitivity cases evaluated, and for these provides the sum of the process equipment and process facility cost increases relative to the same for the reference case cost (no performance risks) tabulated in previous sections. The impacts on balance of plant and operations and maintenance costs were not estimated.

Table 6.15 Performance Risks

Facility	Equipment Additions	% Cost Increase*
Cylinder Transfer	Double no. autoclaves	37
U_3O_8 Conversion: AHF	Double no. defluorination lines; enhance distillation system	16
U_3O_8 Conversion: HF Neutralization	Double no. defluorination lines	14
UO_2 Conversion: AHF	Double no. defluorination lines; enhance distillation system; double no. sintering furnaces	24
UO_2 Conversion: HF Neutralization	Double no. defluorination lines; double no. sintering furnaces	23
U-Metal Conversion: Batch	Double no. UF_6 to UF_4 reactors; double no. leach stages	6
U-Metal Conversion: Continuous	Double no. UF_6 to UF_4 reactors; Double no. UF_4 to U lines; add leach system	29

* Total increase in process equipment and process facility costs (balance of plant impacts not evaluated)

Autoclave transfer of UF_6 is a well-established technology. The comparatively high cost risk assigned to the cylinder transfer facility reflects the unavailability of precise heat transfer data for air-heated autoclaves. Air-heated autoclaves were used in the engineering analysis for the transfer facility due to the assumed condition of the cylinders being transferred and the increased likelihood that a cylinder would breach.

For all oxide conversion cases, there are engineering scaling uncertainties, including residency times, associated with the reactors (kilns) for converting UF_6 to oxide powder (U_3O_8 and UO_2). For the oxide conversion cases in which anhydrous hydrogen fluoride is produced, there is a small likelihood that there would be an unacceptable level of uranium contaminant carryover into the distillation system. Therefore, the reference distillation system was modified to an extractive distillation system using sulfuric acid addition. Finally, for conversion to densified UO_2, there is engineering uncertainty associated with the scaling of the high-temperature sintering furnaces.

The batch metallothermic reduction to uranium metal is a well-established industrial technology. The estimated cost risk reflects (1) the scaling associated with the use of higher throughput tower reactors for the conversion of the UF_6 to the process feed (UF_4), and (2) the possibility that added leaching capacity would be required for the by-product (MgF_2) decontamination for its disposal as a nonhazardous solid waste.

The continuous metallothermic reduction to uranium metal is not an industrial process and requires extensive engineering development and testing. The assigned performance risk reflects the following: (1) the scaling associated with the use of higher throughput tower reactors, as in the case of the batch process, (2) the engineering uncertainties associated with the scaling of the reduction reactors and continuous casters, and (3) the significant possibility that a leaching system would be required to decontaminate the by-product (MgF_2) for its disposal as a nonhazardous solid waste.

6.3 Process Vulnerabilities

This section describes the vulnerability of the oxide conversion process producing CaF_2 and the metal conversion processes producing MgF_2 to changes in disposal requirements.

6.3.1 Disposal of CaF_2 By-product from HF Neutralization Options

As stated in Section 4.2.2, all of the conversion options produce potentially salable by-products—either AHF or CaF_2. Defluorination with AHF production is superior to defluorination with HF neutralization in terms of by-product value and waste avoidance. In the unlikely event that the recovered AHF could not be sold (because of the small [<1 ppm] uranium concentration), the concentrated HF would be neutralized with lime (CaO) to form about 18,600 MT (13,895 cubic yards) of CaF_2. In the absence of regulatory constraints regarding the uranium content, the CaF_2 could be sold as a feedstock for the commercial production of AHF.

If neither the AHF nor the CaF_2 could be sold, then the CaF_2 is assumed to be disposed of as nonhazardous solid waste. This case would result in a large waste stream (approximately 1 kg waste per kg uranium) that would bound the waste for defluorination (U_3O_8 or UO_2). The relatively small amounts of CaF_2 which are produced by the conversion options without neutralization are not considered in this vulnerability analysis. Neutralization of the AHF with lime (CaO) to form CaF_2 is also a reasonable variation for the metal conversion options and the gelation options. However, the impact of adding a neutralization step to the metal and gelation conversion options has not been quantified from either an engineering or a cost perspective.

A potential vulnerability is that disposal as low-level waste (LLW) would be necessary because of the small uranium content in the CaF_2, and the disposal costs would rise significantly. The pessimistic case then assumes that the by-product must be disposed as a LLW. The cost impacts of CaF_2 disposal are summarized in Table 6.16. Assumed disposal costs are $2/ft^3 for nonhazardous solid waste and $100/ft^3 for LLW, as defined in Section 3.2.8.

Table 6.16 Cost Impacts of Disposal of CaF_2 Resulting from Conversion Options with HF Neutralization (Millions of Dollars)

Option	CaF_2 (MT/yr.)	Cost of Disposal as Nonhazardous Solid Waste	Cost of Disposal as LLW	Total Conversion Cost*
U_3O_8 w/HF Neutralization	18,600	$0.75/yr. ($15 total)	$38/yr. ($750 total)	$340 (Nonhazardous) $544 (LLW)
UO_2 w/HF Neutralization	18,600	$0.75/yr. ($15 total)	$38/yr. ($750 total)	$409 (Nonhazardous) $614 (LLW)

* Discounted costs (7% p.a. rate). See Table 4.8 for reference cases involving sale of CaF_2.

The neutralization reference cases have total conversion costs of $325M and $395M for U_3O_8 and UO_2, respectively; therefore, CaF_2 disposal as a nonhazardous solid waste would result in a minor cost increase relative to its sale. However, CaF_2 disposal as a LLW would result in a major cost increase relative to its sale or disposal as a nonhazardous solid waste.

6.3.2 LLW Disposal of MgF_2 By-product from Metal Conversion Options

The metal conversion process produces MgF_2 in substantial quantities (about 10^4 MT or slightly under 8,000 cubic yards annually) which must be disposed as a waste. The batch metallothermic process includes a decontamination step for the MgF_2 by-product, resulting in < 90 ppm uranium. The by-product from the continuous metallothermic process is assumed to have a low enough uranium concentration (< 90 ppm) that decontamination would not be necessary. For both cases, it is assumed that the MgF_2 would be granted a free release exemption for disposal as a nonhazardous solid waste. This is the assumption for all the cost estimates in Chapters 4 and 5.

Exemptions for decontaminated MgF_2 have been granted, but the quantities were substantially smaller. The practical limitations on MgF_2 decontamination are presently unknown, but it is likely that the residual levels of uranium will be at least 10-fold greater than the levels in CaF_2 from the HF neutralization options (Section 6.3.1). Accordingly, and in the absence of a *de minimus* value, MgF_2 is judged to be more vulnerable for disposal as a LLW than CaF_2. The cost impacts for MgF_2 disposal are summarized in Table 6.17. Assumed disposal costs are $2/ft^3 for nonhazardous solid waste and $100/ft^3 for LLW, as defined in Section 3.2.8.

Table 6.17 Cost Impacts of Disposal of MgF_2 Resulting from Metal Conversion Options (Millions of Dollars)

Option	MgF_2 (MT/yr) ***	Cost of Disposal as Nonhazardous Waste (Reference Case)	Cost of Disposal as LLW	Total Conversion Cost*	Cost Increase for Disposal as LLW
Batch metallothermic reduction	9,663	$0.41/yr ($8.3 total)	$20.7/yr ($413 total)	$665 (Nonhazardous) $745 (LLW)**	$80
Continuous metallothermic reduction	10,097	$0.43/yr ($8.6 total)	$21.6/yr ($431 total)	$492 (Nonhazardous) $600 (LLW)	$108

* Discounted costs (7% p.a. rate). See Table 4.8 for reference cases.

** Takes into account increase in nongrouted MgF_2

*** Ungrouted weight.

Disposal as a LLW would result in a major increase in the metal conversion costs. The reference case assumes disposal as nonhazardous waste in bulk form. If grouting were required, there would be additional costs for the grouting operation and the increased disposal volume. In moving from the reference case to the LLW disposal case, the increase in option cost is less for the batch than for the continuous process. This is primarily due to the elimination of the decontamination system for the batch process. This reduces capital costs (process equipment and process facility) and eliminates the operations and maintenance cost associated with the decontamination system.

7. REFERENCES

American National Standards Institute. ANSI N14.1-1995, *American National Standard for Nuclear Materials - Uranium Hexafluoride - Packaging for Transport*. December 1, 1995.

Business Week, March 25, 1996.

Chemical Market Reporter (formerly *Chemical Marketing Reporter*), June 30, 1995-March 29, 1996.

Code of Federal Regulations. Title 40 CFR Parts 1500-1508 (Council on Environmental Quality *Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act*).

Code of Federal Regulations. Title 49 (*Transportation*).

Dubrin, J., et al. *The Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride,* Revision 2. UCRL-AR-124080. Livermore, CA: Lawrence Livermore National Laboratory. May 1997.

Dubrin, J., and J.N. Zoller. *Characterization of Options for the Depleted Uranium Hexafluoride Management Program.* Livermore, CA: Lawrence Livermore National Laboratory. November 1995.

Haelsig, R.T. *Depleted Uranium Concrete Container Feasibility Study.* EGG-MS-1140. Idaho National Engineering Laboratory. September 1994.

Herztler and Nishimoto. *Depleted Uranium Management Alternatives.* August 1994.

Lawrence Livermore National Laboratory. *Depleted Uranium Hexafluoride Management Program Work Breakdown Structure* (Initial Report). Livermore, CA. 1995.

Lawrence Livermore National Laboratory. *Depleted Uranium Hexafluoride Management Program Work Breakdown Structure*, Revision 1. Livermore, CA. May 14, 1996.

Lockheed Martin Energy Systems, Inc. *UF_6 Cylinder Program Management Plan.* K/TSO-30. Oak Ridge, TN: Environmental Management and Enrichment Facilities, Technical Support Organization. July 1996.

Murray, Alex, et al. *Draft Summary Report on Applicability of the Minimum Additive Waste Stabilization (MAWS) Approach to Hanford Waste Streams.* Science Applications International Corp. 1994.

Office of Management and Budget. Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs.* October 29, 1992.

Parks, J.W. "Data for Revised No Action Alternative in the Depleted UF_6 Programmatic Environmental Impact Statement," memorandum from J.W. Parks (Assistant Manager for Enrichment Facilities, EF-20, U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, TN) to C.E. Bradley, Jr. (U.S. Department of Energy, Office of Facilities, NE-40, Germantown, MD). April 7, 1997.

Powell, F.P. *Comparative Economics for DUCRETE Spent Fuel Storage Cask Handling, Transportation, and Capital Requirements*. INEL-95/0166. Idaho National Engineering Laboratory. April 1995.

U.S. Department of Energy, Office of Nuclear Energy. "Management of Depleted Uranium Hexafluoride (UF_6): Request for Recommendations" and "Alternative Strategies for the Long-Term Management of Depleted Uranium Hexafluoride Resources at Several Geographic Locations: Advance notice of intent to prepare an environmental impact statement," *Federal Register*, Vol. 59, November 10, 1994, pp. 56324 and 56325.

U.S. Department of Energy, Office of Nuclear Energy, Science, and Technology. *Draft Programmatic Environmental Impact Statement for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride*. Forthcoming [1997].

U.S. Department of the Interior, Bureau of Mines. Mineral Industry Surveys: Fluorspar. Washington, DC.

United States Enrichment Corporation. *Uranium Hexafluoride: A Manual of Good Handling Practices*. USEC-651. January 1995.

Wall Street Journal, March 13, 1997.

Zoller, J.N. Letter to C.E. Bradley, Jr., Subject: Work Breakdown Structure for the Depleted Uranium Hexafluoride Management Program Engineering and Cost Analysis Projects. UP-DU/95-5-G-207. May 14, 1996.