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AN ADVANCED SOLUTION FOR THE STORAGE, TRANSPORTATION AND DISPOSAL OF SPENT FUEL AND VITRIFIED HIGH LEVEL WASTE

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ABSTRACT

For future nuclear power deployment in the US, certain changes in the back end of the fuel cycle, i.e., disposal of high level waste and spent fuel, must become a real options. However, there exists another problem from the front end of the fuel cycle which has until recently, received less attention. Depleted uranium hexafluoride is a by-product of the enrichment process and has accumulated for over 50 years. It now represents a potential environmental problem. This paper describes a concept for converting the depleted uranium hexafluoride into advanced high level waste and spent fuel storage and transportation casks using DUCRETE concrete. The high density and efficient shielding of DUCRETE concrete enables small diameter, transportable casks to be produced with the low fabrication costs of concrete technology. In making DUCRETE casks, the otherwise unneeded depleted uranium is used in an environmentally responsible manner and one of nuclear power's legacies is resolved.

I. INTRODUCTION

If nuclear energy is to rebound in the US, a variety of things will have to change. Probably most important is that final waste disposal will have to become a reality and at a reasonable cost. At the present time, because of political interference and other factors, the country is struggling to deal with spent fuel and high-level waste on an interim basis while a geologic repository is sited. The costs are escalating yearly and opportunities for cost effective solutions seem to be ignored. Concerns over hypothetical safety issues 10,000 to 100,000 years in the future take precedence over engineering issues for the next 50 to 300 years.

One of the lesser known aspects of the nuclear fuel cycle, which up to recently has had little attention, is a by-product stream of nearly 740,000 metric tons of depleted uranium hexafluoride (UF_6) tails from the United States enrichment facilities.[1] While this material was once considered a feed stock for the United States Breeder Reactor Program, it is no longer needed. Alternative uses of depleted uranium are few. Consequently, the UF_6 is now a liability owned by the USDOE. The UF_6 has been accumulating at the enrichment facilities since the beginning of the nuclear industry or about 50 years. While enrichment activity must continue to supply fuel for the nuclear power industry, indefinite accumulation of the tails cannot. The USDOE is embarking on a program to begin conversion of the depleted uranium tails to an oxide for use or for indefinite storage as the preferred alternative in their Programmatic Environmental Impact Statement.[1] While that strategy improves the safety of the uranium, compared to its current situation as UF_6 in rusting carbon steel cylinders, indefinite storage of over a billion pounds of uranium oxide is still not likely to appease critics of the nuclear industry.

This paper describes a concept for using the depleted uranium oxide to fabricate high-level waste and spent nuclear fuel storage and shipping casks which could be also used as the waste package for ultimate disposal in the future repository. This concept could save billions of dollars in the disposal of these materials by producing storage systems which could have multiple uses including transportation and disposal.

This use of depleted uranium closes one other part of the nuclear fuel cycle mostly ignored by the nuclear utility industry because the USDOE retained the tails when it operated the enrichment facilities. Under the present enrichment plant operation, the private sector owner – the United States Enrichment Corporation – charges their utility industry customers for managing and disposing of the tails. By converting the depleted uranium into storage and shipping casks, a system solution is employed and the nuclear legacy from the front end of the fuel cycle is managed in an environmentally responsible manner.

II. DESCRIPTION OF DUCRETE CONCRETE

Depleted uranium concrete (DUCRETE) was developed at the INEEL as a nuclear shielding material for spent fuel and high level waste.[2,3] It consists of uranium oxide based aggregate and traditional concrete ingredients. The depleted uranium aggregate (DUAGG) is fabricated from uranium oxide to a density of 8.0 to 8.5 g/cm^3. DUAGG is a liquid phase sintered ceramic consisting of about 93% uranium oxide and other silica bearing materials making up the liquid phase. The silica material surrounds the uranium oxide grains essentially encapsulating it at the microscopic scale.

The DUAGG replaces the conventional aggregate in concrete producing concrete with a density of 5.6 to 6.4 g/cm^3 (compared to 2.4 g/cm^3 for conventional concrete). This shielding material has the unique feature of having both high Z and low Z elements in a single matrix. Consequently, it is very effective for the attenuation of gamma and neutron radiation. Several studies have been performed to evaluate its shielding effectiveness . [4,5,6, 7] Comparative shielding calculation results for DUCRETE, concrete, and several materials are shown in Figure 1.

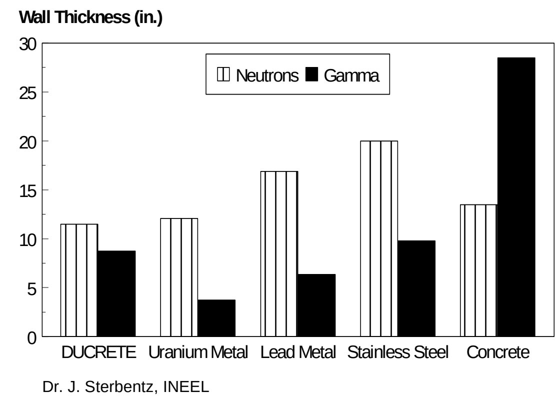

Figure 1. Comparison of Wall Thickness to Attenuate Neutron and Gamma Dose from 24 PWR Spent Fuel Assemblies

DUCRETE concrete mechanical properties have been determined in compression tests conducted at the INEEL and at Starmet. Selected results from those tests are shown in Tables 1 and 2, respectively . Basically, the results show compressive strength similar to conventional concrete. As with conventional concrete, variations in the mixture can produce enhanced compressive strength compared to normal construction grade concrete. Table 1 shows comparisons between DUCRETE samples and conventional concrete samples after aging at elevated temperatures.[8] For the baseline conditions, the compressive strength is essentially the same for both types of concrete. The scatter in the data is consistent with data on ceramic or brittle materials.

These elevated temperature tests were performed to determine if there were any chemical reactions between the DUAGG and the concrete materials. Elevated temperatures were used to accelerate any possible effects. At temperatures up through 150°C, the effect of temperature appears to be accelerating the normal concrete process of strengthening with age. At 250°C, the effect of aging at temperature is to reduce the strength of all samples by driving off the water of hydration. One conclusion from these tests is that there appears to be no adverse effect of using the DUAGG versus conventional aggregate in a concrete mixture. It is also obvious that temperatures of 250°C are beyond the acceptable range for any concrete. The strength reduction is due to the dehydration of the concrete. American Concrete Institute recommendations for concrete applications limit temperatures to 66°C for bulk temperatures and to 93°C for localized temperatures.[9]

Table 1. DUCRETE Compressive Strength after Exposure to Elevated Temperature (INEEL Test Data)

Sample ID	Aggregate Type	Aging Temp.(°C)	Aging Time (days)	Compressive Strength (psi)	Average Strength (psi)
OST-1	Gravel	Baseline	Baseline	3899	
OST-2	Gravel	Baseline	Baseline	4535	4217
ORT-1	DUAGG	Baseline	Baseline	3500	
ORT-2	DUAGG	Baseline	Baseline	4790	4145
OST-3	Gravel	100	28	5033	
OST-4	Gravel	100	28	4239	4636
ORT-3	DUAGG	100	28	6007	
ORT-4	DUAGG	100	28	5399	5703
OST-5	Gravel	150	14	3700	3700
OST-6	Gravel	150	28	5193	
OST-7	Gravel	150	28	6998	6096
ORT-5	DUAGG	150	28	4659	
ORT-6	DUAGG	150	28	3883	4271
OST-9	Gravel	250	14	1655	
OST-10	Gravel	250	14	3026	2341
ORT-8	DUAGG	250	14	2911	2911
OST-11	Gravel	250	28	2349	
OST-12	Gravel	250	28	1545	1947
ORT-9	DUAGG	250	28	2084	2084

Similar testing for compressive strength performed at Starmet CMI yielded similar compression strengths as shown in Table 2. The samples from these tests were aged for 28 days at room temperature prior to testing.

One other parameter measured at Starmet was the leaching behavior of the crushed DUAGG material. This test used the EPA TCLP test protocol. Various uranium materials were subjected to the same leach testing conditions. The data are provided in Table 3. It is clear from this data that the DUAGG provides a superior leach resistant form compared to other uranium materials. This leach resistance comes from the silica materials in the DUAGG aggregate. From this data it is clear that risks of ground water contamination if depleted uranium is disposed are substantially reduced by using DUAGG compared to other forms of uranium. Leaching of uranium from casks using DUCRETE would be even less.

Table 2. DUCRETE Density and Compressive Strength as a Function of Composition

Sample No	Measured Density (lb/ft3)	Strength (psi)	DUAGG Density [1] (g/cm3)	Small Fines
6	5.66	5101	8.1[2]	fly ash
7	5.72	4310	8.1[3]	fly ash
8	5.86	4430	8.1[3]	none
13	4.81	3880	7	micro silica
14	4.73	4390	7	micro silica

1. DUAGG briquettes are crushed and screened to yield American Concrete Institute No. 8 size fraction
2. DUAGG density of 8.6 gm/cm3 has been made in laboratory settings at INEEL. This density aggregate will produce a DUCRETE density of nearly 6.4 g/cm^3
3. Sample contained about 0.36 wt% metal fibers to increase DUCRETE flexural strength

Table 3. Comparison of TCLP Leach Test Results for Different Forms of Uranium

Uranium Form	Concentration in Leachate (mg-U/liter)
DUAGG	4
UO_2	170
U_3O_8	420
UF_4	7367
UO_3	6900

The UO_3 is from the DOE Savannah River Site and was recovered from reprocessing. The U_3O_8 and DUAGG were manufactured at Starmet CMI from SRS UO_3. The UF_4 was converted from UF_6.

III. NUCLEAR WASTE STORAGE NEEDS

The US requirement for spent fuel storage is directly tied to the timing of the Yucca Mountain facility opening. If there were no repository, there are needs for over 9500 storage casks or equivalent holding 21 PWR fuel assemblies or the BWR volume equivalent assuming the plants are operated to their license limit. Given the delays already encountered in the Yucca Mountain Project, a large fraction of this storage capacity will be needed by utilities even if the repository opens on its presently scheduled 2010 schedule. Given past legal challenges for waste disposal facilities of a simpler nature, this repository schedule is doubtful. Consequently, fuel storage at utility sites or at a centralized interim storage facility will continue to be needed for at least the next twenty or more years.

High-level waste produced by DOE at Savannah River, West Valley, Hanford and INEEL will require additional storage facilities for the roughly 20,000 glass logs or canisters projected to be produced.[10] At West Valley, an existing building has been converted to a storage facility for its 300 canisters. At Savannah River, a large storage building costing over $100 million was constructed satisfying the needs for about one half of the projected production. One or more additional storage buildings will be needed for their projected inventory of 5000 to 6000 canisters. Thus, in spite of some existing storage, storage capacity for most of the HLW is yet to be built. This storage capacity could be supplied by additional storage buildings or dry storage casks similar to that provided for spent fuel.

IV. DESIGN CONCEPTS FOR DUCRETE CASKS

In the last few years, two companies[11, 12] have developed low cost, heavy concrete based fuel storage and transportation cask designs. They combine the best performance features of the dual purpose steel casks but at lower costs associated with high density concrete based systems. Both of these cask concepts could be further modified to employ DUCRETE concrete and effect a more compact, lighter weight cask using the more efficient shielding characteristics of DUCRETE.

Although, no low cost concrete based storage and transportation system have been licensed in the US, if available, such a system would offer utilities an improved the fuel cycle cost advantage. Thus, if DUCRETE shielding were employed in these systems, not only would shielding efficiencies be enhanced, but lower costs could be achieved while the remnants of the front end of the fuel cycle would be utilized in a productive fashion.

A. INEEL DUCRETE Cask Studies

In 1995, Sierra Nuclear (now BNFL Fuel Solutions) under contract to the INEEL performed conceptual design studies to evaluate the potential for using DUCRETE concrete in spent fuel storage casks.[6, 13] Sierra Nuclear determined that a DUCRETE version of their VSC 24 would have sufficient weight reduction, such that it would have a total loaded weight of under 100 tons. The diameter of the VSC 24 using conventional concrete was 135 inches; the DUCRETE counterpart was about 90 inches.

This small external diameter led to the question of possible transportability. A second study was done looking at the development of a transportable cask concept. The concept transported the DUCRETE cask inside of an outer steel overpack to give it the needed structural features. The major difficulty with this concept was achieving the required heat transfer, since under the condition of the DUCRETE cask being inside of an overpack, the DUCRETE served as an insulator. The concept was modified to include fins in the DUCRETE wall cross section. Based upon this preliminary study, this concept appeared feasible.

B. Starmet DUCRETE HLW Cask

Duke Engineering and Services, as part of a proposal to the Savannah River Site, evaluated the feasibility of using DUCRETE concrete material for high level waste storage casks[14]. This cask concept is shown in Figure 2. Using DUCRETE, the wall thickness is kept to about 10 inches and results in an external radiation field of 10 mr/h at a 2 meter distance from 5 high-level waste canisters. The cask uses the stainless steel glass canister as the containment and uses natural convection cooling to remove the thermal energy.

This cask is intended to be a storage-only-cask for use at the Savannah River Site as an alternative to a second Glass Waste Storage Building. Cost estimates prepared indicated, that for an equivalent storage facility including pad and handling facilities, the DUCRETE storage cask system would be less expensive then a new Glass Waste Storage Building. It would have the added feature that it would use most of the 55 million pounds of unneeded uranium oxide on the Savannah River site, thus, saving upward of $80 million in disposal costs. While this concept seems to be a very cost effective alternative to a storage building requiring future decommissioning, it still requires a transportation system and additional HLW glass canister handling equipment to get the HLW to its final disposal location.

C. GNB CONSTOR Cask

The Gesellschaft fur Nuklear-Behalter (GNB) CONSTOR cask uses a reinforced heavy concrete between two 4 cm thick steel shells. This cask is shown in Figure 3 with the impact limiters for transportation impact protection. The cask has been developed, tested, and licensed against IAEA criteria for storage and transportation of RBMK spent fuel. The heavy concrete (density of 4.1 gm/cm^3) wall thickness is 35 cm. For approximately the same shielding effectiveness, DUCRETE concrete with a density of 6.0 g/cm3 would have a wall thickness of about 24 cm. Assuming the structural features of the CONSTOR were not

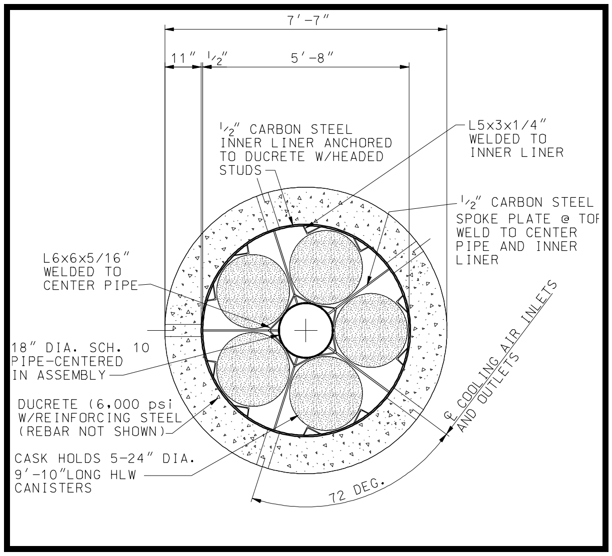

Figure 2. Cross Section of DUCRETE DWPF Cask

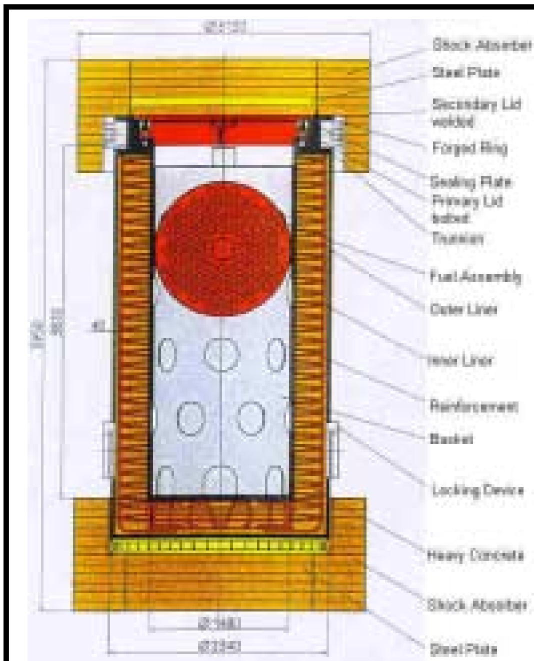

Figure 3. GNB CONSTOR Cask

compromised by the wall thickness reduction, this cask might be redesigned to hold more fuel while maintaining the same external diameter. A capacity increase is a major factor on reducing the overall cost to the utilities.

Alternatively, if the capacity increase is not needed, the diameter reduction (about 22 cm) will reduce the costs of materials and fabrication as well as the overall system weight. Based on a very simple model, the estimated weight reduction for the CONSTOR with DUCRETE would be about 6 MT.

D. CSI Steel and Concrete Cask

The Containment Systems, Inc., (CSI) dual-purpose cask formed by integrating heavy cross section structural steel and high density concrete is shown in Figure 4. Although this design has not been licensed or built, it attempts to introduce new design features to address the functional limitations of low cost concrete systems. It has two unique patented features that deal with heat transfer and structural strength. These two issues have plagued all previous concrete spent fuel storage systems. Concrete, though a good neutron shielding material, is a poor

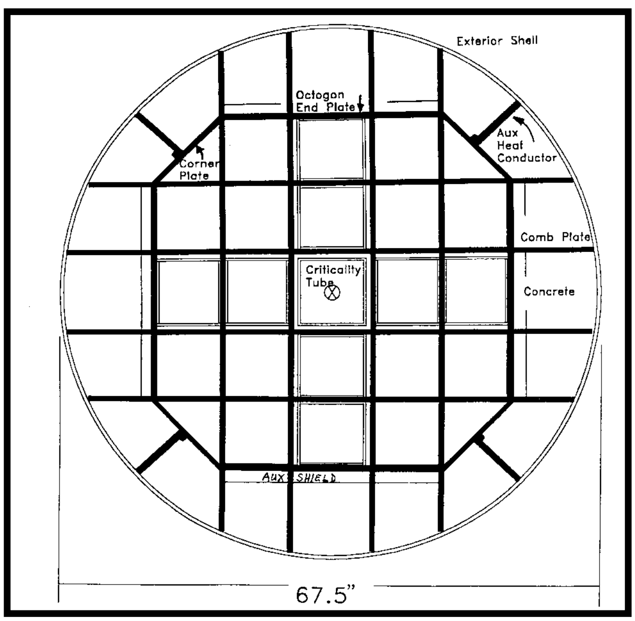

Figure 4. CSI Cask Cross Section for 21 PWR Fuel Assemblies

thermal conductor. Thus, concrete storage systems must be ventilated and the fuel contained inside of a metal canister or basket. These systems also required the use of a transfer cask for in-pool loading since only the canister can be loaded into the pool.

The CSI design Involves a “Shielded Basket” concept which is used in the pool for loading the fuel and transporting the fuel to the storage pad. This component reduces the radiation level to manageable but still high levels (~200 mR/h). At the storage pad, the shielded basket is coupled with a reinforced concrete clamshell overpack to further reduce the radiation level to insignificant levels. For transport, the shielded basket is loaded into a specially designed transport cask. The bulk of the shielding and strength to meet 10CFR71 requirements is provided by the shielded basket.

The CSI spent fuel storage system features include:

- In pool loading.
- Designed for both storage and transportation.
- Utilizes high-density concrete in the outer shell for optimum shielding.
- Offers three containment barriers.
- Provides heat rejection through the concrete via steel fins.
- Can be directly loaded into a transport cask for shipping.
- Reduced handling at utility sites.

The CSI spent fuel storage system overcomes many of the difficulties that previous and current storage and transportation designers have faced. The spent fuel heat source poses difficulties for metal casks in the neutron shield area, since the solid neutron shield materials previously used have been poor thermal conductors. Water jackets and fins through solid neutron shield are some of the solutions to this issue. The ventilated concrete cask designs have used an unshielded metal cylinder (fuel basket) to avoid heat buildup. The trade-off for low cost storage has been complex fuel basket transfers and uncertain future retrievability.

The approach used by CSI adopts the shielded cask concept, but applies high density concrete shielding to minimize costs without compromising structural strength. A proprietary technology maintains the concrete temperature limits within acceptable standards and codes for higher spent fuel heat loads than previously achieved. CSI’s technology relies on solid, metal heat transfer conductors which are integral to the spent fuel basket and pass through the concrete shield, resulting in a totally passive heat removal system.

The net result is a hybrid steel and concrete composite shielding technology which combines the flexibility of metal casks with the economics of ventilated concrete casks.

Although CSI has not evaluated the use of DUCRETE in their design, it should offer even more design optimization potential due to the superior shielding characteristics of depleted uranium.

V. FINAL DISPOSITION OF CASKS

One of the issues with the implementation of DUCRETE storage and/or transportation casks is the end of life disposition. Clearly, once there is a spent fuel disposal alternative, additional casks will not be needed and those in service can be re-used or disposed depending upon several factors including transportability. Unlike large conventional concrete casks, DUCRETE casks are small enough in diameter, that they could be transported by rail to a new storage location for reuse. If no longer needed, DUCRETE casks will need to be disposed as a low-level radioactive material. Thus, cost studies such as that performed for the SRS DUCRETE HLW storage cask accounted for the disposal cost in the overall cost effectiveness argument.

However, DUCRETE cask disposal may not be the only option to consider. At least two other alternatives are viable in addition to re-use as discussed above:

1. Empty DUCRETE casks would make a very effective and long life high integrity container for disposal of high activity low-level waste.
2. Another alternative is to use the cask as the waste package for HLW canisters or spent fuel at Yucca Mountain.

The present plans for HLW disposal assume that it will be encased in a “Waste Package” costing upwards of \$0.25 to \$0.33 million for 5 canisters for a total of \$449 million dollars.[15] This version of the waste package is a metal cask consisting of 2 cm of hasteloy surrounded by 10 cm of carbon steel. Industry comments from the audience in an INMM Meeting in January 1998 suggested that these costs were highly optimistic. The actual costs could be several times that amount based upon the similarity of the waste package to current metal spent fuel storage casks constructed with only one type of material. Thus, if the concept of a HLW storage and transport cask could be used to replace the function of the waste package, then the costs of the HLW waste packages and the attendant repackaging of the canisters might be eliminated. The potential cost savings is well over a billion dollars of capital and operating costs just for the high level waste.

If this concept could be extended to spent fuel using a cask concept such as the GNB or CSI cask combined with a waste package that is added to the exterior of the GNB cask or CSI Shielded Basket, the fuel handling activities at the Yucca Mountain surface facilities could be greatly simplified for a cost savings of several billion dollars in capital and operating cost. Numerous options are available to make the external surface of the cask a corrosion resistant material as required for the waste package. In addition to the direct cost savings, numerous other advantages will accrue by simplifying the design and licensing of the Yucca Mountain repository.[16]

VI. CONCLUSIONS

Although the concepts described above are a long way from reality in the US market, the obvious advantages of lower capital and operating costs provide an incentive to develop and qualify dual purpose spent fuel and HLW cask designs for use in the US market. With DUCRETE providing the high density shielding in a singular material matrix combined with steel shells for the structural strength such as used in the GNB and CSI designs, these concepts or some variant of them could offer the utilities casks that:

- Are economical to purchase,
- Can be loaded in the spent fuel pool and eliminate the need for a transfer cask,
- Can be transported directly to an interim storage site and require no further remote handled operation,
- Can eliminate the need for the fuel storage pool for offsite shipments, and
- May simplify the design and operating activities at Yucca Mountain for spent fuel and HLW disposal.

While a cask that has these ideal attributes is not a proven entity, its eventual design certainly appears feasible based on work performed by GNB and CSI and on the superior shielding characteristics and the low cost of DUCRETE concrete. The challenge facing the industry is to “think out of the box” and develop more innovative solutions for spent fuel and high level waste storage and disposal.

DUCRETE Concrete was created to address the question of what to do with the vast inventory of depleted uranium owned by DOE. With a little innovation in spent fuel and HLW storage technology, DUCRETE concrete can enable practical shielding options which might substantially reduce the cost of the back end of the fuel cycle for both interim storage of spent fuel as well as final disposal. Consuming the depleted uranium tails in this manner also provides a solution to the tails management from the front end of the fuel cycle. Clearly, the future use of nuclear power requires innovative solutions to these front end and back end fuel cycle issues.

ACKNOWLEDGEMENTS

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REFERENCES

[1] USDOE, *Programmatic Environmental Impact Statement for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride*, DOE/EIS-0269, April 1999

[2] Lessing, P. A., *Development of "DUCRETE"*, INEL-94/0029, March 1995

[3] U.S. Patent No. 5,786,611 Radiation Shielding Composition, W. J. Quapp and P. A. Lessing, July 28, 1998

[4] Sterbentz, J. W., *Shielding Evaluation of a Depleted Uranium Heavy Aggregate Concrete for Spent Fuel Storage Casks*, INEL-94/0092, October 1994

[5] Haelsig, R. T. , *Packaging Technology, Inc., Depleted Uranium Concrete Feasibility Study*, EGG-MS-11400, September 1994

[6] Hopf, J. E., Sierra Nuclear Company, "*Conceptual Design Report for the DUCRETE Spent Fuel Storage Cask System*," INEL-95/0030, February 1995

[7] Tang, J., *Shielding Characteristics of Various Materials on PWR Waste Packages*, Yucca Mountain Project Office, M&O Contractor, BBAC00000-001717-0210-00008 Rev 00, February 1998

[8] Lessing, P.A., *High Temperature Oxidation Tests of DUCRETE*, Unpublished Work, October 1997

[9] American Concrete Institute Standard 349, App A4

[10] USDOE, *Integrated Data Base Report—1994: US Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev 11, September 1995

[11] Diersch, R. and Jack, A. , GNB, *The CONSTOR Steel-Concrete Cask for Transport and Storage of Spent Nuclear Fuel from RBMK*, INMM, Washington, DC, January 1998

[12] CSI Cask Design Information Provided by Christopher Kudla, Xynergy, Inc., Atlanta, GA, Personal Communication, May 1999.

[13] Hopf, J. E. , Sierra Nuclear Company, *Conceptual Design Report for a Transportable DUCRETE Spent Fuel Storage Cask System*, INEL-95/0167, August 1995

[14] Seagle, N., DUKE Engineering & Services, *DUCRETE HLW Storage System Feasibility*, Unpublished Report, February 1998

[15] USDOE, *Viability Assessment of a Repository at Yucca Mountain, Volume 5, Costs to Construct and Operate the Repository*, DOE/RW-0508, December 1998

[16] Quapp, W. J., *DUCRETE Shielding Applications in the Yucca Mountain Repository*, Waste Management 1999, Tucson, AZ, March 1999