

DUCRETE: A Cost Effective Radiation Shielding Material

W. J. Quapp, Starmet CMI
W. H. Miller, University of Missouri-Columbia
James Taylor, Starmet CMI
Colin Hundley, Starmet CMI
Nancy Levoy, Starmet Corporation

1. INTRODUCTION

A consequence of uranium enrichment in the US has been the accumulation of nearly 740,000 metric tons of depleted uranium hexafluoride (UF_6) tails.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. Some have been used for medical isotope transport casks, some for industrial radioactive source shields, some for military anti-tank projectiles, some for tank armor, and other minor applications. However, the cumulative total of these uses has not made a dent in the overall inventory.

Consequently, the USDOE has a massive inventory of material to deal with and the states of Ohio, Kentucky, and Tennessee want something done with it. UF_6 is a solid at room temperature but converts to a gas at about 56°C. Exposed to the atmosphere, it readily reacts with moisture in the air to form toxic hydrogen fluoride and a soluble uranium compound – uranium oxyfluoride. Consequently, the states claim it is a hazardous waste under the Resource Conservation and Recovery Act (RCRA).

In addition to the existing inventory which was generated when the USDOE and its predecessor agencies ran the enrichment plants, the US Enrichment Corporation continues to produce another 12,000 MT per year from their operation of the enrichment facilities. 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. Disposal of this quantity of material will present large environmental and political difficulties and will entail great costs.

A process for beneficially using the uranium oxide has been developed. DUCRETE concrete has been developed at the INEEL as a shielding material that could easily be used for interim storage cask systems for the nation's spent nuclear fuel (SNF) and high-level waste (HLW). The interim storage casks could also be integrated with the waste package design for Yucca Mountain to provide a shielded waste package and improve worker safety at the repository².

DUCRETE concrete utilization for spent fuel and HLW storage could be a cost effective end use for the more than 1 billion pounds of depleted uranium for which there is no other significant use. This beneficial use would then disposition one of the largest waste streams in the nuclear fuel cycle which, for the most part, has been given minimal priority by the USDOE and state regulators. Conceptual designs for DUCRETE storage and transportation casks have been previously discussed.³

This paper provides data on the shielding properties for DUCRETE concrete and a comparative evaluation of the economics of DUCRETE compared to other storage system materials. The environmental advantages of the DUCRETE solution are also discussed.

2. 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.^{4,5} It consists of uranium oxide based aggregate and traditional concrete ingredients. The depleted uranium aggregate (DUAGG) is fabricated from uranium oxide to a density up to 8.8 g/cm³. 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 rendering it chemically stable in oxidizing environments.

The DUAGG replaces the conventional aggregate in concrete producing concrete with a density of 5.6 to 6.4 g/cm³ (compared to 2.3 g/cm³ 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 such as from SNF and HLW.

DUCRETE concrete mechanical properties have been determined in compression tests conducted at the INEEL and at Starmet³. Basically, the results show compressive strength similar to conventional concrete. In addition, if desired, the ratio of aggregate to the cement phase in the mixture can be varied to adjust the gamma and neutron attenuation characteristics. An example of such behavior is shown in Figure 2.

The final paper will include discussion of the material properties and microstructural characteristics of the depleted uranium aggregate.

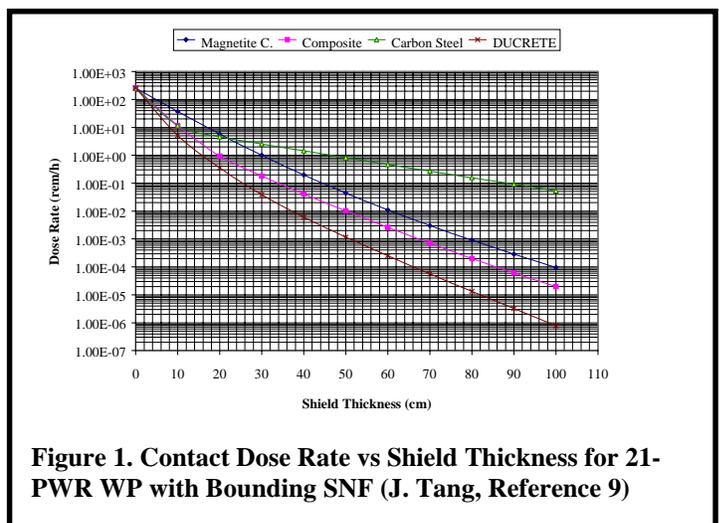


Figure 1. Contact Dose Rate vs Shield Thickness for 21-PWR WP with Bounding SNF (J. Tang, Reference 9)

3. RADIATION SHIELDING PERFORMANCE

The early evaluations of DUCRETE have based on analytical assessments using shielding computer codes typical of those used for cask design and licensing. Several studies have been performed to

evaluate its shielding effectiveness in SNF applications.^{6,7,8,9} Comparative shielding calculation results for DUCRETE, magnetite concrete, steel, and a steel-polyethylene composite materials are shown in Figure 1. This figure classically identifies the benefit of having low Z and high Z material in the same DUCRETE matrix. The steel shield has no neutron moderator and thus, the external dose is dominated by the effects of neutrons.

Recently, samples of DUCRETE have been subjects to a Co60 gamma source at the University of Missouri to experimentally determine the shielding characteristics. This experimentally determined HVL (half value layer thickness) for DUCRETE is presented in Figure 3 for three DUCRETE samples exposed to a 1.2 MEV average energy gamma from a ⁶⁰Co source and it is contrasted to reference values of other common shielding materials for a 1 MEV gamma¹⁰. From this data, it can be seen that the highest density DUCRETE sample is nearly as good as steel for gamma radiation attenuation.

The full paper will also present predictions of gamma attenuation versus wall thickness and compare that to the experimentally derived measurements.

4. Applications and Cost Considerations

Most shielding systems for SNF or HLW use either steel or concrete because of their relatively low cost, wide availability, known fabrication characteristics, and radiation shielding effectiveness. For steel cask systems, separate neutron shields typically containing hydrogenous material are added since the thickness of steel required to attenuate neutrons to acceptable external doses is impractical. While concrete is not a particularly good gamma shield per unit thickness, it is cheap enough that the practical approach is to use lots of it. In sufficient thickness, it effectively shields both the neutron and gamma radiation effectively.

The best way to compare the total effectiveness of a shielding system would be to compare the final cost to the customer for systems having the same performance features. Such data are difficult to obtain because of business considerations. Lacking such data, one can compare the

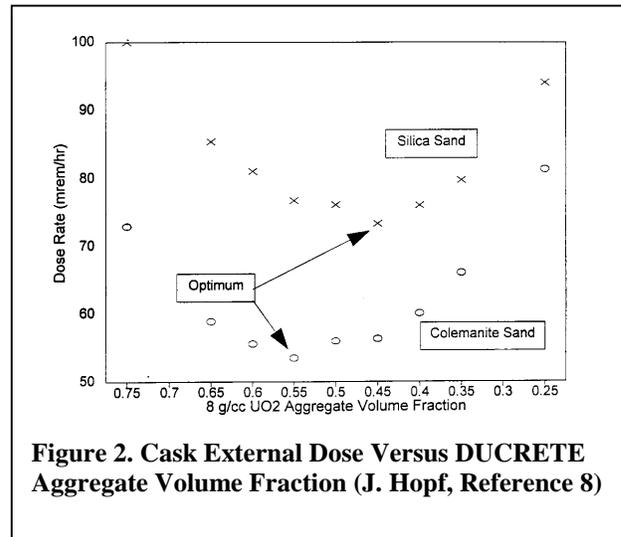


Figure 2. Cask External Dose Versus DUCRETE Aggregate Volume Fraction (J. Hopf, Reference 8)

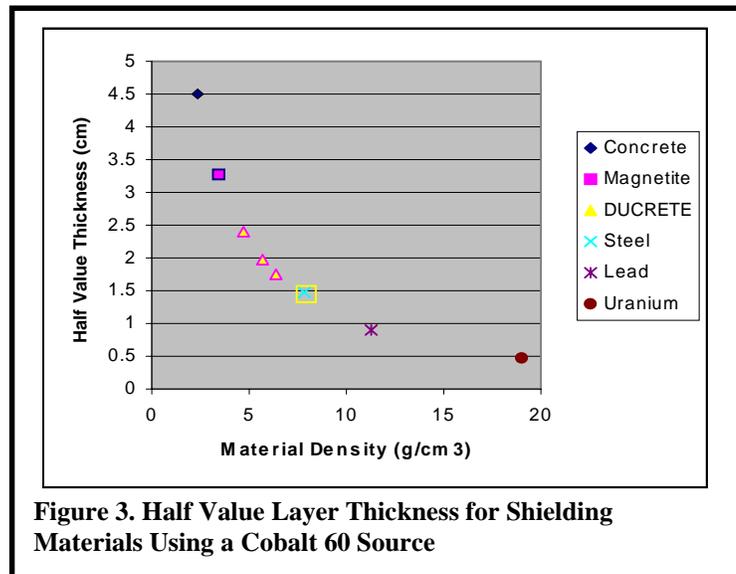


Figure 3. Half Value Layer Thickness for Shielding Materials Using a Cobalt 60 Source

relative unit material costs and general fabrication costs per pound of material. The final paper will present this cost comparison data in detail. However, it can be said that installed concrete costs about \$0.12 per kg, steel costs about \$1.10 per kg, DUCRETE considerably less than \$2.00 per kg, lead about \$1.65 per kg and depleted uranium metal at about \$22 per kg. While fabrication cost for concrete and DUCRETE are low, fabrication cost for the metals are considerable. In addition, metal shielding systems will require additional neutron shields. Consequently, it will be shown that the overall cost effectiveness of DUCRETE is reasonable compared to concrete and considerably less than other materials for SNF and HLW storage applications.

Disposal costs and environmental consequences of the various depleted uranium management options available to DOE will also be discussed as part of the overall system economics.

5. TRANSPORTABILITY

Key to the use of DUCRETE casks at storage sites and reuse as part of the repository waste package is the transportability of the DUCRETE cask. The high density of DUCRETE allows the cask to be considerably smaller in diameter than concrete casks. Consequently, while the cask cannot transport spent fuel, it can be transported empty from the manufacturing facility to a storage site and ultimately to a repository location. This feature also contributes an economic advantage as current concrete storage systems are not transportable, and, they must be built at each location where they are used.

6. CONCLUSIONS

The use of DUCRETE shielding for SNF and HLW storage systems has been shown to be both effective from a radiation shielding perspective and cost effective compared to other materials. Considering that DOE has responsibility for the overall management and disposition of the SNF, HLW, and the depleted UF₆, it seems logical that such problems should be considered synergistically. If DUCRETE is used as an interim storage shielding system, then considerable cost saving will accrue to the taxpayers of the United States. Furthermore, considering the environmental consequences of the various options available to DOE, the use of DUCRETE in storage casks that are ultimately disposed in a geologic repository appears to offer a superior solution.

7. 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 Quapp, W. J., DUCRETE™ Shielding Applications in the Yucca Mountain Repository, Waste Management 99, Tucson, AZ, Feb 1999
 - ³ Quapp, W. J., *An Advanced Solution For The Storage, Transportation And Disposal Of Spent Fuel And Vitrified High Level Waste*. Global 99, Jackson, Wyoming, August 29 – September 2, 1999
 - ⁴ Lessing, P. A., *Development of "DUCRETE"*, INEL-94/0029, March 1995
 - ⁵ U.S. Patent No. 5,786,611 Radiation Shielding Composition, W. J. Quapp and P. A. Lessing, July 28, 1998
 - ⁶ Sterbentz, J. W., *Shielding Evaluation of a Depleted Uranium Heavy Aggregate Concrete for Spent Fuel Storage Casks*, INEL-94/0092, October 1994

⁷ Haelsing, R. T. , *Packaging Technology, Inc., Depleted Uranium Concrete Feasibility Study*, EGG-MS-11400, September 1994

⁸ Hopf, J. E., Sierra Nuclear Company, "*Conceptual Design Report for the DUCRETE Spent Fuel Storage Cask System*," INEL-95/0030, February 1995

⁹ 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

¹⁰ Schultis, J. K. and Faw, R. E., *Radiation Shielding*, American Nuclear Society, 2000