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PARAMETRIC STUDY OF THE RELEASE OF SPENT FUEL AEROSOL RESULTING FROM HEDD ATTACK

Robert E. Luna, Ph.D., PE, Consultant
Albuquerque, NM 87111

H. Richard Yoshimura
Sandia National Laboratories*
Albuquerque, NM 87185

Ken B. Sorenson
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

Upper limit estimates for the release of DUO_2 surrogate respirable aerosols from a spent fuel cask subjected to attack by a HEDD are provided based on an empirical model using data from 1982 Sandia National Laboratories tests and 1994 tests sponsored by GRS.

INTRODUCTION

It has been shown that spent fuel casks can be breached if attacked by High Energy Density Devices (HEDDs) that are akin to anti-armor weapons, resulting in release of particulate spent fuel materials. There have been six total full and scaled experiments completed and a number of related analyses published. Based on that information, it is possible to estimate what release fractions could be realized as a function of the number of fuel assemblies penetrated and the diameter of the affected zone. This approach is largely empirical in nature and is intended to bypass issues relating to attack devices and cask-specific characteristics. Instead, it focuses on the extent of the damaged volume in the spent fuel as the primary determinant of the spent fuel matrix material total respirable release. This is the mass of all respirable particles released during an event. The results provided here should represent a reasonably realistic estimate of release reflecting the existing experimental data and analyses based on that data.

EXPERIMENTAL DATA

There have been two principal experimental programs aimed at determining the release of spent fuel from casks under attack using HEDDs. Three full scale tests with depleted uranium dioxide (DUO_2) surrogate fuel assemblies were conducted in France in 1994 under contract to the Gessellshaft fur Anlagen- und Reaktorsicherheit (GRS) in Cologne, Germany [1]. One full scale test and several ¼ scale tests, also using DUO_2 surrogate fuel pins, were performed at Sandia National Laboratories (SNL), in the early 1980s [2]. In the same time frame as the SNL tests, there were small scale tests with a single pellet or a few single pins performed at Battelle Columbus Laboratories (BCL) [3] and at Idaho National Engineering Laboratory (INEL) [4]. Real spent fuel and DUO_2 surrogate materials were used that allowed linkage between the mass of particulate materials produced from both types of material when subjected to the HEDD-

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produced environment. These tests have been fully documented by the experimenters and discussed and analyzed in prior papers at the Waste Management Conferences held yearly in Tucson, AZ [5]. As a result, these tests and analyses will not be discussed in any detail here, but the principal results will be highlighted as they pertain to this paper's objective.

The principal results used here are as follow:

- Small scale tests suggested that, subjected to the same high energy environments, spent fuel with burnup of about 33Gwd/t produces about 3 times the mass of respirable (<10 µm AED[1]) compared with DUO_2 surrogate material. There is some considerable uncertainty in this SFR[2] value that was to be resolved by new small scale test conducted at SNL [9] through the efforts of the international Working Group for Sabotage Concerns for Transport and Storage Casks (WGSTSC) that is the subject of a paper at this PATRAM and those presented at earlier symposia [6].
- The full scale test with surrogate fuel conducted at SNL penetrated one full assembly and one wall of the cask. It produced a respirable aerosol release that was 7.7×10^{-4} times the estimated mass of disrupted fuel pellets [7].
- The ¼ scale test with surrogate fuel conducted at SNL penetrated one scaled fuel assembly and both walls of the cask (a through shot as a result of the HEDD being a bit more energetic than thefull scale device). It produced a respirable release that was 6 times larger than the full scale test (4.6×10^{-3}), postulated to be a result of through flow of entrained gas and particulate [7].
- The first full scale GRS test with surrogate fuel penetrated 3 assemblies and one wall of the cask and released a little more than 1 gram of respirable aerosol. When put in terms of a fraction of the total mass of disrupted pellets, an estimated release fraction of 3.2×10^{-4} was realized [7].
- The second scale GRS test with surrogate fuel and using the same HEDD penetrated one assembly and one wall of the cask and released a little less than 1 gram of respirable aerosol. A reduced penetration depth (1 assembly vs. 3 assemblies) and larger affected diameter of disrupted fuel in the affected assembly compared to the first test is attributed to a small change in the experimental setup and/or partial failure of the HEDD. The estimated respirable release fraction for this test was 3.1×10^{-4} [7].

The almost identical release from the two GRS tests was interpreted by GRS to mean that material released to the environment outside the cask wall was principally derived from the first assembly penetrated by the HEDD. That is, particulate from assemblies two and three in the compartmented volumes defined by the basket assembly was trapped in those compartments of the basket. When the results of the first GRS test are restated as a fraction of the disrupted mass in only the first assembly, the release fraction for the first GRS test becomes about 1.1×10^{-3} [7], quite close to that for the SNL full scale test.

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[1] AED - Aerodynamic Equivalent Diameter is a measure used to characterize aerosols in terms of their dynamic behavior that takes into account different density, particle shape, and agglomeration character.
[2] SFR - Spent Fuel Ratio is the ratio of the mass of spent fuel aerosol to that of surrogate aerosol in the respirable size range resulting from the same HEDD disruption event in the same apparatus.

The Sandia ¼ scale test is relevant in that it suggests that, in a cask with multiple assemblies, each basket partition may be considered to be like a separate cask. Analogously to the ¼ scale test, some considerable fraction of the particulate produced in the first assembly is swept deeper into the cask where it is unavailable for release as a result of the outflow of fuel pin plenum gases that are released from the disrupted fuel pins.

For an earlier work [8] to estimate releases as a result of HEDD attack on spent fuel casks, an analysis of prior work on the particulate produced from ceramic material subjected to shock loading suggested that approximately 5% of the affected mass subjected to very high shock levels (like HEDDs produce) would end up as respirable material. Recent tests [9] that are part of the WGSTSC effort indicate that the respirable fraction of surrogate material is likely 2% or less. This is the fraction of radioactive material that is respirable (defined as aerosols with diameters smaller than 10 μ AED) when impacted at high shock levels.

EMPIRICAL ANALYSIS

An empirical model was developed to reproduce the release data from three full scale SNL and GRS experiments. The model incorporates the principal results from the experiments together with empirical constants relating to the deposition fraction of aerosols on surfaces within the cask that removes aerosol material that would otherwise be swept out of the cask by the release of the simulated plenum gases, which were features of the GRS tests and which are present in actual spent fuel.

Because the nominally identical HEDD in the second GRS test penetrated only one assembly compared to the three penetrated in the first test, it was estimated that the amount of respirable material produced in the volume of the first assembly was about one third of that produced in the first GRS test.

Results of the empirical model provided an internal deposition fraction that allowed the results of the first and second GRS experiments to be rationalized. The developmental details of this “GRS model” were presented at Waste Management ‘06 [5].

RESULTS

Calculations for this paper were done with the same basic scheme used for the 1999 estimate of respirable material release performed for the Yucca Mountain Program [8] but with inclusion of the features outlined below that mirror the prior discussion.

- Where multiple assemblies were affected, only aerosols remaining in the volume occupied by the first assembly were available for release along with released plenum gases.
- Most of the aerosol generated in the first assembly volume is swept into the second and deeper volumes of the cask. An immediate release described by the Sandia full scale test occurs and 5 times that amount is swept deeper into the cask as suggested by the SNL ¼ scale results.
- Sixty or seventy percent of the aerosols remaining in the first assembly volume deposit and are unavailable for release from the cask by the plenum gases that are released from affected rods in a time scale of second to minutes (depending on fuel condition).

Figure 1 shows the results of the calculations. The figure indicates an increasing release that goes as the square of the hole diameter (D) and linearly with penetration depth (L) until L becomes greater than 1 (into a second assembly). For L greater than 1, the released amount increases only slowly because much of the aerosol remaining in the first cavity has deposited and much of the aerosol produced deeper in the cask has deposited and, in addition, is too far from the entrance hole to be carried out by the released plenum gases.

CONCLUSION

The results provided here reflect the existing full scale cask tests with surrogate fuel. The results given here provide a reasonable upper limit estimate for potential release of spent fuel matrix aerosols for use in estimating potential consequences resulting from an HEDD attack against a cask containing moderate burn up spent fuel. Additional full scale tests with surrogate materials are needed to verify the model given here and to broaden the understanding of internal aerosol processes and to widen the scope of casks for which some understanding of release mechanisms are understood.

To apply this model to estimates of release from actual spent fuel, additional data to better define the SFR and to quantify the phenomena of volatile nuclide enrichment will be needed. Completion of the WGSTSC test program [9, 10], which has been designed to address these parameters, will be needed to obtain a fuller understanding of the consequences of HEDD attack on a spent fuel cask.

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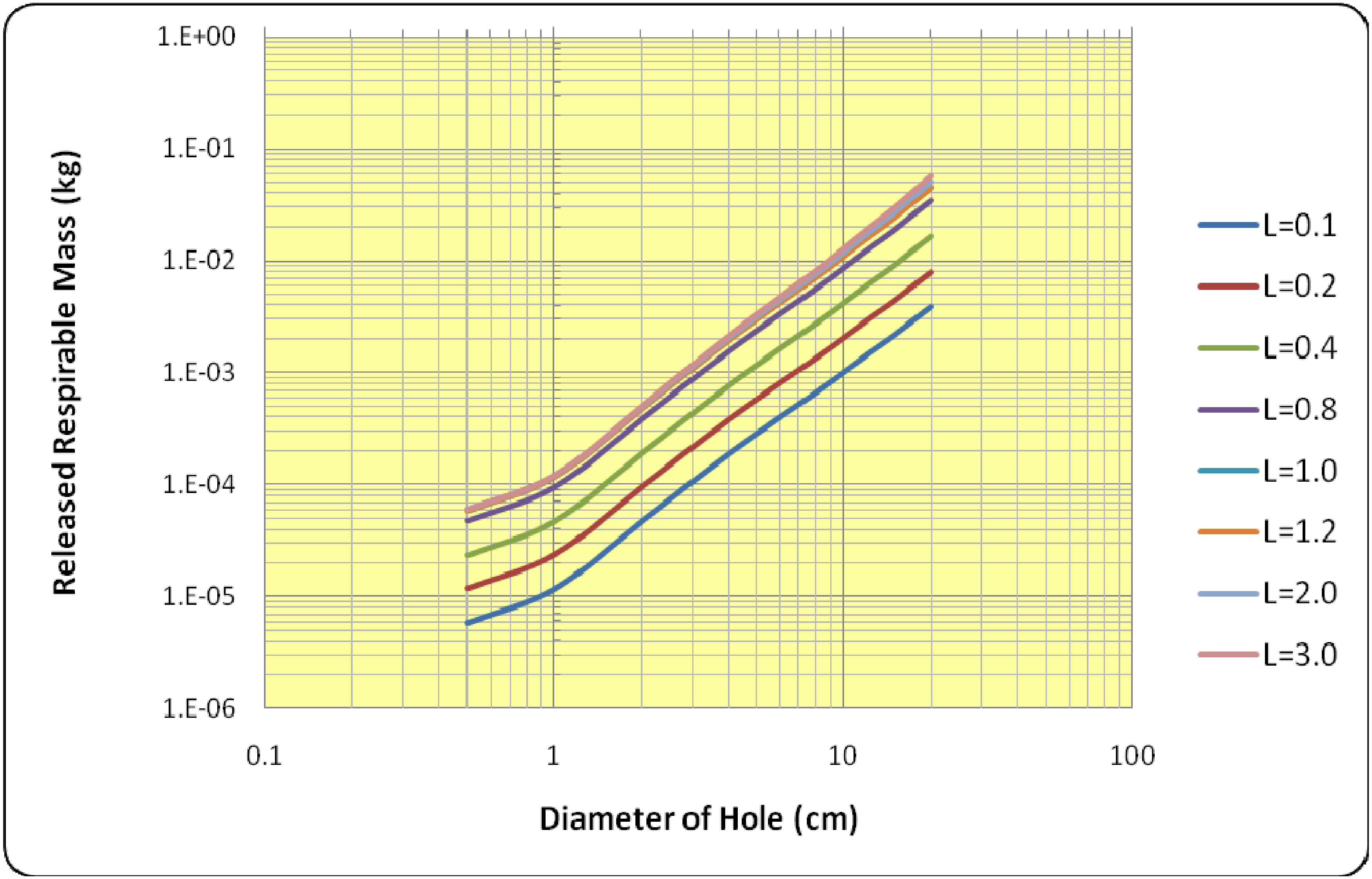

Figure 1: Respirable Mass Release vs. Hole Diameter, D in cm, and Penetration Depth, L in Assemblies