

**INTERNATIONAL COOPERATION IN
MEASURING SPENT FUEL RESPONSE IN HIGH ENERGY ENVIRONMENTS**

William Lake, Ashok Kapoor
United States Department of Energy

Francis Young, Andrew Murphy
United States Nuclear Regulatory Commission

H. Richard Yoshimura, Jeffrey S. Philbin, Jeremy L. Sprung, and Manuel G. Vigil
Sandia National Laboratories*, USA

Florentin Lange, Gunter Pretzsch
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Germany

Wolfgang Koch, Oliver Nolte, and Hubert Lödding
Fraunhofer Institute for Toxicology and Aerosol Research, Germany

Bruno Autrusson, Didier Brochard
Institut de Protection et de Sûreté Nucléaire of France

Robert Luna
Consultant, Albuquerque, NM

ABSTRACT

This paper describes plans for two sets of experiments designed to evaluate the behavior of irradiated nuclear fuel to high-energy shock and collision impact environments. The first is the initiative of an international working group established to study the consequences of terrorist attacks on container systems used to store and transport radioactive materials. A related, but separate, study provides information on spent fuel behavior in high-energy collision impact situations to enhance the fidelity of risk assessments. Both sets of planned experiments include the same organizations and are pursued with similar test protocols. The international group involved with study of terrorist attack consequences includes representatives from France, Germany, the United Kingdom, and the United States. The two experimental programs would be conducted at laboratories in Germany and in the U.S.

INTRODUCTION

Irradiated or “spent” nuclear fuel has the potential to cause significant radiological consequences if released to the environment. Packagings used for its transport in the public domain are extremely resistant to releasing any significant fraction of their contents, but in very severe accidents and in some sabotage attack scenarios it is expected that some release of particles derived from disrupted fuel pellet materials may occur. The amount, nuclide content, and size distribution of the released material is key to predicting radiological impacts, but has only been measured in a few tests involving high-energy impacts or sabotage events employing high

energy density devices (HEDDs) that focus high explosive energy into an energetic penetrator. As a result, conservative assumptions are used in consequence analyses that may not represent what would occur in a real high-energy impact event.

Studying the effects and consequences of high-energy impacts or sabotage attacks involves applying a variety of complex engineering and scientific disciplines. The following list of phenomena, although not exhaustive, provides some insight into that complexity:

1. High-speed collision impact of a cask on hard surfaces or a HEDD's impact on a cask ultimately involves impact forces on spent fuel, leading to a disruption of fuel pellet material,
2. Formation of aerosols within the cask and agglomeration of particles in the cask prior to release to the environment,
3. Dispersion of aerosols released by the event under various environmental conditions,
4. Exposure of downwind population to radiation by cloudshine emissions, inhalation, groundshine emissions, and ingestion pathways, and
5. Occurrence of health effects in exposed individuals and populations.

Within this framework and because experimental work is possible and desirable, issues 1 and 2 are the most challenging and expensive. A group of experts from France, Germany, the United Kingdom, and the United States recognized the difficulties of developing data in this area. The group recognized that resources available among the group might address the common needs. The initial meeting of this group in 1999 led to a cooperative international working group to study the impacts from sabotage of nuclear materials during transport, as well as potential applications to high-energy impact situations.

To leverage the resources and capabilities of interested agencies in the U.S. and abroad, the studies described here involve laboratories in Germany and the U.S. with established capabilities to develop tests and experiments. The data obtained in tests on surrogate and real fuel materials will be the basis of theoretical and empirical models of impact situations. Within the scientific communities, this type of experimental data is typically shared through symposia presentations and publication in technical journals. However, because of the sensitivity of data associated with terrorist attacks on storage and transport systems, this paper and future papers dealing with results must avoid revealing some aspects of the experiments.

INITIAL COOPERATIVE TECHNICAL PROJECTS

In the two sections that follow, the plans for the first two of what is hoped will be several experiments are discussed. The experiments are separate entities, but both will utilize the same basic aerosol measurement system developed at the Fraunhofer Institute for Toxicology and Aerosol Research and Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH in Germany, and both involve the same laboratories.

HEDD-Produced Aerosol Experiments

Significant work has been done in Germany, the U.S., and France to assess the potential impacts of hypothetical sabotage events on spent fuel casks and to develop source terms for aerosols created as a result of HEDD effects. Experiments have delineated damage to the casks and the related release of surrogate aerosols to the environment. Early U.S. experiments on actual spent fuel and surrogate material provided some data (though with significant variation) on the relation between the amounts of aerosols produced from the two materials. These experiments and subsequent analyses predicted the ratio of aerosol production from exposure to HEDD events to be within a range of 0.5 to 12, i.e., about a factor of 10 uncertainty (1, 2, 3). This large spread in values for a parameter that has a direct influence on the predicted consequences of an optimally successful sabotage attack could be narrowed by the experimental program planned and described below.

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH and Sandia National Laboratories (SNL) prepared a common proposal to better determine the ratios of aerosol produced by spent fuel in an energy-intensive attack to aerosol produced by surrogate fuel (depleted uranium oxide) for the same attack. It was decided that the collaborative effort would be supported by the U.S. (performing tests at SNL), Germany (design and manufacturing of the aerosol sampling chamber), and France (manufacturing of the spent fuel rods). The program is designed to define three important features of the interaction of a HEDD with spent fuel:

- Mechanical damage to the impacted fuel rods,
- Mass and physical characteristics of the particles produced – aerodynamic diameters (AED) up to 100 microns with special emphasis on the respirable fraction (<10 micron AED), and
- Enrichment of volatile nuclides like cesium and ruthenium in specific particle size fractions.

These goals are based on a review of the prior experimental investigations concerning an optimally successful HEDD attack on a spent fuel shipping cask. The source term would be improved by a better knowledge of the correlation of aerosol mass release data between the surrogate material and actual spent fuel. In addition, there is insufficient knowledge about the degree of enrichment (fractionation) of volatile elements in smaller particulates as observed, but not well quantified, in studies conducted by Battelle Columbus Laboratory (4) and Idaho National Engineering and Environment Laboratory (5) in the early 1980s.

SNL staff conducted a feasibility study (6) to determine if the desired experiments involving HEDD disruption of spent fuel pellets could be run in an SNL facility. The juxtaposition of a high-explosive device and spent fuel in the experiment gives rise to concerns that include environmental impact, contamination control, radiation control issues, and waste disposal. Since the parallel experiments in this series that use depleted uranium or other surrogate material pose no special waste management or radiation control issues, they were not covered in the feasibility study. The basic conclusions from the study are provided below.

- The spent fuel disruption experiment involves only relatively small quantities of explosive and spent fuel (the active length of spent fuel in a proposed sample rod section is 36 mm and the radioactivity in that sample is ~18 Curies). Nevertheless, the unshielded contact dose rate of the spent fuel sample is estimated to be 6000 rem/hr. Therefore, significant safety documentation, preplanning, and facility preparation would be required to conduct such an experiment in a nuclear facility whose authorization basis allows these types of combined hazards.
- The test concept would require remote handling capability at the facility to retrieve the spent fuel sample from a transportation cask and place it into a shielded experiment chamber. After the test, remote handling would be needed to recover a particle collection device (cascade impactor) and efficiently package remnants of the spent fuel sample, disrupted by the HEDD.
- The experiment could be conducted safely through the careful design and placement of an aerosol test chamber, a mating “boom box” and storage cask, and a particle collection device (see Figure 1). The facility and experiment hardware design must allow (collectively) for close alignment of the HEDD and the spent fuel rod (target), as well as straightforward post-test recovery of the data, experiment hardware, and debris from the test (including the spent fuel remnants).
- Options for disposal of the spent fuel debris follow.
 - Classify the spent fuel debris as “spent fuel” and include it in the SNL spent fuel waste stream.
 - Classify it as remote-handled transuranic waste for transfer to WIPP when WIPP begins to accept this waste category.
- An evaluation of nuclear facilities at SNL was made and showed at least two facilities that could accommodate the experiment. The preferred candidate is the Gamma Irradiation Facility (GIF).
- The cost to field such a test, assuming the experiment is conducted at SNL’s GIF, is estimated to be \$1.23M. If another SNL nuclear facility were used, the cost would be similar.

High-Speed Impact Aerosol Experiments

The goal in this set of experiments is to obtain data on basic aerosol production behavior from high-speed (15 to 50 m/s) end- and side-on impacts of spent fuel pellets contained in Zircalloy cladding. Three areas are of principal interest:

- Behavior of Zircaloy clad with various degrees of embrittlement,
- Aerosols produced from surrogate CRUD deposited on the outer surface of fuel rods, and
- Aerosols produced from surrogate spent fuel materials released from failed cladding.

Because aerosols can be created from CRUD on the surface of the clad, as well as pellet fracturing followed by a release from ruptured cladding, both effects would be included in this set of experiments. These experiments would be conducted with surrogate fuel pellet materials and surrogate CRUD in embrittled Zircalloy cladding. Testing to determine the behavior of spent fuel pellets in a similar impact-energy environment should show whether surrogate and real spent fuel pellets behave similarly. In addition, these experiments would provide additional data needed to fully characterize the comminution behavior of brittle fuel materials in general and

useful baseline data for theoretical analysis of fuel behavior in impact situations. Thus, the following tasks would be performed:

1. After appropriate surrogate pellet materials were selected, pellets would be fabricated and packed into relatively short sections of Zircaloy tubing that have been embrittled by autoclaving under hydrogen gas, and the tubing sections would be capped and pressurized with helium gas.
2. Surrogate CRUD would be synthesized and deposited onto the surface of the Zircaloy tubing, and the characteristics of the deposits would be determined and compared to those of real CRUD deposits on real spent fuel rods.
3. The impact velocities required to produce failures (small tears or cracks) in the short sections of Zircaloy tubing, and the nature of the failures caused by end and side impacts of the tubing sections would be determined.
4. Short sections of Zircaloy tubing that contain surrogate pellets or sections coated with surrogate CRUD deposits would then be subjected to end or side impacts at velocities previously determined to cause the sections to fail by cracking or tearing, and the amount and the size distribution of the fuel fines or CRUD particles released by the impacts would be determined as a function of impact velocity.
5. The particle size distributions produced by impact fracturing of surrogate pellets would be compared to the size distributions produced by impact fracturing of a few real spent fuel pellets that have different fuel burnups.

Task 1 would be performed by Framatome ANP, Tasks 3 and 4 by the Fraunhofer Institute, and Tasks 2 and 5 by SNL.

CONCLUSION

An international cooperative effort has been proposed to accommodate the sharing of information and investigative activities for the study of sabotage effects during the storage and transport of nuclear and radioactive materials. A working group consisting of organizations from four countries has been formed to pursue this international effort. Because the information dealt with in this area is usually classified, a formal agreement between the participating countries is deemed necessary to protect such information.

Initial technical projects that do not involve sensitive information have been identified for study by the working group.

- The first project seeks to establish a quantitative correlation between aerosol release quantities for spent fuel and the surrogate materials commonly used for spent fuel in tests and experiments that study sabotage effects. Estimates of this correlation parameter have ranged from 0.5 to 12. This wide range of values suggests a high degree of uncertainty in the estimates. This technical project is an optimized, three-phase experimental project, offers an economically sound approach to establishing a verified correlation factor to relate the behavior of spent fuel and depleted UO_2 fuel for certain sabotage events. The correlation factor reduces the uncertainties associated with using simulated spent fuel (e.g., UO_2 fuel) in sabotage effects testing and experiments. The initial project would provide useful technical data and test the ability of the international working group to perform a cooperative research and development activity.

- The second project determines spent fuel cladding, CRUD, and pellet behavior in high-speed impact situations for use in risk assessments. Its genesis resulted from discussions to develop the first project, which would use the impact and aerosol measurement apparatus at Fraunhofer Institute to support an area of risk assessment that had previously been based on only the most conservative assumptions of behavior.

These two projects await development of full funding to complete, but needs for the data have been strongly endorsed by U.S. and international participants and significant funding has been committed.

FOOTNOTES

* Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94-AL85000.

REFERENCES

- [1] R. P. Sandoval, J. P. Weber, H. S. Levine, A. D. Romig, J. D. Johnson, R. E. Luna, G. J. Newton, B. A. Wong, R. W. Marshall, Jr., J. L. Alvarez, and F. Gelbard, "An Assessment of the Safety of Spent Fuel Transportation in Urban Environs," SAND82-2365, June 1983.
- [2] U.S. Department of Energy, "Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain," Office of Civilian Radioactive Waste Management, DOE/EIS-0250D, July 1999, Las Vegas, NV.
- [3] R. E. Luna, K. S. Neuhauser, and M. G. Vigil, "Projected Source Terms for Potential Sabotage Events Related to Spent Fuel Shipments," SAND99-0963, June 1999.
- [4] E. W. Schmidt, M. A. Walters, B. D. Trott, and J. A. Gieske, "Final Report on Shipping Cask Sabotage Source Term Investigation," NUREG/CR-2472, Battelle Columbus Laboratories, October 1982.
- [5] J. L. Alvarez, R. C. Green, L. Isaacson, B. B. Kaiser, R. W. Marshall, Jr., and V. J. Novick, "Waste Form Response Project Correlation Testing," Report No. EGG-PR-5590, Idaho National Engineering Laboratory, 1982.
- [6] J. S. Philbin, R. E. Naegeli, R. L. Coats, P. H. Helmick, M. J. McDonald, S. W. Longley, S. A. Walker, and D. T. Berry, "Performing Spent Fuel Ratio Experiments at Sandia National Laboratories: A Feasibility Study", Sandia Report SAND2002 – (to be published), February 2002.

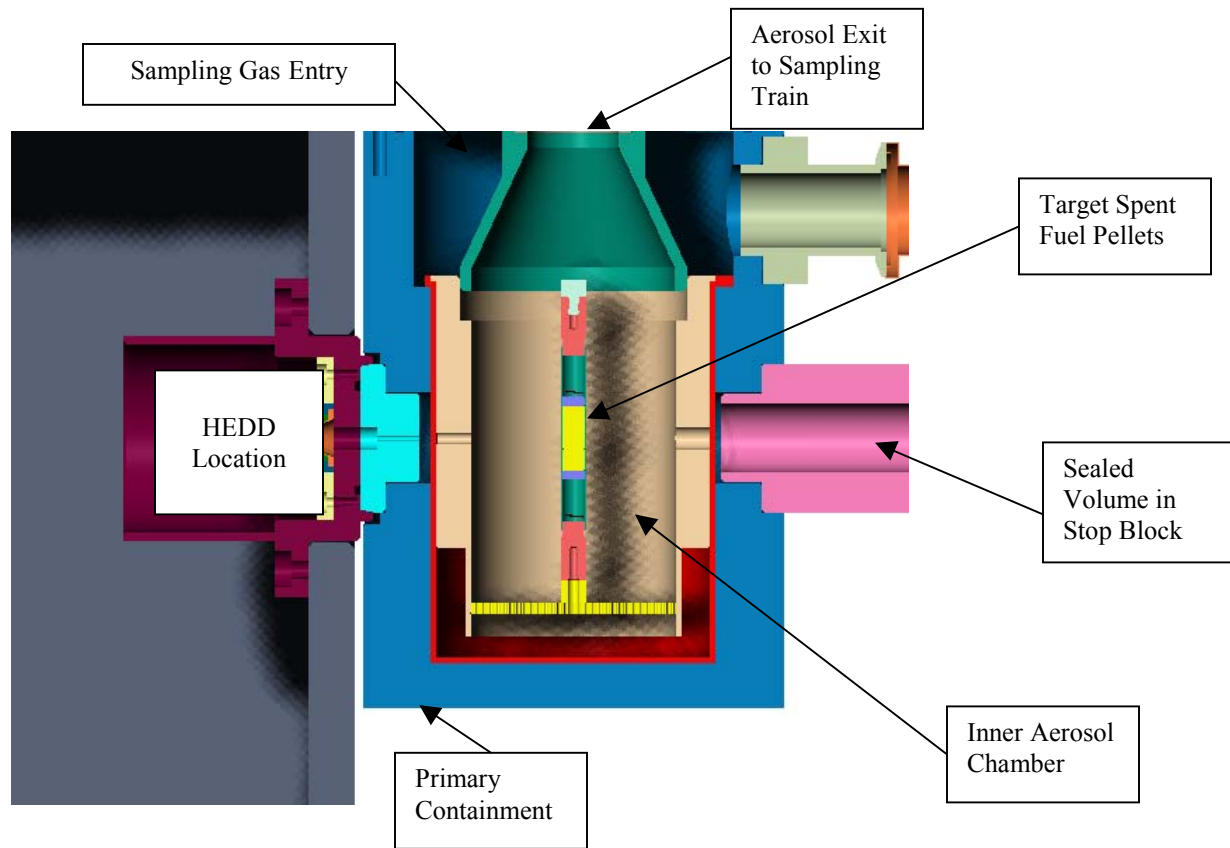


Fig. 1a: Conceptual Drawing of Test Setup

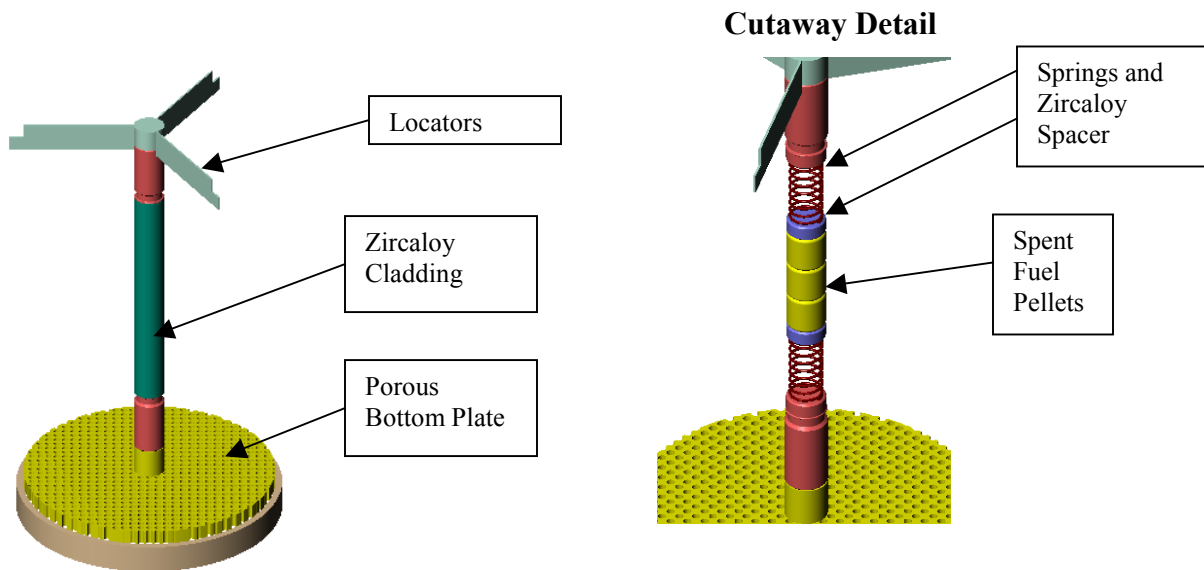


Fig. 1.b: Spent Fuel Target Assembly

