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AN EXPERIMENTAL DATA BASE FOR ESTIMATING THE CONSEQUENCES FROM A HYPOTHETICAL SABOTAGE ATTACK ON A SPENT FUEL SHIPPING CASK

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DISCLAIMER

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INTRODUCTION

This paper describes the results of a program conducted at Sandia National Laboratories for the US Department of Energy to provide an experimental data base for estimating the radiological health effects that could result from the sabotage of a light water reactor spent fuel shipping cask. The primary objectives of the program were limited to: (1) evaluating the effectiveness of selected high energy devices (HED) in breaching full-scale spent fuel shipping casks, (2) quantifying and characterizing relevant aerosol and radiological properties of the released fuel, and (3) using the resulting experimental data to evaluate the radiological health effects resulting from a hypothetical attack on a spent fuel shipping cask in a densely populated urban area. The following tasks were performed to address the programmatic objectives:

1. Subscale and full-scale tests were performed to evaluate the capability of various types of HEDs to breach generic spent fuel truck casks and disperse cask contents. The data obtained from these tests were used to select a reference HED(s) for further evaluation and full-scale testing.
2. Subscale tests subjecting 1/4-scale casks to scaled versions of the selected reference HED were performed to establish measurement techniques and a statistical data base on the released material properties.
3. Subscale tests subjecting surrogate and actual irradiated fuel pellets to scaled versions of the reference HED were performed to provide data on radioactive aerosol and particle production characteristics for a range of energy loadings.
4. A full-scale test subjecting a full-size spent fuel truck cask containing unirradiated UO_2 fuel to a full-scale reference HED was performed to provide data on the dispersed fuel, source term characteristics and cask/fuel response to a full-scale attack.
5. An analysis of the experimental data was performed to develop a model for predicting source term production for a range of HED and cask types.
6. The experimental data were used to evaluate the health consequences resulting from a hypothetical sabotage attack on a spent nuclear fuel shipping cask in a densely populated area.

HED EVALUATION

An extensive survey of available high energy devices (HEDs) was performed to select those devices that might be capable of breaching a full-scale spent fuel truck cask. From the many

different types of attack devices considered in the survey, four types of HEDs were selected for testing and further evaluation. The devices selected were as follows:

1. Conical-shaped charges,
2. Contact-breaching charges,
3. Platter charges,
4. Pyrotechnic torches and thermite devices.

Full scale tests were performed subjecting both simulated and actual spent fuel truck casks to each of the four types of HEDs to assess the capability of these devices to penetrate a full-size cask and disperse its contents. Based upon the results of these tests, an HED was selected from the four device types tested. The selected HED was used as the reference attack device for the source term and health consequence study.

SUBSCALE TESTS

Subscale tests were conducted using 1/4-scale spent fuel casks containing full-size fuel pins made up of unirradiated UO_2 pellets and zircalloy cladding as targets for scaled versions of the full scale reference HED. Subscale tests were performed on both water-filled shipping casks (i.e., water in the fuel cavity and in the moderator shell of the cask) and "dry" shipping casks to provide data on the effects of water on release fractions, source term characteristics, and response of the fuel/cask to the HED. The results of the "dry" shipping cask test indicated that 0.36% of the total fuel mass removed from the fuel assembly was in the respirable size range. Approximately 0.014% of the total fuel mass removed from the fuel assembly in the "wet" shipping cask test was in the respirable size range. "Removed" in this context is defined to be that mass of fuel which is displaced from the fuel assembly as a result of the action of the attack device, but not necessarily displaced from the fuel cavity of the cask. An analysis using the release data obtained from the 1/4-scale "dry" was performed for a full scale event to determine the fraction of solid fuel inventory of a full size spent fuel truck cask could be released as respirable airborne acitivity. The calculation assumed an overweight truck shipping cask (see Ref. 1) containing three pressurized water reactor (PWR) assemblies (an equivalent inventory of 1.4 t of heavy metal) as the target. The damage path was taken to be the longest path through the cask and fuel, and complete penetration of both cask walls was assumed for the analysis. The results of the extrapolated test data indicated that 0.0023% of the total solid fuel inventory of a three PWR fuel assembly truck cask could be released as respirable radioactive material from a full-scale sabotage event.

FULL-SCALE TEST

A full-scale test was performed subjecting a 25.45 t generic spent fuel truck cask containing a single unirradiated depleted UO_2 fuel

assembly to the reference full-scale HED. The unirradiated fuel assembly used in the test closely simulated a full-size irradiated PWR fuel assembly with respect to fuel pin cross-section geometry and HED/fuel penetration and dispersion parameters. A total UO_2 fuel mass of 2.548 kg was released from the cask as a result of the explosive attack. The total released fuel mass released from the cask as a respirable aerosol ranged from 0.00117 to 0.00020%. The full-scale test data were used to calculate the quantity of radioactive fuel that could be released as a result of an explosive attack on a three-PWR fuel assembly generic truck cask. A three-assembly truck cask was chosen as the target for the attack scenario calculation because it is currently the largest licensed truck transported cask available for shipment of spent light water reactor fuel. The extrapolated full-scale test data indicated that 0.0005% (6 g) of the total unirradiated solid fuel inventory (1.4 t) could be released as respirable airborne particulate as a result of an explosive attack on a three-PWR fuel assembly truck cask by a device similar to the reference full scale HED.

CORRELATION TESTS

Effects of various high energy environments on breakup, comminution, and dispersal of spent commercial nuclear reactor fuel were evaluated in a series of tests on single irradiated fuel pellets. Correlation functions were obtained relating particle size distributions for fracture, breakup, and aerosolization of depleted UO_2 fuel to that of irradiated fuel by conducting similar tests on single irradiated fuel pellets and single depleted UO_2 pellets. A range of values of the correlation function, i.e. mass released from irradiated pellets to that released from unirradiated pellets ranging from 0.7 to 5.6, was obtained from these tests depending on collection techniques used in the tests and statistical fluctuations in the data. A value of less than one occurred with the highest frequency. However, for conservatism in the health risk assessment, the correlation function value of 5.6 was used. A correlation value of 5.6 leads to an upper limit release value of 17 g (3.4×10^{-3} %) of aerosolized respirable irradiated fuel for a one-PWR fuel assembly cask and 34 g (2.4×10^{-3}%) for the maximum respirable aerosol release from a three-PWR fuel assembly truck cask.

HEALTH EFFECTS EVALUATION

The reactor safety study consequence model called CRAC[2] was used to estimate the human health consequences resulting from an attack on a three PWR fuel assembly truck cask using the reference HED selected for this study. The basic scenario assumed for this analysis was as follows:

(1) The attack occurred in the borough of Manhattan in New York City;
(2) The attack occurred on a weekday, midafternoon during high motor and pedestrian traffic;
(3) The spent fuel inventroy was typical of PWR assemblies after 150 days cooling at the reactor;
(4) All consequence estimates were made without any evacuation to avoid early exposure;
(5) The attack device was similar to the reference HED device used in the tests of this study.

Using these assumptions and this study's experimentally determined release fraction of 3.4×10^{-3} % for an attack on a single PWR spent fuel assembly truck cask (0.5 tHM inventory and 150 days cooled), values of health consequences were found to be 0/0 (mean/peak) early fatalities, 0/0 (mean/peak) early morbidities, 0.3/1.3 (mean/peak) early latent cancer fatalities, and 2/7 (mean/peak) total latent cancer fatalities. In this context, early fatalities and early morbidities are defined to be fatalities and illnesses occurring within one year after exposure to the radioactive material, respectively. Early latent cancer fatalities are a result of the initial exposure only and can occur at any time subsequent to the initial exposure. Total latent cancer fatalities are the sum of early and long-term exposure cancer fatalities and can occur at any time subsequent to exposure.

Extrapolating the experimentally determined release fractions for a single PWR fuel assembly to that for a three-PWR fuel assembly truck cask (1.4 tHM), an estimate of the health consequences of 0/0 (mean/peak) early fatalities, 0/0 (mean/peak) early morbidities, 1/3 (mean/peak) early latent cancer fatalities, and 4/14 total latent cancer fatalities were obtained. These calculated latent (early) cancer fatalities are smaller by a factor 350/433 (mean/peak) than the original Urban Study[1] estimates upon which the NRC interim regulations for US transport of spent fuel were based.

CONCLUSIONS

The data from this program, together with the study sponsored by the NRC, indicate that the original Urban study greatly overestimated the impact of malevolent acts directed at nuclear spent fuel shipping casks in urban environs. This work has become the basis for ammendments to moderate the current NRC requirements for the protection of commercial spent fuel shipments in the U.S. against radiological sabotage. In a larger sense this work could also be the basis of more credible "worst case" analyses since it defines the results of an event which is well beyond any cask failure scenarios postulated for severe accident environments.

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