Impacts of Acts of Sabotage and Terrorism on Spent Nuclear Fuel Casks

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ABSTRACT

The *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* analyzed the consequences of a successful act of sabotage on a spent nuclear fuel cask. These consequences were estimated for two spent nuclear fuel casks and two high energy density devices. The Environmental Impact Statement found that the consequences of a successful act of sabotage were similar to the consequences of the maximum reasonably foreseeable transportation accident.

INTRODUCTION

The sabotage analysis (Luna et al. 1999) examined two spent nuclear fuel casks, a large rail cask and a smaller truck cask. Figures 1 and 2 show these casks. The rail cask held 26 pressurized water reactor assemblies and the truck cask held 4 pressurized water reactor assemblies.

Two high energy density devices were also examined in Luna et al. (1999). Because of security considerations, these devices could not be identified, but they were denoted HEDD1 and HEDD2. The devices were selected based on the volume of spent nuclear fuel they could disrupt, which is a combination of the depth of penetration and the diameter of the penetration. Another factor in device selection was to include at least one device (HEDD2) that could be delivered from a distance by a launcher/guidance system that is man-portable.

The SCAP computer code was used to model the penetration of the truck and rail casks by HEDD1 and HEDD2. Relative to experimental data, SCAP was found to model penetration depth well but underestimated the diameter of the penetration. Therefore, the SCAP results were calibrated upward to estimate the penetration diameters in the casks.

DOSE ASSESSMENT

The RISKIND computer code (Yuan et al. 1995) was used to model the radiation doses from radioactive material released from the spent nuclear fuel cask during the sabotage event. RISKIND has been benchmarked and verified (Biwer et al. 1997).

Two receptors were evaluated: 1) the maximally exposed individual, and 2) the population within 50 miles (80 km) of the sabotage event. The maximally exposed individual was assumed to be located at the point of maximum downwind air concentration, and was exposed through the inhalation, cloudshine, and groundshine pathways for 2 hours. The population within 50 miles (80 km) was also exposed through the inhalation, cloudshine, and groundshine pathways. In order to provide an upper bound on environmental impacts, the population was exposed for 1 year, and no reductions in the radiation dose through evacuation or other mitigative actions were assumed.

In a prospective dose assessment, it is not possible to say where the sabotage event might occur. Therefore, meteorological data collected at 177 sites across the United States were used to determine atmospheric conditions. To provide a realistic estimate of atmospheric concentrations, 50 percent atmospheric conditions were used to model the atmospheric dispersion of radionuclides released from the cask. These are neutral atmospheric conditions that would not be exceeded 50 percent of the time, and were characterized by Class D stability and a wind speed of 4.5 m/s (10 mph).

Population radiation doses were estimated using 1990 population density data for the 21 largest urbanized areas in the United States. The surrounding population was modeled using 6 successive annular rings, with radii of 5 miles (8 km), 10 miles (16 km), 15 miles (24 km), 20 miles (32 km), 25 miles (40 km), and 50 miles (80 km).

Radiation doses were converted to latent cancer fatalities using a risk coefficient of 0.0005 latent cancer fatalities per rem for low doses and dose rates. For high doses and dose rates (greater than 20 rem over a short period of time), a risk coefficient of 0.001 latent cancer fatalities per rem was used.

RESULTS

Releases from the truck and rail casks were expressed as the fractional releases of the contents of the casks. Tables 1 and 2 present these release fractions. Both HEDD1 and HEDD2 were found to penetrate a single wall of the truck and rail casks, but neither HEDD1 nor HEDD2 fully penetrate both walls of the casks. HEDD1 was found to cause more damage to the casks and spent nuclear fuel than HEDD2. This was because the average diameter of the penetration created by HEDD1 was over twice as large as the average diameter created by HEDD2, while the penetration depths were about the same for the two devices.

In comparison to experimental data from Sandoval et al. (1983), these results are larger than previously estimated. This was because previous experiments were performed on surrogate spent nuclear fuel rods that were unpressurized while this analysis was based on fuel rods that were pressurized. The release of pressure from the fuel rods damaged by HEDD1 or HEDD2 is commonly known as blowdown, and it provides an additional mechanism for radionuclides to be released from the casks.

Luna (2000) discussed experiments where the fuel rods were pressurized. Using the ratio of 0.0024 g of respirable aerosol per g of spent nuclear fuel disrupted by the high energy density device from Luna (2000) and the assembly swept masses and total fuel masses from Tables 1 and 2, smaller release fractions were obtained, which provided confidence that the release fractions have not been underestimated. Table 3 presents a comparison of these release fractions.

Table 4 presents the consequences of a successful sabotage event for truck cask and the rail cask. For a truck cask, the largest amount of damage was done by HEDD1. The sabotage event was estimated to result in a population dose of 31,000 person-rem in an urbanized area. This radiation dose is equivalent to about 15 latent cancer fatalities. The maximally exposed individual would receive a radiation dose of 67 rem, which would increase their risk of a fatal cancer by about 7 percent.

For the rail cask, the largest amount of damage was also done by HEDD1, but the impacts estimated for a rail cask would be less than those estimated for truck cask. The sabotage event was estimated to result in a population dose of 4,900 person-rem in an urbanized area. This radiation dose is equivalent to about 2 latent cancer fatalities. The maximally exposed individual would receive a radiation dose of 11 rem, which would increase their risk of a fatal cancer by about 0.6 percent.

These consequences are similar to the consequences estimated in the *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 1999) for the maximum reasonably foreseeable transportation accident, which were 61,000 person-rem for a rail accident and 9,400 person-rem for a truck accident.

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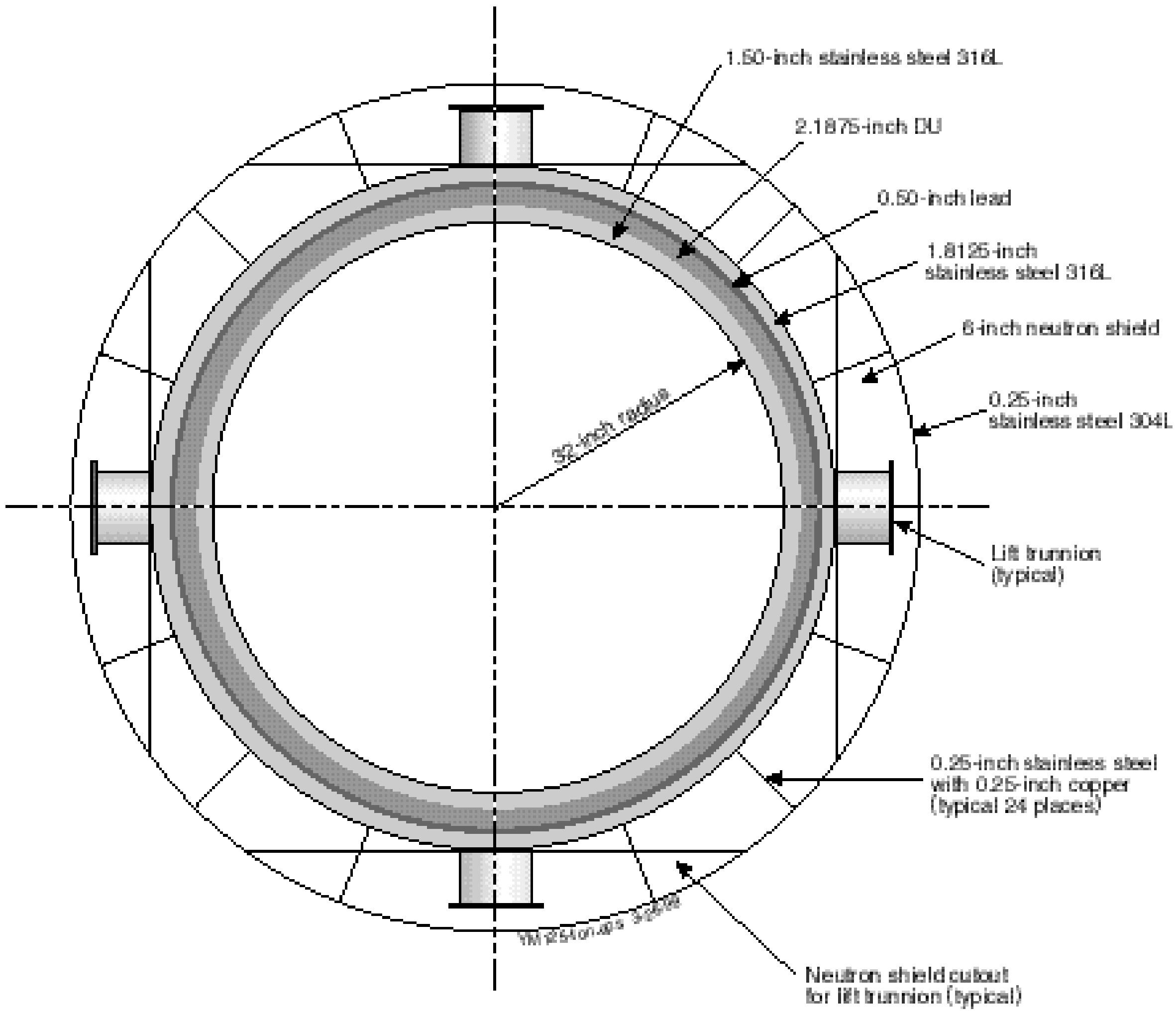
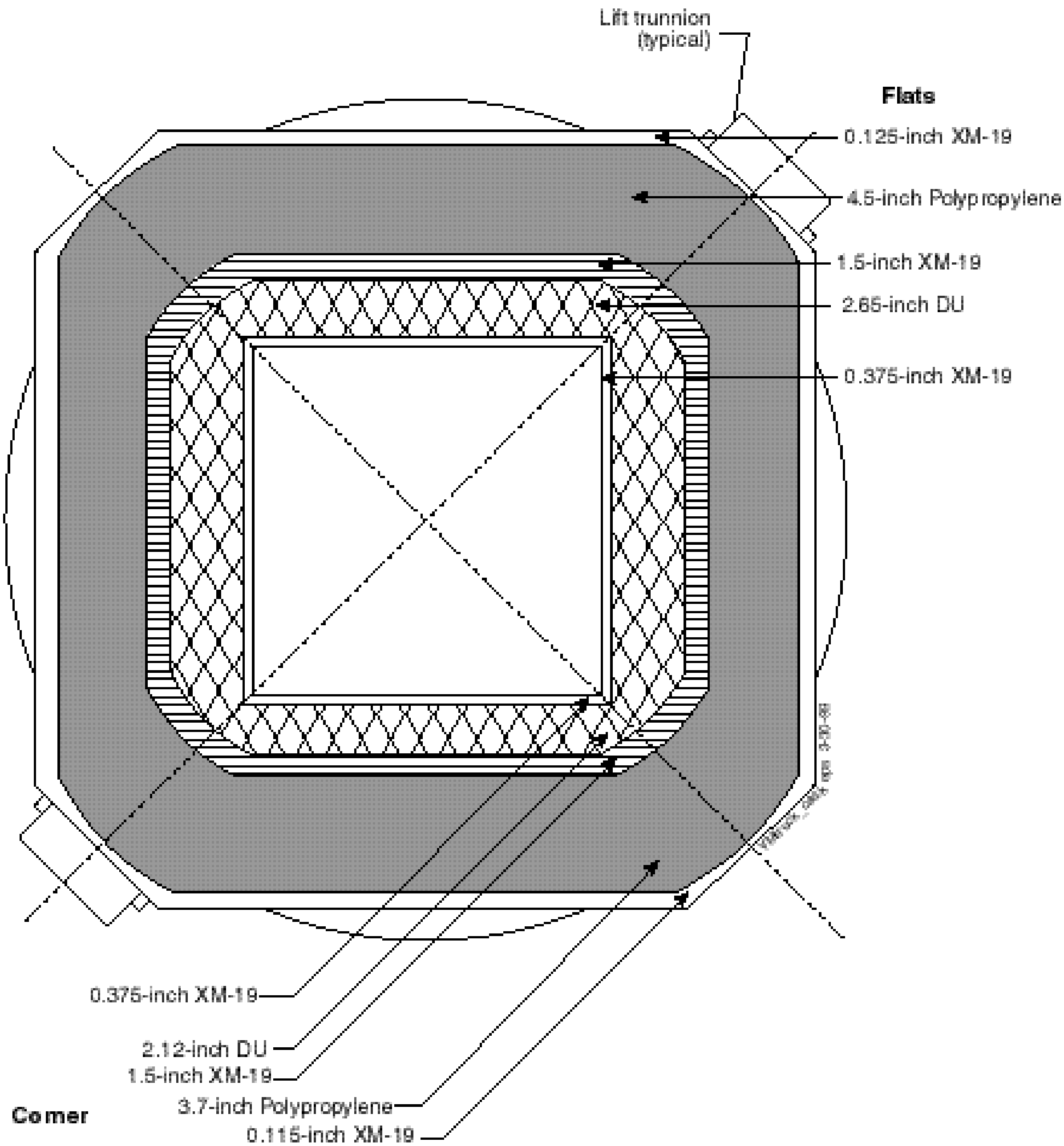


Legend
DU - depleted uranium metal

Figure 1. Cross Sectional Drawing of Rail Cask



Legend
XM-19 - alloy steel
DU - depleted uranium metal

Figure 2. Cross Sectional Drawing of Truck Cask

Table 1. Results for HEDD1

	Truck Cask	Rail Cask
Total fuel mass	2.11E+3 kg	1.37E+4 kg
Effective diameter of penetration	9.0 cm	7.7 cm
Number of assemblies penetrated	2	2.4
Number of fuel rods disrupted	272	294
Average assembly swept mass	7.3 kg	6.6 kg
Maximum assembly swept mass	9.6 kg	8.7 kg
Average respirable release (without blowdown)	1.7E-2 kg	1.5E-2 kg
Maximum respirable release (without blowdown)	2.2E-2 kg	2.0E-2 kg
Average respirable release fraction (without blowdown)	1.0E-5	1.5E-6
Maximum respirable release fraction (without blowdown)	8.0E-6	1.1E-6
Average respirable release (with blowdown)	2.6E-1 kg	4.2E-2 kg
Maximum respirable release (with blowdown)	3.4E-1 kg	5.5E-2 kg
Average respirable release fraction (with blowdown)	1.2E-4	3.1E-6
Maximum respirable release fraction (with blowdown)	1.6E-4	4.0E-6
Crud release fraction	7.5E-5	1.3E-6
Noble gas release fraction	2.0E-2	4.0E-4
Total volatile release fraction[a]	1.0E-3	1.7E-5
Average nonrespirable release	4.9 kg	4.4 kg
Maximum nonrespirable release	6.4 kg	5.8 kg
Average nonrespirable release fraction	2.3E-3	3.2E-4
Maximum nonrespirable release fraction	3.0E-3	4.2E-4
a. Used for cesium and tellurium.		

Table 2. Results for HEDD2

	Truck Cask	Rail Cask
Total fuel mass	2.11E+3 kg	1.37E+4 kg
Effective diameter of penetration	4.1 cm	3.3 cm
Number of assemblies penetrated	2	1.7
Number of fuel rods disrupted	136	90
Average assembly swept mass	1.7 kg	0.87 kg
Maximum assembly swept mass	2.2 kg	1.1 kg
Average respirable release (without blowdown)	3.8E-3 kg	2.0E-3 kg
Maximum respirable release (without blowdown)	5.0E-3 kg	2.6E-3
Average respirable release fraction (without blowdown)	1.8E-6	1.5E-7
Maximum respirable release fraction (without blowdown)	2.4E-6	1.9E-7
Average respirable release (with blowdown)	3.8E-2 kg	3.1E-3 kg
Maximum respirable release (with blowdown)	5.0E-2 kg	4.1E-3 kg
Average respirable release fraction (with blowdown)	1.8E-5	2.3E-7
Maximum respirable release fraction (with blowdown)	2.4E-5	3.0E-7
Crud release fraction	9.1E-6	4.7E-8
Noble gas release fraction	6.2E-3	3.9E-5
Total volatile release fraction[a]	1.4E-4	7.2E-7
Average nonrespirable release	1.1 kg	0.58 kg
Maximum nonrespirable release	1.4 kg	0.76 kg
Average nonrespirable release fraction	5.3E-4	4.3E-5
Maximum nonrespirable release fraction	6.9E-4	5.6E-5
a. Used for cesium and tellurium.		

Table 3. Comparison of Release Fractions

	Truck Cask	Rail Cask
Average respirable release fraction		
HEDD1 (this study)	1.2E-4	3.1E-6
HEDD1 (estimated from Luna (2000)[1]	8.3E-6	1.2E-6
HEDD2 (this study)	1.8E-5	2.3E-7
HEDD2 (estimated from Luna (2000)[1]	1.9E-6	1.5E-7
Maximum respirable release fraction		
HEDD1 (this study)	1.6E-4	4.0E-6
HEDD1 (estimated from Luna (2000)[1]	1.1E-5	1.5E-6
HEDD2 (this study)	2.4E-5	3.0E-7
HEDD2 (estimated from Luna (2000)[1]	2.5E-6	1.9E-7
1. Estimated using the ratio of 0.0024 g of respirable aerosol per g of spent nuclear fuel disrupted by the high energy density device from Luna (2000) and the assembly swept masses and total fuel masses from Tables 1 and 2.		

Table 4. Consequences of Acts of Sabotage.

	Truck Cask	Rail Cask
HEDD1		
Population Dose (person-rem)	31,000	4,900
Latent Cancer Fatalities	15	2
Individual Dose (rem)	67	11
Risk of Latent Cancer Fatality	0.07	0.006
HEDD2		
Population Dose (person-rem)	4,400	350
Latent Cancer Fatalities	2	0.2
Individual Dose (rem)	9.7	0.85
Risk of Latent Cancer Fatality	0.005	0.0004