Offsite Radiation Doses Resulting from Seismic Events at the Yucca Mountain Repository

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1.0 INTRODUCTION

This paper describes a preliminary study to evaluate the offsite doses resulting from seismic events postulated to occur during the preclosure period at the proposed Yucca Mountain repository. The work reported here is part of a larger preliminary study (Subramanian et al., 1989) of the costs and benefits of designing the waste-handling building (WHB) at the repository for seismic events of varying severity.

During an earthquake, the quantity of radiological releases is dependent on the damage state of the structure or facility under construction. For the purpose of this study, four damage states are used: light, moderate, heavy, and total. These damage states are characterized by various degrees of spalling of concrete pieces from the walls and cracking of the walls (Subramanian et al., 1989). The spalling concrete may hit the spent fuel assemblies and cause radiological releases. In Section 2.0, the maximum total radionuclide inventory in the WHB is estimated. In Section 3.0, the quantities of radioactive material released for each damage state are evaluated. The offsite doses resulting from these releases are calculated in Section 4.0. Section 5.0 presents the conclusions.

2.0 RADIONUCLIDE INVENTORY IN THE WASTE-HANDLING BUILDING (WHB)

In this study, all waste forms in the WHB are assumed to be PWR spent fuel assemblies. During repository operations, fuel assemblies are unloaded in the unloading hot cell and placed directly in eight transfer/storage carts. Each cart can hold a total of 36 PWR assemblies. The consolidation hot cell and the packaging hot cell do not provide any significant number of storage racks; therefore, the eight transfer/storage carts represent the total storage capacity in the unloading, consolidation, and packaging hot cells.

In addition to the above hot cells, spent fuel is also contained in shipping casks in the cask inspection and preparation area, and in emplacement containers in the surface storage vault area. A preliminary calculation indicates that the shipping cask and the emplacement container can withstand the impact of pieces of spalling concrete; therefore, no radioactivity will be released in these two areas in the WHB.

3.0 RELEASE QUANTITIES FOR THE DAMAGE STATES

3.1 Spalling Concrete Pieces

The radiological releases from the PWR fuel assemblies in the WHB are estimated below. During an earthquake, concrete pieces may spall from the surface of the walls of the unloading hot cell. A schematic view of the unloading hot cell is depicted in Figure 1. Table 1 gives the number of pieces of spalling concrete from the walls above and below grade, the average dropping height, and the calculated impact energy, E, of the concrete pieces for the four damage states. The concrete density is taken to be 150 lb/ft^3.

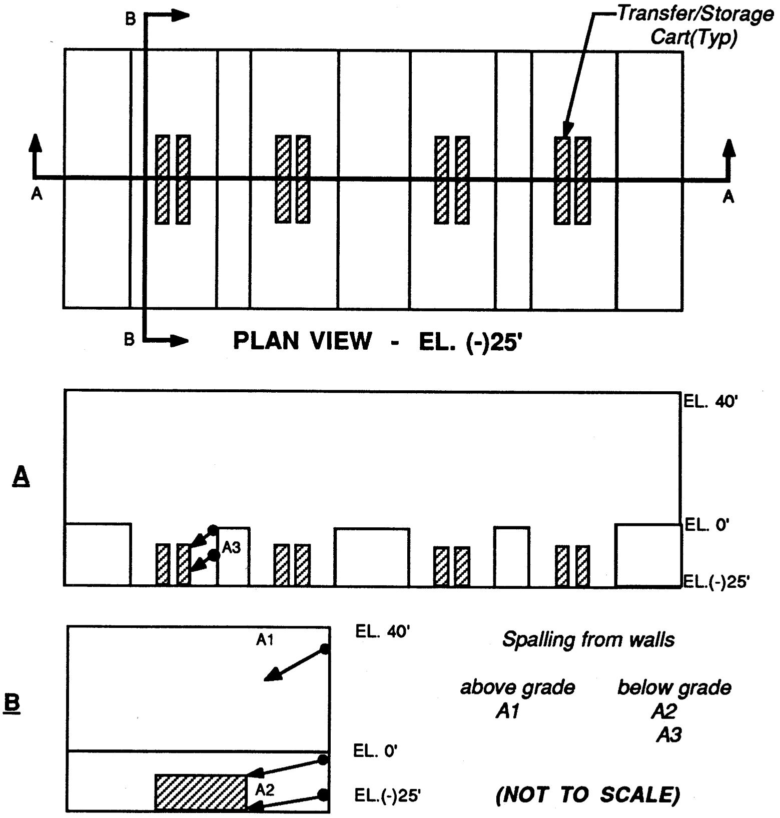

Figure 1
Schematic View of Unloading Hot Cell

3.2 Release Fractions and Quantities

When the spalling concrete hits a fuel assembly, the impact may damage the spent fuel and cause a radiological release of Kr-85 due to a cladding breach and a release of airborne particles due to a fuel pellet fracture. It is assumed that 30 percent of the Kr-85 inventory in a breached fuel rod will be released (NRC, 1972). The fracture of unirradiated fuel pellets was studied in Jardine (1982) and was summarized in the Preliminary Radiological Safety Analysis (PRSA) Report (Appendix F of MacDougall, 1987). Based on these studies, it is assumed that the airborne fraction of an irradiated UO_2 specimen (i.e., particles with count diameter less than 10 microns) resulting from a mechanical impact is linearly proportional to the impact energy density according to the expression

$$\text{PULF} = 2 \times 10^{-4} \cdot \frac{E}{V} \qquad (1)$$

Table 1

NUMBER OF PIECES AND IMPACT ENERGY OF SPALLING CONCRETE, ENERGY PARTITION FACTOR, BREACH FRACTION, AND NUMBER OF BREACHED ASSEMBLIES IN THE UNLOADING HOT CELL

Damage State	Size of Spalling Concrete[a] (in.)	No. of Pieces of Spalling Concrete[b]		Average Dropping Height[b,c] (ft)		Impact Energy[d] (J)	Energy Partition Factor (EPF)		Breach Fraction		No. of Breached Assemblies (N)
		from walls above grade	from walls below grade	from walls above grade	from walls below grade		Top Hit	Side Hit	Top Hit	Side Hit	
Light	No spalling	--	--	--	--	0	--	--	--	--	0
Moderate	6 x 6 x 3	13	26	32.5	12.5	9.5×10^3	0	0.5	0.01	0.1	2
Heavy	6 x 6 x 6	125	252	32.5	12.5	1.8×10^5	0	0.5	0.01	0.1	21
Total	6 x 6 x 6	250	504	32.5	12.5	3.6×10^5	0	0.5	0.01	0.1	42
	24 x 24 x 3	83	168	32.5	12.5	9.6×10^5	0.2	0.5	0.1	0.5	75

(a) This table is based on information given in Subramanian et al. (1989).

(b) The dimensions of the unloading hot cell above grade are 300(L) x 29(W) x 40(H) ft; the dimensions of each cell below grade are 13(L) x 29(W) x 25(H) ft.

(c) The average drop height is taken to be one half the distance from the top of the wall to the floor.

(d) Impact energy = mgh, where m is the mass of the concrete piece, h is the average dropping height, and g is the gravitational acceleration.

where PULF is the fraction of the irradiated UO_2 specimen that becomes airborne (i.e., with sizes less than 10 microns); E is the impact energy, i.e., energy absorbed by the UO_2 specimen (Joules); and V is the volume of UO_2 specimen (cm^3).

It should be noted that Eq. 1 is an empirical formula obtained from simulated waste glass specimens and therefore does not indicate the constitutive dependence on physical properties of the fuel matrix.

Only a fraction of the mechanical impact energy will be absorbed by the fuel pellets; the rest will be absorbed by cladding, end fittings, hardware, etc. In this study, an energy partition factor, EPF, is introduced to account for the energy absorption by the fuel assembly hardware and end fittings.

The releases of Kr-85 and the airborne fuel particles due to the impact of the spalling concrete are evaluated using the following pair of equations:

$$\begin{aligned} A\ (\text{Kr-85}) &= 0.3 \cdot N \cdot A_1\ (\text{Kr-85}) \\ A\ (\text{Part}) &= \text{PULF} \cdot A_v\ (\text{Part}) \cdot \text{EPF} \end{aligned} \qquad (2)$$

where A_1 (Kr-85) is the number of Curies of Kr-85 per PWR assembly; A_v (Part) is the number of Curies of the irradiated UO_2 fuel pellets of volume V that absorb the impact energy; N is the number of breached assemblies; and EPF and PULF are the energy partition factor and the fraction of fuel pellet fracture, respectively. The volume of the fuel rods of a typical PWR assembly is taken to be 7.9×10^4 cm^3.

To evaluate the releases expressed by Eq. 2, it is assumed that 50 percent of the spalling concrete will hit the top of the fuel assembly and the remaining 50 percent will hit the side of the fuel assembly. Because a PWR assembly is protected by the end fitting and spring on the top but basically has no protection at the sides, the severity of damage to a fuel assembly by a piece of concrete depends on whether the concrete hits the top or the side.

To evaluate the release of Kr-85, the number of breached assemblies must first be determined. It is assumed that if a PWR assembly is hit by a piece of concrete, a fraction of the fuel rods of this assembly will breach. The assumed breach fractions for a top hit and for a side hit are summarized, respectively, in the 10th and 11th columns of Table 1. The number of breached assemblies, N, is equal to the breach fraction multiplied by the number of pieces of spalling concrete (Table 1). In addition, the calculated value of N should not exceed 288, which is the maximum total number of PWR assemblies in the unloading hot cell. The number of breached assemblies thus obtained is given in the last column of Table 1.

The EPF for the side hit is assumed to be larger than the EPF for the top hit because, as mentioned above, the side of a fuel rod is less protected. The assumed values of the EPF are summarized in the 8th and 9th columns of Table 1.

In the above calculations, PULF is linearly proportional to the energy density, E/V. Therefore, for a given impact energy E, the result of the released activity, A_V (Part), is not affected by the value of volume V assumed to absorb the impact energy. In this study, it is assumed that the impact energy is absorbed by one PWR fuel assembly; consequently, A_v(Part) is the activity of the fuel pellets of one PWR assembly.

Radioactive materials released into the unloading hot cell are evaluated according to Eq. 2 for the four damage states and are summarized in Table 2. In this study, all radionuclides released into the unloading hot cell are also conservatively assumed to be released to the atmosphere.

Table 2

QUANTITIES OF RADIOACTIVE MATERIAL RELEASED INTO THE UNLOADING HOT CELL FOR FOUR DAMAGE STATES

Damage State	Radiological Release (Ci) Kr-85	 Airborne Fuel Particles
Light	0	0
Moderate	1.3×10^{3}	6.6×10^{-1}
Heavy	1.4×10^{4}	1.3×10^{1}
Total	7.7×10^{4}	1.2×10^{2}

4.0 EVALUATION OF OFFSITE DOSES

The released airborne radionuclides will be diluted as they are dispersed through the atmospheric pathway. The airborne fuel particles will also be deposited on the ground. The dilution factor, χ/Q, was calculated to be 6.4×10^{-5} sec/m^3 for an instantaneous ground release, a wind speed of 1 m/sec in a uniform direction, Pasquill Stability Class F, and a distance of 5 km to the site boundary (Appendix F, MacDougall, 1987). The above assumed values are consistent with the regulatory guidance and assumptions given in NRC (1972). In Appendix F, MacDougall (1987), it was calculated that 95 percent of the airborne fuel UO_2 particles will be deposited on the ground prior to reaching the site boundary. The same dry deposition factor is used in this study.

The inhalation dose, D, to an organ is calculated by the following equations:

$$\begin{aligned} D(Kr) &= A(Kr) \,.\, \chi/Q \,.\, BR \,.\, DCF(Kr) \\ D(Part) &= A(Part) \,.\, \chi/Q \,.\, G \,.\, BR \,.\, DCF(Part) \qquad (3) \end{aligned}$$

where A(Kr) and A(Part) are the radiological releases (in Ci) into the unloading hot cell for Kr-85 and airborne fuel particles, respectively, as given in Table 2; χ/Q and G are the dispersion factor and the dry deposition factor, respectively; BR is the breathing rate, taken to be 1.2 m^3/hr; and DCF is the 50 yr commitment dose conversion factor (in rem/Ci).

The maximum doses to an individual at the site boundary (5 km from the repository) are calculated for the four damage states, and the results are given in Table 3. The maximum individual dose ranges from 0 to 9 rem, with the airborne fuel particles source term being the dominant factor. The dose resulting from Kr-85 for the total damage state is about 4 mrem, which is insignificant.

Table 3
OFFSITE MAXIMUM INDIVIDUAL DOSES

Damage State	Maximum Individual Dose (rem)	Probability of Exceedance of Damage States[a] (yr^{-1})
Light	0	1.0×10^{-6}
Moderate	5×10^{-2}	4.8×10^{-8}
Heavy	1	1.6×10^{-8}
Total	9	1.2×10^{-8}

(a) The probabilities of exceedance are for a design level of 0.4 g.

For a given seismic design, each damage state has a specific probability of occurrence. These probabilities were calculated for five seismic design bases (0.2, 0.4, 0.6, 0.8, and 1.0 g) by integrating the site-specific seismic hazard and the structural fragility of the WHB (Subramanian et al., 1989). The probabilities of occurrence and the offsite doses of the four damage states for the five seismic design bases are plotted in Figure 2.

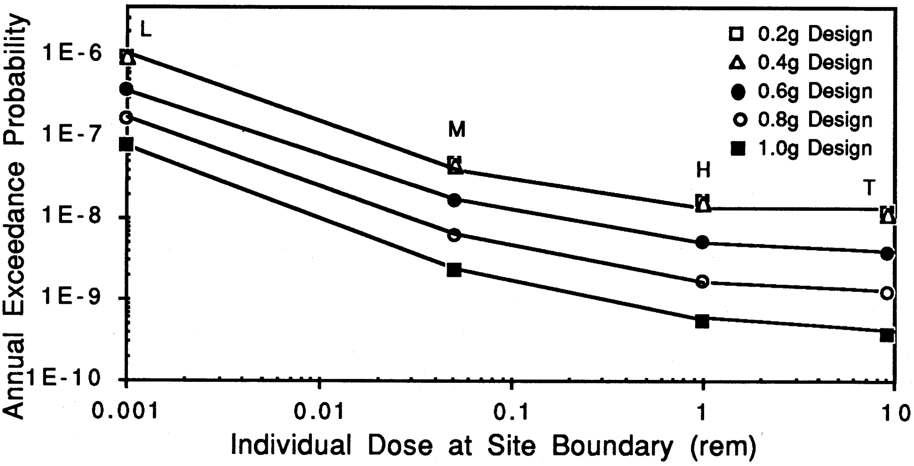

Figure 2
Probability of Radiation Doses for Various Seismic Designs

5.0 CONCLUSIONS

The study shows that the source term of the airborne spent fuel particles is the dominant factor in the radiation dose to an individual off site. The individual doses range from 0 to a maximum of 9 rem for the worst case. The dose results given above are preliminary and may be modified by further calculations. All the calculated probabilities of damage states resulting in significant offsite doses are less than about 10^{-8}/yr for all of the seismic design bases considered. Probabilities as low as these suggest that the occurrence of such damage states and the corresponding offsite doses resulting from any postulated seismic event are not credible.

6.0 REFERENCES

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