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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., 1988) 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., 1988). The spalling concrete may hit the spent fuel
assemblies and cause radiological releases. An estimate of the
maximum total radionuclide inventory in the WHB is made in Section
2.0. 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 waste handling building are
assumed to be PWR spent fuel assemblies. During repository
operations, fuel assemblies are unloaded in the unloading hot cell

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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 $/ft^3$.

(NOT TO SCALE)

B

Transfer/Storage
Cart(Typ)

A   A

B

PLAN VIEW - EL. (-)25'

EL. 40'

A

EL. 0'

A3

EL.(-)25'

A1   EL. 40'

Spalling from walls

B

EL. 0'

A2   EL.(-)25'

above grade   below grade
A1   A2
                     A3
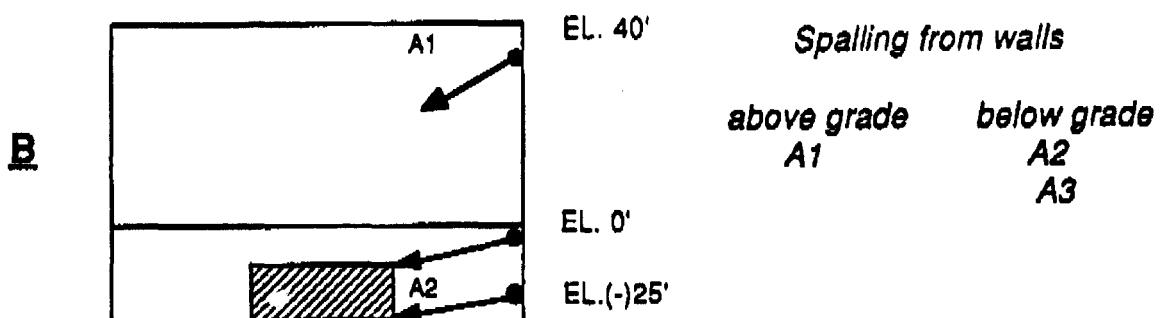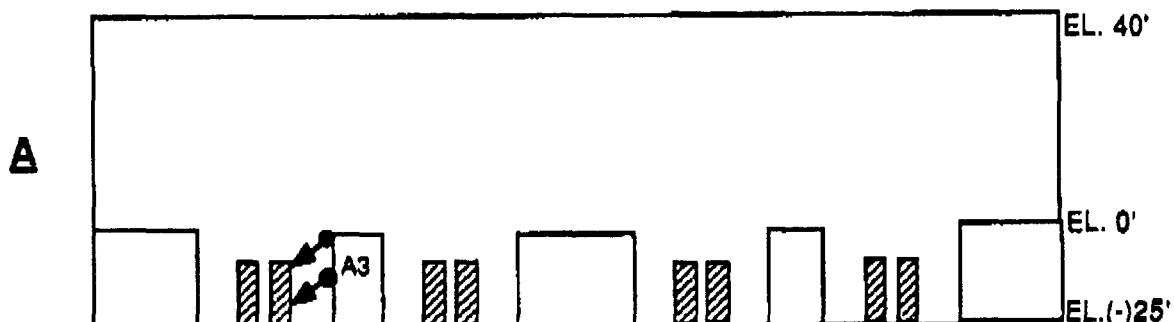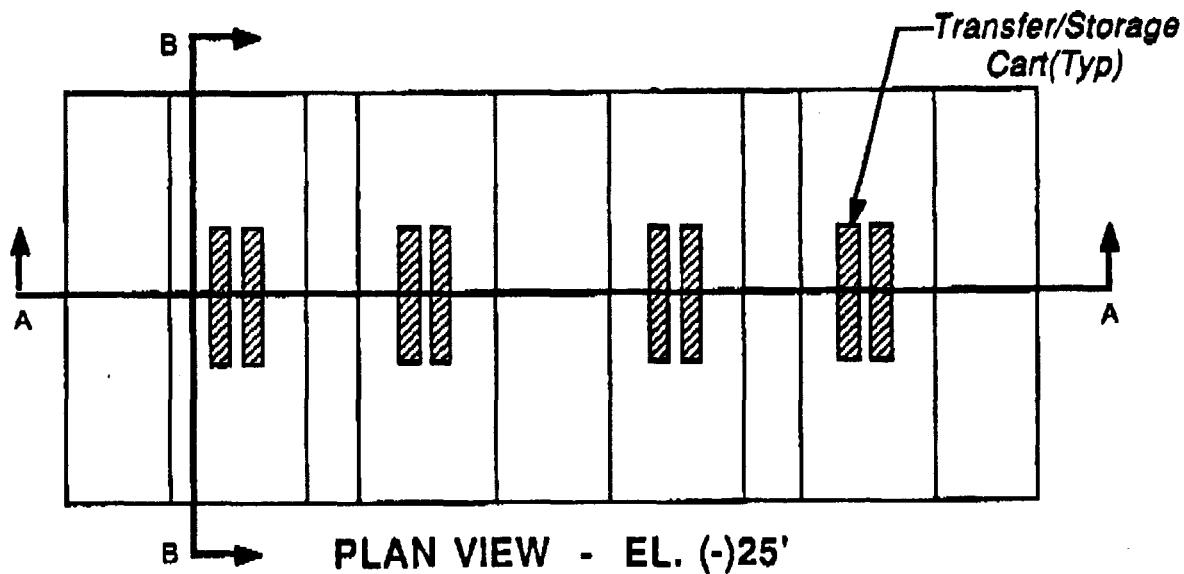
Figure 1
Schematic View of Unloading Hot Cell

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] (Joule)	Energy Partition Factor, EPF		Breach Fraction		Number 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. (1988).

(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.

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 the 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

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

where PULF = fraction of irradiated UO_2 specimen that becomes airborne
       (i.e., with sizes less than 10 microns)
    E = impact energy, i.e., energy absorbed by the UO_2 specimen
       (Joules)
    V = 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 below:

$$A \; (Kr-85) \quad = 0.3 \; . \; N \; . \; A_1 \; (Kr-85)$$

$$A \; (Part) \quad = PULF \; . \; A_V \; (Part) \; . \; EPF \qquad\qquad (2)$$

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 $7.9 \times 10^4 \; cm^3$.

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 energy partition factor, 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, the fraction of fuel fracture, 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 fuel pellets of one PWR assembly.

The radioactive releases of Kr-85 and the airborne fuel particles into the unloading hot cell are evaluated according to Eq. 2 for the four damage states and are summarized in Table 2.

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 the above report (Appendix F in 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:

$$D(Kr) = A(Kr) \cdot \chi/Q \cdot BR \cdot DCF(Kr)$$

$$D(Part) = A(Part) \cdot \chi/Q \cdot G \cdot BR \cdot DCF(Part) \qquad (3)$$

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 are calculated for the four damage states, and the results are given in Table 3. Table 3 shows that the maximum individual dose ranges from 0 to 9 rem . The airborne fuel particles source term is the dominant factor in the calculated offsite exposure. 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[a] (rem)	Probability of Exceedance of Damage States[b] (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 individual is assumed to be at the site boundary, i.e., 5 km from the repository.

(b) 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., 1988). The probabilities
of occurrence and the offsite doses of the four damage states for
the five seismic design bases are plotted in Figure 2.

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 offsite. The individual doses range from 0 to a maximum
of 9 rem for the worst case. It should be emphasized that 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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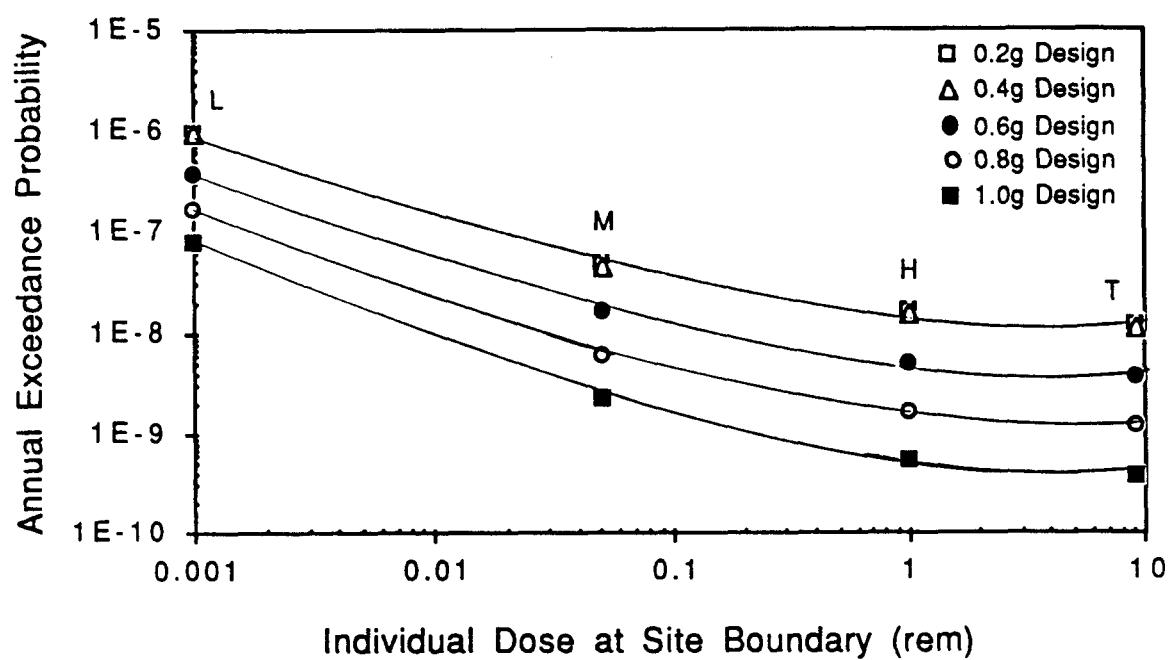
Figure 2

Probability of Radiation Doses for Various Seismic Designs

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Subramanian, C. V., N. Abrahamson, A. H. Hadjian, L. J. Jardine, J. B. Kemp, O. K. Kiciman, C. W. Ma, J. King, W. Andrews, and R. P. Kennedy, 1988. Preliminary Seismic Design Cost-Benefit Assessment of the Tuff Repository Waste-Handling Facilities, SAND88-1600, Sandia National Laboratories, Albuquerque, NM.

APPENDIX

Information from the Reference Information Base
Used in this Report

This report contains no information from the Reference Information Base.

Candidate Information
for the
Reference Information Base

This report contains no candidate information for the Reference Information Base.

Candidate Information
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Site & Engineering Properties Data Base

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