APPENDIX E: Consequence Analysis

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Appendix E

Consequence Analysis

E.1 Introduction

The analysis presented in this Appendix comprises a more detailed explanation of the consequence analysis presented in Section 6.0 for the Dry Cask PRA. This consequence assessment addresses a severe accident scenario related to an inadvertent, 100-foot drop of a HI-STORM 100 Cask system while in the transfer process (Reference E.1). The consequence measures chosen for this study were the mean values given by MACCS2 for individual risk of early fatality within 1.6 km (1 mile) and the individual risk of cancer fatality within 16 km (10 miles)[1]. The 1.6 km (1 mile) value, is the measured distance from the exclusion area boundary (EAB), assumed to be 0.5 km (0.3 miles), out to a distance of 2.1 km (1.3 miles). These consequence measures were chosen to allow comparison to the NRC's quantitative health objectives for reactor accident risk. Because cask accident consequences in terms of individual risks of early fatality and cancer fatality are small, the consequence mean value calculated for individual lifetime dose commitment (the mean value of the variable known in MACCS2 as "peak dose found on spatial grid") may also be of interest. Therefore, this report includes the mean individual lifetime dose between 1.2 and 1.6 km (0.75 and 1.0 miles) as measured from the release point. Also, close-in consequences estimates are generally more dependant on the source term and evacuation timing, while consequences further away tend to be controlled by long-term relocation assumptions. The MACCS2 consequences analysis performed for this study does not consider sheltering and evacuation.

E.2 Approach

This assessment was performed using the MELCOR Accident Consequence Code System (MACCS2) (Reference E.2) for a representative site.

Site specific data important to the modeling of a HI-STORM Dry Cask 100 foot drop accident scenario in the MACCS2 consequence calculation were collected and used. The important parameters/variables required to model the site are: the population density/distribution, and the site meteorology. The radionuclide inventory, the source term (i.e. release fraction, release start time, and release duration), the initial plume dimensions (related to the system geometry), and the plume heat content are discussed below. Other settings and models necessary for a MACCS2 calculation (e.g. food chain model) were taken from the NUREG-1150 study MACCS2 input file prepared for the Surry nuclear power plant. The input file is documented in Appendix C of the MACCS2 code manual and is referred there as Sample Problem-A. Sample Problem-A was chosen because of its ready availability and previous use by NRC in scoping studies of various types. Discussions of some of the values used for the MACCS2 calculations are given in sections E.3 to E.11.

E.3 Dose Conversion Factor

The dose conversion factors (DCF) used in this study are the same as those used in the NUREG-1150 study (DOSDATA.INP). The DCFs were provided by K. Eckerman from Oak Ridge National Laboratory

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[1]Note: All consequence measures given in this appendix are mean values as calculated by the MACCS2 code unless it is stated otherwise. The mean value in MACCS2 is defined as the average (expected) consequence over all weather trials (Reference E.2).

(Reference E.3). These DCFs include definitions for 19 Organs and for 60 radionuclides important in reactor accidents.

E.4 Radionuclide Inventory

High burnup spent fuel is placed inside a HI-STORM cask no sooner than ten years after being removed from the reactor. A maximum of 68 BWR assemblies can be loaded in a HI-STORM Cask. The inventory per cask calculated with the ORIGEN code (References E.4 and E.5) is presented in Table E.1. The analysis assumes that the spent fuel placed in HI-STORM canister for the 100-ft drop accident is a 10 year-cooled high burnup spent fuel.

Table E.1. Dry Cask Nuclide Inventory: SNL ORIGEN 50,008 MWD/MTIHM (10 yrs cooled)

Nuclide	Bq	Ci	Nuclide	Bq	Ci
Co-60	1.61×10^{14}	3133	Pu-238	3.98×10^{15}	107440
Kr-85	2.77×10^{15}	74800	Pu-239	1.87×10^{14}	5060
Y-90	3.40×10^{16}	918000	Pu-240	3.47×10^{14}	9384
Sr-90	3.40×10^{16}	918000	Pu-241	5.23×10^{16}	1414400
Ru-106	2.92×10^{14}	7888	Am-241	1.20×10^{15}	32504
Cs-134	5.13×10^{15}	138720	Am-242m	1.97×10^{13}	532
Cs-137	5.54×10^{16}	1496000	Am-243	3.07×10^{13}	830
Ce-144	5.08×10^{13}	1374	Cm-243	3.02×10^{13}	816
Pm-147	3.37×10^{15}	91120	Cm-244	5.66×10^{15}	153000
Eu-154	4.15×10^{15}	112200			

The radionuclide inventory in Table E.1 was generated using the ORIGEN code, corresponding to an 8×8, 50 GWd/MTU, 10 year cooled high burnup BWR spent fuel. This inventory was used to demonstrate the methodology of developing a consequence analysis. As recommended in Appendix D, specific radionuclide ORIGEN calculation should be performed for the actual spent fuel loaded inside the Hi-STORM casks.

Cobalt-60 is formed in spent fuel by activation of Ni-60 in cladding, but its most important source is in the CRUD (Reference E.6 to E.8) that forms on cladding surfaces during reactor operation. During an 100 foot dropped impact accident, the amount of Co-60 that was formed by activation of Ni in cladding will tend to remain trapped where it formed, while the Co-60 in CRUD can be released by spallation. Therefore, the Co-60 inventory in Table E.4.1 represents the CRUD inventory. The value was calculated from the Appendix D inventory of 0.72 Ci/rod for a 10×10 fuel assembly (see Table D.7). This value was assumed to be similar for the inventory used in this analysis. The value for CRUD in Table E.1 is for 64 BWR rods per assembly and 68 assemblies per cask.

E.5 Chemical Element Groups

Separate release fractions need not be developed for each element in a dry cask inventory. The releases for the cask drop accident are from mechanical means, not because of differing volatilities. Accordingly, release fractions need to be developed only for three chemical element groups: Noble Gases, CRUD, and Particles. Inspection of Table E.1 shows that the noble gas chemical element group contains only Kr_{85}, the CRUD chemical element group contains only Co-60, and that all other elements in the canister inventory are members of the particle chemical element group because these elements can only escape from failed fuel rods as constituents of fuel fine particles. These chemical elements groups for the 100 ft dropped cask accident scenario, are consistent with the analysis and methodology presented in Appendix D.

E.6 Source Term

E.6.1 Release Fraction

The release fractions for the calculations are given in Appendix D. Two different source terms were evaluated. The first represents a large release, one that assumes little reduction in fuel fines escaping from the cask while the second represents a median estimate of fuel fine reduction in the escape path. Further, for those cases where filters are assumed to be operable, a reduction of a factor of 10 for particulates and CRUD has been assumed. In all cases, no credit is given for deposition within the reactor building. Table E.3 includes the release fraction for each of the consequence results analyzed.

E.6.2 Release Start Time

The MACCS2 calculation assumed that the release to the environment occurs immediately.

E.6.3 Release Duration

The release duration used in the MACCS2 consequence calculation was assumed to be 2 minutes. A methodology for estimating this value is presented in Appendix D.

E.7 Release Height

The dropped cask scenario occurs inside the reactor building. Two different release locations are possible. The first one is through vents located 50 meters (164 feet) above ground. These vents contain filters which, when operating, could reduce the release as discussed above. The second release path of radionuclides to the environment is through the stack. The opening from the stack to the environment is located at a height of about 120 meters (394 feet) from ground. Table E.3 include the release height and the reduced release fraction from filters, as applicable, for each of the consequence results analyzed.

E.8 Initial Plume Dimension

The initial plume dimensions (i.e., the plume dimensions at the release point) are determined by the width and the height of the building wake. In MACCS2, the initial plume dimension is specified by the user in terms of σ_y and σ_z, which represent the lateral and vertical plume spreading from the release point respectively. To reduce the effect of plume spreading due to the building wake effect, it was decided to assume the release is from a point source. This was implemented in the MACCS2 calculation by setting the dimensions of the structure releasing the radioactive material to be 4 meters (height) by 4 meters (width) (13 feet by 13 feet) (i.e. approximately the cask dimension). The vertical and lateral spreading, σ_y and σ_z, is then estimated by dividing the building width and the building height by 4.3 and 2.15, respectively. These values are shown in Table E.2.

Table E.2 Plume Dimensions at the Release Point

	Point Source
structure width	4 meters (13.1 feet)
structure height	4 meters (13.1 feet)
σ_y	0.93
σ_z	1.86

E.9 Plume Heat Content

The plume heat content determines the rise of the plume in the atmosphere. The plume heat content for the dropped cask accident is expected to be approximately equal to the heat content of the spent fuel. For ten-year cooled spent fuel, the maximum decay heat load is 264.0 watts per assembly. The MACCS2 calculations used 18.0 kilowatts for 68 high burnup fuel in a cask. The plume resulting from this release will not be hot enough to produce significant plume rise.

E.10 Population Distribution

The population distribution for the site was obtained from the SECPOP code (Reference E.9), based on year 2000 census data.

E.11 Site Weather

MACCS2 code samples from one year of hourly weather data to calculate offsite radiological consequences. This weather data includes wind speed, wind direction, atmospheric stability, and rainfall. The weather data file in MACCS2 format was requested and obtained from the site licensee. Because this file had some missing hourly weather data, it was modified in two ways. First, if a number of consecutive hours of data were missing, the weather of the previous day was used. Second, if only one hour of data was missing, either the hour before or the average of the hour before and the hour after was used. In addition, the weather data provided by the licensee did not include the mixing layer height for each season. The mixing layer height is the top of the well-mixed surface layer of air, and is used in MACCS2 to limit both buoyant plume rise and vertical dispersion. Therefore, the Sample Problem-A MACCS2 mixing heights were used in the calculation. The option used in MACCS2 to sample weather data was the weather category bin sampling. This option is typically used in MACCS2 in order to ensure adequate sampling of rain cases.

E.12 Results

Six separate MACCS2 calculations were performed. For each of the two source terms, releases at 50 meters (164 feet) with and without filter operation and at 120 meters (393 feet) were evaluated. The results are presented in Table E.3 and are mean values as calculated by MACCS2, where mean is the average (expected) consequence over all weather trials (Reference E.2). In all cases, the health impacts are small.

Table E.3 MACCS2 Consequence Calculation Results

Release Fraction			Release Height meters (feet)	Individual Risk of Prompt Fatality within 16 km (10 miles)	Individual Risk of Cancer Fatality within 16 km (10miles)	Individual Peak Dose at 1.2-1.6 km Sv (rem)
Noble Gases	Particles	CRUD				
.12	1.2×10^{-3}	1.5×10^{-3}	50 (164)	0	3.6×10^{-4}	1.85 (185)
.12	1.2×10^{-3}	1.5×10^{-3}	120 (393)	0	2.1×10^{-4}	0.14 (14)
.12	1.2×10^{-4}	1.5×10^{-4}	50[1] (164)	0	5.2×10^{-5}	0.22 (22)
.12	7×10^{-6}	1.5×10^{-3}	50 (164)	0	4.3×10^{-6}	0.026 (2.6)
.12	7×10^{-6}	1.5×10^{-3}	120 (393)	0	2.6×10^{-6}	0.0032 (0.32)
.12	7×10^{-7}	1.5×10^{-4}	50[1] (164)	0	4.3×10^{-7}	0.0027 (0.27)

[1] Results corresponding to a release fraction with filters operable.

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