

**Table Of Contents**

7.0	Environmental Impacts of Postulated Accidents Involving Radioactive Materials .....	7-3
7.1	Design Basis Accidents .....	7-4
7.1.1	References .....	7-5
7.2	Severe Accidents .....	7-44
7.2.1	Methodology .....	7-44
7.2.2	Consequences to Population Groups .....	7-46
7.2.3	Conclusions .....	7-48
7.2.4	References .....	7-49
7.3	Severe Accident Mitigation Alternatives .....	7-53
7.3.1	SAMDA Analysis Methodology .....	7-53
7.3.2	Severe Accident Cost Impact and Maximum Benefit for {Callaway Plant Unit 2} .....	7-53
7.3.3	Results and Summary .....	7-55
7.3.4	References .....	7-56
7.4	Transportation Accidents .....	7-60
7.4.1	Radiological Impacts .....	7-61
7.4.2	Non-Radiological Impacts .....	7-63
7.4.3	Summary and Conclusion .....	7-65
7.4.4	References .....	7-65

**List of Tables**

Table 7.1-1—Design Basis Accidents .....	7-6
Table 7.1-2—U.S. EPR Design Basis Primary Coolant Activity.....	7-8
Table 7.1-4—U.S. EPR Bounding Core Inventory.....	7-13
Table 7.1-5—{50th Percentile Callaway Site Atmospheric Dispersion Factors} .....	7-15
Table 7.1-6—{Steam System Piping Failure}.....	7-16
Table 7.1-7—{Reactor Coolant Pump Locked Rotor Accident / Broken Shaft}.....	7-17
Table 7.1-8—{Failure of Small Lines Carrying Primary Coolant Outside Containment} ..	7-18
Table 7.1-9—{Steam Generator Tube Rupture (SGTR)}.....	7-19
Table 7.1-10—{Loss of Coolant Accident (LOCA)}.....	7-20
Table 7.1-11—{Fuel Handling Accident} .....	7-21
Table 7.1-12—{Rod Ejection Accident (REA)} .....	7-22
Table 7.1-13—{Summary of DBA Radiological Consequences at Offsite Receptors from Callaway Plant Unit 2} .....	7-23
Table 7.1-14—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Pre-Accident Iodine Spike} .....	7-24
Table 7.1-15—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Concurrent Iodine Spike} .....	7-26
Table 7.1-16—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Accident-Induced 1.24% Clad Failure}.....	7-28
Table 7.1-16—{Radionuclide Releases to Atmosphere for Pump Locked Rotor Accident (LRA) with Accident-Induced 8.0% Clad Failure} .....	7-29
Table 7.1-17—{Radionuclide Releases to Atmosphere for Design-Basis Small Line Break}.....	7-31
Table 7.1-18—{Radionuclide Releases to Atmosphere for SGTR with Pre-Accident Iodine Spike} .....	7-32
Table 7.1-19—{Radionuclide Releases to Atmosphere for SGTR with Concurrent Iodine Spike}.....	7-34
Table 7.1-21—{Radionuclide Releases to Atmosphere for Design Basis LOCA}.....	7-37
Table 7.1-22—{Radionuclide Releases to Atmosphere for Fuel Handling Accident} .....	7-41
Table 7.1-22—{Radionuclide Releases to Atmosphere for Rod Ejection Accident (REA) with Accident-Induced 26% Clad Failure}.....	7-41
Table 7.2-1—Release Category Descriptions .....	7-50
Table 7.2-2—Source Term Release Fractions .....	7-51
Table 7.2-3—{U.S. EPR Severe Accidents Analysis Impacts – 50-mile Radius and 2050 Population} .....	7-52
Table 7.3-1—{Severe Accident Cost Impact} .....	7-57
Table 7.3-2—{SAMDA Candidates – Already Implemented}.....	7-58
Table 7.4-1—10 CFR 51.52 Summary Table S-4 Excerpt Environmental Impact of Transportation of Fuel and Waste to and from One Light-Water-Cooled Nuclear Power Reactor Accidents in Transport .....	7-66
Table 7.4-2—{RADTRAN/TRAGIS Model Irradiated Fuel Input Parameters} .....	7-67
Table 7.4-3—{Irradiated Fuel Source Term} .....	7-68
Table 7.4-4—{Irradiated Fuel Callaway Plant Model Accident and Fatality Rates} .....	7-69
Table 7.4-5—{Irradiated Fuel and Radioactive Waste Models Severity and Release Fractions}.....	7-69
Table 7.4-6—{Irradiated Fuel Callaway Transportation Injury Rates}.....	7-71
Table 7.4-7—{New Fuel Callaway Transportation Fatality and Injury Rates}.....	7-72
Table 7.4-8—{U.S. EPR Radwaste Annual Generation} .....	7-73
Table 7.4-9—{RADTRAN/TRAGIS Radwaste Model Input Parameters} .....	7-74
Table 7.4-10—{Radwaste Annual Source Term} .....	7-75
Table 7.4-11—{Radwaste Callaway Transportation Accident, Fatality and	

Injury Rates} ..... 7-75  
Table 7.4-12—{Population Dose from Transportation Accidents} ..... 7-77  
Table 7.4-13—{Callaway Plant Unit 2 Summary of Annual Transportation Accident  
Non-Radiological Impact} ..... 7-78

## 7.0 ENVIRONMENTAL IMPACTS OF POSTULATED ACCIDENTS INVOLVING RADIOACTIVE MATERIALS

### 7.1 DESIGN BASIS ACCIDENTS

Design basis accidents (DBAs) are events that are not expected to occur, but are evaluated to demonstrate the adequacy of the plant design since the consequences of their occurrence have the potential for radioactive material to be released to the environment. DBAs having a potential for radiological releases to the environment are identified in Section 7.1, Appendix A of NUREG-1555 (NRC, 1999) and are listed in [Table 7.1-1](#) along with DBAs applicable for the U.S. EPR. The DBAs are based on Chapter 15 of NUREG-0800 (NRC, 2007) and Regulatory Guide 1.183 (NRC, 2000).

Sources of radioactivity are generated within the reactor core. Radioactivity releases are dependent on the specific accident and may be released from the primary coolant, from the secondary coolant, and from the core if the accident involves fuel failures. Design input used in the DBA radiological consequences evaluations for the U.S. EPR follows the Alternative Source Term Methodology outlined in Regulatory Guide 1.183 (NRC, 2000). The design basis primary and secondary coolant source term activity concentrations for the U.S. EPR are provided in [Table 7.1-2](#) and [Table 7.1-3](#), respectively. [Table 7.1-4](#) lists the design basis source term inventories for the core.

Primary and secondary coolant concentrations are based on the U.S. EPR Technical Specification limits for halogens and noble gases, the American National Standards Institute/American Nuclear Society (ANSI/ANS)-18.1 Standard (ANS, 1999) for activation products and tritium, and 0.25% fuel defects for remaining radionuclides. For certain accidents (i.e., Steam System Piping Failures, Feedwater Pipe Break, and Steam Generator Tube Rupture), the radiological consequences analyses account for iodine spiking which causes the concentration of various radioactive iodines in the primary coolant to significantly increase to levels described in [Table 7.1-2](#). The iodine appearance rates (i.e., rates at which iodine isotopes are transferred from the core to the primary coolant via assumed fuel cladding defects) used in DBA analyses for the U.S. EPR were based on a conservative Reactor Coolant System letdown purification flow rate. Referring to [Table 7.1-3](#), no secondary coolant noble gas source term is applicable since noble gas leakage from the Reactor Coolant System is assumed to enter the steam phase directly. Design basis core source terms were determined for a power level of 4,612 MWt, which is equivalent to the rated core thermal power of 4,590 MWt refer to ER Section 3.2) plus 0.48% calorimetric uncertainty. Core inventories are bounding for U-235 fuel enrichments ranging between two and five% and burnups up to 62,000 megawatt days per metric ton uranium (MWd/MTU).

For each of the accident scenarios listed for the U.S. EPR in [Table 7.1-1](#), it is postulated that some quantity of radioactivity is released at the accident location inside a plant building and eventually released into the environment. Radiological consequences of these accidents depend on the type and amount of radioactivity released and meteorological conditions. Potential consequences are assessed to demonstrate that environmental impacts, quantified in doses to individuals at the {radial distance of 0.5 miles (0.8 km), measured from the center of the Callaway Plant Unit 2 containment building at the Callaway Site, and the radial distance of 1.5 miles (2.4 km)}, meet regulatory dose acceptance criteria.

The accident doses are expressed as Total Effective Dose Equivalent (TEDE). For each applicable DBA, TEDE/accident doses are calculated based on time-dependent activities released to the

environment. Dose receptor variables include the exposure interval, the atmospheric dispersion of the activity during transport from the release point to the 0.5 mile (0.8 km) radius and 1.5 mile (2.4 km) radius, the breathing rate of an individual at the 0.5 mile (0.8 km) radius and 1.5 mile (2.4 km) radius, and dose conversion factors for the inhalation and external exposure pathways. In accordance with Section C.4.1.5 of Regulatory Guide 1.183 (NRC, 2000), the period of most adverse release of radioactive materials to the environment was assumed to occur coincident with the period of most unfavorable atmospheric dispersion. Except for atmospheric dispersion, the other variables are independent of the {Callaway} site and specific to the U.S. EPR design.

{Callaway site-specific atmospheric dispersion factors ( $\chi/Q_s$ ) are provided in ER Section 2.7. As shown in Table 2.7-52, the 50th percentile  $\chi/Q$  values for Callaway for the Exclusion Area Boundary (EAB) of 0.83 miles (1.34 km) and for the low population zone (LPZ) of 2.6 miles (4.2 km) are bounded by the 50th percentile site-specific  $\chi/Q$  values for the 0.5 mile (0.8 km) radius and 1.5 mile (2.4 km) radius, respectively. Therefore, the TEDE/accident doses calculated for the EAB and LPZ are also bounded by the TEDE/accident doses calculated for the radial distances of 0.5 miles (0.8 km) and 1.5 miles (2.4 km), which were used in this analysis.

The 50th percentile  $\chi/Q$  values for Callaway were based on meteorological data collected onsite over a 5 year period (2003 to 2007) and are shown in Table 7.1-5. For the 0.5 mile (0.8 km) radius, the postulated DBA doses and  $\chi/Q$  values are calculated for a 2-hr interval. For the 1.5 mile (2.4 km) radius, doses and  $\chi/Q$  values are calculated for the accident duration (up to 30 days).

For DBAs applicable to the U.S. EPR, the time-dependent releases to the atmosphere are presented in Table 7.1-14 to Table 7.1-23. The time-dependent postulated TEDE doses at the radial distances of 0.5 miles (0.8 km) and 1.5 miles (2.4 km) are provided in Table 7.1-6 through Table 7.1-12, and an overall summary is presented in Table 7.1-13. It is seen that all doses are below the dose acceptance criteria.}

### 7.1.1 REFERENCES

**{ANS, 1999.}** Radioactive Source Term for Normal Operation for Light Water Reactors, ANSI/ANS-18.1, American National Standards Institute/American Nuclear Society, 1999.

**NRC, 1999** Environmental Standard Review Plan, NUREG-1555, Nuclear Regulatory Commission, October 1999.

**NRC, 2000.** Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors, Regulatory Guide 1.183, Nuclear Regulatory Commission, July 2000.

**NRC, 2007.** Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800, Nuclear Regulatory Commission, March 2007.}

**Table 7.1-1—Design Basis Accidents**

(Page 1 of 2)

<b>NUREG-1555 DBA Description</b>	<b>U.S. EPR DBA Description</b>	<b>Remarks</b>
Radiological Consequences of Main Steam Line Failures Outside Containment of a PWR	Steam System Piping Failures	Following the guidance provided in Section 15.0.3 of NUREG-0800 and Regulatory Guide 1.183, the limiting accident for the U.S. EPR Steam System Piping Failures was determined to be a double-ended guillotine break of a main steam line in one of the Safeguards Buildings.
Feedwater System Pipe Breaks Inside and Outside Containment (PWR)	Not Applicable	For the U.S. EPR, the radiological consequences for Steam System Piping Failures were determined to bound those for Feedwater System Line Breaks.
Reactor Coolant Pump Rotor Seizure Reactor Coolant Pump Shaft Break	Reactor Coolant Pump Locked Rotor Accident / Broken Shaft	For the U.S. EPR, this postulated accident scenario is based on Section 15.0.3 of NUREG-0800 and the Alternative Source Term Methodology in Appendix G of Regulatory Guide 1.183.
Radiological Consequences of Control Rod Drop Accident (BWR)	Not Applicable	The U.S. EPR is a pressurized water reactor. Refer to ER Section 3.2.
Radiological Consequences of the Failure of Small Lines Carrying Primary Coolant Outside Containment	Failure of Small Lines Carrying Primary Coolant Outside Containment	Based on the guidance in Section 15.6.2 of NUREG-0800, the limiting accident scenario for the U.S. EPR Failure of Small Lines Carrying Primary Coolant Outside Containment was determined to be a double-ended guillotine break in the Fuel Building of a sampling line connected to the RCS cross-over leg #3.
Radiological Consequences of Steam Generator Tube Failures (PWR)	Steam Generator Tube Rupture	The analysis was based on guidance in Section 15.0.3 of NUREG-0800 and in Regulatory Guide 1.183 and incorporated the clarifications provided in NRC Regulatory Issue Summary 2006-04, Section 9, namely, the inclusion of the alkalis (in addition to the halogens and noble gases). Two alternative accident scenarios were postulated: A Steam Generator Tube Rupture (SGTR) with a pre-accident iodine spike and a SGTR with a concurrent iodine spike.
Radiological Consequences of a Design Basis Loss of Coolant Accident Including Containment Leakage Contribution	Loss of Coolant Accidents resulting from a Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary	For the U.S. EPR, a radiological analysis was performed to determine the EAB and LPZ cloud immersion and inhalation doses at the EAB and LPZ for Loss of Coolant Accidents using the Alternative Source Term Methodology.
Radiological Consequences of a Design Basis Loss of Coolant Accident: Leakage from Engineered Safety Feature Components Outside Containment	Loss of Coolant Accidents resulting from a Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary	For the U.S. EPR, a radiological analysis was performed to determine the EAB and LPZ cloud immersion and inhalation doses at the EAB and LPZ for Loss of Coolant Accidents using the Alternative Source Term Methodology.
Radiological Consequences of a Design Basis Loss of Coolant Accident: Leakage from Main Steam Isolation Valve Leakage Control System (BWR)	Not Applicable	The U.S. EPR is a pressurized water reactor. Refer to ER Section 3.2.
Radiological Consequences of Fuel Handling Accidents	Fuel Handling Accident	The postulated accident scenario followed the guidance in Section 15.0.3 of NUREG-0800 and in Regulatory Guide 1.183, and was postulated to occur in either an open Containment or in the Fuel Building, following a 34-hr decay.

**Table 7.1-1—Design Basis Accidents**

(Page 2 of 2)

<b>NUREG-1555 DBA Description</b>	<b>U.S. EPR DBA Description</b>	<b>Remarks</b>
Not Applicable	Rod Ejection Accident	The analysis was based on the guidance in Section 15.0.3 of NUREG-0800 and in Regulatory Guide 1.183. The recent NRC concern regarding the fission-product gap inventory for reactivity-induced accidents and the interim acceptance criteria and guidance, were also considered.
Not Applicable	Rod Ejection Accident	The analysis was based on the guidance in Section 15.0.3 of NUREG-0800 and in Regulatory Guide 1.183. The recent NRC concern regarding the fission-product gap inventory for reactivity-induced accidents and the interim acceptance criteria and guidance, were also considered.

**Table 7.1-2—U.S. EPR Design Basis Primary Coolant Activity**

Notes (1)(2)

(Page 1 of 3)

Radionuclide	Activity μCi/gm (Bq/gm)
<b>Noble Gases</b>	
Kr-83m	1.28E-01 (4.74E+03)
Kr-85m	5.71E-01 (2.11E+04)
Kr-85	5.31E+00 (1.96E+05)
Kr-87	3.26E-01 (1.21E+04)
Kr-88	1.03E+00 (3.81E+04)
Kr-89	2.42E-02 (8.95E+02)
Xe-131m	1.08E+00 (4.00E+04)
Xe-133m	1.35E+00 (5.00E+04)
Xe-133	9.47E+01 (3.50E+06)
Xe-135m	1.95E-01 (7.22E+03)
Xe-135	3.40E+00 (1.26E+05)
Xe-137	4.57E-02 (1.69E+03)
Xe-138	1.64E-01 (6.07E+03)
<b>Halogens</b>	
Br-83	3.16E-02 (1.17E+03)
Br-84	1.67E-02 (6.18E+02)
Br-85	2.01E-03 (7.44E+01)
I-129	4.59E-08 (1.70E-03)
I-130	4.97E-02 (1.84E+03)
I-131	7.43E-01 (2.75E+04)
I-132	3.71E-01 (1.37E+04)
I-133	1.25E+00 (4.63E+04)
I-134	2.40E-01 (8.88E+03)
I-135	7.90E-01 (2.92E+04)
<b>Alkalis</b>	
Rb-86m	5.32E-07 (1.97E-02)
Rb-86	3.66E-03 (1.35E+02)
Rb-88	1.02E+00 (3.77E+04)
Cs-134	4.18E-01 (1.55E+04)
Cs-136	1.00E-01 (3.70E+03)
Cs-137	1.60E-01 (5.92E+03)
Cs-138	2.35E-01 (8.07E+03)
<b>Tellurium Group</b>	
Sb-125	1.56E-06 (5.77E-02)
Sb-127	6.99E-06 (2.59E-01)
Sb-129	8.53E-06 (3.16E-01)
Te-127m	6.19E-04 (2.29E+01)
Te-127	3.05E-03 (1.13E+02)
Te-129m	1.79E-03 (6.62E+01)
Te-129	3.00E-03 (1.11E+02)
Te-131m	4.36E-03 (1.61E+02)
Te-131	3.01E-03 (1.11E+02)
Te-132	4.70E-02 (1.74E+03)
Te-134	6.80E-03 (2.52E+02)
<b>Barium/Strontium Group</b>	
Sr-89	6.35E-04 (2.35E+01)

**Table 7.1-2—U.S. EPR Design Basis Primary Coolant Activity**

Notes (1)(2)

(Page 2 of 3)

Radionuclide	Activity μCi/gm (Bq/gm)
Sr-90	4.32E-05 (1.60E+00)
Sr-91	1.02E-03 (3.77E+01)
Sr-92	1.73E-04 (6.40E+00)
Ba-137m	1.50E-01 (5.55E+03)
Ba-139	2.30E-02 (8.51E+02)
Ba-140	6.74E-04 (2.49E+01)
<b>Noble Metals</b>	
Mo-99	1.21E-01 (4.48E+03)
Tc-99m	5.24E-02 (1.94E+03)
Ru-103	1.00E-04 (3.70E+00)
Ru-105	1.47E-04 (5.44E+00)
Ru-106	5.83E-05 (2.16E+00)
Rh-103m	8.85E-05 (3.27E+00)
Rh-105	6.62E-05 (2.45E+00)
Rh-106	5.84E-05 (2.16E+00)
<b>Cerium Group</b>	
Ce-141	9.12E-05 (3.37E+00)
Ce-143	7.96E-05 (2.95E+00)
Ce-144	6.93E-05 (2.56E+00)
Pu-238	5.97E-07 (2.21E-02)
Pu-239	2.51E-08 (9.29E-04)
Pu-240	5.72E-08 (2.12E-03)
Pu-241	1.03E-05 (3.81E-01)
Np-239	1.41E-03 (5.22E+01)
<b>Lanthanides</b>	
Y-90	1.03E-05 (3.81E-01)
Y-91m	5.23E-04 (1.94E+01)
Y-91	8.10E-05 (3.00E+00)
Y-92	1.41E-04 (5.22E+00)
Y-93	6.50E-05 (2.41E+00)
Zr-95	9.31E-05 (3.44E+00)
Zr-97	7.37E-05 (2.73E+00)
Nb-95	9.35E-05 (3.46E+00)
Ag-110m	9.87E-07 (3.65E-02)
Ag-110	4.72E-08 (1.75E-03)
La-140	1.76E-04 (6.51E+00)
La-141	5.77E-05 (2.13E+00)
La-142	3.38E-05 (1.25E+00)
Pr-143	9.20E-05 (3.40E+00)
Pr-144	6.94E-05 (2.57E+00)
Nd-147	3.77E-05 (1.39E+00)
Am-241	1.18E-08 (4.37E-04)
Cm--242	5.35E-06 (1.98E-01)
Cm--244	2.83E-06 (1.05E-01)
<b>Activation Products</b>	
Na-24	3.7E-02 (1.37E+03)
Cr-51	2.0E-03 (7.40E+01)

**Table 7.1-2—U.S. EPR Design Basis Primary Coolant Activity**

Notes (1)(2)

(Page 3 of 3)

<b>Radionuclide</b>	<b>Activity μCi/gm (Bq/gm)</b>
Mn-54	1.0E-03 (3.70E+01)
Fe-55	7.6E-04 (2.81E+01)
Fe-59	1.9E-04 (7.03E+00)
Co-58	2.9E-03 (1.07E+02)
Co-60	3.4E-04 (1.26E+01)
Zn-65	3.2E-04 (1.18E+01)
W-187	1.8E-03 (6.66E+01)
<b>Tritium</b>	
H-3	1.0E+00 (3.70E+04)

Key:

μCi/gm – Microcuries per gram

Bq/gm – Becquerels per gram

Notes:

- (1) This table lists the design basis source term activity and the magnitude of source terms for offsite releases for the U.S. EPR primary coolant.
- (2) Following an accident, iodine spiking causes the concentration of radioactive iodines I-131 through I-135 to significantly increase.

**Table 7.1-3—U.S. EPR Design Basis Secondary Coolant Activity)**

Notes (1)(2)

(Page 1 of 2)

Radionuclide	Activity μCi/gm (Bq/gm)
<b>Halogens</b>	
Br-83	1.61E-03 (5.96E+01)
Br-84	3.05E-04 (1.13E+01)
Br-85	3.93E-06 (1.45E-01)
I-129	4.81E-09 (1.78E-04)
I-130	4.33E-03 (1.60E+02)
I-131	7.67E-02 (2.84E+03)
I-132	2.27E-02 (8.40E+02)
I-133	1.17E-01 (4.33E+03)
I-134	6.68E-03 (2.47E+02)
I-135	5.99E-02 (2.22E+03)
<b>Alkalis</b>	
Rb-86m	3.99E-12 (1.48E-07)
Rb-86	7.27E-06 (2.69E-01)
Rb-88	1.26E-04 (4.66E+00)
Rb-89	5.02E-06 (1.86E-01)
Cs-134	8.38E-04 (3.10E+01)
Cs-136	1.98E-04 (7.33E+00)
Cs-137	3.21E-04 (1.19E+01)
Cs-138	5.00E-05 (1.85E+00)
<b>Tellurium Group</b>	
Sb-125	1.74E-09 (6.44E-05)
Sb-127	7.60E-09 (2.81E-04)
Sb-129	6.01E-09 (2.22E-04)
Te-127m	6.89E-07 (2.55E-02)
Te-127	2.82E-06 (1.04E-01)
Te-129m	1.99E-06 (7.36E-02)
Te-129	1.94E-06 (7.18E-02)
Te-131m	4.48E-06 (1.66E-01)
Te-131	1.33E-06 (4.92E-02)
Te-132	5.07E-05 (1.88E+00)
Te-134	1.64E-06 (6.07E+00)
<b>Barium/Strontium Group</b>	
Sr-89	7.16E-07 (2.64E-02)
Sr-90	4.81E-08 (1.78E-03)
Sr-91	9.01E-07 (3.33E-02)
Sr-92	1.00E-07 (3.70E-03)
Ba-137m	3.01E-04 (1.11E+01)
Ba-139	1.03E-05 (3.81E-01)
Ba-140	7.45E-07 (2.76E-02)
<b>Noble Metals</b>	
Mo-99	1.30E-04 (4.81E+00)
Tc-99m	7.47E-05 (2.76E+00)
Ru-103	1.11E-07 (4.11E-03)
Ru-105	1.09E-07 (4.03E-03)
Ru-106	6.49E-08 (2.40E-03)
Rh-103m	9.97E-08 (3.69E-03)
Rh-105	7.58E-08 (2.80E-03)
Rh-106	6.49E-08 (2.40E-03)

**Table 7.1-3—U.S. EPR Design Basis Secondary Coolant Activity)**

Notes (1)(2)

(Page 2 of 2)

Radionuclide	Activity μCi/gm (Bq/gm)
<b>Cerium Group</b>	
Ce-141	1.01E-07 (3.74E-03)
Ce-143	8.24E-08 (3.05E-03)
Ce-144	7.72E-08 (2.86E-03)
Pu-238	6.65E-10 (2.46E-05)
Pu-239	2.80E-11 (1.04E-06)
Pu-240	6.37E-11 (2.36E-06)
Pu-241	1.15E-08 (4.26E-04)
Np-239	1.50E-06 (5.55E-02)
<b>Lanthanides</b>	
Y-90	1.29E-08 (4.77E-04)
Y-91m	5.38E-07 (1.99E-02)
Y-91	9.17E-08 (3.39E-03)
Y-92	1.33E-07 (4.92E-03)
Y-93	5.81E-08 (2.15E-03)
Zr-95	1.04E-07 (3.85E-03)
Zr-97	7.15E-08 (2.65E-03)
Nb-95	1.04E-07 (3.85E-03)
Ag-110m	1.10E-09 (4.07E-05)
Ag-110	1.47E-11 (5.44E-07)
La-140	2.28E-07 (8.44E-03)
La-141	4.06E-08 (1.50E-03)
La-142	1.51E-08 (5.59E-04)
Pr-143	1.02E-07 (3.77E-03)
Pr-144	7.72E-08 (2.86E-03)
Nd-147	4.16E-08 (1.54E-03)
Am-241	1.32E-11 (4.88E-07)
Cm-242	5.96E-09 (2.21E-04)
Cm-244	3.15E-09 (1.17E-04)
<b>Activation Products</b>	
Na-24	3.53E-05 (1.31E+00)
Cr-51	2.22E-06 (8.21E-02)
Mn-54	1.11E-06 (4.11E-02)
Fe-55	8.47E-07 (3.13E-02)
Fe-59	2.11E-07 (7.81E-03)
Co-58	3.23E-06 (1.20E-01)
Co-60	3.79E-07 (1.40E-02)
Zn-65	3.56E-07 (1.32E-02)
W-187	1.81E-06 (6.70E-02)
<b>Tritium</b>	
H-3	1.0E-03 (3.70E+01)

Key:

μCi/gm – microcuries per gram

Bq/gm – Becquerels per gram

Notes:

- (1) This table lists the design basis source term activity and the magnitude of source terms for offsite releases for the U.S. EPR secondary coolant.
- (2) Noble gases are not applicable since they are assumed to enter the steam phase.

**Table 7.1-4—U.S. EPR Bounding Core Inventory**

Notes (1)(2)(3)

(Page 1 of 2)

Radionuclide	Activity μCi/gm (Bq/gm)
<b>Noble Gases</b>	
Kr-83m	1.96E+07 (7.25E+17)
Kr-85m	4.50E+07 (1.67E+18)
Kr-85	2.10E+06 (7.77E+16)
Kr-87	9.02E+07 (3.34E+18)
Kr-88	1.28E+08 4.74E+18)
Kr-89	1.61E+08 (5.96E+18)
Xe-131m	1.54E+06 (5.70E+16)
Xe-133m	8.92E+06 (3.30E+17)
Xe-133	2.89E+08 (1.07E+19)
Xe-135m	5.49E+07 (2.03E+18)
Xe-135	9.26E+07 (3.43E+18)
Xe-137	2.52E+08 (9.32E+18)
Xe-138	2.45E+08 (9.07E+18)
<b>Halogens</b>	
Br-83	1.96E+07 (7.25E+17)
Br-84	3.62E+07 (1.34E+18)
Br-85	4.45E+07 (1.65E+18)
I-129	8.33E+00 (3.08E+11)
I-130	1.32E+07 (4.88E+17)
I-131	1.39E+08 (5.14E+18)
I-132	2.01E+08 (7.44E+18)
I-133	2.90E+08 (1.07E+19)
I-134	3.18E+08 (1.18E+19)
I-135	2.69E+08 (9.95E+18)
<b>Alkalis</b>	
Rb-86m	5.53E+04 (2.05E+15)
Rb-86	5.80E+05 (2.15E+16)
Rb-88	1.29E+08 (4.77E+18)
Rb-89	1.67E+08 (6.18E+18)
Cs-134	6.48E+07 (2.40E+18)
Cs-136	1.61E+07 (5.96E+17)
Cs-137	2.47E+07 (9.14E+17)
Cs-138	2.69E+08 (9.95E+18)
<b>Tellurium Group</b>	
Sb-125	3.83E+06 (1.42E+17)
Sb-127	1.80E+07 (6.66E+17)
Sb-129	4.85E+07 (1.79E+18)
Te-127m	2.43E+06 (8.99E+16)
Te-127	1.79E+07 (6.62E+17)
Te-129m	7.08E+06 (2.62E+17)
Te-129	4.78E+07 (1.77E+18)
Te-131m	2.04E+07 (7.55E+17)
Te-131	1.24E+08 (4.59E+18)
Te-132	1.98E+08 (7.33E+18)
Te-134	2.50E+08 (9.25E+18)
<b>Barium/Strontium Group</b>	
Sr-89	1.61E+08 (5.96E+18)
Sr-90	1.69E+07 (6.25E+17)
Sr-91	2.07E+08 (7.66E+18)
Sr-92	2.14E+08 (7.92E+18)
Ba-137m	2.34E+07 (8.66E+17)

**Table 7.1-4—U.S. EPR Bounding Core Inventory**

Notes (1)(2)(3)

(Page 2 of 2)

Radionuclide	Activity μCi/gm (Bq/gm)
Ba-139	2.62E+08 (9.69E+18)
Ba-140	2.52E+08 (9.32E+18)
<b>Noble Metals</b>	
Mo-99	2.59E+08 (9.58E+18)
Tc-99m	2.27E+08 (8.40E+18)
Ru-103	2.42E+08 (8.95E+18)
Ru-105	1.96E+08 (7.25E+18)
Ru-106	1.43E+08 (5.29E+18)
Rh-103m	2.18E+08 (8.07E+18)
Rh-105	1.75E+08 (6.48E+18)
Rh-106	1.58E+08 (5.85E+18)
<b>Cerium Group</b>	
Ce-141	2.24E+08 (8.29E+18)
Ce-143	2.28E+08 (8.44E+18)
Ce-144	1.70E+08 (6.29E+18)
Pu-238	1.46E+06 (5.40E+16)
Pu-239	6.14E+04 (2.27E+15)
Pu-240	1.40E+05 (5.18E+15)
Pu-241	2.53E+07 (9.36E+17)
Np-239	3.82E+09 (1.41E+20)
<b>Lanthanides</b>	
Y-90	1.79E+07 (6.62E+17)
Y-91m	1.20E+08 (4.44E+18)
Y-91	1.96E+08 (7.25E+18)
Y-92	2.14E+08 (7.92E+18)
Y-93	2.34E+08 (8.66E+18)
Zr-95	2.29E+08 (8.47E+18)
Zr-97	2.43E+08 (8.99E+18)
Nb-95	2.29E+08 (8.47E+18)
Ag-110m	2.42E+06 (8.95E+16)
Ag-110	7.15E+07 (2.65E+18)
La-140	2.54E+08 (9.40E+18)
La-141	2.41E+08 (8.92E+18)
La-142	2.35E+08 (8.70E+18)
Pr-143	2.26E+08 (8.36E+18)
Pr-144	1.72E+08 (6.36E+18)
Nd-147	9.44E+07 (3.49E+18)
Am-241	2.88E+04 (1.07E+15)
Cm-242	1.31E+07 (4.85E+17)
Cm-244	6.94E+06 (2.57E+17)

Key:

Ci - Curies

Bq - Becquerels

Notes:

- (1) This table lists the design basis source term inventories for radiological consequences for the U.S. EPR core.
- (2) Core inventories are bounding for U-235 fuel enrichment ranging between 2% and 5% and burnups up to 62,000 MWd/MTU.
- (3) The design basis power level is 4,612 MWt.

**Table 7.1-5—{50th Percentile Callaway Site Atmospheric Dispersion Factors}**

Time Interval (hrs)	Atmospheric Dispersion Factor (sec/m <sup>3</sup> ) (Nominal, 50% Meteorology)	
	0.5 mile (0.8 km) radius (Worst 2-hr)	1.5 mile (2.4 km) radius (0 to 30 days)
<b>Loss of Coolant Accidents (LOCA)</b>		
0 to 1.5	n/a	1.110E-05
1.5 to 3.5 <sup>(1)</sup>	8.332E-05	1.524E-05
3.5 to 8	n/a	1.110E-05
8 to 24		8.364E-06
24 to 96		5.419E-06
96 to 720		2.906E-06
<b>All Other Accidents</b>		
0 to 2	8.332E-05	1.524E-05
2 to 8	n/a	1.110E-05
8 to 24		8.364E-06
24 to 96		5.419E-06
96 to 720		2.906E-06

## Notes:

- (1) In accordance with Regulatory Guide 1.183 (Section 4.1.5), the period of most adverse release of radioactive materials to the environment was assumed to occur coincident with the period of most unfavorable atmospheric dispersion.

**Table 7.1-6—{Steam System Piping Failure}**

Time	Site TEDE Dose (rem / Sieverts)	
	0.5 mile (0.8 km) radius	1.5 mile (2.4 km) radius
<b>Pre-Accident Iodine Spike</b>		
0-2 hr	2.03E-02 / 2.03E-04	3.71E-03 / 3.71E-05
2-8 hr		1.49E-03 / 1.49E-05
8-24 hr		8.10E-05 / 8.10E-07
24-96 hr		0.00E+00 / 0.00E+00
96-720 hr		0.00E+00 / 0.00E+00
Total	2.03E-02 / 2.03E-04	5.28E-03 / 5.28E-05
Limit	25 / 0.25	25 / 0.25
<b>Concurrent Iodine Spike</b>		
0-2 hr	2.24E-02 / 2.24E-04	4.10E-03 / 4.10E-05
2-8 hr		1.18E-02 / 1.18E-04
8-24 hr		1.16E-03 / 1.16E-05
24-96 hr		0.00E+00 / 0.00E+00
96-720 hr		0.00E+00 / 0.00E+00
Total	2.24E-02 / 2.24E-04	1.71E-02 / 1.71E-04
Limit	2.5 / 0.025	2.5 / 0.025
<b>Accident-Induced 1.24% Fuel Rod Clad Failure</b>		
0-2 hr	1.75E-01 / 1.75E-03	3.20E-02 / 3.20E-04
2-8 hr		4.98E-02 / 4.98E-04
8-24 hr		2.89E-03 / 2.89E-05
24-96 hr		0.00E+00 / 0.00E+00
96-720 hr		0.00E+00 / 0.00E+00
Total	1.75E-01 / 1.75E-03	8.47E-02 / 8.47E-04
Limit	25 / 0.25	25 / 0.25

**Table 7.1-7—{Reactor Coolant Pump Locked Rotor Accident / Broken Shaft}**

Time	Site TEDE Dose (rem / Sieverts)	
	0.5 mile (0.8 km) radius	1.5 mile (2.4 km) radius
0-2 hr	1.59E-01 / 1.59E-03	2.91E-02 / 2.91E-04
2-8 hr		3.27E-02 / 3.27E-04
8-24 hr		0.00E+00 / 0.00E+00
24-96 hr		0.00E+00 / 0.00E+00
96-720 hr		0.00E+00 / 0.00E+00
Total	1.59E-01 / 1.59E-03	6.18E-02 / 6.18E-04
Limit	2.5 / 0.025	2.5 / 0.025

**Table 7.1-8—{Failure of Small Lines Carrying Primary Coolant Outside Containment}**

Time	Site TEDE Dose (rem / Sieverts)	
	0.5 mile (0.8 km) radius	1.5 mile (2.4 km) radius
0-2 hr	1.50E-01 / 1.50E-03	2.75E-02 / 2.75E-04
2-8 hr		0.00E+00 / 0.00E+00
8-24 hr		0.00E+00 / 0.00E+00
24-96 hr		0.00E+00 / 0.00E+00
96-720 hr		0.00E+00 / 0.00E+00
Total	1.50E-01 / 1.50E-03	2.75E-02 / 2.75E-04
Limit	2.5 / 0.025	2.5 / 0.025

Note:

The Nuclear Sampling System Line Break (1/4" line) bounds the Chemical and Volume Control System Line Break (6" line) for the 0.5 mile (0.8 km) radius and 1.5 mile (2.4 km) radius.

**Table 7.1-9—{Steam Generator Tube Rupture (SGTR)}**

Time	Site TEDE Dose (rem / Sieverts)	
	0.5 mile (0.8 km) radius	1.5 mile (2.4 km) radius
<b>Pre-Accident Iodine Spike</b>		
0-2 hr	9.21E-02 / 9.21E-04	1.68E-02 / 1.68E-04
2-8 hr		3.04E-03 / 3.04E-05
8-24 hr		2.20E-03 / 2.20E-05
24-96 hr		9.55E-04 / 9.55E-06
96-720 hr		3.69E-03 / 3.69E-05
Total	9.21E-02 / 9.21E-04	2.67E-02 / 2.67E-04
Limit	25 / 0.25	25 / 0.25
<b>Concurrent Iodine Spike</b>		
0-2 hr	6.08E-02 / 6.08E-04	1.11E-02 / 1.11E-04
2-8 hr		2.20E-03 / 2.20E-05
8-24 hr		2.52E-03 / 2.52E-05
24-96 hr		5.84E-03 / 5.84E-05
96-720 hr		3.36E-02 / 3.36E-04
Total	6.08E-02 / 6.08E-04	5.53E-02 / 5.53E-04
Limit	2.5 / 0.025	2.5 / 0.025

**Table 7.1-10—{Loss of Coolant Accident (LOCA)}**

Time	Site TEDE Dose (rem / Sieverts)	
	0.5 mile (0.8 km) radius	1.5 mile (2.4 km) radius
0-1.5 hr		4.25E-02 / 4.25E-04
1.5-3.5	1.04E+00 / 1.04E-02	1.90E-01 / 1.90E-03
3.5-8 hr		2.24E-01 / 2.24E-03
8-24 hr		2.79E-01 / 2.79E-03
24-96 hr		1.64E-01 / 1.64E-03
96-720 hr		1.15E-01 / 1.15E-03
Total	1.04E+00 / 1.04E-02	1.01E+00 / 1.01E-02
Limit	25 / 0.25	25 / 0.25

**Table 7.1-11—{Fuel Handling Accident}**

Time	Site TEDE Dose (rem / Sieverts)	
	0.5 mile (0.8 km) radius	1.5 mile (2.4 km) radius
0-2 hr	4.68E-01 / 4.68E-03	8.56E-02 / 8.56E-04
2-8 hr		2.46E-03 / 2.46E-05
8-24 hr		1.48E-03 / 1.48E-05
24-96 hr		2.80E-04 / 2.80E-06
96-720 hr		5.30E-06 / 5.30E-08
Total	4.68E-01 / 4.68E-03	8.98E-02 / 8.98E-04
Limit	6.3 / 0.063	6.3 / 0.063

**Table 7.1-12—{Rod Ejection Accident (REA)}**

Time	Site TEDE Dose (rem / Sieverts)	
	0.5 mile (0.8 km) radius	1.5 mile (2.4 km) radius
0-2 hr	3.34E-01 / 3.34E-03	6.10E-02 / 6.10E-04
2-8 hr		1.46E-01 / 1.46E-03
8-24 hr		0.00E+00 / 0.00E+00
24-96 hr		0.00E+00 / 0.00E+00
96-720 hr		0.00E+00 / 0.00E+00
Total	3.34E-01 / 3.34E-03	2.07E-01 / 2.07E-03
Limit	6.3 / 0.063	6.3 / 0.063

**Table 7.1-13—{Summary of DBA Radiological Consequences at Offsite Receptors from Callaway Plant Unit 2}**

Design Basis Accident		0.5 mile (0.8 km) radius TEDE Dose (rem / Sieverts)	1.5 mile (2.4 km) radius TEDE Dose (rem / Sieverts)	Regulatory TEDE Dose Acceptance Criteria (rem / Sieverts)
Steam System Piping Failures	Pre-accident iodine spike	2.0E-02 / 2.0E-04	5.3E-03 / 5.3E-05	25 / 0.25
	Concurrent iodine spike	2.2E-02 / 2.2E-04	1.7E-02 / 1.7E-04	2.5 / 0.025
	1.24% clad failure	1.8E-01 / 1.8E-03	8.5E-02 / 8.5E-04	25 / 0.25
Reactor Coolant Pump Locked Rotor Accident / Broken Shaft (8% clad failure)		1.6E-01 / 1.6E-03	6.2E-02 / 6.2E-04	2.5 / 0.025
Failure of Small Lines Carrying Primary Coolant Outside Containment		1.5E-01 / 1.5E-03	2.8E-02 / 2.8E-04	2.5 / 0.025
Steam Generator Tube Rupture	Pre-accident Iodine Spike	9.2E-02 / 9.2E-04	2.7E-02 / 2.7E-04	25 / 0.25
	Concurrent Iodine Spike	6.1E-02 / 6.1E-04	5.5E-02 / 5.5E-04	2.5 / 0.025
Loss Of Coolant Accident		1.0E+00 / 1.0E-02	1.0E+00 / 1.0E-02	25 / 0.25
Fuel Handling Accident (34-hr decay)		4.7E-01 / 4.7E-03	9.0E-02 / 9.0E-04	6.3 / 0.063
Rod Ejection Accident (26% clad failure)		3.3E-01 / 3.3E-03	2.1E-01 / 2.1E-03	6.3 / 0.063

Key:  
TEDE – Total effective dose equivalent

**Table 7.1-14—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Pre-Accident Iodine Spike}**

(Page 1 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]			
	0 to 2	2 to 8	8 to 24	Total
Kr-83m	2.167E-02 (8.018E+08)	2.145E-02 (7.937E+08)	3.182E-04 (1.177E+07)	4.344E-02 (1.607E+09)
Kr-85m	1.115E-01 (4.126E+09)	1.858E-01 (6.875E+09)	4.350E-03 (1.610E+08)	3.016E-01 (1.116E+10)
Kr-85	1.205E+00 (4.459E+10)	3.613E+00 (1.337E+11)	1.505E-01 (5.569E+09)	4.969E+00 (1.839E+11)
Kr-87	4.505E-02 (1.667E+09)	2.194E-02 (8.118E+08)	9.099E-05 (3.367E+06)	6.709E-02 (2.482E+09)
Kr-88	1.849E-01 (6.841E+09)	2.258E-01 (8.355E+09)	3.674E-03 (1.359E+08)	4.144E-01 (1.533E+10)
Kr-89	2.093E-04 (7.744E+06)	8.419E-16 (3.115E-05)	1.370E-50 (5.069E-40)	2.093E-04 (7.744E+06)
Xe-131m	2.446E-01 (9.050E+09)	7.271E-01 (2.690E+10)	3.027E-02 (1.120E+09)	1.002E+00 (3.707E+10)
Xe-133m	3.042E-01 (1.126E+10)	8.850E-01 (3.275E+10)	3.985E-02 (1.474E+09)	1.229E+00 (4.547E+10)
Xe-133	2.140E+01 (7.918E+11)	6.307E+01 (2.334E+12)	2.646E+00 (9.790E+10)	8.711E+01 (3.223E+12)
Xe-135m	3.843E-01 (1.422E+10)	8.821E-01 (3.264E+10)	8.834E-02 (3.269E+09)	1.355E+00 (5.014E+10)
Xe-135	9.137E-01 (3.381E+10)	3.733E+00 (1.381E+11)	4.540E-01 (1.680E+10)	5.100E+00 (1.887E+11)
Xe-137	4.777E-04 (1.767E+07)	1.767E-13 (6.538E-03)	2.237E-42 (8.277E-32)	4.777E-04 (1.767E+07)
Xe-138	6.324E-03 (2.340E+08)	1.790E-05 (6.623E+05)	9.525E-14 (3.524E-03)	6.341E-03 (2.346E+08)
Br-83	2.522E-01 (9.331E+09)	4.130E-03 (1.528E+08)	7.641E-05 (2.827E+06)	2.564E-01 (9.487E+09)
Br-84	4.771E-02 (1.765E+09)	4.524E-05 (1.674E+06)	7.550E-09 (2.794E+02)	4.775E-02 (1.767E+09)
Br-85	6.133E-04 (2.269E+07)	1.092E-18 (4.040E-08)	1.546E-56 (5.720E-46)	6.133E-04 (2.269E+07)
I-129	7.539E-07 (2.789E+04)	3.757E-08 (1.390E+03)	1.301E-09 (4.814E+01)	7.928E-07 (2.933E+04)
I-130	6.787E-01 (2.511E+10)	2.685E-02 (9.935E+08)	8.749E-04 (3.237E+07)	7.064E-01 (2.614E+10)
I-131	1.516E+01 (5.609E+11)	8.621E+00 (3.190E+11)	1.226E+00 (4.536E+10)	2.501E+01 (9.254E+11)
I-132	4.788E+00 (1.772E+11)	1.069E+00 (3.955E+10)	4.889E-02 (1.809E+09)	5.906E+00 (2.185E+11)
I-133	2.350E+01 (8.695E+11)	1.244E+01 (4.603E+11)	1.602E+00 (5.927E+10)	3.754E+01 (1.389E+12)
I-134	1.620E+00 (5.994E+10)	1.135E-01 (4.200E+09)	5.052E-04 (1.869E+07)	1.734E+00 (6.416E+10)
I-135	1.246E+01 (4.610E+11)	5.510E+00 (2.039E+11)	5.515E-01 (2.041E+10)	1.852E+01 (6.852E+11)
Rb-86m	1.353E-09 (5.006E+01)	1.255E-45 (4.644E-35)	0.000E+00 (0.000E+00)	1.353E-09 (5.006E+01)
Rb-86	1.398E-03 (5.173E+07)	7.207E-04 (2.667E+07)	1.024E-04 (3.789E+06)	2.221E-03 (8.218E+07)

**Table 7.1-14—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Pre-Accident Iodine Spike}**

(Page 2 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]			
	0 to 2	2 to 8	8 to 24	Total
Rb-88	1.915E-01 (7.086E+09)	2.517E-01 (9.313E+09)	4.103E-03 (1.518E+08)	4.474E-01 (1.655E+10)
Rb-89	1.838E-03 (6.801E+07)	3.266E-06 (1.208E+05)	1.619E-13 (5.990E-03)	1.841E-03 (6.812E+07)
Cs-134	1.609E-01 (5.953E+09)	8.300E-02 (3.071E+09)	1.185E-02 (4.385E+08)	2.557E-01 (9.461E+09)
Cs-136	3.808E-02 (1.409E+09)	1.963E-02 (7.263E+08)	2.782E-03 (1.029E+08)	6.048E-02 (2.238E+09)
Cs-137	6.160E-02 (2.279E+09)	3.177E-02 (1.175E+09)	4.536E-03 (1.678E+08)	9.791E-02 (3.623E+09)
Cs-138	2.051E-02 (7.589E+08)	1.254E-03 (4.640E+07)	1.886E-07 (6.978E+03)	2.177E-02 (8.055E+08)
Sr-89	7.189E-07 (2.660E+04)	2.557E-06 (9.461E+04)	3.082E-07 (1.140E+04)	3.584E-06 (1.326E+05)
Ba-137m	5.786E-02 (2.141E+09)	3.006E-02 (1.112E+09)	4.291E-03 (1.588E+08)	9.220E-02 (3.411E+09)
Total	8.386E+01 (3.103E+12)	1.016E+02 (3.759E+12)	6.875E+00 (2.544E+11)	1.923E+02 (7.115E+12)

**Table 7.1-15—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Concurrent Iodine Spike}**

(Page 1 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]			
	0 to 2	2 to 8	8 to 24	Total
Kr-83m	2.167E-02 (8.018E+08)	2.145E-02 (7.937E+08)	3.182E-04 (1.177E+07)	4.344E-02 (1.607E+09)
Kr-85m	1.115E-01 (4.126E+09)	1.858E-01 (6.875E+09)	4.350E-03 (1.610E+08)	3.016E-01 (1.116E+10)
Kr-85	1.205E+00 (4.459E+10)	3.613E+00 (1.337E+11)	1.505E-01 (5.569E+09)	4.969E+00 (1.839E+11)
Kr-87	4.505E-02 (1.667E+09)	2.194E-02 (8.118E+08)	9.099E-05 (3.367E+06)	6.709E-02 (2.482E+09)
Kr-88	1.849E-01 (6.841E+09)	2.258E-01 (8.355E+09)	3.674E-03 (1.359E+08)	4.144E-01 (1.533E+10)
Kr-89	2.093E-04 (7.744E+06)	8.419E-16 (3.115E-05)	1.370E-50 (5.069E-40)	2.093E-04 (7.744E+06)
Xe-131m	2.446E-01 (9.050E+09)	7.308E-01 (2.704E+10)	3.188E-02 (1.180E+09)	1.007E+00 (3.726E+10)
Xe-133m	3.045E-01 (1.127E+10)	9.837E-01 (3.640E+10)	8.092E-02 (2.994E+09)	1.369E+00 (5.065E+10)
Xe-133	2.140E+01 (7.918E+11)	6.448E+01 (2.386E+12)	3.237E+00 (1.198E+11)	8.912E+01 (3.297E+12)
Xe-135m	7.205E-01 (2.666E+10)	1.136E+01 (4.203E+11)	2.616E+00 (9.679E+10)	1.470E+01 (5.439E+11)
Xe-135	1.023E+00 (3.785E+10)	1.721E+01 (6.368E+11)	5.434E+00 (2.011E+11)	2.367E+01 (8.758E+11)
Xe-137	4.777E-04 (1.767E+07)	1.767E-13 (6.538E-03)	2.237E-42 (8.277E-32)	4.777E-04 (1.767E+07)
Xe-138	6.324E-03 (2.340E+08)	1.790E-05 (6.623E+05)	9.525E-14 (3.524E-03)	6.341E-03 (2.346E+08)
Br-83	2.522E-01 (9.331E+09)	4.130E-03 (1.528E+08)	7.641E-05 (2.827E+06)	2.564E-01 (9.487E+09)
Br-84	4.771E-02 (1.765E+09)	4.524E-05 (1.674E+06)	7.550E-09 (2.794E+02)	4.775E-02 (1.767E+09)
Br-85	6.133E-04 (2.269E+07)	1.092E-18 (4.040E-08)	1.546E-56 (5.720E-46)	6.133E-04 (2.269E+07)
I-129	7.539E-07 (2.789E+04)	3.757E-08 (1.390E+03)	1.301E-09 (4.814E+01)	7.928E-07 (2.933E+04)
I-130	6.787E-01 (2.511E+10)	2.685E-02 (9.935E+08)	8.749E-04 (3.237E+07)	7.064E-01 (2.614E+10)
I-131	1.627E+01 (6.020E+11)	6.254E+01 (2.314E+12)	1.557E+01 (5.761E+11)	9.438E+01 (3.492E+12)
I-132	8.145E+00 (3.014E+11)	3.962E+01 (1.466E+12)	6.683E+00 (2.473E+11)	5.445E+01 (2.015E+12)
I-133	2.653E+01 (9.816E+11)	1.129E+02 (4.177E+12)	2.685E+01 (9.935E+11)	1.663E+02 (6.153E+12)
I-134	5.642E+00 (2.088E+11)	2.468E+01 (9.132E+11)	2.899E+00 (1.073E+11)	3.322E+01 (1.229E+12)
I-135	1.595E+01 (5.902E+11)	7.814E+01 (2.891E+12)	1.675E+01 (6.198E+11)	1.108E+02 (4.100E+12)
Rb-86m	1.353E-09 (5.006E+01)	1.255E-45 (4.644E-35)	0.000E+00 (0.000E+00)	1.353E-09 (5.006E+01)
Rb-86	1.398E-03 (5.173E+07)	7.207E-04 (2.667E+07)	1.024E-04 (3.789E+06)	2.221E-03 (8.218E+07)

**Table 7.1-15—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Concurrent Iodine Spike}**

(Page 2 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]			
	0 to 2	2 to 8	8 to 24	Total
Rb-88	1.915E-01 (7.086E+09)	2.517E-01 (9.313E+09)	4.103E-03 (1.518E+08)	4.474E-01 (1.655E+10)
Rb-89	1.838E-03 (6.801E+07)	3.266E-06 (1.208E+05)	1.619E-13 (5.990E-03)	1.841E-03 (6.812E+07)
Cs-134	1.609E-01 (5.953E+09)	8.300E-02 (3.071E+09)	1.185E-02 (4.385E+08)	2.557E-01 (9.461E+09)
Cs-136	3.808E-02 (1.409E+09)	1.963E-02 (7.263E+08)	2.782E-03 (1.029E+08)	6.048E-02 (2.238E+09)
Cs-137	6.160E-02 (2.279E+09)	3.177E-02 (1.175E+09)	4.536E-03 (1.678E+08)	9.791E-02 (3.623E+09)
Cs-138	2.051E-02 (7.589E+08)	1.254E-03 (4.640E+07)	1.886E-07 (6.978E+03)	2.177E-02 (8.055E+08)
Sr-89	7.189E-07 (2.660E+04)	2.557E-06 (9.461E+04)	3.082E-07 (1.140E+04)	3.584E-06 (1.326E+05)
Ba-137m	5.786E-02 (2.141E+09)	3.006E-02 (1.112E+09)	4.291E-03 (1.588E+08)	9.220E-02 (3.411E+09)
Total	9.932E+01 (3.675E+12)	4.172E+02 (1.544E+13)	8.034E+01 (2.973E+12)	5.968E+02 (2.208E+13)

**Table 7.1-16—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Accident-Induced 1.24% Clad Failure}**

(Page 1 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]			
	0 to 2	2 to 8	8 to 24	Total
Kr-83m	1.234E+01 (4.566E+11)	1.339E+01 (4.954E+11)	4.654E-01 (1.722E+10)	2.619E+01 (9.690E+11)
Kr-85m	3.180E+01 (1.177E+12)	5.299E+01 (1.961E+12)	1.250E+00 (4.625E+10)	8.604E+01 (3.183E+12)
Kr-85	4.628E+00 (1.712E+11)	1.388E+01 (5.136E+11)	5.781E-01 (2.139E+10)	1.908E+01 (7.060E+11)
Kr-87	4.483E+01 (1.659E+12)	2.183E+01 (8.077E+11)	9.054E-02 (3.350E+09)	6.675E+01 (2.470E+12)
Kr-88	8.286E+01 (3.066E+12)	1.011E+02 (3.741E+12)	1.647E+00 (6.094E+10)	1.857E+02 (6.871E+12)
Kr-89	5.007E+00 (1.853E+11)	2.014E-11 (7.452E-01)	3.276E-46 (1.212E-35)	5.007E+00 (1.853E+11)
Xe-131m	1.499E+00 (5.546E+10)	4.467E+00 (1.653E+11)	1.887E-01 (6.982E+09)	6.154E+00 (2.277E+11)
Xe-133m	7.499E+00 (2.775E+11)	2.160E+01 (7.992E+11)	9.244E-01 (3.420E+10)	3.002E+01 (1.111E+12)
Xe-133	2.563E+02 (9.483E+12)	7.562E+02 (2.798E+13)	3.187E+01 (1.179E+12)	1.044E+03 (3.863E+13)
Xe-135m	1.561E+01 (5.776E+11)	1.737E+01 (6.427E+11)	1.804E+00 (6.675E+10)	3.479E+01 (1.287E+12)
Xe-135	7.553E+01 (2.795E+12)	2.021E+02 (7.478E+12)	1.331E+01 (4.925E+11)	2.910E+02 (1.077E+13)
Xe-137	9.450E+00 (3.497E+11)	3.495E-09 (1.293E+02)	4.426E-38 (1.638E-27)	9.450E+00 (3.497E+11)
Xe-138	3.388E+01 (1.254E+12)	9.589E-02 (3.548E+09)	5.105E-10 (1.889E+01)	3.398E+01 (1.257E+12)
Br-83	4.268E+00 (1.579E+11)	3.443E+00 (1.274E+11)	1.707E-01 (6.316E+09)	7.881E+00 (2.916E+11)
Br-84	4.045E+00 (1.497E+11)	2.171E-01 (8.033E+09)	5.883E-05 (2.177E+06)	4.262E+00 (1.577E+11)
Br-85	6.252E-01 (2.313E+10)	8.120E-14 (3.004E-03)	1.228E-51 (4.544E-41)	6.252E-01 (2.313E+10)
I-129	2.904E-06 (1.074E+05)	5.616E-06 (2.078E+05)	8.492E-07 (3.142E+04)	9.369E-06 (3.467E+05)
I-130	3.923E+00 (1.452E+11)	6.706E+00 (2.481E+11)	8.338E-01 (3.085E+10)	1.146E+01 (4.240E+11)
I-131	6.926E+01 (2.563E+12)	1.468E+02 (5.432E+12)	2.198E+01 (8.133E+11)	2.380E+02 (8.806E+12)
I-132	4.433E+01 (1.640E+12)	3.363E+01 (1.244E+12)	1.588E+00 (5.876E+10)	7.955E+01 (2.943E+12)
I-133	9.127E+01 (3.377E+12)	1.655E+02 (6.124E+12)	2.231E+01 (8.255E+11)	2.791E+02 (1.033E+13)
I-134	4.733E+01 (1.751E+12)	8.856E+00 (3.277E+11)	4.002E-02 (1.481E+09)	5.623E+01 (2.081E+12)
I-135	7.309E+01 (2.704E+12)	1.083E+02 (4.007E+12)	1.126E+01 (4.166E+11)	1.926E+02 (7.126E+12)
Rb-86m	6.630E-04 (2.453E+07)	1.126E-39 (4.166E-29)	0.000E+00 (0.000E+00)	6.630E-04 (2.453E+07)
Rb-86	3.593E-01 (1.329E+10)	9.232E-01 (3.416E+10)	1.396E-01 (5.165E+09)	1.422E+00 (5.261E+10)

**Table 7.1-16—{Radionuclide Releases to Atmosphere for Main Steam Line Break with Accident-Induced 1.24% Clad Failure}**

(Page 2 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]			
	0 to 2	2 to 8	8 to 24	Total
Rb-88	9.053E+01 (3.350E+12)	1.129E+02 (4.177E+12)	1.838E+00 (6.801E+10)	2.052E+02 (7.592E+12)
Rb-89	3.107E+01 (1.150E+12)	9.210E-02 (3.408E+09)	4.812E-09 (1.780E+02)	3.116E+01 (1.153E+12)
Cs-134	4.026E+01 (1.490E+12)	1.041E+02 (3.852E+12)	1.582E+01 (5.853E+11)	1.602E+02 (5.927E+12)
Cs-136	9.981E+00 (3.693E+11)	2.558E+01 (9.465E+11)	3.858E+00 (1.427E+11)	3.942E+01 (1.459E+12)
Cs-137	1.537E+01 (5.687E+11)	3.975E+01 (1.471E+12)	6.041E+00 (2.235E+11)	6.116E+01 (2.263E+12)
Cs-138	1.013E+02 (3.748E+12)	8.553E+00 (3.165E+11)	1.560E-03 (5.772E+07)	1.099E+02 (4.066E+12)
Sr-89	2.066E-02 (7.644E+08)	7.312E-02 (2.705E+09)	9.210E-03 (3.408E+08)	1.030E-01 (3.811E+09)
Ba-137m	1.454E+01 (5.380E+11)	3.760E+01 (1.391E+12)	5.714E+00 (2.114E+11)	5.785E+01 (2.140E+12)
Total	1.223E+03 (4.525E+13)	2.008E+03 (7.430E+13)	1.437E+02 (5.317E+12)	3.375E+03 (1.249E+14)

**Table 7.1-17—{Radionuclide Releases to Atmosphere for Pump Locked Rotor Accident (LRA) with Accident-Induced 8.0% Clad Failure}**

(Page 1 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]		
	0 to 2	2 to 8	Total
Kr-83m	5.781E+01 (2.139E+12)	4.552E+01 (1.684E+12)	1.033E+02 (3.822E+12)
Kr-85m	1.604E+02 (5.935E+12)	2.552E+02 (9.442E+12)	4.156E+02 (1.538E+13)
Kr-85	1.822E+01 (6.741E+11)	5.241E+01 (1.939E+12)	7.063E+01 (2.613E+12)
Kr-87	2.309E+02 (8.543E+12)	1.056E+02 (3.907E+12)	3.365E+02 (1.245E+13)
Kr-88	4.212E+02 (1.558E+13)	4.890E+02 (1.809E+13)	9.102E+02 (3.368E+13)
Kr-89	3.203E+01 (1.185E+12)	9.752E-11 (3.608E+00)	3.203E+01 (1.185E+12)
Xe-131m	6.515E+00 (2.411E+11)	1.857E+01 (6.871E+11)	2.509E+01 (9.283E+11)
Xe-133m	3.645E+01 (1.349E+12)	9.966E+01 (3.687E+12)	1.361E+02 (5.036E+12)
Xe-133	1.201E+03 (4.444E+13)	3.385E+03 (1.252E+14)	4.585E+03 (1.696E+14)
Xe-135m	4.917E+01 (1.819E+12)	9.850E+00 (3.645E+11)	5.902E+01 (2.184E+12)
Xe-135	3.604E+02 (1.333E+13)	7.953E+02 (2.943E+13)	1.156E+03 (4.277E+13)
Xe-137	6.002E+01 (2.221E+12)	1.694E-08 (6.268E+02)	6.002E+01 (2.221E+12)
Xe-138	1.927E+02 (7.130E+12)	4.645E-01 (1.719E+10)	1.931E+02 (7.145E+12)
Br-83	3.612E+00 (1.336E+11)	1.721E+00 (6.368E+10)	5.333E+00 (1.973E+11)
Br-84	5.315E+00 (1.967E+11)	7.391E-02 (2.735E+09)	5.389E+00 (1.994E+11)
Br-85	1.964E+00 (7.267E+10)	2.103E-14 (7.781E-04)	1.964E+00 (7.267E+10)
I-129	1.995E-06 (7.382E+04)	3.356E-06 (1.242E+05)	5.352E-06 (1.980E+05)
I-130	2.843E+00 (1.052E+11)	3.859E+00 (1.428E+11)	6.702E+00 (2.480E+11)
I-131	4.887E+01 (1.808E+12)	8.686E+01 (3.214E+12)	1.357E+02 (5.021E+12)
I-132	3.739E+01 (1.383E+12)	1.672E+01 (6.186E+11)	5.410E+01 (2.002E+12)
I-133	6.484E+01 (2.399E+12)	9.667E+01 (3.577E+12)	1.615E+02 (5.976E+12)
I-134	5.113E+01 (1.892E+12)	3.473E+00 (1.285E+11)	5.460E+01 (2.020E+12)
I-135	5.503E+01 (2.036E+12)	6.044E+01 (2.236E+12)	1.155E+02 (4.274E+12)
Rb-86m	2.139E-03 (7.914E+07)	2.855E-40 (1.056E-29)	2.139E-03 (7.914E+07)
Rb-86	2.655E-01 (9.824E+09)	5.398E-01 (1.997E+10)	8.053E-01 (2.980E+10)

**Table 7.1-17—{Radionuclide Releases to Atmosphere for Pump Locked Rotor  
Accident (LRA) with Accident-Induced 8.0% Clad Failure}**

(Page 2 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]		
	0 to 2	2 to 8	Total
Rb-88	3.718E+02 (1.376E+13)	5.449E+02 (2.016E+13)	9.167E+02 (3.392E+13)
Rb-89	7.557E+01 (2.796E+12)	1.480E-01 (5.476E+09)	7.572E+01 (2.802E+12)
Cs-134	2.971E+01 (1.099E+12)	6.089E+01 (2.253E+12)	9.061E+01 (3.353E+12)
Cs-136	7.377E+00 (2.729E+11)	1.495E+01 (5.532E+11)	2.232E+01 (8.258E+11)
Cs-137	1.134E+01 (4.196E+11)	2.325E+01 (8.603E+11)	3.460E+01 (1.280E+12)
Cs-138	2.418E+02 (8.947E+12)	2.320E+01 (8.584E+11)	2.650E+02 (9.805E+12)
Sr-89	2.770E-02 (1.025E+09)	1.157E-01 (4.281E+09)	1.434E-01 (5.306E+09)
Ba-137m	8.491E+00 (3.142E+11)	2.200E+01 (8.140E+11)	3.049E+01 (1.128E+12)
Total	3.844E+03 (1.422E+14)	6.216E+03 (2.300E+14)	1.006E+04 (3.722E+14)

**Table 7.1-18—{Radionuclide Releases to Atmosphere for Design-Basis Small Line Break}**

[Rupture of 1/4" NSS sampling line outside primary containment]

<b>Nuclide</b>	<b>Total Release to Atmosphere, Ci (Bq) [0 - 2 hr]</b>
Kr-83m	1.653E+00 (6.116E+10)
Kr-85m	7.066E+00 (2.614E+11)
Kr-85	6.827E+01 (2.526E+12)
Kr-87	3.672E+00 (1.359E+11)
Kr-88	1.247E+01 (4.614E+11)
Kr-89	4.810E-02 (1.780E+09)
Xe-131m	1.389E+01 (5.139E+11)
Xe-133m	1.750E+01 (6.475E+11)
Xe-133	1.219E+03 (4.510E+13)
Xe-135m	1.652E+02 (6.112E+12)
Xe-135	6.941E+01 (2.568E+12)
Xe-137	1.093E-01 (4.044E+09)
Xe-138	1.111E+00 (4.111E+10)
Br-83	1.514E-01 (5.602E+09)
Br-84	6.319E-02 (2.338E+09)
Br-85	1.447E-03 (5.354E+07)
I-129	2.360E-07 (8.732E+03)
I-130	2.521E-01 (9.328E+09)
I-131	9.400E+01 (3.478E+12)
I-132	1.132E+02 (4.188E+12)
I-133	1.828E+02 (6.764E+12)
I-134	1.347E+02 (4.984E+12)
I-135	1.502E+02 (5.557E+12)
Rb-86	1.881E-02 (6.960E+08)
Rb-88	5.174E+00 (1.914E+11)
Rb-89	1.458E-01 (5.395E+09)
Cs-134	2.150E+00 (7.955E+10)
Cs-136	5.140E-01 (1.902E+10)
Cs-137	8.228E-01 (3.044E+10)
Cs-138	1.032E+00 (3.818E+10)
Sr-89	2.485E-05 (9.195E+05)
Ba-137m	7.775E-01 (2.877E+10)
Total	2.265E+03 (8.381E+13)

**Table 7.1-19—{Radionuclide Releases to Atmosphere for SGTR with Pre-Accident Iodine Spike}**

(Page 1 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]					
	0 to 2	2 to 8	8 to 24	24 to 96	96 to 720	Total
Kr-83m	5.579E+01 (2.064E+12)	5.208E+01 (1.927E+12)	1.113E+01 (4.118E+11)	1.110E-01 (4.107E+09)	1.024E-10 (3.789E+00)	1.191E+02 (4.407E+12)
Kr-85m	2.745E+01 (1.016E+12)	9.737E-02 (3.603E+09)	5.647E-02 (2.089E+09)	5.168E-03 (1.912E+08)	7.391E-08 (2.735E+03)	2.761E+01 (1.022E+12)
Kr-85	2.693E+02 (9.964E+12)	1.875E+00 (6.938E+10)	4.878E+00 (1.805E+11)	2.172E+01 (8.036E+11)	1.734E+02 (6.416E+12)	4.711E+02 (1.743E+13)
Kr-87	1.365E+01 (5.051E+11)	1.170E-02 (4.329E+08)	4.390E-04 (1.624E+07)	7.132E-08 (2.639E+03)	6.326E-25 (2.341E-14)	1.366E+01 (5.054E+11)
Kr-88	4.786E+01 (1.771E+12)	1.186E-01 (4.388E+09)	3.368E-02 (1.246E+09)	6.881E-04 (2.546E+07)	1.565E-11 (5.791E-01)	4.801E+01 (1.776E+12)
Kr-89	1.260E-01 (4.662E+09)	4.744E-16 (1.755E-05)	2.768E-50 (1.024E-39)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	1.260E-01 (4.662E+09)
Xe-131m	5.483E+01 (2.029E+12)	7.018E-01 (2.597E+10)	1.810E+00 (6.697E+10)	7.458E+00 (2.759E+11)	3.116E+01 (1.153E+12)	9.596E+01 (3.551E+12)
Xe-133m	7.072E+01 (2.617E+12)	7.102E+00 (2.628E+11)	1.379E+01 (5.102E+11)	2.108E+01 (7.800E+11)	4.983E+00 (1.844E+11)	1.177E+02 (4.355E+12)
Xe-133	4.829E+03 (1.787E+14)	1.262E+02 (4.669E+12)	2.600E+02 (9.620E+12)	5.499E+02 (2.035E+13)	6.459E+02 (2.390E+13)	6.411E+03 (2.372E+14)
Xe-135m	1.530E+03 (5.661E+13)	3.263E+03 (1.207E+14)	3.062E+03 (1.133E+14)	7.187E+02 (2.659E+13)	4.064E-01 (1.504E+10)	8.574E+03 (3.172E+14)
Xe-135	4.299E+02 (1.591E+13)	5.069E+02 (1.876E+13)	4.845E+02 (1.793E+13)	1.206E+02 (4.462E+12)	1.232E-01 (4.558E+09)	1.542E+03 (5.705E+13)
Xe-137	2.887E-01 (1.068E+10)	9.932E-14 (3.675E-03)	4.492E-42 (1.662E-31)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	2.887E-01 (1.068E+10)
Xe-138	3.434E+00 (1.271E+11)	9.959E-06 (3.685E+05)	2.041E-13 (7.552E-03)	8.199E-34 (3.034E-23)	0.000E+00 (0.000E+00)	3.434E+00 (1.271E+11)
Br-83	2.004E+00 (7.415E+10)	2.840E-03 (1.051E+08)	7.849E-04 (2.904E+07)	1.620E-05 (5.994E+05)	4.395E-14 (1.626E-03)	2.008E+00 (7.430E+10)
Br-84	5.904E-01 (2.184E+10)	4.270E-05 (1.580E+06)	1.939E-08 (7.174E+02)	4.027E-17 (1.490E-06)	1.788E-57 (6.616E-47)	5.904E-01 (2.184E+10)
Br-85	6.852E-04 (2.535E+07)	1.190E-18 (4.403E-08)	2.448E-56 (9.058E-46)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	6.852E-04 (2.535E+07)
I-129	3.454E-06 (1.278E+05)	1.964E-08 (7.267E+02)	8.140E-08 (3.012E+03)	1.077E-06 (3.985E+04)	4.192E-05 (1.551E+06)	4.655E-05 (1.722E+06)
I-130	3.616E+00 (1.338E+11)	1.503E-02 (5.561E+08)	3.374E-02 (1.248E+09)	5.191E-02 (1.921E+09)	2.304E-03 (8.525E+07)	3.719E+00 (1.376E+11)
I-131	5.578E+01 (2.064E+12)	3.103E-01 (1.148E+10)	1.236E+00 (4.573E+10)	1.376E+01 (5.091E+11)	1.542E+02 (5.705E+12)	2.253E+02 (8.336E+12)
I-132	2.339E+01 (8.654E+11)	3.417E-02 (1.264E+09)	8.312E-03 (3.075E+08)	1.407E-04 (5.206E+06)	1.667E-13 (6.168E-03)	2.343E+01 (8.669E+11)
I-133	9.220E+01 (3.411E+12)	4.337E-01 (1.605E+10)	1.242E+00 (4.595E+10)	3.997E+00 (1.479E+11)	9.448E-01 (3.496E+10)	9.882E+01 (3.656E+12)
I-134	1.140E+01 (4.218E+11)	3.079E-03 (1.139E+08)	3.155E-05 (1.167E+06)	2.442E-10 (9.035E+00)	1.584E-34 (5.861E-24)	1.140E+01 (4.218E+11)
I-135	5.584E+01 (2.066E+12)	1.805E-01 (6.679E+09)	2.463E-01 (9.113E+09)	1.167E-01 (4.318E+09)	1.685E-04 (6.235E+06)	5.639E+01 (2.086E+12)
Rb-86	4.589E-03 (1.698E+08)	2.766E-05 (1.023E+06)	1.086E-04 (4.018E+06)	1.305E-03 (4.829E+07)	2.814E-02 (1.041E+09)	3.417E-02 (1.264E+09)
Rb-88	1.105E+00 (4.089E+10)	1.286E-03 (4.758E+07)	6.410E-04 (2.372E+07)	2.976E-05 (1.101E+06)	2.261E-12 (8.366E-02)	1.107E+00 (4.096E+10)

**Table 7.1-19—{Radionuclide Releases to Atmosphere for SGTR with Pre-Accident Iodine Spike}**

(Page 2 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]					
	0 to 2	2 to 8	8 to 24	24 to 96	96 to 720	Total
Rb-89	1.257E-02 (4.651E+08)	4.677E-08 (1.730E+03)	4.331E-15 (1.602E-04)	1.140E-33 (4.218E-23)	0.000E+00 (0.000E+00)	1.257E-02 (4.651E+08)
Cs-134	5.246E-01 (1.941E+10)	3.196E-03 (1.183E+08)	1.275E-02 (4.718E+08)	1.648E-01 (6.098E+09)	6.259E+00 (2.316E+11)	6.964E+00 (2.577E+11)
Cs-136	1.253E-01 (4.636E+09)	7.520E-04 (2.782E+07)	2.931E-03 (1.084E+08)	3.415E-02 (1.264E+09)	5.875E-01 (2.174E+10)	7.507E-01 (2.778E+10)
Cs-137	2.008E-01 (7.430E+09)	1.224E-03 (4.529E+07)	4.884E-03 (1.807E+08)	6.322E-02 (2.339E+09)	2.436E+00 (9.013E+10)	2.706E+00 (1.001E+11)
Cs-138	1.397E-01 (5.169E+09)	9.813E-06 (3.631E+05)	5.129E-09 (1.898E+02)	1.405E-17 (5.199E-07)	2.046E-57 (7.570E-47)	1.397E-01 (5.169E+09)
Ba-137m	1.883E-01 (6.967E+09)	1.148E-03 (4.248E+07)	4.579E-03 (1.694E+08)	5.927E-02 (2.193E+09)	2.284E+00 (8.451E+10)	2.537E+00 (9.387E+10)
Total	7.580E+03 (2.805E+14)	3.959E+03 (1.465E+14)	3.841E+03 (1.421E+14)	1.458E+03 (5.395E+13)	1.023E+03 (3.785E+13)	1.786E+04 (6.608E+14)

**Table 7.1-20—{Radionuclide Releases to Atmosphere for SGTR with Concurrent Iodine Spike}**

(Page 1 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]					
	0 to 2	2 to 8	8 to 24	24 to 96	96 to 720	Total
Kr-83m	5.286E+01 (1.956E+12)	6.506E+01 (2.407E+12)	2.614E+01 (9.672E+11)	5.395E-01 (1.996E+10)	1.229E-09 (4.547E+01)	1.446E+02 (5.350E+12)
Kr-85m	2.938E+01 (1.087E+12)	2.475E-01 (9.158E+09)	2.560E-01 (9.472E+09)	2.342E-02 (8.665E+08)	3.350E-07 (1.240E+04)	2.990E+01 (1.106E+12)
Kr-85	2.693E+02 (9.964E+12)	1.875E+00 (6.938E+10)	4.878E+00 (1.805E+11)	2.172E+01 (8.036E+11)	1.734E+02 (6.416E+12)	4.711E+02 (1.743E+13)
Kr-87	1.365E+01 (5.051E+11)	1.170E-02 (4.329E+08)	4.390E-04 (1.624E+07)	7.132E-08 (2.639E+03)	6.326E-25 (2.341E-14)	1.366E+01 (5.054E+11)
Kr-88	4.786E+01 (1.771E+12)	1.186E-01 (4.388E+09)	3.368E-02 (1.246E+09)	6.881E-04 (2.546E+07)	1.565E-11 (5.791E-01)	4.801E+01 (1.776E+12)
Kr-89	1.260E-01 (4.662E+09)	4.744E-16 (1.755E-05)	2.768E-50 (1.024E-39)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	1.260E-01 (4.662E+09)
Xe-131m	5.476E+01 (2.026E+12)	5.269E-01 (1.950E+10)	1.550E+00 (5.735E+10)	9.473E+00 (3.505E+11)	8.667E+01 (3.207E+12)	1.530E+02 (5.661E+12)
Xe-133m	6.924E+01 (2.562E+12)	4.025E+00 (1.489E+11)	1.188E+01 (4.396E+11)	4.107E+01 (1.520E+12)	2.417E+01 (8.943E+11)	1.504E+02 (5.565E+12)
Xe-133	4.808E+03 (1.779E+14)	8.294E+01 (3.069E+12)	2.349E+02 (8.691E+12)	9.134E+02 (3.380E+13)	1.558E+03 (5.765E+13)	7.597E+03 (2.811E+14)
Xe-135m	9.009E+02 (3.333E+13)	2.273E+03 (8.410E+13)	2.859E+03 (1.058E+14)	1.054E+03 (3.900E+13)	1.262E+00 (4.669E+10)	7.088E+03 (2.623E+14)
Xe-135	3.154E+02 (1.167E+13)	3.712E+02 (1.373E+13)	6.204E+02 (2.295E+13)	3.471E+02 (1.284E+13)	1.427E+00 (5.280E+10)	1.655E+03 (6.124E+13)
Xe-137	2.887E-01 (1.068E+10)	9.932E-14 (3.675E-03)	4.492E-42 (1.662E-31)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	2.887E-01 (1.068E+10)
Xe-138	3.434E+00 (1.271E+11)	9.959E-06 (3.685E+05)	2.041E-13 (7.552E-03)	8.199E-34 (3.034E-23)	0.000E+00 (0.000E+00)	3.434E+00 (1.271E+11)
Br-83	3.105E+00 (1.149E+11)	2.064E-02 (7.637E+08)	3.304E-02 (1.222E+09)	1.187E-03 (4.392E+07)	4.062E-12 (1.503E-01)	3.159E+00 (1.169E+11)
Br-84	3.844E+00 (1.422E+11)	4.306E-03 (1.593E+08)	7.921E-04 (2.931E+07)	7.298E-12 (2.700E-01)	4.404E-52 (1.629E-41)	3.849E+00 (1.424E+11)
Br-85	7.119E-01 (2.634E+10)	4.381E-05 (1.621E+06)	6.904E-07 (2.554E+04)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	7.120E-01 (2.634E+10)
I-129	1.942E-06 (7.185E+04)	3.838E-08 (1.420E+03)	4.662E-07 (1.725E+04)	9.049E-06 (3.348E+05)	3.973E-04 (1.470E+07)	4.088E-04 (1.513E+07)
I-130	2.679E+00 (9.912E+10)	3.998E-02 (1.479E+09)	3.041E-01 (1.125E+10)	6.765E-01 (2.503E+10)	3.436E-02 (1.271E+09)	3.734E+00 (1.382E+11)
I-131	3.199E+01 (1.184E+12)	6.194E-01 (2.292E+10)	7.305E+00 (2.703E+11)	1.192E+02 (4.410E+12)	1.500E+03 (5.550E+13)	1.659E+03 (6.138E+13)
I-132	3.721E+01 (1.377E+12)	2.421E-01 (8.958E+09)	3.626E-01 (1.342E+10)	1.103E-02 (4.081E+08)	1.671E-11 (6.183E-01)	3.782E+01 (1.399E+12)
I-133	6.155E+01 (2.277E+12)	1.022E+00 (3.781E+10)	9.383E+00 (3.472E+11)	4.389E+01 (1.624E+12)	1.163E+01 (4.303E+11)	1.275E+02 (4.718E+12)
I-134	4.170E+01 (1.543E+12)	9.438E-02 (3.492E+09)	3.336E-02 (1.234E+09)	7.756E-07 (2.870E+04)	6.711E-31 (2.483E-20)	4.183E+01 (1.548E+12)
I-135	5.032E+01 (1.862E+12)	6.126E-01 (2.267E+10)	3.161E+00 (1.170E+11)	2.185E+00 (8.085E+10)	3.747E-03 (1.386E+08)	5.629E+01 (2.083E+12)
Rb-86	4.589E-03 (1.698E+08)	2.766E-05 (1.023E+06)	1.086E-04 (4.018E+06)	1.305E-03 (4.829E+07)	2.814E-02 (1.041E+09)	3.417E-02 (1.264E+09)
Rb-88	1.105E+00 (4.089E+10)	1.286E-03 (4.758E+07)	6.410E-04 (2.372E+07)	2.976E-05 (1.101E+06)	2.261E-12 (8.366E-02)	1.107E+00 (4.096E+10)

**Table 7.1-20—{Radionuclide Releases to Atmosphere for SGTR with Concurrent Iodine Spike}**

(Page 2 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]					
	0 to 2	2 to 8	8 to 24	24 to 96	96 to 720	Total
Rb-89	1.257E-02 (4.651E+08)	4.677E-08 (1.730E+03)	4.331E-15 (1.602E-04)	1.140E-33 (4.218E-23)	0.000E+00 (0.000E+00)	1.257E-02 (4.651E+08)
Cs-134	5.246E-01 (1.941E+10)	3.196E-03 (1.183E+08)	1.275E-02 (4.718E+08)	1.648E-01 (6.098E+09)	6.259E+00 (2.316E+11)	6.964E+00 (2.577E+11)
Cs-136	1.253E-01 (4.636E+09)	7.520E-04 (2.782E+07)	2.931E-03 (1.084E+08)	3.415E-02 (1.264E+09)	5.875E-01 (2.174E+10)	7.507E-01 (2.778E+10)
Cs-137	2.008E-01 (7.430E+09)	1.224E-03 (4.529E+07)	4.884E-03 (1.807E+08)	6.322E-02 (2.339E+09)	2.436E+00 (9.013E+10)	2.706E+00 (1.001E+11)
Cs-138	1.397E-01 (5.169E+09)	9.813E-06 (3.631E+05)	5.129E-09 (1.898E+02)	1.405E-17 (5.199E-07)	2.046E-57 (7.570E-47)	1.397E-01 (5.169E+09)
Ba-137m	1.883E-01 (6.967E+09)	1.148E-03 (4.248E+07)	4.579E-03 (1.694E+08)	5.927E-02 (2.193E+09)	2.284E+00 (8.451E+10)	2.537E+00 (9.387E+10)
Total	6.801E+03 (2.516E+14)	2.802E+03 (1.037E+14)	3.780E+03 (1.399E+14)	2.554E+03 (9.450E+13)	3.368E+03 (1.246E+14)	1.930E+04 (7.141E+14)

**Table 7.1-21—{Radionuclide Releases to Atmosphere for Design Basis LOCA}**

(Page 1 of 4)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]						
	0 to 1.5	1.5 to 3.5	3.5 to 8	8 to 24	24 to 96	96 to 720	Total
Kr-83m	7.297E+02 (2.700E+13)	2.751E+03 (1.018E+14)	4.641E+03 (1.717E+14)	4.187E+03 (1.549E+14)	1.072E+02 (3.966E+12)	3.150E-07 (1.166E+04)	1.242E+04 (4.595E+14)
Kr-85m	1.709E+03 (6.323E+13)	6.303E+03 (2.332E+14)	8.876E+03 (3.284E+14)	8.074E+03 (2.987E+14)	3.703E+02 (1.370E+13)	5.366E-03 (1.985E+08)	2.533E+04 (9.372E+14)
Kr-85	1.126E+02 (4.166E+12)	4.307E+02 (1.594E+13)	9.847E+02 (3.643E+13)	3.497E+03 (1.294E+14)	7.845E+03 (2.903E+14)	6.661E+04 (2.465E+15)	7.948E+04 (2.941E+15)
Kr-87	2.224E+03 (8.229E+13)	4.925E+03 (1.822E+14)	2.337E+03 (8.647E+13)	2.199E+02 (8.136E+12)	1.791E-02 (6.627E+08)	1.613E-19 (5.968E-09)	9.706E+03 (3.591E+14)
Kr-88	4.382E+03 (1.621E+14)	1.434E+04 (5.306E+14)	1.548E+04 (5.728E+14)	7.580E+03 (2.805E+14)	7.766E+01 (2.873E+12)	1.794E-06 (6.638E+04)	4.186E+04 (1.549E+15)
Kr-89	9.523E+00 (3.524E+11)	3.044E-06 (1.126E+05)	1.461E-17 (5.406E-07)	3.346E-43 (1.238E-32)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	9.523E+00 (3.524E+11)
Xe-131m	7.277E+01 (2.692E+12)	3.151E+02 (1.166E+13)	7.225E+02 (2.673E+13)	2.650E+03 (9.805E+13)	8.448E+03 (3.126E+14)	8.304E+04 (3.072E+15)	9.525E+04 (3.524E+15)
Xe-133m	4.023E+02 (1.489E+13)	1.806E+03 (6.682E+13)	4.148E+03 (1.535E+14)	1.551E+04 (5.739E+14)	3.840E+04 (1.421E+15)	2.689E+04 (9.949E+14)	8.716E+04 (3.225E+15)
Xe-133	1.326E+04 (4.906E+14)	5.898E+04 (2.182E+15)	1.353E+05 (5.006E+15)	4.923E+05 (1.822E+16)	1.172E+06 (4.336E+16)	2.331E+06 (8.625E+16)	4.202E+06 (1.555E+17)
Xe-135m	1.676E+03 (6.201E+13)	1.283E+04 (4.747E+14)	5.187E+04 (1.919E+15)	1.495E+05 (5.532E+15)	6.371E+04 (2.357E+15)	8.257E+01 (3.055E+12)	2.797E+05 (1.035E+16)
Xe-135	4.390E+03 (1.624E+14)	2.130E+04 (7.881E+14)	5.958E+04 (2.204E+15)	2.402E+05 (8.887E+15)	1.708E+05 (6.320E+15)	9.095E+02 (3.365E+13)	4.971E+05 (1.839E+16)
Xe-137	2.238E+01 (8.281E+11)	1.730E-04 (6.401E+06)	7.545E-14 (2.792E-03)	4.529E-35 (1.676E-24)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	2.238E+01 (8.281E+11)
Xe-138	6.229E+02 (2.305E+13)	9.854E+01 (3.646E+12)	3.005E-01 (1.112E+10)	5.518E-07 (2.042E+04)	1.111E-27 (4.111E-17)	0.000E+00 (0.000E+00)	7.217E+02 (2.670E+13)
Br-83	3.714E+00 (1.374E+11)	7.476E+00 (2.766E+11)	5.922E+00 (2.191E+11)	1.578E+00 (5.839E+10)	9.943E-03 (3.679E+08)	7.939E-12 (2.937E-01)	1.870E+01 (6.919E+11)
Br-84	3.206E+00 (1.186E+11)	1.399E+00 (5.176E+10)	1.010E-01 (3.737E+09)	2.106E-04 (7.792E+06)	1.010E-13 (3.737E-03)	1.200E-54 (4.440E-44)	4.706E+00 (1.741E+11)
Br-85	7.005E-01 (2.592E+10)	3.783E-10 (1.400E+01)	1.011E-22 (3.741E-12)	3.330E-51 (1.232E-40)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	7.005E-01 (2.592E+10)
I-129	2.143E-06 (7.929E+04)	6.460E-06 (2.390E+05)	1.204E-05 (4.455E+05)	2.778E-05 (1.028E+06)	8.971E-05 (3.319E+06)	6.739E-04 (2.493E+07)	8.120E-04 (3.004E+07)
I-130	3.160E+00 (1.169E+11)	8.910E+00 (3.297E+11)	1.395E+01 (5.162E+11)	1.919E+01 (7.100E+11)	9.181E+00 (3.397E+11)	1.557E-01 (5.761E+09)	5.455E+01 (2.018E+12)
I-131	3.558E+01 (1.316E+12)	1.070E+02 (3.959E+12)	1.971E+02 (7.293E+12)	4.395E+02 (1.626E+13)	1.216E+03 (4.499E+13)	3.310E+03 (1.225E+14)	5.305E+03 (1.963E+14)
I-132	3.928E+01 (1.453E+12)	8.453E+01 (3.128E+12)	8.515E+01 (3.151E+12)	8.672E+01 (3.209E+12)	1.646E+02 (6.090E+12)	1.700E+02 (6.290E+12)	6.303E+02 (2.332E+13)
I-133	7.134E+01 (2.640E+12)	2.071E+02 (7.663E+12)	3.479E+02 (1.287E+13)	5.859E+02 (2.168E+13)	5.389E+02 (1.994E+13)	5.089E+01 (1.883E+12)	1.802E+03 (6.667E+13)
I-134	4.192E+01 (1.551E+12)	4.308E+01 (1.594E+12)	1.043E+01 (3.859E+11)	2.466E-01 (9.124E+09)	4.949E-07 (1.831E+04)	8.736E-32 (3.232E-21)	9.568E+01 (3.540E+12)
I-135	6.120E+01 (2.264E+12)	1.615E+02 (5.976E+12)	2.183E+02 (8.077E+12)	2.005E+02 (7.419E+12)	3.195E+01 (1.182E+12)	1.584E-02 (5.861E+08)	6.735E+02 (2.492E+13)
Rb-86m	2.457E-04 (9.091E+06)	8.331E-31 (3.082E-20)	2.805E-66 (1.038E-55)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	0.000E+00 (0.000E+00)	2.457E-04 (9.091E+06)
Rb-86	1.268E-01 (4.692E+09)	3.249E-01 (1.202E+10)	5.175E-01 (1.915E+10)	6.158E-01 (2.278E+10)	1.784E-01 (6.601E+09)	3.473E-02 (1.285E+09)	1.798E+00 (6.653E+10)
Rb-88	6.288E+01 (2.327E+12)	1.545E+02 (5.717E+12)	1.636E+02 (6.053E+12)	8.009E+01 (2.963E+12)	8.460E-01 (3.130E+10)	1.980E-08 (7.326E+02)	4.619E+02 (1.709E+13)

**Table 7.1-21—{Radionuclide Releases to Atmosphere for Design Basis LOCA}**

(Page 2 of 4)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]						
	0 to 1.5	1.5 to 3.5	3.5 to 8	8 to 24	24 to 96	96 to 720	Total
Rb-89	1.126E+01 (4.166E+11)	5.235E-01 (1.937E+10)	1.960E-03 (7.252E+07)	4.966E-09 (1.837E+02)	5.198E-29 (1.923E-18)	0.000E+00 (0.000E+00)	1.178E+01 (4.359E+11)
Cs-134	1.418E+01 (5.247E+11)	3.636E+01 (1.345E+12)	5.818E+01 (2.153E+12)	7.012E+01 (2.594E+12)	2.128E+01 (7.874E+11)	5.202E+00 (1.925E+11)	2.053E+02 (7.596E+12)
Cs-136	3.511E+00 (1.299E+11)	9.004E+00 (3.331E+11)	1.431E+01 (5.295E+11)	1.694E+01 (6.268E+11)	4.810E+00 (1.780E+11)	8.548E-01 (3.163E+10)	4.943E+01 (1.829E+12)
Cs-137	5.419E+00 (2.005E+11)	1.389E+01 (5.139E+11)	2.223E+01 (8.225E+11)	2.679E+01 (9.912E+11)	8.142E+00 (3.013E+11)	2.002E+00 (7.407E+10)	7.848E+01 (2.904E+12)
Cs-138	4.511E+01 (1.669E+12)	2.603E+01 (9.631E+11)	1.839E+00 (6.804E+10)	3.106E-03 (1.149E+08)	3.645E-13 (1.349E-02)	3.186E-55 (1.179E-44)	7.298E+01 (2.700E+12)
Sb-125	7.674E-02 (2.839E+09)	3.605E-01 (1.334E+10)	5.787E-01 (2.141E+10)	6.973E-01 (2.580E+10)	2.117E-01 (7.833E+09)	5.185E-02 (1.918E+09)	1.977E+00 (7.315E+10)
Sb-127	3.566E-01 (1.319E+10)	1.658E+00 (6.135E+10)	2.602E+00 (9.627E+10)	2.947E+00 (1.090E+11)	7.152E-01 (2.646E+10)	6.814E-02 (2.521E+09)	8.347E+00 (3.088E+11)
Sb-129	8.062E-01 (2.983E+10)	3.074E+00 (1.137E+11)	3.076E+00 (1.138E+11)	1.172E+00 (4.336E+10)	1.262E-02 (4.669E+08)	9.903E-09 (3.664E+02)	8.142E+00 (3.013E+11)
Te-127m	5.087E-02 (1.882E+09)	2.290E-01 (8.473E+09)	3.677E-01 (1.360E+10)	4.432E-01 (1.640E+10)	1.345E-01 (4.977E+09)	3.221E-02 (1.192E+09)	1.257E+00 (4.651E+10)
Te-127	3.679E-01 (1.361E+10)	1.678E+00 (6.209E+10)	2.678E+00 (9.909E+10)	3.139E+00 (1.161E+11)	8.103E-01 (2.998E+10)	9.679E-02 (3.581E+09)	8.769E+00 (3.245E+11)
Te-129m	1.475E-01 (5.458E+09)	6.643E-01 (2.458E+10)	1.065E+00 (3.941E+10)	1.276E+00 (4.721E+10)	3.779E-01 (1.398E+10)	8.132E-02 (3.009E+09)	3.612E+00 (1.336E+11)
Te-129	9.137E-01 (3.381E+10)	3.758E+00 (1.390E+11)	4.244E+00 (1.570E+11)	2.219E+00 (8.210E+10)	2.610E-01 (9.657E+09)	5.294E-02 (1.959E+09)	1.145E+01 (4.237E+11)
Te-131m	4.117E-01 (1.523E+10)	1.808E+00 (6.690E+10)	2.706E+00 (1.001E+11)	2.700E+00 (9.990E+10)	4.296E-01 (1.590E+10)	9.844E-03 (3.642E+08)	8.066E+00 (2.984E+11)
Te-131	4.731E-01 (1.750E+10)	6.764E-01 (2.503E+10)	6.180E-01 (2.287E+10)	6.079E-01 (2.249E+10)	9.670E-02 (3.578E+09)	2.216E-03 (8.199E+07)	2.474E+00 (9.154E+10)
Te-132	4.076E+00 (1.508E+11)	1.819E+01 (6.730E+11)	2.841E+01 (1.051E+12)	3.181E+01 (1.177E+12)	7.423E+00 (2.747E+11)	6.147E-01 (2.274E+10)	9.053E+01 (3.350E+12)
Te-134	1.637E+00 (6.057E+10)	2.306E+00 (8.532E+10)	2.992E-01 (1.107E+10)	1.926E-03 (7.126E+07)	2.642E-11 (9.775E-01)	1.491E-43 (5.517E-33)	4.244E+00 (1.570E+11)
Sr-89	1.295E+00 (4.792E+10)	6.070E+00 (2.246E+11)	9.727E+00 (3.599E+11)	1.167E+01 (4.318E+11)	3.484E+00 (1.289E+11)	7.831E-01 (2.897E+10)	3.303E+01 (1.222E+12)
Sr-90	1.352E-01 (5.002E+09)	6.346E-01 (2.348E+10)	1.019E+00 (3.770E+10)	1.228E+00 (4.544E+10)	3.731E-01 (1.380E+10)	9.176E-02 (3.395E+09)	3.481E+00 (1.288E+11)
Sr-91	1.523E+00 (5.635E+10)	6.489E+00 (2.401E+11)	8.369E+00 (3.097E+11)	5.720E+00 (2.116E+11)	3.029E-01 (1.121E+10)	1.462E-04 (5.409E+06)	2.240E+01 (8.288E+11)
Sr-92	1.273E+00 (4.710E+10)	4.299E+00 (1.591E+11)	3.300E+00 (1.221E+11)	7.207E-01 (2.667E+10)	1.556E-03 (5.757E+07)	1.220E-12 (4.514E-02)	9.594E+00 (3.550E+11)
Ba-137m	4.246E+00 (1.571E+11)	1.310E+01 (4.847E+11)	2.103E+01 (7.781E+11)	2.535E+01 (9.380E+11)	7.702E+00 (2.850E+11)	1.894E+00 (7.008E+10)	7.332E+01 (2.713E+12)
Ba-139	1.252E+00 (4.632E+10)	2.933E+00 (1.085E+11)	1.185E+00 (4.385E+10)	7.377E-02 (2.729E+09)	2.809E-06 (1.039E+05)	3.953E-23 (1.463E-12)	5.444E+00 (2.014E+11)
Ba-140	2.011E+00 (7.441E+10)	9.409E+00 (3.481E+11)	1.500E+01 (5.550E+11)	1.775E+01 (6.568E+11)	5.031E+00 (1.861E+11)	8.876E-01 (3.284E+10)	5.008E+01 (1.853E+12)
Mo-99	6.680E-01 (2.472E+10)	1.185E+00 (4.385E+10)	1.843E+00 (6.819E+10)	2.036E+00 (7.533E+10)	4.535E-01 (1.678E+10)	3.193E-02 (1.181E+09)	6.218E+00 (2.301E+11)
Tc-99m	4.054E-01 (1.500E+10)	1.062E+00 (3.929E+10)	1.685E+00 (6.235E+10)	1.916E+00 (7.089E+10)	4.358E-01 (1.612E+10)	3.075E-02 (1.138E+09)	5.535E+00 (2.048E+11)
Ru-103	2.419E-01 (8.950E+09)	1.134E+00 (4.196E+10)	1.816E+00 (6.719E+10)	2.175E+00 (8.048E+10)	6.463E-01 (2.391E+10)	1.417E-01 (5.243E+09)	6.155E+00 (2.277E+11)

**Table 7.1-21—{Radionuclide Releases to Atmosphere for Design Basis LOCA}**

(Page 3 of 4)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]						
	0 to 1.5	1.5 to 3.5	3.5 to 8	8 to 24	24 to 96	96 to 720	Total
Ru-105	1.639E-01 (6.064E+09)	6.263E-01 (2.317E+10)	6.347E-01 (2.348E+10)	2.485E-01 (9.195E+09)	2.881E-03 (1.066E+08)	3.096E-09 (1.146E+02)	1.676E+00 (6.201E+10)
Ru-106	1.433E-01 (5.302E+09)	6.720E-01 (2.486E+10)	1.079E+00 (3.992E+10)	1.299E+00 (4.806E+10)	3.939E-01 (1.457E+10)	9.568E-02 (3.540E+09)	3.683E+00 (1.363E+11)
Rh-103m	2.180E-01 (8.066E+09)	1.022E+00 (3.781E+10)	1.637E+00 (6.057E+10)	1.961E+00 (7.256E+10)	5.827E-01 (2.156E+10)	1.277E-01 (4.725E+09)	5.549E+00 (2.053E+11)
Rh-105	1.753E-01 (6.486E+09)	8.191E-01 (3.031E+10)	1.284E+00 (4.751E+10)	1.375E+00 (5.088E+10)	2.453E-01 (9.076E+09)	7.574E-03 (2.802E+08)	3.907E+00 (1.446E+11)
Rh-106	1.433E-01 (5.302E+09)	6.720E-01 (2.486E+10)	1.079E+00 (3.992E+10)	1.299E+00 (4.806E+10)	3.939E-01 (1.457E+10)	9.568E-02 (3.540E+09)	3.683E+00 (1.363E+11)
Ce-141	4.504E-02 (1.666E+09)	2.100E-01 (7.770E+09)	3.363E-01 (1.244E+10)	4.027E-01 (1.490E+10)	1.191E-01 (4.407E+09)	2.551E-02 (9.439E+08)	1.139E+00 (4.214E+10)
Ce-143	4.473E-02 (1.655E+09)	2.032E-01 (7.518E+09)	3.060E-01 (1.132E+10)	3.105E-01 (1.149E+10)	5.212E-02 (1.928E+09)	1.426E-03 (5.276E+07)	9.179E-01 (3.396E+10)
Ce-144	3.421E-02 (1.266E+09)	1.595E-01 (5.902E+09)	2.560E-01 (9.472E+09)	3.085E-01 (1.141E+10)	9.342E-02 (3.457E+09)	2.261E-02 (8.366E+08)	8.743E-01 (3.235E+10)
Np-239	7.573E-01 (2.802E+10)	3.479E+00 (1.287E+11)	5.379E+00 (1.990E+11)	5.860E+00 (2.168E+11)	1.242E+00 (4.595E+10)	7.389E-02 (2.734E+09)	1.679E+01 (6.212E+11)
Pu-238	2.937E-04 (1.087E+07)	1.371E-03 (5.073E+07)	2.200E-03 (8.140E+07)	2.652E-03 (9.812E+07)	8.060E-04 (2.982E+07)	1.984E-04 (7.341E+06)	7.522E-03 (2.783E+08)
Pu-239	1.236E-05 (4.573E+05)	5.767E-05 (2.134E+06)	9.263E-05 (3.427E+06)	1.118E-04 (4.137E+06)	3.413E-05 (1.263E+06)	8.458E-06 (3.129E+05)	3.171E-04 (1.173E+07)
Pu-240	2.817E-05 (1.042E+06)	1.315E-04 (4.866E+06)	2.110E-04 (7.807E+06)	2.543E-04 (9.409E+06)	7.729E-05 (2.860E+06)	1.901E-05 (7.034E+05)	7.212E-04 (2.668E+07)
Pu-241	5.110E-03 (1.891E+08)	2.385E-02 (8.825E+08)	3.828E-02 (1.416E+09)	4.613E-02 (1.707E+09)	1.402E-02 (5.187E+08)	3.446E-03 (1.275E+08)	1.308E-01 (4.840E+09)
Y-90	3.140E-03 (1.162E+08)	2.339E-02 (8.654E+08)	6.936E-02 (2.566E+09)	1.818E-01 (6.727E+09)	1.423E-01 (5.265E+09)	7.603E-02 (2.813E+09)	4.961E-01 (1.836E+10)
Y-91m	5.663E-01 (2.095E+10)	3.441E+00 (1.273E+11)	5.191E+00 (1.921E+11)	3.634E+00 (1.345E+11)	1.924E-01 (7.119E+09)	9.288E-05 (3.437E+06)	1.302E+01 (4.817E+11)
Y-91	1.652E-02 (6.112E+08)	8.019E-02 (2.967E+09)	1.426E-01 (5.276E+09)	2.021E-01 (7.478E+09)	7.064E-02 (2.614E+09)	1.656E-02 (6.127E+08)	5.286E-01 (1.956E+10)
Y-92	3.112E-01 (1.151E+10)	2.236E+00 (8.273E+10)	3.968E+00 (1.468E+11)	2.181E+00 (8.070E+10)	2.160E-02 (7.992E+08)	1.599E-09 (5.916E+01)	8.719E+00 (3.226E+11)
Y-93	1.749E-02 (6.471E+08)	7.414E-02 (2.743E+09)	9.685E-02 (3.583E+09)	6.832E-02 (2.528E+09)	3.943E-03 (1.459E+08)	2.631E-06 (9.735E+04)	2.607E-01 (9.646E+09)
Zr-95	1.861E-02 (6.886E+08)	8.589E-02 (3.178E+09)	1.377E-01 (5.095E+09)	1.654E-01 (6.120E+09)	4.955E-02 (1.833E+09)	1.135E-02 (4.200E+08)	4.685E-01 (1.733E+10)
Zr-97	1.877E-02 (6.945E+08)	8.243E-02 (3.050E+09)	1.169E-01 (4.325E+09)	1.014E-01 (3.752E+09)	1.051E-02 (3.889E+08)	5.726E-05 (2.119E+06)	3.300E-01 (1.221E+10)
Nb-95	1.862E-02 (6.889E+08)	8.599E-02 (3.182E+09)	1.380E-01 (5.106E+09)	1.664E-01 (6.157E+09)	5.053E-02 (1.870E+09)	1.232E-02 (4.558E+08)	4.719E-01 (1.746E+10)
La-140	6.044E-02 (2.236E+09)	4.868E-01 (1.801E+10)	1.509E+00 (5.583E+10)	3.941E+00 (1.458E+11)	2.736E+00 (1.012E+11)	9.057E-01 (3.351E+10)	9.639E+00 (3.566E+11)
La-141	1.590E-02 (5.883E+08)	5.866E-02 (2.170E+09)	5.613E-02 (2.077E+09)	1.940E-02 (7.178E+08)	1.590E-04 (5.883E+06)	3.935E-11 (1.456E+00)	1.502E-01 (5.557E+09)
La-142	1.132E-02 (4.188E+08)	2.986E-02 (1.105E+09)	1.382E-02 (5.113E+08)	1.118E-03 (4.137E+07)	1.026E-07 (3.796E+03)	7.220E-23 (2.671E-12)	5.612E-02 (2.076E+09)
Pr-143	1.844E-02 (6.823E+08)	8.551E-02 (3.164E+09)	1.384E-01 (5.121E+09)	1.698E-01 (6.283E+09)	5.241E-02 (1.939E+09)	1.030E-02 (3.811E+08)	4.748E-01 (1.757E+10)
Pr-144	3.272E-02 (1.211E+09)	1.590E-01 (5.883E+09)	2.560E-01 (9.472E+09)	3.085E-01 (1.141E+10)	9.343E-02 (3.457E+09)	2.261E-02 (8.366E+08)	8.722E-01 (3.227E+10)

**Table 7.1-21—{Radionuclide Releases to Atmosphere for Design Basis LOCA}**

(Page 4 of 4)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]						
	0 to 1.5	1.5 to 3.5	3.5 to 8	8 to 24	24 to 96	96 to 720	Total
Nd-147	7.658E-03 (2.833E+08)	3.525E-02 (1.304E+09)	5.615E-02 (2.078E+09)	6.621E-02 (2.450E+09)	1.857E-02 (6.871E+08)	3.127E-03 (1.157E+08)	1.870E-01 (6.919E+09)
Am-241	2.343E-06 (8.669E+04)	1.083E-05 (4.007E+05)	1.740E-05 (6.438E+05)	2.105E-05 (7.789E+05)	6.475E-06 (2.396E+05)	1.695E-06 (6.272E+04)	5.978E-05 (2.212E+06)
Cm-242	1.065E-03 (3.941E+07)	4.917E-03 (1.819E+08)	7.889E-03 (2.919E+08)	9.495E-03 (3.513E+08)	2.870E-03 (1.062E+08)	6.862E-04 (2.539E+07)	2.692E-02 (9.960E+08)
Cm-244	5.651E-04 (2.091E+07)	2.610E-03 (9.657E+07)	4.190E-03 (1.550E+08)	5.049E-03 (1.868E+08)	1.534E-03 (5.676E+07)	3.772E-04 (1.396E+07)	1.432E-02 (5.298E+08)
Total	3.005E+04 (1.112E+15)	1.250E+05 (4.625E+15)	2.852E+05 (1.055E+16)	9.254E+05 (3.424E+16)	1.463E+06 (5.413E+16)	2.512E+06 (9.294E+16)	5.341E+06 (1.976E+17)

**Table 7.1-22—{Radionuclide Releases to Atmosphere for Fuel Handling Accident}**

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]					
	0 to 2	2 to 8	8 to 24	24 to 96	96 to 720	Total
Kr-83m	1.437E+00 (5.317E+10)	2.129E-01 (7.877E+09)	4.404E-02 (1.629E+09)	4.294E-04 (1.589E+07)	3.665E-13 (1.356E-02)	1.694E+00 (6.268E+10)
Kr-85m	7.810E+01 (2.890E+12)	3.881E-01 (1.436E+10)	4.693E-08 (1.736E+03)	1.678E-26 (6.209E-16)	0.000E+00 (0.000E+00)	7.849E+01 (2.904E+12)
Kr-85	1.471E+03 (5.443E+13)	9.977E+00 (3.691E+11)	3.052E-06 (1.129E+05)	1.296E-23 (4.795E-13)	0.000E+00 (0.000E+00)	1.481E+03 (5.480E+13)
Kr-87	2.330E-04 (8.621E+06)	5.290E-07 (1.957E+04)	6.148E-15 (2.275E-04)	4.260E-36 (1.576E-25)	0.000E+00 (0.000E+00)	2.335E-04 (8.640E+06)
Kr-88	1.016E+01 (3.759E+11)	4.220E-02 (1.561E+09)	2.983E-09 (1.104E+02)	2.549E-28 (9.431E-18)	0.000E+00 (0.000E+00)	1.020E+01 (3.774E+11)
Xe-131m	5.637E+02 (2.086E+13)	1.475E+01 (5.458E+11)	2.813E+01 (1.041E+12)	1.084E+02 (4.011E+12)	3.282E+02 (1.214E+13)	1.043E+03 (3.859E+13)
Xe-133m	2.609E+03 (9.653E+13)	8.098E+01 (2.996E+12)	1.193E+02 (4.414E+12)	1.540E+02 (5.698E+12)	1.538E+01 (5.691E+11)	2.979E+03 (1.102E+14)
Xe-133	9.442E+04 (3.494E+15)	1.533E+03 (5.672E+13)	1.684E+03 (6.231E+13)	2.174E+03 (8.044E+13)	2.171E+02 (8.033E+12)	1.000E+05 (3.700E+15)
Xe-135m	1.089E+03 (4.029E+13)	1.975E+03 (7.308E+13)	1.834E+03 (6.786E+13)	4.211E+02 (1.558E+13)	2.219E-01 (8.210E+09)	5.319E+03 (1.968E+14)
Xe-135	1.407E+04 (5.206E+14)	7.705E+02 (2.851E+13)	6.412E+02 (2.372E+13)	1.472E+02 (5.446E+12)	7.759E-02 (2.871E+09)	1.563E+04 (5.783E+14)
Xe-138	1.825E-39 (6.753E-29)	3.471E-44 (1.284E-33)	2.388E-58 (8.836E-48)	4.092E-96 (1.514E-85)	0.000E+00 (0.000E+00)	1.825E-39 (6.753E-29)
Br-83	1.610E-03 (5.957E+07)	6.097E-06 (2.256E+05)	3.273E-13 (1.211E-02)	1.343E-32 (4.969E-22)	0.000E+00 (0.000E+00)	1.616E-03 (5.979E+07)
Br-84	2.046E-18 (7.570E-08)	1.009E-21 (3.733E-11)	1.206E-31 (4.462E-21)	4.188E-58 (1.550E-47)	0.000E+00 (0.000E+00)	2.047E-18 (7.574E-08)
I-129	1.459E-05 (5.398E+05)	9.898E-08 (3.662E+03)	3.028E-14 (1.120E-03)	1.286E-31 (4.758E-21)	0.000E+00 (0.000E+00)	1.469E-05 (5.435E+05)
I-130	3.363E+00 (1.244E+11)	2.038E-02 (7.541E+08)	4.453E-09 (1.648E+02)	7.713E-27 (2.854E-16)	0.000E+00 (0.000E+00)	3.383E+00 (1.252E+11)
I-131	3.443E+02 (1.274E+13)	2.319E+00 (8.580E+10)	6.942E-07 (2.569E+04)	2.784E-24 (1.030E-13)	0.000E+00 (0.000E+00)	3.466E+02 (1.282E+13)
I-132	1.118E-02 (4.137E+08)	4.139E-05 (1.531E+06)	2.076E-12 (7.681E-02)	7.100E-32 (2.627E-21)	0.000E+00 (0.000E+00)	1.122E-02 (4.151E+08)
I-133	1.615E+02 (5.976E+12)	1.025E+00 (3.793E+10)	2.567E-07 (9.498E+03)	6.398E-25 (2.367E-14)	0.000E+00 (0.000E+00)	1.625E+02 (6.013E+12)
I-134	8.997E-10 (3.329E+01)	1.249E-12 (4.621E-02)	3.325E-21 (1.230E-10)	4.528E-44 (1.675E-33)	0.000E+00 (0.000E+00)	9.009E-10 (3.333E+01)
I-135	1.282E+01 (4.743E+11)	7.041E-02 (2.605E+09)	1.148E-08 (4.248E+02)	9.113E-27 (3.372E-16)	0.000E+00 (0.000E+00)	1.289E+01 (4.769E+11)
Rb-88	4.884E+00 (1.807E+11)	4.672E-02 (1.729E+09)	3.332E-09 (1.233E+02)	2.846E-28 (1.053E-17)	0.000E+00 (0.000E+00)	4.931E+00 (1.824E+11)
Cs-138	6.206E-40 (2.296E-29)	1.019E-42 (3.770E-32)	1.379E-52 (5.102E-42)	6.210E-79 (2.298E-68)	0.000E+00 (0.000E+00)	6.216E-40 (2.300E-29)
Total	1.148E+05 (4.248E+15)	4.388E+03 (1.624E+14)	4.307E+03 (1.594E+14)	3.005E+03 (1.112E+14)	5.610E+02 (2.076E+13)	1.271E+05 (4.703E+15)

**Table 7.1-23—{Radionuclide Releases to Atmosphere for Rod Ejection Accident (REA)  
with Accident-Induced 26% Clad Failure}**

(Page 1 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]		
	0 to 2	2 to 8	Total
Kr-83m	4.713E+02 (1.744E+13)	3.879E+02 (1.435E+13)	8.592E+02 (3.179E+13)
Kr-85m	1.326E+03 (4.906E+13)	2.209E+03 (8.173E+13)	3.535E+03 (1.308E+14)
Kr-85	7.302E+01 (2.702E+12)	2.188E+02 (8.096E+12)	2.918E+02 (1.080E+13)
Kr-87	1.878E+03 (6.949E+13)	9.137E+02 (3.381E+13)	2.791E+03 (1.033E+14)
Kr-88	3.466E+03 (1.282E+14)	4.228E+03 (1.564E+14)	7.695E+03 (2.847E+14)
Kr-89	2.102E+02 (7.777E+12)	8.446E-10 (3.125E+01)	2.102E+02 (7.777E+12)
Xe-131m	5.278E+01 (1.953E+12)	1.566E+02 (5.794E+12)	2.094E+02 (7.748E+12)
Xe-133m	3.008E+02 (1.113E+13)	8.563E+02 (3.168E+13)	1.157E+03 (4.281E+13)
Xe-133	9.847E+03 (3.643E+14)	2.890E+04 (1.069E+15)	3.875E+04 (1.434E+15)
Xe-135m	3.493E+02 (1.292E+13)	6.359E+01 (2.353E+12)	4.129E+02 (1.528E+13)
Xe-135	2.976E+03 (1.101E+14)	6.805E+03 (2.518E+14)	9.781E+03 (3.619E+14)
Xe-137	3.971E+02 (1.469E+13)	1.468E-07 (5.432E+03)	3.971E+02 (1.469E+13)
Xe-138	1.423E+03 (5.265E+13)	4.026E+00 (1.490E+11)	1.427E+03 (5.280E+13)
Br-83	2.318E+00 (8.577E+10)	1.109E+01 (4.103E+11)	1.341E+01 (4.962E+11)
Br-84	1.340E+00 (4.958E+10)	4.784E-01 (1.770E+10)	1.818E+00 (6.727E+10)
Br-85	1.816E-02 (6.719E+08)	1.358E-13 (5.025E-03)	1.816E-02 (6.719E+08)
I-129	1.451E-06 (5.369E+04)	2.134E-05 (7.896E+05)	2.279E-05 (8.432E+05)
I-130	2.119E+00 (7.840E+10)	2.472E+01 (9.146E+11)	2.684E+01 (9.931E+11)
I-131	2.406E+01 (8.902E+11)	3.485E+02 (1.289E+13)	3.726E+02 (1.379E+13)
I-132	2.343E+01 (8.669E+11)	1.077E+02 (3.985E+12)	1.311E+02 (4.851E+12)
I-133	4.811E+01 (1.780E+12)	6.162E+02 (2.280E+13)	6.643E+02 (2.458E+13)
I-134	2.052E+01 (7.592E+11)	2.249E+01 (8.321E+11)	4.300E+01 (1.591E+12)
I-135	4.045E+01 (1.497E+12)	3.877E+02 (1.434E+13)	4.282E+02 (1.584E+13)
Rb-86m	3.435E-06 (1.271E+05)	9.253E-40 (3.424E-29)	3.435E-06 (1.271E+05)
Rb-86	1.192E-01 (4.410E+09)	1.756E+00 (6.497E+10)	1.876E+00 (6.941E+10)

**Table 7.1-23—{Radionuclide Releases to Atmosphere for Rod Ejection Accident (REA)  
with Accident-Induced 26% Clad Failure}**

(Page 2 of 2)

Nuclide	Releases to Atmosphere [Ci (Bq)] During Specified Time Intervals [hrs]		
	0 to 2	2 to 8	Total
Rb-88	2.836E+03 (1.049E+14)	4.711E+03 (1.743E+14)	7.548E+03 (2.793E+14)
Rb-89	2.112E+02 (7.814E+12)	1.177E+00 (4.355E+10)	2.124E+02 (7.859E+12)
Cs-134	1.337E+01 (4.947E+11)	1.981E+02 (7.330E+12)	2.114E+02 (7.822E+12)
Cs-136	3.309E+00 (1.224E+11)	4.861E+01 (1.799E+12)	5.192E+01 (1.921E+12)
Cs-137	5.096E+00 (1.886E+11)	7.554E+01 (2.795E+12)	8.064E+01 (2.984E+12)
Cs-138	1.250E+03 (4.625E+13)	1.935E+02 (7.160E+12)	1.443E+03 (5.339E+13)
Sr-89	1.940E-01 (7.178E+09)	8.238E-01 (3.048E+10)	1.018E+00 (3.767E+10)
Ba-137m	4.812E+00 (1.780E+11)	7.146E+01 (2.644E+12)	7.627E+01 (2.822E+12)
Total	2.726E+04 (1.009E+15)	5.156E+04 (1.908E+15)	7.882E+04 (2.916E+15)

## 7.2 SEVERE ACCIDENTS

This section evaluates the potential environmental impacts of severe accidents from the U.S. EPR plant. The environmental impacts from a postulated severe accident have been estimated using {Callaway Plant} site-specific data to demonstrate acceptability for a Combined License (COL) Application.

Severe accidents are defined as accidents with substantial damage to the reactor core and degradation of containment systems. Because the probability of a severe accident is very low for the U.S. EPR, such accidents are not part of the design basis for the plant. However, the Nuclear Regulatory Commission (NRC) requires, in its Policy Statement on Severe Reactor Accidents Regarding Future Designs and Existing Plants (FR, 1985), the completion of a probabilistic risk assessment (PRA) for severe accidents for new reactor designs. This requirement is codified in regulation 10 CFR 52.47, Contents of Applications (CFR, 2007).

A PRA was completed for the U.S. EPR as part of the application for design certification. This section presents the applicable results of the probabilistic risk assessment and includes site-specific characteristics of the {Callaway Plant} site and impacts of a severe accident over the entire life cycle. The purpose of this report is to identify the severe accident offsite radiological impacts, demonstrate that the impacts are acceptable, and support the severe accident mitigation alternatives analyses in Section 7.3.

### 7.2.1 METHODOLOGY

#### 7.2.1.1 Offsite Consequences

The probabilistic risk assessment for the U.S. EPR established containment event trees that define the possible end states of the containment following an accident sequence. The end states are grouped into five broad categories as follows:

1. Containment intact, isolated and not bypassed (RC 101)
2. Containment bypassed (RC 701, 702, 802)
3. Containment not isolated (isolation failure) (RC 201-206)
4. Early failures (excluding not isolated and bypassed) (RC 301-304, 401-404)
5. Late containment failures (RC 501-504, 602)

Using the Electric Power Research Institute code Modular Accident Analysis Program (MAAP), 23 release consequence (RC) categories are assigned to represent all potential severe accident release scenarios. The release categories are described in [Table 7.2-1](#). An accident frequency (release category frequency) is assigned to each of the 23 categories, and these are shown in [Table 7.2-3](#). The results from the U.S. EPR base case are applicable to {Callaway Plant Unit 2}.

The NRC code MACCS2 (Sandia, 1997) was used to model the environmental consequences of the severe accidents. MACCS2 was developed specifically for NRC to evaluate severe accidents at nuclear power plants. The exposure pathways modeled include external exposure to the passing plume, external exposure to material deposited on the ground, inhalation of material in the passing plume or resuspended from the ground, and ingestion of contaminated food and surface water.

The MACCS2 code primarily addresses dose from the air pathway, but also calculates dose from surface runoff and deposition on surface water. The code also evaluates the extent of contamination. The meteorology data used in the analysis was hourly data for one year that includes wind velocity (speed and direction), stability class, and rainfall.

To assess human health impacts, the analysis determined the expected number of early fatalities, expected number of latent cancer fatalities, and collective whole body dose from a severe accident to the year 2050 population within a 50 mile (80 km) radius of the plant. Economic costs were also determined, including the costs associated with short-term relocation of people, decontamination of property and equipment, and interdiction of food supplies.

MACCS2 requires five input files: MET, SITE, ATMOS, EARLY, and CHRONC. ATMOS provides data to calculate the amount of material released to the atmosphere that is dispersed and deposited. The calculation uses a Gaussian plume model. Important site-specific inputs in this file include the core inventory, release fractions, and geometry of the reactor and associated buildings. EARLY provides inputs to calculations regarding exposure in the time period immediately following the release. Important site-specific information includes emergency response information such as evacuation time. CHRONC provides data for calculating long-term impacts and economic costs and includes region-specific data on agriculture and economic factors. These files access a meteorological file, which uses {Callaway Site} meteorological monitoring data from the year {2005} and a site characteristics file, which uses site-specific population data, land usage, watershed index, and regions.

### 7.2.1.2 Population Data

{The population in the 50-mile (80-km) region surrounding the Callaway Site was estimated based on the most recent U.S. Census Bureau decennial census data (Census 2000). As explained in Callaway Plant Unit 2 FSAR Section 2.1.3, SECPOP 2000 was used to calculate the resident population by emergency planning zone sectors, and the populations for years 2010 through 2060 were projected by calculating a growth rate using state population projections. The population projections for years 2060 through 2080 were computed with the same methodology used in FSAR Section 2.1.3. The population distributions were then adjusted to include transient population.

The consequences of a severe accident at Callaway Plant Unit 2 were determined using 2050 population. The population for 2050 was chosen because Callaway Plant Unit 2 has an expected start-up date of 2017 and operating life of 60 years. Recognizing that consequences increase with time (i.e., increasing population), a time-averaged consequence can be estimated by looking at the midpoint of the U.S. EPR operational life, 2047. To be conservative, this was rounded up to 2050. As a sensitivity case, the endpoint of the U.S. EPR operational life, 2077, round up to 2080, is also evaluated. The 2080 population was not checked for realistic results, such as unattainable population densities and is believed to be overly conservative due to the projection of a conservative growth rate over a time period of 80 years.}

### 7.2.1.3 Risk Calculation

Release heights vary, depending on the event sequence, ranging from ground level to the top of the containment annulus. The time window for the analysis is 24 hours following core damage.

The results of the MACCS2 calculations and accident frequency information were used to determine risk. The sum of all release category frequencies is the core damage frequency and

includes internal and external initiating events. External events include internal fire events and internal flood events. Risk is the set of accident sequences, their respective frequencies and their respective consequences. Risk is often more simply quantified as the sum of the products of accident sequence frequencies and consequences. The consequence can be radiation dose or economic cost. Therefore, risk can be reported as a combination of person-rem per year and dollars per year.

### 7.2.2 CONSEQUENCES TO POPULATION GROUPS

This section evaluates impacts of severe accidents from air, surface water and groundwater pathways. The MACCS2 code was used to evaluate the doses from the air pathway and from water ingestion with {Callaway} site-specific data. MACCS2 does not model other surface water and groundwater dose pathways. These were analyzed qualitatively based on a comparison of the U.S. EPR atmospheric doses to those of the existing U.S. nuclear fleet.

The current U.S. nuclear fleet has an exceptional safety record. Through evolutionary and innovative design, the U.S. EPR has enhanced the ability to both prevent potential core damage events and to mitigate them should they occur. A list of example U.S. EPR design features which reduce plant risk is provided below.

- ◆ Increased redundancy and separation
- ◆ Four independent safety trains including four independent Emergency Feedwater (EFW) divisions
- ◆ Separate power divisions for each safety train, each with dedicated battery division and Emergency Diesel Generator (EDG)
- ◆ Two divisions each have a backup alternate ac diesel generator for station blackout-type (SBO-type) scenario
- ◆ State-of-the-art digital I&C
- ◆ Stand-still Seal System for backup to Reactor Coolant Pump (RCP) seals
- ◆ Main Feedwater System with Startup and Shutdown System
- ◆ In-containment refueling water storage tank to eliminate transfer to long term recirculation
- ◆ Two dedicated severe accident battery divisions
- ◆ Dedicated severe accident depressurization valves to prevent high pressure melt scenarios which can challenge containment due to postulated direct containment heating
- ◆ Containment combustible gas control system, including passive autocatalytic recombiners and gas mixing system
- ◆ Core stabilization system
- ◆ Passive cooling of molten core debris

- ◆ Active spray for environmental control of the containment atmosphere
- ◆ Active recirculation cooling of the molten core debris and containment atmosphere

The core damage frequency (CDF) is a measure of the impacts of potential accidents. CDF is estimated using PRA modeling which evaluates how changes to the reactor or auxiliary systems can change the severity of the accident. The CDF for the U.S. EPR is less than the CDFs for the current U.S. nuclear fleet.

### 7.2.2.1 Air Pathways

The potential severe accidents for the U.S. EPR were grouped into 23 release categories based on their similarity of characteristics. Each release category was assigned a set of characteristics representative of the elements of that class. Each release category was analyzed with MACCS2 to estimate population dose, number of early and latent fatalities, cost, and farm land requiring decontamination. The analysis assumed that 95% of the population was evacuated following declaration of a general emergency.

For each release category, risk was calculated by multiplying each consequence (population dose, fatalities, cost, and contaminated land) with its corresponding frequency. A summary of the results are provided in [Table 7.2-3](#). The calculation considers other consequences, such as evacuation costs, value of crops contaminated and condemned, value of milk contaminated and condemned, cost of decontamination of property, and indirect costs resulting from loss of use of the property and incomes derived as a result of the accident.

### 7.2.2.2 Surface Water Pathways

Population can be exposed to radiation when airborne radioactivity is deposited onto surface water. The exposure pathway can be from drinking the water, external radiation from submersion in the water, external radiation from activities near the shoreline, or ingestion of fish or shellfish. MACCS2 only calculates the dose from drinking water. The MACCS2 severe accident dose-risk to the 50 mile (80 km) population from drinking water is {7.48E-04} person-rem per year for the U.S. EPR and for {Callaway Plant Unit 2}. This value is the sum of all 23 release categories.

Surface water pathways involving swimming, fishing, and boating are not modeled by MACCS2. {Surface water bodies within the 50 mile (80 km) region of the Callaway Site include the Missouri River, Osage River, Bourbeuse River and other smaller bodies of water}. The NRC evaluated doses from the aquatic food pathway (fishing) for the current nuclear fleet discharging to various bodies of water {(including the sites discharging to rivers like Callaway Plant Unit 1 as listed in [Table 5.16](#))} in NUREG-1437, the Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NRC, 1996). The NRC evaluation concluded that with interdiction, the risk associated with the aquatic food pathway is found to be small relative to the atmospheric pathway for most sites {(including river sites like Callaway Plant Unit 1)} and essentially the same as the atmospheric pathway for the few sites with large annual aquatic food harvests. Because the U.S. EPR atmospheric pathway doses are significantly lower than those of the current U.S. nuclear fleet, the doses from surface water sources would be consistently lower for the U.S. EPR and for {Callaway Plant Unit 2}, as well.

### 7.2.2.3 Groundwater Pathways

Population can also receive a dose from groundwater pathways. Radioactivity released during an accident can enter groundwater that serves as a source of drinking water or irrigation, or can move through an aquifer that eventually discharges to surface water. In order to evaluate the

potential harm from a release to groundwater, the consequences of an accidental release of radioactive liquid to groundwater was modeled in COL application FSAR Section 2.4.13. The release of radioactive liquid from a tank rupture was studied and the results show that groundwater concentrations are less than permissible concentrations before reaching the surface water discharge locations.

NUREG-1437 also evaluated the groundwater pathway dose, based on the analysis in NUREG-0440 (NRC, 1978), the Liquid Pathway Generic Study (LPGS). NUREG-0440 analyzed a core meltdown that contaminated groundwater that subsequently contaminated surface water. However, NUREG-0440 did not analyze direct drinking of groundwater because of the limited number of potable groundwater wells.

The LPGS results provide conservative, uninterdicted population dose estimates for six generic categories of plants. These dose estimates were one or more orders of magnitude less than those attributed to the atmospheric pathway. NUREG-1437 compared potential contamination at representative sites, {one of which was the Callaway Site analyzed as a small river site}. The conclusion for those sites is that the uninterdicted population doses are significantly less than the NUREG-0440 generic site. {The location for Callaway Plant Unit 2 has the same groundwater characteristics as the location of the existing unit and the CDF for the U.S. EPR is lower than that of the existing unit. Therefore, the doses from the U.S. EPR and Callaway Plant Unit 2 groundwater pathway would be smaller than from the existing Callaway Plant Unit 1.}

### 7.2.3 CONCLUSIONS

The total calculated dose-risk to the {50 mile (80 km), year 2050} estimated population from airborne releases from a U.S. EPR reactor at {Callaway} is expected to be approximately {0.0571} person-rem per year (Table 7.2-3). The fraction of core inventory assumed to be released in each of the release categories is also included in Table 7.2-2. {The number of persons exposed to doses greater than 2 Sv (200 rem) and 0.25 Sv (25 rem) are 2.75E-04 and 5.05E-03, respectively.} It must be noted that these populations exceeding a dose are only calculated by MACCS2 for the early phase of an accident, the long-term dose that could be accumulated is not included in this result.

The U.S. EPR dose-risk at the {Callaway} site is less than the population risk for all current reactors that have undergone license renewal, and less than that for the five reactors analyzed in NUREG-1150 (NRC, 1990). As reported in NUREG-1811 (NRC, 2006), the lowest dose-risk reported for reactors currently undergoing license renewal is 0.55 person-rem per year.

The qualitative analysis indicates that risk from the surface water pathway is small. The risks of groundwater contamination from a U.S. EPR accident are one or more orders of magnitude less than the risk from the atmospheric pathway. The risk of groundwater contamination from an U.S. EPR accident is smaller than the risk from currently licensed reactors. Additionally, interdiction could substantially reduce the groundwater pathway risks.

For comparison, as reported in ER Section 5.4, the total collective dose from normal operations is expected to be {0.93 person-rem per year for Callaway Plant Unit 2 (based on liquid and gaseous effluent for the projected 50 mile (80 km) population for year 2080)}. As previously described, dose-risk is dose times frequency. Normal operation has a frequency of one. Therefore, the dose-risk for normal operation is {0.93 person-rem per year}. Comparing this value to the severe accident dose-risk of approximately {0.0597} person-rem per year {(2080 conservative estimate)} indicates that the dose risk from severe accidents is approximately {6}% of dose risk from normal operations.

The probability-weighted number of cancer fatalities from a severe accident for the U.S. EPR at {Callaway} is reported in Table 7.2-3 as {3.27E-05} per year. The lifetime probability of an individual dying from any cancer is 2.3 E-01 (NCHS, 2007).

#### 7.2.4 REFERENCES

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**NRC, 1996**. Generic Environmental Impact Statement for License Renewal of Nuclear Plants, NUREG-1437, Vol. 1, Nuclear Regulatory Commission, May 1996.

**NRC, 2006**. Environmental Impact Statement for an Early Site Permit (ESP) at the North Anna ESP Site, NUREG-1811, Nuclear Regulatory Commission, December 2006.}

**Table 7.2-1—Release Category Descriptions**

<b>Release Category</b>	<b>Description</b>
RC101	No containment failure
RC201	Containment fails before vessel breach due to isolation failure, melt retained in vessel
RC202	Containment fails before vessel breach due to isolation failure, melt released from vessel, with molten core-concrete interaction (MCCI), melt not flooded ex-vessel, with containment spray
RC203	Containment fails before vessel breach due to isolation failure, melt released from vessel, with MCCI, melt not flooded ex-vessel, without containment spray
RC204	Containment fails before vessel breach due to isolation failure, melt released from vessel, without MCCI, melt flooded ex-vessel with containment spray
RC205	Containment failures before vessel breach due to isolation failure, melt released from vessel, without MCCI, melt flooded ex-vessel without containment spray
RC206	Small containment failure due to failure to isolate 2" or smaller lines
RC301	Containment fails before vessel breach due to containment rupture, with MCCI, melt not flooded ex-vessel, with containment spray
RC302	Containment fails before vessel breach due to containment rupture, with MCCI, melt not flooded ex-vessel, without containment spray
RC303	Containment fails before vessel breach due to containment rupture, without MCCI, melt flooded ex-vessel, with containment spray
RC304	Containment fails before vessel breach due to containment rupture, without MCCI, melt flooded ex-vessel, without containment spray
RC401	Containment failures after breach and up through debris quench due to containment rupture, with MCCI, without debris flooding, with containment spray
RC402	Containment failures after breach and up through debris quench due to containment rupture, with MCCI, without debris flooding, without containment spray
RC403	Containment failures after breach and up through debris quench due to containment rupture, without MCCI, with debris flooding, with containment spray
RC404	Containment failures after breach and up through debris quench due to containment rupture, without MCCI, with debris flooding, without containment spray
RC501	Long term containment failure after debris quench due to rupture, with MCCI, without debris flooding, with containment spray
RC502	Long term containment failure after debris quench due to rupture, with MCCI, without debris flooding, without containment spray
RC503	Long term containment failure after debris quench due to rupture, without MCCI, with debris flooding, with containment spray
RC504	Long term containment failure after debris quench due to rupture, without MCCI, with debris flooding, without containment spray
RC602	Long term containment failure due to basemat failure, without debris flooding, without containment spray
RC701	Steam Generator Tube Rupture with Fission Product Scrubbing
RC702	Steam Generator Tube Rupture without Fission Product Scrubbing
RC802	Interfacing System LOCA without Fission Product Scrubbing

Table 7.2-2—Source Term Release Fractions

Release Category	XE/KR	I	Cs	Te	Sr	Ru	La	Ce	Ba
RC101	1.9E-3	3.1E-5	2.6E-5	6.7E-5	8.0E-6	5.8E-5	4.1E-7	9.7E-7	2.7E-5
RC201	3.2E-1	8.1E-2	8.4E-2	2.4E-2	6.9E-5	4.4E-3	6.4E-6	1.1E-5	1.0E-3
RC202	8.4E-1	3.1E-2	2.2E-2	5.3E-2	7.6E-4	8.6E-3	1.1E-4	1.7E-4	2.1E-3
RC203	8.8E-1	3.6E-2	2.3E-2	8.3E-2	2.0E-4	1.4E-2	3.0E-5	8.5E-5	4.1E-3
RC204	9.2E-1	3.0E-2	1.9E-2	8.1E-2	5.5E-4	6.1E-3	7.9E-5	1.5E-4	3.3E-3
RC205	9.9E-1	4.1E-2	2.6E-2	2.7E-1	4.8E-4	7.2E-3	7.6E-5	2.2E-4	7.2E-3
RC206	1.8E-1	8.9E-3	8.2E-3	1.0E-2	2.2E-3	9.0E-3	9.7E-5	3.1E-4	5.4E-3
RC301	8.4E-1	3.1E-2	2.2E-2	5.3E-2	7.6E-4	8.6E-3	1.1E-4	1.7E-4	2.1E-3
RC302	8.8E-1	3.6E-2	2.3E-2	8.3E-2	2.0E-4	1.4E-2	3.0E-5	8.5E-5	4.1E-3
RC303	9.2E-1	3.0E-2	1.9E-2	8.1E-2	5.5E-4	6.1E-3	7.9E-5	1.5E-4	3.3E-3
RC304	9.9E-1	4.1E-2	2.6E-2	2.7E-1	4.8E-4	7.2E-3	7.6E-5	2.2E-4	7.2E-3
RC401	8.0E-1	6.8E-3	2.8E-3	4.8E-3	2.9E-3	2.8E-3	1.1E-4	2.6E-4	5.8E-3
RC402	9.7E-1	2.8E-2	1.3E-2	1.1E-2	4.1E-3	4.0E-3	1.6E-4	3.9E-4	8.2E-3
RC403	8.0E-1	6.8E-3	2.8E-3	4.8E-3	2.9E-3	2.8E-3	1.1E-4	2.6E-4	5.8E-3
RC404	9.7E-1	2.8E-2	1.3E-2	1.1E-2	4.1E-3	4.0E-3	1.6E-4	3.9E-4	8.2E-3
RC501	9.8E-1	1.9E-3	1.9E-3	3.8E-3	1.1E-5	5.8E-5	4.9E-7	9.5E-7	6.1E-5
RC502	9.8E-1	1.9E-3	1.9E-3	3.8E-3	1.1E-5	5.8E-5	4.9E-7	9.5E-7	6.1E-5
RC503	1.0E+0	8.5E-3	7.9E-4	4.3E-2	8.0E-6	5.8E-5	4.1E-7	9.7E-7	2.7E-5
RC504	1.0E+0	8.5E-3	7.9E-4	4.3E-2	8.0E-6	5.8E-5	4.1E-7	9.7E-7	2.7E-5
RC602	9.8E-1	1.9E-3	1.9E-3	3.8E-3	1.1E-5	5.8E-5	4.9E-7	9.5E-7	6.1E-5
RC701	1.1E-1	4.1E-3	4.1E-3	6.6E-3	5.1E-4	5.2E-3	4.3E-5	1.6E-4	2.8E-3
RC702	1.1E-1	8.1E-2	8.2E-2	1.3E-1	1.0E-2	1.0E-1	8.6E-4	3.3E-3	5.5E-2
RC802	3.9E-1	2.8E-2	2.8E-2	1.5E-2	2.9E-4	3.2E-3	1.9E-5	6.1E-5	2.1E-3

**Table 7.2-3—{U.S. EPR Severe Accidents Analysis Impacts – 50-mile Radius and 2050 Population}**

Release Category	Release Category Frequency (per year)	Number of Fatalities (per year)		Environmental Risk (per year)		
		Early Fatalities	Latent Cancers	Population Dose-Risk (person-rem)	Cost (dollars)	Land Requiring Decontamination (acres)
RC101	3.39E-07	0.00E+00	3.00E-06	5.46E-03	5.80E-01	7.39E-04
RC201	4.98E-10	2.15E-13	1.08E-07	2.12E-04	3.26E-01	1.51E-04
RC202	4.00E-14	8.28E-20	1.16E-11	2.20E-08	2.24E-05	1.58E-08
RC203	8.45E-13	2.16E-18	2.71E-10	4.73E-07	5.03E-04	3.46E-07
RC204	2.41E-11	7.52E-17	6.39E-09	1.25E-05	1.23E-02	9.40E-06
RC205	4.10E-10	3.82E-14	1.34E-07	2.56E-04	2.53E-01	1.74E-04
RC206	1.64E-08	4.36E-11	4.44E-06	7.56E-03	5.81E+00	4.49E-03
RC301	1.63E-12	3.37E-18	4.73E-10	8.95E-07	9.14E-04	6.44E-07
RC302	1.51E-11	3.87E-17	4.85E-09	8.46E-06	8.98E-03	6.19E-06
RC303	2.29E-09	7.14E-15	6.07E-07	1.19E-03	1.17E+00	8.93E-04
RC304	1.76E-08	1.64E-12	5.77E-06	1.10E-02	1.09E+01	7.48E-03
RC401	1.38E-11	0.00E+00	2.30E-09	4.64E-06	2.62E-03	2.80E-06
RC402	2.75E-10	0.00E+00	6.33E-08	1.31E-04	1.29E-01	1.06E-04
RC403	6.82E-10	0.00E+00	1.14E-07	2.29E-04	1.30E-01	1.38E-04
RC404	1.35E-08	0.00E+00	3.11E-06	6.43E-03	6.35E+00	5.20E-03
RC501	2.65E-13	0.00E+00	2.94E-11	6.39E-08	1.53E-05	2.76E-08
RC502	1.11E-10	0.00E+00	1.23E-08	2.68E-05	6.43E-03	1.15E-05
RC503	3.65E-10	0.00E+00	1.73E-08	3.76E-05	2.52E-02	7.34E-05
RC504	1.19E-07	0.00E+00	5.65E-06	1.23E-02	8.22E+00	2.39E-02
RC602	3.61E-10	0.00E+00	4.01E-08	8.70E-05	2.09E-02	3.75E-05
RC701	1.02E-08	0.00E+00	2.08E-06	3.77E-03	2.30E+00	2.11E-03
RC702	5.37E-09	4.17E-10	7.46E-06	8.32E-03	6.93E+00	2.92E-03
RC802	2.64E-10	4.59E-15	6.31E-08	1.29E-04	1.46E-01	1.01E-04
<b>Total</b>	<b>5.26E-07</b>	<b>4.63E-10</b>	<b>3.27E-05</b>	<b>5.71E-02</b>	<b>4.33E+01</b>	<b>4.86E-02</b>

## 7.3 SEVERE ACCIDENT MITIGATION ALTERNATIVES

The purpose of the severe accident mitigation alternatives (SAMA) analysis is to review and evaluate both design and non-hardware (i.e., operation and maintenance programs) alternatives that could significantly reduce the radiological risk from a postulated severe accident by preventing core damage and significant releases from the containment. The U.S. EPR Design Certification Environmental Report (U.S. EPR DC ER) (AREVA, 2007) for the U.S. EPR submitted by AREVA NP evaluated both design and non-hardware alternatives.

The primary focus of the U.S. EPR DC ER was the severe accident mitigation design alternatives (SAMDA). However, non-hardware alternatives were identified in the analysis and will be addressed when the plant design is finalized and processes and procedures are being developed for the U.S. EPR. The conclusions drawn in the U.S. EPR DC ER are applicable to {Callaway Plant Unit 2}.

### 7.3.1 SAMDA ANALYSIS METHODOLOGY

The methodology used to develop a comprehensive list of U.S. EPR SAMDA candidates, define the screening criteria used to categorize the SAMDA candidates, and the cost-benefit evaluation is summarized in this section based on the U.S. EPR DC ER (AREVA, 2007) for the U.S. EPR.

The comprehensive list of SAMDA candidates was developed for the U.S. EPR by reviewing industry documents for generic PWR enhancements and considering plant-specific enhancements. The SAMDA candidates were defined as enhancements to the U.S. EPR plant that have the potential to prevent core damage and significant releases from the containment. The primary industry document supporting the development of U.S. EPR generic PWR SAMDA candidates was NEI 05-01 (NEI, 2005).

The top 100 U.S. EPR Level 1 PRA cutsets were evaluated to identify plant-specific modifications for inclusion in the comprehensive list of SAMDA candidates. The top 100 cutsets represent approximately 50% of the total core damage frequency (CDF) for the U.S. EPR. The percentage of contribution to the total CDF for the cutsets below the top 100 was minimal. Therefore, these cutsets were not likely contributors for identification of cost beneficial enhancements for the U.S. EPR design.

An extensive evaluation of the top 100 cutsets was completed in order to establish that all possible design alternatives for the U.S. EPR were addressed. Through the evaluation, numerous U.S. EPR specific operator actions and hardware-based SAMDA candidates were developed. The U.S. EPR DC ER (AREVA, 2007) provides a detailed list of the SAMDA candidates for the U.S. EPR. The SAMDA candidates identified in the U.S. EPR DC ER (AREVA, 2007) are applicable to {Callaway Plant Unit 2}.

The SAMDA candidates developed for the U.S. EPR design were qualitatively screened using seven categories. The intent of the screening is to identify the candidates for further risk-benefit calculation. For each SAMDA candidate, a screening criteria and basis for screening was identified to justify the implementation or exclusion of the SAMDA candidate in the U.S. EPR. The seven categories used during the screening process included:

- ◆ Not applicable. The SAMDA candidates were identified to determine which are definitely not applicable to the U.S. EPR. Potential enhancements that are not considered applicable to the U.S. EPR are those developed for systems specifically

associated with boiling water reactors (BWR) or with specific PWR equipment that is not in the U.S. EPR design.

- ◆ Already implemented. The SAMDA candidates were reviewed to ensure that the U.S. EPR design does not already include features recommended by a particular SAMDA candidate. Also, the intent of a particular SAMDA candidate may have been fulfilled by another design feature or modification. In these cases the SAMDA candidates are already implemented in the U.S. EPR plant design. If a SAMDA candidate has already been implemented at the plant, it is not retained.
- ◆ Combined. If one SAMDA candidate is similar to another SAMDA candidate, and can be combined with that candidate to develop a more comprehensive or plant-specific SAMDA candidate, only the combined SAMDA candidate is retained for screening.
- ◆ Excessive implementation cost. If a SAMDA candidate requires extensive changes that will obviously exceed the maximum benefit, even without an implementation cost estimate and therefore incurs an excessive implementation cost, it is not retained.
- ◆ Very low benefit. If a SAMDA candidate is related to a non-risk significant system for which change in reliability is known to have negligible impact on the risk profile, it is deemed to have a very low benefit and is not retained.
- ◆ Deferred to detail design. Evaluation of any potential procedural or surveillance action SAMDA candidates are not appropriate until the plant design is finalized and the plant procedures are being developed. Therefore, if a SAMDA candidate is related to any of these enhancements, it is not retained for this analysis and will be evaluated during the detailed design phase of the U.S. EPR.
- ◆ Considered for further evaluation. If a particular SAMDA candidate was not categorized by any of the preceding categories, then the SAMDA candidate is considered for further evaluation and subject to a cost-benefit analysis.

The screening categories were chosen based on guidance from NEI 05-01. The U.S. EPR DC ER (AREVA, 2007) contains a detailed description of each of the categories. The screening categories are applicable to {Callaway Plant Unit 2}.

After the screening process was completed, the SAMDA candidates that were placed in the Considered for Further Evaluation category would require a cost-benefit evaluation. The cost-benefit evaluation of each SAMDA candidate would determine the cost of implementing the specific SAMDA candidate with the maximum averted cost risk from the implementation of the specific SAMDA candidate. The maximum averted cost risk, typically referred to as the maximum benefit, equates to the cost obtained by the elimination of all severe accident risk.

### 7.3.2 SEVERE ACCIDENT COST IMPACT AND MAXIMUM BENEFIT FOR {CALLAWAY PLANT UNIT 2}

The severe accident impact is determined by summing the occupational exposure cost, on-site cost, public exposure, and off-site property damage. The methodologies provided in NEI 05-01 (NEI, 2005) and NUREG/BR-1084 (NRC, 1997) were used as guidance. The principal inputs to the calculations were the CDF, 2,000 dollars per person-rem (NRC, 1997), impact evaluation period of 60 years, 7% best estimate discount rate (NEI, 2005), and 3% upper bound discount rate (NEI, 2005). The maximum benefit calculation performed in the U.S. EPR DC ER (AREVA, 2007) used the whole body dose and economic impact from U.S. EPR Level 3 PRA analysis, which was

based on population data from 2000. The maximum benefit calculation for {Callaway Plant Unit 2} uses the economic impact and whole body dose for a 2050 population (Table 7.3-1). The best estimate and upper bound severe accident impact cost for {Callaway Plant Unit 2} is also shown in Table 7.3-1.

The severe accident impact cost calculated in Table 7.3-1 accounts for the risk of internal events, internal flooding, and internal fires. To determine the total cost of severe accident risk the contribution of external events (e.g., seismic risk, as other external event contributors are small) needs to be included. Assuming that fire risk is the dominant contributor to external events risk, the seismic risk contribution was conservatively accounted for by assuming that it is equivalent to the internal fire risk. A scaling factor was calculated by dividing the internal fire CDF (1.76 E-07 per year) by the total CDF (5.30 E-07 per year) resulting in an increase of 33% (AREVA, 2007). Increasing the severe accident impact by 33% includes the seismic risk and is the maximum benefit for {Callaway Plant Unit 2}.

The maximum benefit for {Callaway Plant Unit 2} is \$42,773 (best estimate) and \$69,160 (upper bound). The best estimate maximum benefit for Callaway Plant Unit 2 is approximately \$7,800 less than the maximum benefit calculated in the U.S. EPR DC ER (AREVA, 2007). The minimum implementation cost for a SAMDA candidate was determined to be \$150,000 (AREVA, 2007), which exceeds the maximum benefit calculated for {Callaway Plant Unit 2}. Therefore, the U.S. EPR DC ER (AREVA, 2007) analysis is applicable to {Callaway Plant Unit 2}.

### 7.3.3 RESULTS AND SUMMARY

A total of 167 SAMDA candidates developed from industry and U.S. EPR documents were evaluated in the U.S. EPR DC ER (AREVA, 2007) completed by AREVA NP. The basis for screening is provided in detail for each SAMDA candidate in the U.S. EPR DC ER (AREVA, 2007). Below is a summary of the results of the SAMDA analysis performed for the U.S. EPR and is applicable to {Callaway Plant Unit 2}.

- ◆ Twenty-one SAMDA candidates were not applicable to the U.S. EPR design.
- ◆ Sixty-seven SAMDA candidates were already implemented into the U.S. EPR design either as suggested in the SAMDA or an equivalent replacement that fulfilled the intent of the SAMDA. These SAMDA candidates are summarized in Table 7.3-2.
- ◆ Four SAMDA candidates were combined with another SAMDA because they had the same intent.
- ◆ Fifty-one SAMDA candidates were categorized as deferred to detail design because they were related to a procedural or surveillance action. Evaluation of any potential administrative SAMDA candidates (i.e., those candidates related to procedures and training) is not appropriate until the plant design is finalized and plant administrative processes, procedures, and training programs are being developed. However, the plant administrative processes, procedures, and training programs will be developed to address appropriate maintenance and use of the U.S. EPR design features which have been credited with the reduction of risk associated with postulated severe accidents. As such, appropriate administrative controls on plant operations will be incorporated into the {Callaway Plant Unit 2} management systems as part of the initial administrative processes, procedures, and training program development process.
- ◆ One SAMDA candidate was categorized as very low benefit.

- ◆ Twenty-three SAMDA candidates were categorized as excessive implementation cost.
- ◆ None of the SAMDA candidates were categorized as consider for further evaluation.

The low probability of core damage events in the U.S. EPR coupled with reliable severe accident mitigation features provide significant protection to the public and the environment. Specific severe accident mitigation design alternatives from previous industry studies, and from U.S. EPR probabilistic risk assessment (PRA) insights, were measured against broad acceptance criteria in the U.S. EPR DC ER (AREVA, 2007). Since none of the SAMDA candidates were categorized as considered for further evaluation, a cost-benefit analysis (i.e., risk reduction, value impact ratios) was not required for the U.S. EPR SAMDA analysis. The overall conclusion of the U.S. EPR SAMDA analysis is that no additional plant modifications are cost beneficial to implement due to the robust design of the U.S. EPR with respect to prevention and mitigation of severe accidents. The maximum benefit from the U.S. EPR DC ER (AREVA, 2007) was reevaluated for {Callaway Plant Unit 2}. The detailed analysis and conclusions in the U.S. EPR DC ER (AREVA, 2007) remain applicable for {Callaway Plant Unit 2}.

#### 7.3.4 REFERENCES

**{AREVA, 2007}**. "AREVA NP Environmental Report Standard Design Certification," ANP-10290, Revision 0, AREVA NP, November 2007.

**NEI, 2005**. "Severe Accident Mitigation Alternatives (SAMA) Analysis, Guidance Document," NEI 05-01, Revision A, Nuclear Energy Institute November 2005.

**NRC, 1997**. "Regulatory Analysis Technical Evaluation Handbook," NUREG/BR-1084, Nuclear Regulatory Commission, January 1997.}

**Table 7.3-1—{Severe Accident Cost Impact}**

	<b>Best Estimate (7% Discount Rate)</b>	<b>Upper Bound (3% Discount Rate)</b>
Averted Occupational Exposure	\$264	\$607
Averted On-site Costs	\$29,680	\$47,011
Averted Public Exposure	\$1,607	\$3,177
Averted Off-site Property Damage Costs	\$609	\$1,205
<b>Severe Accident Cost Impact<sup>(1)</sup></b> Internal Events, Internal Flooding, Internal Fire	\$32,160	\$52,000
<b>Maximum Benefit<sup>(2)</sup></b> Internal Events, Internal Flooding, Internal Fire, Seismic	<b>\$42,773</b>	<b>\$69,160</b>

Notes:

- (1) Severe Accident Cost Impact is the sum of Averted Occupational Exposure, Averted On-site Costs, Averted Public Exposure and Averted Off-site Property Damage Costs.
- (2) Maximum Benefit is calculated by increasing the Severe Accident Cost Impact by 33%.

**Table 7.3-2—{SAMDA Candidates – Already Implemented}**

(Page 1 of 2)

<b>SAMDA ID</b>	<b>Potential Enhancement</b>
AC/DC-01	Provide additional DC battery capacity.
AC/DC-03	Add additional battery charger or portable, diesel-driven battery charger to existing DC system.
AC/DC-04	Improve DC bus load shedding.
AC/DC-06	Provide additional DC power to the 120/240V vital AC system.
AC/DC-07	Add an automatic feature to transfer the 120V vital AC bus from normal to standby power.
AC/DC-09	Provide an additional diesel generator.
AC/DC-11	Improve 4.16 kV bus cross-tie ability.
AC/DC-14	Install a gas turbine generator.
AC/DC-16	Improve uninterruptible power supplies.
AC/DC-24	Bury off-site power lines.
AT-01	Add an independent boron injection system.
AT-02	Add a system of relief valves to prevent equipment damage from pressure spikes during an ATWS.
AT-07	Install motor generator set trip breakers in control room.
AT-08	Provide capability to remove power from the bus powering the control rods.
CB-01	Install additional pressure or leak monitoring instruments for detection of ISLOCAs.
CB-04	Install self-actuating containment isolation valves.
CB-10	Replace SGs with a new design.
CB-12	Install a redundant spray system to depressurize the primary system during an SGTR.
CB-14	Provide improved instrumentation to detect SGTR, such as Nitrogen-16 monitors.
CB-16	Install a highly reliable (closed loop) SG shell-side heat removal system that relies on natural circulation and stored water sources.
CB-20	Install relief valves in the CCWS.
CC-01	Install an independent active or passive high pressure injection system.
CC-04	Add a diverse low pressure injection system.
CC-05	Provide capability for alternate injection via diesel-driven fire pump.
CC-06	Improve ECCS suction strainers.
CC-07	Add the ability to manually align ECCS recirculation.
CC-10	Provide an in-containment reactor water storage tank.
CC-15	Replace two of the four electric safety injection pumps with diesel-powered pumps.
CC-17	Create a reactor coolant depressurization system.
CC-21	Modify the containment sump strainers to prevent plugging.
CP-01	Create a reactor cavity flooding system.
CP-03	Use the fire water system as a backup source for the containment spray system.
CP-07	Provide post-accident containment inerting capability.
CP-08	Create a large concrete crucible with heat removal potential to contain molten core debris.
CP-11	Increase depth of the concrete base mat or use an alternate concrete material to ensure melt-through does not occur.
CP-13	Construct a building to be connected to primary/secondary containment and maintained at a vacuum.
CP-17	Install automatic containment spray pump header throttle valves.
CP-20	Install a passive hydrogen control system.
CP-21	Erect a barrier that would provide enhanced protection of the containment walls (shell) from ejected core debris following a core melt scenario at high pressure.
CP-22	Install a secondary containment filtered ventilation.
CW-01	Add redundant DC control power for SW pumps.
CW-02	Replace ECCS pump motors with air-cooled motors.
CW-04	Add a SW pump.
CW-05	Enhance the screen wash system.
CW-06	Cap downstream piping of normally closed component cooling water drain and vent valves.
CW-10	Provide hardware connections to allow another essential raw cooling water system to cool charging pump seals.

**Table 7.3-2—{SAMDA Candidates – Already Implemented}**

(Page 2 of 2)

<b>SAMDA ID</b>	<b>Potential Enhancement</b>
CW-15	Use existing hydro test pump for RCP seal injection.
CW-16	Install improved RCP seals.
CW-17	Install an additional component cooling water pump.
EPR-01	Provide an additional SCWS train.
EPR-05	Add redundant pressure sensors to the pressurizer and SG.
FR-03	Install additional transfer and isolation switches.
FR-05	Enhance control of combustibles and ignition.
FW-01	Install a digital feed water upgrade.
FW-02	Create ability for emergency connection of existing or new water sources to feedwater and condensate systems.
FW-04	Add a motor-driven feedwater pump.
FW-07	Install a new condensate storage tank (auxiliary feedwater storage tank).
FW-11	Use fire water system as a backup for SG inventory.
FW-15	Replace existing pilot-operated relief valves with larger ones, such that only one is required for successful feed and bleed.
HV-01	Provide a redundant train or means of ventilation to the switch gear rooms.
HV-02	Add a diesel building high temperature alarm or redundant louver and thermostat.
HV-04	Add a switchgear room high temperature alarm.
HV-05	Create ability to switch EFW room fan power supply to station batteries in an SBO.
SR-01	Increase seismic ruggedness of plant components.
SR-02	Provide additional restraints for CO <sub>2</sub> tanks.
OT-01	Install digital large break LOCA protection system.

## 7.4 TRANSPORTATION ACCIDENTS

The NRC evaluated the environmental effects of transportation of fuel and waste for light water reactors in WASH-1238, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Plants" (AEC, 1972) and NUREG-75/038, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, Supplement 1" (NRC, 1975) and found the impacts to be small. These NRC analyses provided the basis for Table S-4 in 10 CFR 51.52 (CFR, 2007) which summarizes the environmental impacts of transportation of fuel and radioactive wastes to and from a reference reactor.

10 CFR 51.52 requires that:

Every environmental report prepared for ... a light-water-cooled nuclear power reactor... contain a statement concerning transportation of fuel and radioactive wastes to and from the reactor. That statement shall indicate that the reactor and this transportation either meet all of the conditions in paragraph (a) of this section or all of the conditions in paragraph (b) of this section.

Table S-4 of 10 CFR 51.52 addresses two categories of environmental considerations: (1) normal conditions of transport, and (2) accidents in transport.

The U.S. EPR design varies from the conditions of 10 CFR 51.52(a). Specifically,

- ◆ The reactor has a core thermal power level exceeding 3,800 MWth;
- ◆ The reactor fuel has a uranium-235 enrichment that may exceed 4% by weight;
- ◆ The uranium dioxide pellets are not encapsulated in Zircaloy rods; and
- ◆ The average level of burnup of the irradiated fuel removed from the reactor will exceed 33,000 MWd/MTU.

Because the U.S. EPR varies from the conditions of 10 CFR 51.52(a), a full description and analysis of transportation environmental impacts is required in accordance with 10 CFR 51.52(b). This section describes the environmental impact of postulated transportation accidents involving the shipment of radioactive materials including unirradiated (new) fuel, irradiated fuel, and radioactive waste as required by 10 CFR 51.52. The environmental impacts from the incident-free transportation of fuel and wastes to and from the new reactor are summarized in Section 5.11.

The environmental impacts from transportation accidents listed in Table S-4 of 10 CFR 51.52 are presented in [Table 7.4-1](#).

Radiological and non-radiological types of accident effects are analyzed. Two computer programs were used to perform this analysis. The TRAGIS (ORNL, 2003) computer code was used to determine the distance traveled by truck, the roads taken, and the population density along the routes. The RADTRAN 5.6 computer code was used to calculate population doses from the shipment (direct and effluent sources, not ingestion) given the routes defined by TRAGIS. The inputs to these codes are listed in [Table 7.4-2](#) through [Table 7.4-7](#) and [Table 7.4-9](#) through [Table 7.4-11](#).

## 7.4.1 RADIOLOGICAL IMPACTS

The radiological impact population dose was calculated using the RADTRAN computer code. The population dose impact from postulated accidents associated with the transportation of unirradiated fuel, irradiated fuel, and radioactive waste are provided in [Table 7.4-12](#). The dose impact from all postulated transportation accident sources is {1.2E-04 person-rem/year (1.2E-06 person-Sv/year)}.

### 7.4.1.1 Unirradiated (New) Fuel

The WASH-1238 analysis (AEC, 1972) of postulated accidents during the transportation of unirradiated fuel found accident impacts to be negligible. The analysis states “the impact on the environment from radiation in transportation accidents involving unirradiated (current) fuel is considered to be negligible.”

Additionally, as noted in NUREG-1815 (NRC, 2006), accident frequencies are likely to be lower in the future than those used in the analysis in WASH-1238 (AEC, 1972) because traffic accident, injury, and fatality rates have fallen since the initial analyses were performed.

Finally, advanced fuel behaves like fuel evaluated in the analyses provided in WASH-1238 (AEC, 1972). Again as noted in NUREG-1815 (NRC, 2006), there is no significant difference in the consequences of accidents severe enough to result in a release of unirradiated fuel particles to the environment between advanced light water reactors (LWRs) and previous-generation LWRs because the fuel form, cladding, and packaging are similar to those analyzed in WASH-1238 (AEC, 1972).

Based on this information, the dose impact from nuclides released from postulated accidents involving new fuel is assumed to be negligible when compared to dose impact from postulated irradiated fuel and radiation waste transportation accidents. Therefore, quantitative analysis of dose from new fuel accidents was not performed.

### 7.4.1.2 Irradiated Fuel

The dose impact from postulated accidents during the shipment of irradiated fuel was evaluated using the TRAGIS code (ORNL, 2003) to define appropriate routing and population density along the route. This information was used as input to the RADTRAN code with U.S. EPR-specific design information to calculate a postulated annual dose from irradiated fuel transportation accidents.

The evaluation model assumed that irradiated fuel will be shipped to the site of the proposed Yucca Mountain repository. The distance from the {Callaway} site to the proposed repository is {1,819 miles (2,927 km)} based on a TRAGIS Highway Route Controlled Quantity (HRCQ) distance.

The model accident rate is the probability that an accident will occur during the trip along each route through each state. The route’s average accident rate is the sum of the distance weighted accident rate through each state.

State-specific accident data from Table 4 of ANL/ESD/TM-150 (ANL, 1999) are shown in [Table 7.4-4](#). Only the interstate data are used because the HRCQ route is mainly on Interstate roads.

The distance and demographic data for input to RADTRAN are listed in [Table 7.4-2](#). The U.S. EPR average annual quantity of irradiated fuel shipped is assumed, consistent with NUREG-1815

(NRC, 2006), to equal the average annual reload quantity. For the U.S. EPR this is 37.5 MTU of irradiated fuel per year (as provided in Section 5.11) to be shipped.

The source term in [Table 7.4-3](#) is based on an equilibrium burnup of 52 GWd/MTU. The activity was decayed 5 years to account for the minimum decay period prior to shipment of irradiated fuel to the proposed geologic repository at Yucca Mountain, NV. The nuclides evaluated are those dominant nuclides described and listed in Appendix G of NUREG-1815 (NRC, 2006).

In addition to the source term assumed above, Cobalt-60 was used to represent fuel surface contamination and added at a level of 0.2 Ci/rod (7.4E+09 Bq/rod). This use of Cobalt-60 in the model was consistent with previously performed studies (SNL, 1991) (NRC, 2000) (DOE, 2002) that quantified fuel rod contamination levels and that concluded the maximum contribution from contamination is Cobalt-60. NUREG/CR-6672 estimated the maximum contamination from Cobalt-60 for PWR fuel at zero year decay is 0.168 Ci/rod (6.22E+09 Bq/rod) (or approximately 0.2 Ci/rod (7.4E+09 Bq/rod)). A U.S. EPR-specific calculation of Ci/rod was carried out that confirmed the 0.2 Ci/rod (7.4E+09 Bq/rod) value was conservative.

The accident severity categories and related releases from Appendix G of NUREG-1815 (NRC, 2006) were used and are presented in [Table 7.4-5](#). The model deposition velocities were consistent with Appendix E in DOE/EIS-0250 (DOE, 2002). The model severity fractions, release fractions, aerosol and respirable fractions are the conditional probabilities, given an accident occurs, for specific severity categories. The model severity and release fractions are for the 19 severity categories and the 5 chemical groups identified in NUREG-1815 (NRC, 2006) and are presented in [Table 7.4-5](#). Gases are not deposited and have a 0.0 m/s deposition velocity. All other chemical groups are defined consistent with DOE/EIS-0250 (DOE, 2002) at 0.03 ft/s (0.01 m/s). Other RADTRAN parameters used were the default values from the RADCAT 2.3 User Guide (SNL, 2006), and from Appendix G of NUREG-1815 (NRC, 2006).

The evaluation determined that the dose impact from postulated transportation accidents involving irradiated fuel was {3.16E-06 person-rem/MTU (3.16E-08 person-Sv/MTU)}. Using the average annual reload requirements for a U.S. EPR of 37.5 MTU, the annual population dose impact is {1.19E-04 person-rem/year (1.19E-06 person-Sv/year)} from postulated transportation accidents involving irradiated fuel.

### 7.4.1.3 Radioactive Waste

The population risk from radwaste transportation accidents is {3.20E-06 person-rem/yr (3.20E-08 person-Sv/year).} This is the population dose for an accident divided by the mean number of years between accidents.

The TRAGIS computer code was used to calculate the routes, distances, and demographics along the route. It was conservatively assumed that all radwaste would be shipped to the farthest disposal repository in commercial mode. The route was from the plant to the {Hanford site located in Washington State.} It was along roads which allowed trucks and avoided ferry crossings. TRAGIS calculated the total one-way distance to be {1,855 miles (2,985 km)}. The distances through each state are listed in [Table 7.4-11](#). The distances and population densities through the rural, suburban and urban settings are listed in [Table 7.4-9](#) as well as the time spent stopped. These were all used as inputs to RADTRAN.

The RADTRAN computer code was used to calculate accident probability and population risk for the route. In an average year, 2.54E+03 Ci (9.41E+13 Bq) is forecast to be shipped. This is described in [Table 7.4-8](#) and will involve 15 shipments per year (as described in Section 5.11). The fraction of various nuclides released, by accident category, are listed in [Table 7.4-5](#). These

release fractions are a function of 19 accident severity categories and 5 chemical groups. The values are from NUREG-1815 (NRC, 2006). The model release fractions, aerosol and respirable fractions are the conditional probabilities, given an accident occurs, for specific severity categories.

The model deposition velocities are consistent with Appendix E in DOE/EIS-0250 (DOE, 2002). All chemical groups are defined at 0.01 m/s.

Other RADTRAN parameters were the default values from the RADCAT 2.3 User Guide (SNL, 2006), and from Appendix G of NUREG-1815 (NRC, 2006).

The source term in [Table 7.4-10](#) is based on the sum of all waste type expected (average) annual activities. The radionuclides chosen are greater than 1% of the total activity (with the exception of Ag-110m, which is not in the RADTRAN 5.6 Library), and those in Table G-9 of NUREG-1815 (NRC, 2006) plus isotopes in the same family (such as Co-58 and Ru-103). On page G-23 of that report, the NRC performed a screening analysis that showed that these were the dominant nuclides.

The model accident rate is the probability that an accident will occur during the trip along each road through each state. The route's average accident rate is the sum of the distance weighted accident rate through each state. [Table 7.4-11](#) presents the individual state accident rate data compiled from ANL/ESD/TM-150 (ANL, 1999) and the associated average rate. Since the commercial route is mainly on Interstate roads, only the interstate rate data was used in the model.

The result from RADTRAN is the annual population dose per year of {3.20E-06 person-rem/yr (3.20E-08 person-Sv/yr)}.

## 7.4.2 NON-RADIOLOGICAL IMPACTS

Two non-radiological impacts associated with the postulated accidents during transportation of new fuel, irradiated fuel, and radioactive waste were calculated, the fatal injury rate per 100 reactor years and the nonfatal injury rate per 10 reactor years.

### 7.4.2.1 New Fuel

TRAGIS (ORNL, 2003) was used to calculate the commercial routing through each state. Interstate travel is the dominant road designation and was used for all route types. It was assumed that all shipments came from the fuel fabrication facility furthest from {Callaway Site; the facility is located in Richland, WA.}

As described in Section 5.11.3.1, the average number of new fuel shipments was assumed to be 7.5 per year, each covering the {1,828 miles (2,942 km)} distance, including the return of the empty truck the same distance. This is based on the distances and road types from the calculation of radiological impacts above and the fatal injury rates from Table 4 of ANL/ESD/TM-150 (ANL, 1999).

Based on the above and the average fatality rate from [Table 7.4-7](#) of {1.89E-08 fatalities per truck-mile (1.17E-08 fatalities per truck-km)}, the non-radiological fatal injury rate impact associated with postulated accidents as a result of new fuel shipments is {5.16E-02} per 100 reactor years.

Based on the same routes, distances, and assumptions above and the average nonfatal injury rate from [Table 7.4-7](#) of {4.13E-07 nonfatal injuries per truck-mile (2.57E-07 nonfatal injuries per truck-km)}, the non-radiological nonfatal injury rate impact associated with postulated accidents as a result of new fuel shipments is {1.13E-01} nonfatal injuries per 10 reactor years.

#### 7.4.2.2 Irradiated Fuel

The methodology for evaluating the fatal and nonfatal injury rates as a result of postulated accidents during the transportation of irradiated fuel is the same as that described in Section 7.4.2.1 above with the exceptions of the number of trips and the routing assumed in the TRAGIS evaluation. Twenty-one irradiated fuel shipments from the {Callaway} site to the proposed Yucca Mountain repository per year were evaluated (as discussed in Section 5.11) and the TRAGIS Highway Route Controlled Quantity was utilized as the basis to calculate the shipping distance.

Based on the above and the accident rates from [Table 7.4-4](#), the non-radiological fatal injury rate impact associated with postulated accidents as a result of irradiated fuel shipments is {1.17E-01} per 100 reactor years.

Based on the above and the accident rates from [Table 7.4-6](#), the non-radiological nonfatal injury rate impact associated with postulated accidents as a result of irradiated fuel shipments is {3.32E-01} nonfatal injuries per 10 reactor years.

#### 7.4.2.3 Radioactive Waste

The fatal injury rate for accidents associated with radwaste shipments is {1.04E-01} fatal injuries per 100 reactor years. This is based on the fatality rates from Table 4 of ANL/ESD/TM-150 (ANL, 1999). TRAGIS was used to calculate the commercial routing through each state. Interstate travel is the dominant road designation and was used for all route types.

It is assumed that all shipments go from the {Callaway} Site to the farthest potential disposal repository located in {Hanford, WA (1,855 miles (2,985 km))} and that the truck conservatively returns to the plant empty (doubling the traveled distance). The state-specific fatality rates are in [Table 7.4-11](#). The number of radwaste shipments from the site to {Hanford} per year is 15 as described in Section 5.11.3.3. The distance weighted fatality rate from [Table 7.4-11](#) is {1.86E-08 fatalities per truck-mile (1.16E-08 fatalities per truck-km)}. The Radwaste Fatality (SFF) rate was calculated to be {1.04E-01 fatal injuries per 100 reactor years.}

The nonfatal injury rate associated with radwaste shipments is {2.29E-01} nonfatal injuries per 10 reactor years. This is based on the distances and road types from the radiological impact calculations and the injury rates from Table 4 of ANL/ESD/TM-150 (ANL, 1999). TRAGIS was used to calculate the commercial routing through each state. Interstate travel is the dominant road designation and was used for all route types.

It is assumed that all shipments go from the site to the farthest potential disposal repository located in {Hanford, WA (1,855 mi (2,985 km))} and that the truck conservatively returns to plant empty (doubling the traveled distance.) The state-specific fatality rates are in [Table 7.4-11](#). The number of radwaste shipments from the site to {Hanford} per year is 15 as described in Section 5.11.3.3. The average injury rate from [Table 7.4-11](#) is {4.11E-07 injuries per truck-mile (2.56E-07 injuries per truck-km)}. The nonfatal Radwaste Injury rate was calculated to be {2.29E-01} nonfatal injuries per 10 reactor years.

### 7.4.3 SUMMARY AND CONCLUSION

A detailed accident analysis of the environmental impacts for the transportation of unirradiated fuel, irradiated fuel, and radioactive waste (DOE, 1981) transported to and from the {Callaway} site has been performed in accordance with 10 CFR 51.52(b) (CFR, 2007).

Table 7.4-12 summarizes the radiological impact, and Table 7.4-13 summarizes the non-radiological impact. These environmental impact results are bounded by 10 CFR 51.52(c) (CFR, 2007), Table S-4. These impacts represent the contribution of postulated transportation accidents to the environmental costs of operating the facility.

As shown in Table 7.4-13, the calculated impacts from transportation accidents are less than those corresponding impacts listed in Table S-4 of 10 CFR 51.52 (CFR, 2007). Therefore, the corresponding impacts from transportation accidents for the transportation of fuel and waste to and from the facility are small and will be less than those accepted by 10 CFR 51.52 (CFR, 2007).

### 7.4.4 REFERENCES

**{AEC, 1972.}** Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, WASH-1238, Atomic Energy Commission, December 1972.

**ANL, 1999.** State-Level Accident Rates of Surface Freight Transportation: A Reexamination, ANL/ESD/TM-150, Argonne National Laboratory, 1999.

**CFR, 2007.** Title 10, Code of Federal Regulations, Part 51, Environmental Protection Regulations for Domestic Licensing and related Regulatory Functions, 2007.

**DOE, 2002.** Final Environmental Impact Statement for a Geologic Repository for the Disposal of Irradiated Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, DOE/EIS-0250, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, 2002.

**DOE, 1981.** Radioactive Decay Data Tables, DOE/TIC-11026, U.S. Department of Energy, D. Kocher, 1981.

**NRC, 1975.** Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, Supplement 1, NUREG-75/038, Nuclear Regulatory Commission, April 1975.

**NRC, 2000.** Re-Examination of Spent Fuel Shipment Risk Estimates, NUREG/CR-6672, Nuclear Regulatory Commission, 2000.

**NRC, 2006.** Environmental Impact Statement for an Early Site Permit (ESP) at the Exelon ESP Site Final Report, NUREG-1815, Nuclear Regulatory Commission, July, 2006.

**ORNL, 2003.** Transportation Routing Analysis Geographic Information System (TRAGIS) User's Manual, ORNL/NTRC-006, P. Johnson, and R. Michelhaugh, Oak Ridge National Laboratory, 2003.

**SNL, 2006.** RADCAT 2.3 User Guide, SAND2006-6315, Sandia National Laboratories, R. Weiner, D. Osborn, G. Mills, D. Hinojosa, T. Heames, and D. Orcutt, 2006.}

**Table 7.4-1—10 CFR 51.52 Summary Table S-4 Excerpt Environmental Impact of Transportation of Fuel and Waste to and from One Light-Water-Cooled Nuclear Power Reactor Accidents in Transport**

Types of Effects	Environmental Risk
Radiological Effects	Small
Common (nonradiological) causes	1 fatal injury in 100 reactor years 1 nonfatal injury in 10 reactor years \$475 property damage per reactor year

**Table 7.4-2—{RADTRAN/TRAGIS Model Irradiated Fuel Input Parameters}**

Parameter	Callaway Model U.S. EPR (English Units)	Callaway Model U.S. EPR (SI Units)
TRAGIS Input:		
Route Mode	HRCQ	
Route Origin	Callaway	
Route Destination	Yucca Mt, NV	
RADTRAN Input TRAGIS:		
Total Shipping Distance	1,818.5 mi	2,926.5 km
Travel Distance – Rural	1,556.9 mi	2,505.5 km
Travel Distance – Suburban	219.5 mi	353.2 km
Travel Distance – Urban	42.2 mi	67.8 km
Population Density – Rural	20.7 person/mi <sup>2</sup>	8.0 person/km <sup>2</sup>
Population Density – Suburban	897.3 person/mi <sup>2</sup>	346.5 person/km <sup>2</sup>
Population Density – Urban	6,050.9 person/mi <sup>2</sup>	2,336.3 person/km <sup>2</sup>
Stop Time, hr/trip	4.0 <sup>(1)</sup>	
RADTRAN Input from NRC Models		
Vehicle Speed	55 mph	88.49 km/hr
Traffic Count – Rural, vehicles/hr	530	
Traffic Count – Suburban, vehicles/hr	760	
Traffic Count – Urban, vehicles/hr	2,400	
Dose Rate at 3.3 ft (1 m) from Vehicle <sup>(2)</sup>	14 mrem/hr	0.14 mSv/hr
Packaging Length <sup>(3)</sup>	17.1 ft	5.2 m
Packaging Diameter	3 ft	1.0 m
Number of Truck Crew	2	
Population Density at Stops (radii: 3.3 to 33 ft (1 to 10 m))	77,700 person/mi <sup>2</sup>	30,000 person/km <sup>2</sup>
Population Density at Stops (radii: 33 to 2,625 ft (10 to 800 m))	880 person/mi <sup>2</sup>	340 person/km <sup>2</sup>
Shielding Factor at Stops (radii: 3.3 to 33 ft (1 to 10 m))	1	
Shielding Factor at Stops (radii: 33 to 2,625 ft (10 to 800 m))	0.2	

Notes:

(1) Based on TRAGIS output: 8 stops at 30 minutes each.

$$(2) \quad 0.14 \text{ mSv/hr} * \frac{100 \text{ mrem}}{\text{mSv}} = 14 \text{ mrem/hr}$$

$$(3) \quad 5.2 \text{ m} * \frac{3.2808 \text{ ft}}{1 \text{ m}} = 17.06 \text{ ft}$$

**Table 7.4-3—{Irradiated Fuel Source Term}**

<b>Radionuclide (a)</b>	<b>Callaway Model U.S. EPR 5 Year Decay Ci/MTU</b>	<b>Callaway Model U.S. EPR 5 Year Decay<sup>(1)</sup> Bq/MTU</b>
Am-241	1.25E+03	4.62E+13
Am-242m	2.38E+01	8.82E+11
Am-243	3.22E+01	1.19E+12
Ce-144	1.52E+04	5.62E+14
Cm-242	4.35E+01	1.61E+12
Cm-243	3.19E+01	1.18E+12
Cm-244	4.84E+03	1.79E+14
Cm-245	6.19E-01	2.29E+10
Co-60	7.59E+01	2.81E+12
Cs-134	5.84E+04	2.16E+15
Cs-137	1.42E+05	5.25E+15
Eu-154	1.16E+04	4.31E+14
Eu-155	5.73E+03	2.12E+14
I-129	4.65E-02	1.72E+09
Kr-85	1.05E+04	3.88E+14
Pm-147	3.54E+04	1.31E+15
Pu-238	6.95E+03	2.57E+14
Pu-239	4.24E+02	1.57E+13
Pu-240	7.24E+02	2.68E+13
Pu-241	1.17E+05	4.34E+15
Pu-242	2.28E+00	8.44E+10
Ru-106	2.05E+04	7.59E+14
Sb-125	5.35E+03	1.98E+14
Sr-90	1.03E+05	3.81E+15
Y-90	1.03E+05	3.82E+15

**Table 7.4-4—{Irradiated Fuel Callaway Plant Model Accident and Fatality Rates}**

State	Accident Rate Accidents / truck-mi (Accidents / truck-km)	Fatality Rate Fatalities / truck-mi (Fatalities / truck-km)	Distance mi (km)	Accident Rate distance weighted fraction accident / truck-mi (accident / truck-km) <sup>(1)</sup>	Fatality Rate distance weighted fraction fatality / truck-mi (fatality / truck-km) <sup>(2)</sup>
AZ	2.12E-07 (1.32E-07)	1.51E-08 (9.40E-09)	29.3 (47.1)	3.42E-09 (2.12E-09)	2.43E-10 (1.51E-10)
CO	7.18E-07 (4.46E-07)	1.83E-08 (1.14E-08)	258.9 (416.7)	1.02E-07 (6.35E-08)	2.61E-09 (1.62E-09)
KS	4.57E-07 (2.84E-07)	8.37E-09 (5.20E-09)	432.2 (695.6)	1.09E-07 (6.75E-08)	1.99E-09 (1.24E-09)
MO	7.47E-07 (4.64E-07)	2.00E-08 (1.24E-08)	184.8 (297.4)	7.59E-08 (4.72E-08)	2.03E-09 (1.26E-09)
NV	3.62E-07 (2.25E-07)	1.06E-08 (6.60E-09)	167.5 (269.5)	3.33E-08 (2.07E-08)	9.78E-10 (6.08E-10)
UT	4.67E-07 (2.90E-07)	1.92E-08 (1.19E-08)	379.2 (610.3)	9.73E-08 (6.05E-08)	3.99E-09 (2.48E-09)
WY	1.08E-06 (6.74E-07)	1.74E-08 (1.08E-08)	366.5 (589.8)	2.19E-07 (1.36E-07)	3.50E-09 (2.18E-09)
<b>Sum:</b>			1818.5 (2926.4)	6.39E-07 (3.97E-07)	1.53E-08 (9.54E-09)
				Fatalities per Accident <sup>(3)</sup>	
				2.40E-02	

Notes:

(1) Accident rate distance weighted fraction = (Accident rate\*Distance) / Total distance

Sample Calculation:

(2.12E-07 accidents/truck-mi\* 29.3 mi) / 1818.5 mi = 3.42E-09 accident/truck-mi

(2) Fatality rate distance weighted fraction = (Fatality rate\*Distance) / Total distance

(3) Fatalities per accident = Sum of Fatality Rate / Sum of Accident Rate.

Reference: ANL, 1999. State-Level Accident Rates of Surface Freight Transportation: A Reexamination, Table 4, ANL/ESD/TM-150, Argonne National Laboratory, 1999.

**Table 7.4-5—{Irradiated Fuel and Radioactive Waste Models Severity and Release Fractions}**

Severity Category	Severity Fraction	Release Fractions				
		Gas	Cesium	Ruthenium	Particulate	Corrosion Product
1	1.53E-08	0.8	2.4E-08	6.0E-07	6.0E-07	2.0E-03
2	5.88E-05	0.14	4.1E-09	1.0E-07	1.0E-07	1.4E-03
3	1.81E-06	0.18	5.4E-09	1.3E-07	1.3E-07	1.8E-03
4	7.49E-08	0.84	3.6E-05	3.8E-06	3.8E-06	3.2E-03
5	4.65E-07	0.43	1.3E-08	3.2E-07	3.2E-07	1.8E-03
6	3.31E-09	0.49	1.5E-08	3.7E-07	3.7E-07	2.1E-03
7	0	0.85	2.7E-05	2.1E-06	2.1E-06	3.1E-03
8	1.13E-08	0.82	2.4E-08	6.1E-07	6.1E-07	2.0E-02
9	8.03E-11	0.89	2.7E-08	6.7E-07	6.7E-07	2.2E-03
10	0	0.91	5.9E-06	6.8E-07	6.8E-07	2.5E-03
11	1.44E-10	0.82	2.4E-08	6.1E-07	6.1E-07	2.0E-03
12	1.02E-12	0.89	2.7E-08	6.7E-07	6.7E-07	2.2E-03
13	0	0.91	5.9E-06	6.8E-07	6.8E-07	2.5E-03
14	7.49E-11	0.84	9.6E-05	8.4E-05	1.8E-05	6.4E-03
15	0	0.85	5.5E-05	5.0E-05	9.0E-06	5.9E-03
16	0	0.91	5.9E-06	6.4E-06	6.8E-07	3.3E-03
17	0	0.91	5.9E-06	6.4E-06	6.8E-07	3.3E-03
18	5.86E-06	0.84	1.7E-05	6.7E-08	6.7E-08	2.5E-03
19	0.99993	0	0	0	0	0

Note:

Aerosol and Respirable Fractions set to 1.0.

Reference: NRC, 2006. Environmental Impact Statement for an Early Site Permit (ESP) at the Exelon ESP Site Final Report, NUREG-1815, Table G-10, Nuclear Regulatory Commission, July, 2006.

**Table 7.4-6—{Irradiated Fuel Callaway Transportation Injury Rates}**

State	Injury Rate Injury / truck-mi (Injury / truck-km)	Distance mi (km)	Injury Rate Distance Weighted Fraction Injury / truck-mi (Injury / truck-km) <sup>(1)</sup>
AZ	1.88E-07 (1.17E-07)	29.3 (47.1)	3.03E-09 (1.88E-09)
CO	5.07E-07 (3.15E-07)	258.9 (416.7)	7.22E-08 (4.49E-08)
KS	4.09E-07 (2.54E-07)	432.2 (695.6)	9.72E-08 (6.04E-08)
MO	5.05E-07 (3.14E-07)	184.8 (297.4)	5.14E-08 (3.19E-08)
NV	2.38E-07 (1.48E-07)	167.5 (269.5)	2.19E-08 (1.36E-08)
UT	4.07E-07 (2.53E-07)	379.2 (610.3)	8.49E-08 (5.28E-08)
WY	5.20E-07 (3.23E-07)	366.5 (589.8)	1.05E-07 (6.51E-08)
<b>Sum:</b>		1818.5 (2926.4)	4.35E-07 (2.71E-07)

Note:

(1) Injury rate distance weighted fraction = (Injury rate \* Distance) / Total distance

Reference: ANL, 1999. State-Level Accident Rates of Surface Freight Transportation: A Reexamination, Table 4, ANL/ESD/TM-150, Argonne National Laboratory, 1999.

**Table 7.4-7—{New Fuel Callaway Transportation Fatality and Injury Rates}**

State	Fatality Rate Fatalities / Truck-mi (fatality / truck-km)	Injury Rate Injuries Truck-mi (injury / truck-km)	Distance mi (km)	Fatality Rate Distance Weighted Fraction Fatality / Truck-mi (fatality / truck-km) <sup>(1)</sup>	Injury Rate Distance Weighted Fraction Injury / Truck-mi (injury / truck-km) <sup>(2)</sup>
ID	6.12E-09 (3.80E-09)	4.94E-07 (3.07E-07)	275.6 (443.5)	9.22E-10 (5.73E-10)	7.45E-08 (4.63E-08)
IA	1.51E-08 (9.40E-09)	1.38E-07 (8.60E-08)	13.3 (21.4)	1.10E-10 (6.84E-11)	1.01E-09 (6.26E-10)
MO	2.00E-08 (1.24E-08)	5.05E-07 (3.14E-07)	296.5 (477.2)	3.24E-09 (2.01E-09)	8.20E-08 (5.09E-08)
NE	2.20E-08 (1.37E-08)	3.17E-07 (1.97E-07)	448.6 (721.9)	5.41E-09 (3.36E-09)	7.78E-08 (4.83E-08)
OR <sup>(3)</sup>	3.28E-08 (2.04E-08)	2.19E-07 (1.36E-07)	208.5 (335.5)	3.74E-09 (2.33E-09)	2.50E-08 (1.55E-08)
UT	1.92E-08 (1.19E-08)	4.07E-07 (2.53E-07)	149.1 (240.0)	1.56E-09 (9.71E-10)	3.32E-08 (2.06E-08)
WA	2.90E-09 (1.80E-09)	2.90E-07 (1.80E-07)	35.7 (57.4)	5.65E-11 (3.51E-11)	5.65E-09 (3.51E-09)
WY	1.74E-08 (1.08E-08)	5.20E-07 (3.23E-07)	400.6 (644.6)	3.81E-09 (2.37E-09)	1.14E-07 (7.08E-08)
<b>Sum:</b>			1827.8 (2941.5)	1.89E-08 (1.17E-08)	4.13E-07 (2.57E-07)

Notes:

- (1) Fatality rate distance weighted fraction = (Fatality rate\*Distance) / Total distance  
(2) Injury rate distance weighted fraction = (Injury rate\*Distance) / Total distance  
(3) Interstate data not provided. Values for Total Composite Fatality and Injury Rates used instead.

Reference: ANL, 1999. State-Level Accident Rates of Surface Freight Transportation: A Reexamination, Table 4, ANL/ESD/TM-150, Argonne National Laboratory, 1999.

**Table 7.4-8—{U.S. EPR Radwaste Annual Generation}**

Waste Type	Annual Activity <sup>(a)</sup>	
	Bq	Ci
Evaporator Concentrates	5.55E+12	1.50E+02
Spent Resins (other)	3.96E+13	1.07E+03
Spent Resins (Radwaste Demineralizer System)	5.55E+12	1.50E+02
Wet Waste from Demineralizers	5.55E+12	1.50E+02
Waste Drum for Solids Collection from Centrifuge System of KPF	5.55E+12	1.50E+02
Filters (quantity)	2.54E+13	6.86E+02
Sludge	5.55E+12	1.50E+02
Mixed Waste	1.48E+09	4.00E-02
Non-Compressible Dry Active Waste (DAW)	1.10E+10	2.97E-01
Compressible DAW	2.22E+11	6.01E+00
Combustible DAW	1.18E+12	3.19E+01
Total	9.41E+13	2.54E+03

Note:

(a) Refer to Section 3.5.

Reference: U.S. EPR FSAR, Chapter 11, Table 11.4-1 "Estimated Solid Waste Activity and Volume".

**Table 7.4-9—{RADTRAN/TRAGIS Radwaste Model Input Parameters}**

Parameter	Callaway Model
	EPR
TRAGIS Input:	
Route Mode	Commercial
Route Origin	Callaway
Route Destination	Hanford, WA
RADTRAN Input from TRAGIS:	
Total Shipping Distance, mi (km)	1,854.7 (2,984.7)
Travel Distance - Rural, mi (km)	1,587.6 (2,554.8)
Travel Distance - Suburban, mi (km)	236.8 (381.1)
Travel Distance - Urban, mi (km)	30.5 (49.1)
Population Density - Rural, person/mi <sup>2</sup> (person/km <sup>2</sup> )	23.0 (8.9)
Population Density - Suburban, person/mi <sup>2</sup> (person/km <sup>2</sup> )	850.6 (328.4)
Population Density - Urban, person/mi <sup>2</sup> (person/km <sup>2</sup> )	5,686.3 (2,195.5)
Stop Time, hr/trip	4.5 <sup>(b)</sup>
RADTRAN Input from NRC Models <sup>(a)</sup>	
Vehicle Speed, mph (km/hr)	55 (88.49)
Traffic Count - Rural, vehicles/hr	530
Traffic Count - Suburban, vehicles/hr	760
Traffic Count - Urban, vehicles/hr	2,400
Dose Rate at 3 ft (1 m) from Vehicle, mrem/hr (mSv/hr)	14 (0.14)
Packaging Length, ft (m)	17.1 (5.2)
Packaging Diameter, ft (m)	3.3 (1.0)
Number of Truck Crew	2
Population Density at Stops (radii: 3.3 to 33 ft (1 to 10 m)), person/mi <sup>2</sup> (person/km <sup>2</sup> )	77,700 (30,000)
Population Density at Stops (radii: 33 to 2,655 ft (10 to 800 m)), person/mi <sup>2</sup> (person/km <sup>2</sup> )	880 (340)
Shielding Factor at Stops (radii: 3.3 to 33 ft (1 to 10 m))	1
Shielding Factor at Stops (radii: 33 to 2,655 ft (10 to 800 m))	0.2

Notes:

- (a) From NUREG-1815 for spent fuel shipments.  
 (b) Based on TRAGIS output: 9 stops at 30 minutes each.

**Table 7.4-10—{Radwaste Annual Source Term}**

Radionuclide	RADTRAN Input	
	Annual Activity <sup>(1)</sup>	
	Bq	Ci
Ce-144	3.88E+10	1.05E+00
Co-58	5.37E+12	1.45E+02
Co-60	9.86E+12	2.67E+02
Cs-134	1.06E+13	2.85E+02
Cs-137	1.94E+13	5.25E+02
Fe-55	1.98E+13	5.36E+02
I-129	3.35E+07	9.06E-04
I-131	3.39E+08	9.16E-03
Mn-54	1.55E+13	4.18E+02
Pu-241	1.25E+10	3.39E-01
Ru-103	8.03E+11	2.17E+01
Ru-106	1.04E+12	2.81E+01
Sb-124	4.21E+08	1.14E-02
Sb-125	1.39E+09	3.74E-02
Sr-89	4.92E+08	1.33E-02
Sr-90	1.24E+11	3.36E+00
Y-90	1.21E+11	3.27E+00
Zn-65	4.07E+12	1.10E+02

Note:

(1) Annual Activity = Sum of Activity of Total Dry Solid Waste, Total Wet Solid Waste, and Mixed Waste.

**Table 7.4-11—{Radwaste Callaway Transportation Accident, Fatality and Injury Rates}**

State	Accident Rate	Fatality Rate	Injury Rate	Distance	Distance Weighted Fraction		
	Accidents / truck-mi (Accidents / truck-km)	Fatalities / truck-mi (Fatalities / truck-km)	Injuries / truck-mi (Injuries / truck-km)	mi (km) <sup>(a)</sup>	Accident Rate <sup>(b)</sup> Accidents / truck-mi (Accidents / truck-km)	Fatality Rate <sup>(c)</sup> Fatalities / truck-mi (Fatalities / truck-km)	Injury Rate <sup>(d)</sup> Injuries / truck-mi (Injuries / truck-km)
ID	4.75E-07 (2.95E-07)	6.12E-09 (3.80E-09)	4.94E-07 (3.07E-07)	275.6 (443.5)	7.05E-08 (4.38E-08)	9.09E-10 (5.65E-10)	7.34E-08 (4.56E-08)
IA	1.80E-07 (1.12E-07)	1.51E-08 (9.40E-09)	1.38E-07 (8.60E-08)	13.3 (21.4)	1.29E-09 (8.03E-10)	1.08E-10 (6.74E-11)	9.92E-10 (6.17E-10)
MO	7.47E-07 (4.64E-07)	2.00E-08 (1.24E-08)	5.05E-07 (3.14E-07)	296.5 (477.2)	1.19E-07 (7.42E-08)	3.19E-09 (1.98E-09)	8.08E-08 (5.02E-08)
NE	5.13E-07 (3.19E-07)	2.20E-08 (1.37E-08)	3.17E-07 (1.97E-07)	448.6 (721.9)	1.24E-07 (7.72E-08)	5.33E-09 (3.31E-09)	7.67E-08 (4.76E-08)
OR <sup>(e)</sup>	3.48E-07 (2.16E-07)	3.28E-08 (2.04E-08)	2.19E-07 (1.36E-07)	208.5 (335.5)	3.91E-08 (2.43E-08)	3.69E-09 (2.29E-09)	2.46E-08 (1.53E-08)
UT	4.67E-07 (2.90E-07)	1.92E-08 (1.19E-08)	4.07E-07 (2.53E-07)	149.1 (240.0)	3.75E-08 (2.33E-08)	1.54E-09 (9.57E-10)	3.27E-08 (2.03E-08)
WA	4.26E-07 (2.65E-07)	2.90E-09 (1.80E-09)	2.90E-07 (1.80E-07)	62.5 (100.6)	1.44E-08 (8.93E-09)	9.76E-11 (6.07E-11)	9.76E-09 (6.07E-09)
WY	1.08E-06 (6.74E-07)	1.74E-08 (1.08E-08)	5.20E-07 (3.23E-07)	400.6 (644.6)	2.34E-07 (1.46E-07)	3.75E-09 (2.33E-09)	1.12E-07 (6.98E-08)
Sum:				1854.7 (2984.7)	6.41E-07 (3.98E-07)	1.86E-08 (1.16E-08)	4.11E-07 (2.56E-07)
Fatalities per Accident <sup>(f)</sup>						2.91E-02	

Notes:

- (a) From TRAGIS.  
 (b) Accident rate distance weighted fraction = (Accident rate \* Distance) / Total distance  
 (c) Fatality rate distance weighted fraction = (Fatality rate \* Distance) / Total distance  
 (d) Injury rate distance weighted fraction = (Injury rate \* Distance) / Total distance  
 (e) Interstate data not provided. Values for Total Composite Accident, Fatality and Injury Rates used instead.  
 (f) Fatalities per accident = Fatality Rate / Accident Rate.

**Table 7.4-12—{Population Dose from Transportation Accidents}**

<b>Environmental Impact</b>	<b>New Fuel</b>	<b>Irradiated Fuel</b>	<b>Radwaste</b>	<b>Total</b>
U.S. EPR Dose Person-rem/ U.S. EPR-reactor-year (person-Sv/ U.S. EPR-reactor-year) <sup>(1)</sup>	See below	1.19E-04 <sup>(2)</sup> (1.19E-06)	3.20E-06 (3.20E-08)	1.22E-04 (1.22E-06)
Normalized Dose Person-rem/1100 MWe reactor-year (person-Sv/1100 MWe reactor-year)	See below	6.64E-05 (6.64E-07)	1.79E-06 (1.79E-08)	6.82E-05 (6.82E-07)

The dose from new fuel accidents is assumed to be negligible compared to the doses from Irradiated Fuel and Radioactive Waste as described in Section 7.4.2.

Note:

(1) RADTRAN 5.6 program output.

(2)  $(3.16\text{E-}06 \text{ person-rem/MTU}) \times (37.5 \text{ MTU/yr}) = 1.19\text{E-}04 \text{ person-rem/yr.}$

**Table 7.4-13—{Callaway Plant Unit 2 Summary of Annual Transportation Accident  
Non-Radiological Impact}**

<b>Environmental Impact</b>	<b>New Fuel</b>	<b>Irradiated Fuel</b>	<b>Radwaste</b>	<b>Total</b>	<b>10 CFR 51.52 Table S-4</b>
Fatal Injury per 100 reactor years	5.16E-02	1.17E-01	1.04E-01	2.73E-01	1.0
Non-Fatal Injury per 10 reactor years	1.13E-01	3.32E-01	2.29E-01	6.75E-01	1.0