12.2 Radiation Sources

This section describes the sources of radiation that form the basis for shielding design calculations and the sources of airborne radioactivity used for the design of personnel protection measures and dose assessment.

12.2.1 Contained Sources

The shielding design source terms are based on the three plant conditions of normal full-power operation, shutdown, and design basis accident events.

12.2.1.1 Sources for Full-Power Operation

The primary sources of radioactivity during normal full-power operation are direct core radiation, coolant activation processes, leakage of fission products from pinhole defects in fuel rod cladding, and activation of reactor coolant corrosion products. The design basis for fission product activities is operation with cladding defects in fuel rods producing 0.25 percent of the core thermal power. The design basis for activation and corrosion product activities is derived from measurements at operating plants and is independent of the fuel defect level.

12.2.1.1.1 Reactor Core

The neutron and gamma flux from the reactor core is reduced by the reactor internals and by the reactor vessel. Table 12.2-1 lists the neutron and gamma energy flux spectra in the reactor cavity outside the reactor vessel for several energy groups. The values are maximum values on the inside surface of the primary shield concrete at the core midplane.

12.2.1.1.2 Reactor Coolant System

Sources of radiation in the reactor coolant system are fission products released from fuel and activation of the coolant and of corrosion products that are circulated in the reactor coolant. These sources and their bases are described in Section 11.1.

The activation product, nitrogen-16 (N-16), is the predominant contributor to the activity in the reactor coolant pumps, steam generators, and reactor coolant piping during operation. The N-16 activity in each of the components depends on the total transit time to the component and the average residence time in the component. Table 12.2-3 presents the reactor coolant N-16 activity as a function of transport time in a reactor coolant loop. The N-16 activity for the pressurizer is tabulated in Table 12.2-4.

Fission and corrosion product activities circulating in the reactor coolant system and out-of-core crud deposits comprise the remaining significant radiation sources during full-power operation. The fission and corrosion product activities circulating in the reactor coolant are given in Section 11.1. The fission and corrosion product source strengths and specific activities in the pressurizer liquid and vapor phases are given in Table 12.2-5.

The isotopic composition and specific activity of typical out-of-core crud deposits are given in Table 12.2-6. Typically, one milligram of deposited crud material is found on one square centimeter of a relatively smooth surface. This may be as much as 50 times higher in crud trap areas. Crud trap areas are generally locations of high turbulence, areas of high momentum change, gravitational sedimentation areas, high affinity material areas, and possibly thin boundary layer regions.

The N-16 activity is not a factor in the radiation sources for systems and components located outside containment. This is due to its short, half-life (7.11 seconds) and the greater than one minute transport time before flow exits the containment. The normal letdown flow path is entirely inside containment. Primary coolant is directed outside containment only when it is diverted to the liquid radwaste system (e.g., due to boron dilution operations or for degassing prior to shutdown).

12.2.1.1.3 Chemical and Volume Control System

Radiation sources in the chemical and volume control system consist of radionuclides carried in the reactor coolant. The chemical and volume control system components in the purification path are located inside containment. The chemical and volume control system carries radioactive fluid out of the containment only when reactor coolant is directed to the liquid radwaste system.

The shielding design of the chemical and volume control system components is based on processing reactor coolant having the design basis source term presented in Section 11.1. The regenerative and letdown heat exchanger sources include contributions from N-16. Owing to its short half-life, the concentration of N-16 is highly sensitive to the location of these heat exchangers with respect to the reactor coolant loop piping. The concentration of N-16 at the heat exchangers is assumed to be the value in the reactor coolant when it exits the steam generator (see Table 12.2-3). The radiation sources for the other components in the purification loop do not include a contribution from N-16. The N-16 contribution to the shielding source term for the filter and demineralizers is determined based on the additional decay afforded by the time delay resulting from the system layout. The chemical and volume control system component sources are provided in Table 12.2-7.

12.2.1.1.4 Service Water System and Component Cooling Water System

These systems are normally nonradioactive or, if there is inleakage of radioactive material into the systems, of very low level activity. For shielding and dose assessment purposes, these systems are assumed to be nonradioactive.

12.2.1.1.5 Spent Fuel Pool Cooling System

One of the functions of the spent fuel pool cooling system is to provide cleanup of the water in the spent fuel pool, the refueling cavity, and the in-containment refueling water storage tank. The equipment considered in designing shielding are the spent fuel pool cooling system demineralizers and filters which accumulate activity, primarily Co-58 and Co-60 from radioactive crud that is resuspended in the water during the course of fuel handling. The source terms for this equipment are provided in Table 12.2-8. Based on operating experience, the remainder of the spent fuel pool cooling system may contain a significant amount of crud and thus requires shielding. The composition of crud is provided in Table 12.2-6.

12.2.1.1.6 Main Steam Supply System

Potential radioactivity in the main steam supply system is a result of steam generator tube leaks and is sufficiently low so that no radiation shielding for equipment in secondary systems is required to meet radiation zone requirements.

12.2.1.1.7 Liquid Radwaste System

Radioactive inputs include fission and activation product radionuclides produced in the core and reactor coolant. Shielding for each component of the liquid radwaste system is based on the sources listed on Table 12.2-9. Radiation sources for the various pumps in the liquid radwaste system are assumed to be identical to the liquid sources in the tank from which the pump takes suction.

12.2.1.1.8 Gaseous Radwaste System

Radioactive gases and hydrogen removed from the reactor coolant when coolant is discharged to the liquid radwaste system comprise the bulk of the gas processed by the gaseous radwaste system. There is no gas stripping performed in the reactor coolant purification loop of the chemical and volume control system. The result is that the volume of gases processed by the gaseous radwaste system is small. Table 12.2-10 lists the shielding sources for the components in the gaseous radwaste system.

12.2.1.1.9 Solid Radwaste System

The solid radwaste system handles various radioactive waste products ranging from relatively low activity materials to high activity spent resins and filter cartridges. Solid wastes are packaged for shipment to a burial or long-term storage facility.

Prior to packaging, the spent resin is stored in a spent resin storage tank. Two spent resin storage tanks are provided, one for high activity resins and the other for low activity resins. The initial gamma source strength in the high activity spent resin storage tank is assumed to be the same as that in the chemical and volume control system mixed bed demineralizer. After a 30-day decay period, only the cesium and cobalt isotopes are significant contributors to the radiation field. Table 12.2-11 lists the source strengths and specific activities both initially and after 30 days of decay.

Spent filter cartridge sources are as listed in Tables 12.2-7, 12.2-8, and 12.2-9.

12.2.1.1.10 Miscellaneous Sources

There are additional contained sources used for instrument calibration or for radiography. The Combined License applicant will identify these sources.

12.2.1.2 Sources for Shutdown

In the reactor shutdown condition, the only additional significant sources requiring permanent shielding consideration are the spent reactor fuel, the residual heat removal system, and the incore detector system. Individual components may require shielding during shutdown due to deposited crud material. Estimates of accumulated crud in the reactor coolant system are given in subsection 12.2.1.1. The radiation sources in the reactor coolant system and other systems addressed in subsection 12.2.1.1 are bounded by the sources given for full power operation with the exception of a short time period (less than 24 hours) following shutdown, during which crud bursts can result in increased radiation sources. Crud bursts are the resuspension of a portion of the accumulated deposited corrosion products into the reactor coolant system during shutdown operation. Activity increases also occur during planned coolant oxygenation procedures prior to refueling activities.

12.2.1.2.1 Normal Residual Heat Removal System

The maximum gamma ray source strengths in the normal residual heat removal system for four and eight hours after reactor shutdown are given in Table 12.2-12 along with the listing of contributing nuclides. The system may be placed in operation at the maximum flow rate at approximately four hours following a shutdown. The system removes decay heat from the reactor for the duration of the shutdown. The sources given are maximum values taking into account activity increases due to coolant oxygenation measures.

12.2.1.2.2 Reactor Core

The core average gamma ray and neutron source strengths are used in the evaluation of radiation levels within and around the shutdown reactor.

The basis for the core average source strengths is an equilibrium cycle core at end-of-life. Feed enrichments of 4.7 (12 assemblies) and 4.8 (36 assemblies) weight-percent U-235 were assumed. The regions operate at a specific power of 28.9 megawatts (thermal) per metric ton of uranium for 635, 1271, and 1906 effective full-power days, respectively (this is for a 24 month fuel cycle with an 87 percent capacity factor).

Core average gamma ray source strengths are presented in Table 12.2-2 for various times after shutdown. These source strengths may be put on a per-unit volume of homogenized core basis by multiplying them by the core power density (78.8 watts/cc).

Neutrons are produced in the shutdown reactor by spontaneous fission of the transplutonium isotopes and by (α,n) reactions of alpha particles with 0-17 and 0-18 in the uranium dioxide fuel.

Core average neutron source strengths are given in Table 12.2-13 for various times after shutdown. The neutron source strengths may be put on a per-unit volume of homogenized core basis by multiplying them by the power density.

12.2.1.2.3 Spent Fuel

Spent fuel gamma ray and neutron source strengths are used in the evaluation of radiation levels for fuels handling, spent fuel storage, and shipping.

The basis for the spent fuel data presented here is the discharge region of an equilibrium cycle core at end of life. A feed enrichment of 4.8 weight-percent U-235 is assumed. The discharge region was operated at a specific power of 28.9 megawatts (thermal) per metric ton of uranium for 1906 effective full-power days.

Spent fuel gamma ray source strengths are presented in Table 12.2-14 for various times after shutdown. These source strengths may be put on a per-unit volume of homogenized core basis by multiplying by the power density (78.8 watts/cc).

Spent fuel neutron source strengths are given in Table 12.2-13 for various times after shutdown. The neutron source strengths may be put on a per-unit volume of homogenized core basis by multiplying them by the power density.

12.2.1.2.4 Irradiated Control Rods, Gray Rods, and Secondary Source Rods

The gamma ray source strengths of the irradiated control rods, gray rods, and secondary source rods are used in establishing radiation shielding requirements during refueling operations and during shipping of irradiated rods.

The absorber material used in the control rods is silver-indium-cadmium (Ag-In-Cd). The gray rods contain either type 304 stainless steel or Ag-In-Cd pellets. The gamma ray source strengths associated with the irradiated Ag-In-Cd absorber are listed in Table 12.2-15 for various times after shutdown.

The photoneutron source material used in the secondary source rods is an equal volume mixture of antimony and beryllium (Sb-Be). The gamma ray source strengths associated with the secondary source rods are listed in Table 12.2-16 for various times after shutdown and Table 12.2-17 lists the neutron source strengths. The source values are per cubic centimeter of source material for an irradiation period of 400 days.

The material used for the control rod cladding, gray rod cladding and/or pellets and secondary source rod cladding is Type 304 stainless steel with an assumed maximum cobalt content of 0.12 weight percent. The gamma ray source strengths associated with the irradiated stainless steel are listed in Table 12.2-18 for various times after shutdown.

12.2.1.2.5 Incore Flux Thimbles

Irradiated incore flux thimble gamma ray source strengths are given in Table 12.2-19. These source strengths are used in determining shielding requirements during refueling operations when the flux thimbles are withdrawn from the reactor core.

12.2.1.3 Sources for the Core Melt Accident

The AP600 is designed to provide adequate core cooling in the event of a postulated loss of coolant accident (LOCA) so that there is no significant core damage. Following a LOCA, the normal residual heat removal system could be used, if available, to provide post-accident cooling, use of the normal residual heat removal system is acceptable only if the source term is close to the design basis source term (see Table 12.2-12).

For the evaluation of the radiological consequences of the LOCA, it is assumed that major degradation of the core takes place, including melting of the core. The source term used for the LOCA dose analysis assumes no core release for 10 minutes, then there is a gap release from a small number of fuel rods before the onset of core degradation. The first half hour of core release is restricted to releases from the fuel cladding gap; this gap release phase is followed by the in-vessel core melt phase that has a duration of 1.3 hours. After the in-vessel core melt phase, there is assumed to be no further release of activity from the core. This core activity release model is based on the source term model from NUREG-1465 (Reference 1). The source term is described in detail in subsection 15.6.5.3.

If there is core degradation, core cooling would be provided by the passive core cooling system which is totally inside the containment such that no high activity sump solution would be recirculated outside the containment. The shielding provided for the containment addresses this post-LOCA source term. The source strengths as a function of time are provided in Table 12.2-20 and the integrated source strengths are provided in Table 12.2-21.

12.2.2 Airborne Radioactive Material Sources

This subsection deals with the models, parameters, and sources required to evaluate airborne concentration of radionuclides during plant operations in various plant radiation areas where personnel occupancy is expected.

12.2.2.1 Containment Atmosphere

The main sources of airborne activity in the containment is leakage of primary coolant and activation of naturally occurring argon in the atmosphere. During normal power operation, excessive activity buildup in the containment atmosphere is prevented by periodic purging of the containment (approximately 20 hours per week). When the plant is shut down for refueling or maintenance, additional purging of the containment atmosphere is performed to further reduce the activity levels consistent with the increased level of worker presence in the containment. The assumptions and parameters used to determine the airborne activity levels in the containment are listed in Table 12.2-22. The airborne concentrations are provided in

Table 12.2-23. Three situations are considered: normal power operation without purge, normal power operation with 20 hours of purge operation per week, and shutdown operation.

12.2.2.2 Fuel-Handling Area Atmosphere

The source of airborne activity in the fuel-handling area is leakage from stored spent fuel assemblies and the evaporation losses from the spent fuel pool. The maximum airborne concentration in the fuel-handling area is calculated using the assumptions and parameters in Table 12.2-24. The resulting airborne isotopic concentrations are provided in Table 12.2-25.

12.2.2.3 Auxiliary Building Atmosphere

The source of airborne activity in the auxiliary building atmosphere is primarily equipment leakage. The ventilation system constantly removes activity and discharges it to the plant vent. The maximum airborne concentration in the auxiliary building is calculated using the assumptions and parameters in Table 12.2-26. The resulting airborne isotopic concentrations are provided in Table 12.2-27.

12.2.2.4 Airborne Activity Model

The airborne concentration of each nuclide in the atmosphere is calculated by:

$$C_i(t) = \frac{(LR)_i A_i \, (PF)_i \, (1 - e^{-\lambda_{Ti} t})}{(V)\,(\lambda_{Ti})}$$

where:

$(LR)_i$ = leak or evaporation rate of the i^{th} radioisotope in the applicable region (g/s)

A_i = activity concentration of the i^{th} leaking or evaporating radioisotope (μCi/g)

$(PF)_i$ = partition factor or the fraction of the leaking activity that is airborne for the i^{th} radioisotope

λ_{Ti} = total removal rate constant for the i^{th} radioisotope from the applicable region (s^{-1})

= $\lambda_{di} + \lambda_e$, the removal rate constants in s^{-1} due to radioactive decay for the i^{th} radioisotope and the exhaust from the applicable region, respectively

t = time elapsed from the start of the leak and the time at which the concentration is evaluated (s)

V = free volume of the region in which the leak occurs (cm^3)

$C_i(t)$ = airborne concentration of the i^{th} radioisotope at time t in the applicable region ($\mu Ci/cm^3$).

From the above equation, the peak or equilibrium concentration, C_{Egi}, of the i^{th} radioisotope in the applicable volume is given by the following expression:

$$C_{Egi} = (LR)_i \, A_i \, (PF)_i \, /V\lambda_{Ti}$$

With high exhaust rates, this peak concentration is reached within a few hours.

12.2.3 Combined License Information

The Combined License applicant will address any additional contained radiation sources not identified in subsection 12.2.1, including radiation sources used for instrument calibration or radiography.

12.2.4 References

1. L. Soffer, et al., "Accident Source Terms for Light-Water Nuclear Power Plants," NUREG-1465, February 1995.

Table 12.2-1

RADIATION FLUX AT THE PRIMARY SHIELD CONCRETE

Neutron Flux

Energy	Flux (n/cm^2-sec)
$\geq$ 1 Mev	2.9×10^8
0.1 Mev to 1 Mev	2.8×10^9
0.414 kev to 0.1 Mev	4.6×10^9
< 0.414 kev	8.0×10^8

Gamma Energy Flux

Energy	Flux (Mev/cm^2-sec)
$\geq$ 6.0 Mev	3.2×10^9
3.0 Mev to 6.0 Mev	2.1×10^9
1.0 Mev to 3.0 Mev	1.5×10^9
< 1.0 Mev	9.8×10^8

Table 12.2-2

CORE AVERAGE GAMMA RAY SOURCE STRENGTHS AT VARIOUS TIMES AFTER SHUTDOWN

Energy Group Mev/gamma	Source Strength at Time After Shutdown (Mev/watt-sec) 12 Hours	24 Hours	100 Hours	1 Week	1 Month
<0.15	2.0×10^{9}	1.8×10^{9}	8.6×10^{8}	5.0×10^{8}	1.1×10^{8}
0.15 - 0.45	2.8×10^{9}	2.4×10^{9}	1.1×10^{9}	6.7×10^{8}	8.2×10^{7}
0.45 - 1.0	1.1×10^{10}	9.5×10^{9}	6.3×10^{9}	5.4×10^{9}	3.4×10^{9}
1.0 - 1.5	1.8×10^{9}	1.1×10^{9}	4.6×10^{8}	3.2×10^{8}	9.4×10^{7}
1.5 - 2.0	3.1×10^{9}	2.9×10^{9}	2.4×10^{9}	2.1×10^{9}	6.0×10^{8}
2.0 - 2.5	2.8×10^{8}	1.9×10^{8}	1.4×10^{8}	1.2×10^{8}	4.8×10^{7}
2.5 - 3.0	1.7×10^{8}	1.6×10^{8}	1.4×10^{8}	1.2×10^{8}	3.5×10^{7}
3.0 - 4.0	4.8×10^{6}	1.8×10^{6}	1.5×10^{6}	1.3×10^{6}	4.0×10^{5}
4.0 - 6.0	3.3×10^{5}	1.8×10^{4}	-	-	-

Energy Group Mev/gamma	3 Months	6 Months	1 Year	5 Years
<0.15	4.3×10^{7}	2.2×10^{7}	1.3×10^{7}	1.7×10^{6}
0.15 - 0.45	7.1×10^{6}	3.4×10^{6}	2.5×10^{6}	9.2×10^{5}
0.45 - 1.0	1.9×10^{9}	1.0×10^{9}	4.5×10^{8}	1.4×10^{8}
1.0 - 1.5	4.6×10^{7}	3.7×10^{7}	2.9×10^{7}	9.7×10^{6}
1.5 - 2.0	2.6×10^{7}	2.9×10^{6}	1.9×10^{6}	3.5×10^{5}
2.0 - 2.5	2.0×10^{7}	1.5×10^{7}	9.8×10^{6}	3.0×10^{5}
2.5 - 3.0	1.5×10^{6}	1.6×10^{5}	1.1×10^{5}	6.8×10^{3}
3.0 - 4.0	4.8×10^{4}	2.9×10^{4}	2.0×10^{4}	1.3×10^{3}
4.0 - 6.0	-	-	-	-

Table 12.2-3

REACTOR COOLANT NITROGEN-16 ACTIVITY

Position in Loop	Loop Transit Time (sec)	Nitrogen-16 Activity (μCi/g)
Leaving core	0.0	163
Leaving reactor vessel	1.8	136
Entering steam generator	2.1	133
Leaving steam generator	7.3	80
Entering reactor vessel	8.5	71
Entering core	11.5	58
Leaving core	12.5	163

Table 12.2-4

PRESSURIZER NITROGEN-16 SOURCE STRENGTHS

		Source Strength	
Discrete Energy (Mev/gamma)	Energy Group (Mev/gamma)	Liquid Phase[(a)] (Mev/gram-sec)	Steam Phase[(b)] (Mev/cm^3-sec)
1.75	1.35 - 1.80	5.9	8.6×10^{-2}
2.74	2.6 - 3.0	5.4×10^{1}	7.8×10^{-1}
6.13	6.0 - 7.0	1.1×10^{4}	1.6×10^{2}
7.12	7.0 - 7.5	9.1×10^{2}	1.3×10^{1}

Notes:
(a) Based on an insurge to the pressurizer following a ten percent step load power increase.
(b) Based on a boron equalization spray rate of 80 gpm.

Table 12.2-5 (Sheet 1 of 3)

PRESSURIZER LIQUID AND STEAM PHASE SOURCE STRENGTHS AND SPECIFIC ACTIVITY

1100 Cubic Foot Liquid Phase Source Strengths

Energy Group (Mev/gamma)		Source Strength (Mev/gram-sec)
0.2 - 0.4		1.1×10^{5} [(a)]
0.4 - 0.9		1.1×10^{5}
0.9 - 1.35		4.8×10^{4}
1.35 - 1.8		3.0×10^{4}
1.8 - 2.2		3.7×10^{4}
2.2 - 2.6		3.7×10^{4}
2.6 - 3.0		4.0×10^{3}
3.0 - 4.0		1.5×10^{3}
4.0 - 5.0		1.7×10^{2}
	TOTAL	3.8×10^{5}

800 Cubic Foot Liquid Phase Specific Activity

Nuclide	Activity (μCi/gram)
Kr-88	7.7×10^{-1}
Kr-89	1.7×10^{-2}
Xe-133	6.9×10^{1}
Xe-135	2.1
I-132	4.8×10^{-1}
I-133	5.8×10^{-1}
I-135	3.2×10^{-1}
Rb-88	7.6×10^{-1}
Cs-134	2.3×10^{-1}
Cs-136	5.3×10^{-1}
Cs-138	1.8×10^{-1}

Note:
(a) Includes 80 kev Xe-133

Table 12.2-5 (Sheet 2 of 3)

PRESSURIZER LIQUID AND STEAM PHASE SOURCE STRENGTHS AND SPECIFIC ACTIVITY

800 Cubic Foot Steam Phase Source Strengths (Mev/cm^3-sec)

Energy Group (Mev/gamma)		Normal 2-gpm Spray
0.2 - 0.4		1.8×10^5 (a)
0.4 - 0.9		1.7×10^3
0.9 - 1.35		3.3×10^2
1.35 - 1.8		5.5×10^2
1.8 - 2.2		7.9×10^2
2.2 - 2.6		1.6×10^3
2.6 - 3.0		8.1
3.0 - 4.0		2.7
	TOTAL	1.8×10^5

Note:
(a) Includes 80 kev Xe-133

Table 12.2-5 (Sheet 3 of 3)

PRESSURIZER LIQUID AND STEAM PHASE SOURCE STRENGTHS AND SPECIFIC ACTIVITY

800 Cubic Foot Steam Phase Specific Activity (μCi/cm^3)

Nuclide	Normal 2-gpm Spray
Kr-83m	2.9×10^{-3}
Kr-85m	4.1×10^{-2}
Kr-85	6.4
Kr-87	5.0×10^{-3}
Kr-88	4.0×10^{-2}
Kr-89	1.4×10^{-8}
Xe-131m	1.6
Xe-133m	1.1
Xe-133	1.5×10^{2}
Xe-135m	1.3×10^{-4}
Xe-135	4.0×10^{-1}
Xe-137	1.3×10^{-7}
Xe-138	1.3×10^{-4}
I-129	6.7×10^{-11}
I-130	4.0×10^{-5}
I-131	2.8×10^{-3}
I-132	4.8×10^{-3}
I-133	5.8×10^{-3}
I-134	1.0×10^{-3}
I-135	3.2×10^{-3}

Table 12.2-6

ISOTOPIC COMPOSITION AND SPECIFIC ACTIVITY OF TYPICAL OUT-OF-CORE CRUD DEPOSITS[(a)]

Composition (Nuclide)	Activity (μCi/mg) of Deposited Crud for Effective Full Power Years of Plant Operation			
	1 Year	**2 Years**	**5 Years**	**10 Years**
Mn-54	1.0	1.1	1.3	1.4
Fe-59	0.5	0.5	0.5	0.5
Co-58	12.0	12.0	12.0	12.0
Co-60	1.5	2.3	4.0	6.0

Note:
(a) In addition to corrosion products, about 1.0 μg of mixed actinides and fission products may be present for each 1 g of deposited crud.

Table 12.2-7 (Sheet 1 of 5)

CHEMICAL AND VOLUME CONTROL SYSTEM COMPONENTS SOURCE STRENGTHS AND SPECIFIC ACTIVITY

A. Regenerative heat exchanger

Energy Group		Source Strength (Mev/gram-sec)	
Mev/gamma		**Tube Side**	**Shell Side**
0.2 - 0.4		1.1×10^5	1.1×10^5
0.4 - 0.9		1.1×10^5	5.6×10^4
0.9 - 1.35		4.8×10^4	3.1×10^4
1.35 - 1.8		3.7×10^4	2.0×10^4
1.8 - 2.2		3.7×10^4	3.1×10^4
2.2 - 2.6		3.7×10^4	3.7×10^4
2.6 - 3.0		6.6×10^4	3.8×10^3
3.0 - 4.0		1.5×10^3	1.4×10^3
6.0 - 7.0		1.3×10^7	-
7.0 - 7.5		1.1×10^6	-
	Total	1.4×10^7	2.9×10^5

	Activity (μCi/gram)	
Nuclide	**Tube Side**	**Shell Side**
Kr-88	7.7×10^{-1}	7.7×10^{-1}
Kr-89	1.7×10^{-2}	1.7×10^{-2}
Xe-133	6.9×10^1	6.9×10^1
Xe-135	2.1	2.1
I-132	4.8×10^{-1}	-
I-135	3.2×10^{-1}	-
Rb-88	7.6×10^{-1}	7.6×10^{-1}
Cs-134	2.3×10^{-1}	2.3×10^{-1}
Cs-136	5.3×10^{-1}	5.3×10^{-1}
Cs-138	1.8×10^{-1}	1.8×10^{-1}
N-16	8.0×10^1	-

Table 12.2-7 (Sheet 2 of 5)

CHEMICAL AND VOLUME CONTROL SYSTEM COMPONENTS SOURCE STRENGTHS AND SPECIFIC ACTIVITY

B. Letdown heat exchanger

Energy Group Mev/gamma		Source Strength (Mev/gram-sec)
0.2 - 0.4		1.1×10^{5} (a)
0.4 - 0.9		1.1×10^{5}
0.9 - 1.35		4.8×10^{4}
1.35 - 1.8		3.7×10^{4}
1.8 - 2.2		3.7×10^{4}
2.2 - 2.6		3.7×10^{4}
2.6 - 3.0		6.6×10^{4}
3.0 - 4.0		1.5×10^{3}
6.0 - 7.0		1.3×10^{7}
7.0 - 7.5		1.1×10^{6}
	TOTAL	1.4×10^{7}

Nuclide	Activity (μCi/gram)
Kr-88	7.7×10^{-1}
Kr-89	1.7×10^{-2}
Xe-133	6.9×10^{1}
Xe-135	2.1
I-132	4.8×10^{-1}
I-135	3.2×10^{-1}
Rb-88	7.6×10^{-1}
Cs-134	2.3×10^{-1}
Cs-136	5.3×10^{-1}
Cs-138	1.8×10^{-1}
N-16	8.0×10^{1}

Note:
(a) Includes 80 kev Xe-133

Table 12.2-7 (Sheet 3 of 5)

CHEMICAL AND VOLUME CONTROL SYSTEM COMPONENTS SOURCE STRENGTHS AND SPECIFIC ACTIVITY

C. Mixed bed demineralizer (50 cubic feet of resin)

Energy Group (Mev/gamma)	Source Strength (Mev/gram-sec)
0.2 - 0.4	1.6×10^7
0.4 - 0.9	1.6×10^8
0.9 - 1.35	1.6×10^7
1.35 - 1.8	4.4×10^6
1.8 - 2.2	6.2×10^5
2.2 - 2.6	1.2×10^5
2.6 - 3.0	4.1×10^4
3.0 - 4.0	1.1×10^4
4.0 - 5.0	7.2×10^2
TOTAL	2.0×10^8

Nuclide	Activity (μCi/gram)
I-131	1.2×10^3
I-135	4.9×10^1
Rb-88	3.6
Cs-134	1.7×10^3
Cs-136	7.4×10^1
Ba-137m	2.0×10^3
Cs-138	2.0
Co-60	8.6×10^1

Table 12.2-7 (Sheet 4 of 5)

CHEMICAL AND VOLUME CONTROL SYSTEM COMPONENTS SOURCE STRENGTHS AND SPECIFIC ACTIVITY

D. Cation bed demineralizer (50 cubic feet of resin)

Energy Group (Mev/gamma)	Source Strength (Mev/gram-sec)
0.2 - 0.4	8.7×10^5
0.4 - 0.9	1.4×10^8
0.9 - 1.35	5.2×10^6
1.35 - 1.8	3.0×10^6
1.8 - 2.2	6.0×10^4
2.2 - 2.6	2.9×10^4
2.6 - 3.0	2.5×10^4
3.0 - 4.0	5.1×10^3
4.0 - 5.0	6.8×10^2
TOTAL	1.5×10^8

Nuclide	Activity (μCi/gram)
Rb-88	3.6
Cs-134	1.7×10^3
Cs-136	7.4×10^1
Cs-137	2.1×10^3
Cs-138	2.0
Ba-137m	2.0×10^3

Table 12.2-7 (Sheet 5 of 5)

CHEMICAL AND VOLUME CONTROL SYSTEM COMPONENTS SOURCE STRENGTHS AND SPECIFIC ACTIVITY

E. Reactor coolant filter

Energy Group (Mev/gamma)	Source Strength (Mev/cm^3-sec)
0.4 - 0.9	5.7×10^7
0.9 - 1.35	1.5×10^7

Table 12.2-8

SPENT FUEL POOL COOLING SYSTEM COMPONENT SOURCE STRENGTHS AND SPECIFIC ACTIVITY

A. Demineralizer (50 cubic feet of resin)

Energy Group (Mev/gamma)	Source Strength (Mev/cm^3-sec)
0.4 - 0.9	3.0×10^6
0.9 - 1.35	4.7×10^6

Nuclide	Activity (µCi/cm^3)
Co-58	1.2×10^2
Co-60	7.1×10^1

B. Filters

Energy Group (Mev/gamma)	Source Strength (Mev/cm^3-sec)
0.4 - 0.9	1.1×10^7
0.9 - 1.35	3.0×10^6

Source Dimensions (inches)	Source Composition (volume percent)
Radius = 3.375	Air - 67
Length = 19	Water - 33

Table 12.2-9 (Sheet 1 of 5)

LIQUID RADWASTE SYSTEM COMPONENT SOURCE TERMS

A. Reactor coolant drain tank

	Source Strength (Mev/cc-sec)	
Energy Group (Mev/gamma)	**Liquid Phase (466 gallons)**	**Gas Space (58 cubic feet)**
0.2 - 0.4	1.1×10^5	1.7×10^5 (a)
0.4 - 0.9	1.1×10^5	4.2×10^3
0.9 - 1.35	4.8×10^4	1.6×10^2
1.35 - 1.8	3.0×10^4	4.7×10^2
1.8 - 2.2	3.7×10^4	8.3×10^2
2.2 - 2.6	3.7×10^4	1.7×10^3
2.6 - 3.0	4.0×10^3	--
3.0 - 4.0	1.5×10^3	--
4.0 - 5.0	1.7×10^2	
Total	3.8×10^5	1.8×10^5

	Activity (μCi/cm³)	
Nuclide	**Liquid Phase**	**Gas Space**
I-132	4.8×10^{-1}	--
I-133	5.8×10^{-1}	--
I-135	3.2×10^{-1}	--
Cs-134	2.3×10^{-1}	--
Cs-136	5.3×10^{-1}	--
Cs-138	1.8×10^{-1}	--
Kr-85	--	4.4×10^1
Kr-87	--	6.2×10^{-3}
Kr-88	--	4.2×10^{-2}
Kr-89	--	1.8×10^{-5}
Xe-133	--	1.4×10^2

Note:
(a) Includes 80 kev Xe-133

Table 12.2-9 (Sheet 2 of 5)

LIQUID RADWASTE SYSTEM COMPONENT SOURCE TERMS

B. Effluent tank (28,000 gal) and waste holdup tank (15,000 gal)

Energy Group (Mev/gamma)	Source Strength (Mev/cc-sec) Effluent Tank Liquid Phase	Effluent Tank Vapor Phase	Holdup Tank Liquid
0.2 - 0.4	5.6×10^{3}	4.3×10^{5}	5.5×10^{3}
0.4 - 0.9	4.5×10^{4}	2.0×10^{4}	3.9×10^{4}
0.9 - 1.35	2.8×10^{4}	5.8×10^{3}	2.4×10^{4}
1.35 - 1.8	9.5×10^{3}	1.7×10^{4}	1.4×10^{3}
1.8 - 2.2	1.3×10^{4}	3.1×10^{4}	6.7×10^{2}
2.2 - 2.6	3.0×10^{3}	6.5×10^{4}	6.5×10^{1}
2.6 - 3.0	3.5×10^{3}	3.2×10^{2}	1.8×10^{1}
3.0 - 4.0	9.8×10^{2}	1.1×10^{2}	-
4.0 -5.0	1.5×10^{2}	-	-
Total	1.1×10^{5}	5.7×10^{5}	7.0×10^{4}

Nuclides	Activity (µCi/cc) Effluent Tank Liquid Phase	Effluent Tank Vapor Phase	Holdup Tank Liquid
I-131	2.8×10^{-2}	-	2.8×10^{-2}
I-132	4.8×10^{-2}	-	4.8×10^{-2}
I-133	5.8×10^{-2}	-	5.8×10^{-2}
I-135	3.2×10^{-2}	-	3.2×10^{-2}
Cs-134	2.3×10^{-1}	-	2.3×10^{-1}
Cs-136	5.3×10^{-1}	-	5.3×10^{-1}
Kr-85	-	9.6	-
Kr-85M	-	1.3	-
Kr-87	-	2.0×10^{-1}	-
Kr-88	-	1.6	-
Xe-131M	-	3.4	-
Xe-133	-	3.1×10^{2}	-
Xe-133M	-	4.3×10^{1}	-
Xe-135	-	7.6	-

Table 12.2-9 (Sheet 3 of 5)

LIQUID RADWASTE SYSTEM
COMPONENT SOURCE TERMS

C. Chemical waste tank (2,000 gal)

Energy Group (Mev/gamma)	Source Strength (Mev/gram-sec)
0.2 - 0.4	1.2×10^{1}
0.4 - 0.9	8.7×10^{3}
0.9 - 1.35	1.7×10^{2}
1.35 - 1.8	2.0×10^{2}
1.8 - 2.2	--
2.2 - 2.6	--
2.6 - 3.0	--
Total	9.1×10^{3}
Nuclide	**Activity (µCi/gram)**
Co-60	2.2×10^{-4}
Cs-134	1.2×10^{-1}
Cs-137	1.1×10^{-1}
Ba-137m	1.0×10^{-1}
Pr-144	2.4×10^{-5}

Table 12.2-9 (Sheet 4 of 5)

LIQUID RADWASTE SYSTEM COMPONENT SOURCE TERMS

D. Waste ion exchanger and charcoal deep bed filter vessel(a)

Energy Group (Mev/gamma)	Source Strength (Mev/cm^3-sec)
0.2 - 0.4	9.9×10^5
0.4 - 0.9	6.1×10^6
0.9 - 1.35	3.4×10^6
1.35 - 1.8	3.7×10^5
1.8 - 2.2	1.5×10^5
2.2 - 2.6	2.1×10^4
2.6 - 3.0	4.0×10^3
3.0 - 4.0	9.2×10^2
Total	1.1×10^7
Nuclide	**Activity (µCi/cm^3)**
I-131	3.5×10^1
I-132	9.6×10^1
I-133	4.3×10^1
I-135	1.2×10^1
Cs-134	3.1×10^1
Cs-136	6.7×10^1

Note:
(a) Source term for the charcoal deep bed filter vessel is based on operation charged with resin instead of charcoal since this is the most conservative mode of operation for source terms.

Table 12.2-9 (Sheet 5 of 5)

LIQUID RADWASTE SYSTEM COMPONENT SOURCE TERMS

E. Waste prefilter and waste after filter

Energy Group (Mev/gamma)	**Source Strength (Mev/cm^3-sec)**
0.4 - 0.9	1.1×10^7
0.9 - 1.35	3.0×10^6
Total	1.4×10^7

Source Dimensions (inches)	**Source Composition (volume percent)**
Radius = 3.375	Air - 67
Length = 19	Water - 33

Table 12.2-10 (Sheet 1 of 2)

GASEOUS RADWASTE SYSTEM COMPONENT SOURCE TERMS

A. Gas cooler and moisture separator

Energy Group (Mev/gamma)	Source Strength (Mev/cm^3-sec)
0.2 - 0.4	9.8×10^{4} [(a)]
0.4 - 0.9	1.1×10^{4}
0.9 - 1.35	3.3×10^{3}
1.35 - 1.8	1.0×10^{4}
1.8 - 2.2	1.7×10^{4}
2.2 - 2.6	3.2×10^{4}
2.6 - 3.0	3.0×10^{2}
3.0 - 4.0	3.6×10^{2}
4.0 - 5.0	2.1×10^{1}
Total	1.7×10^{5}

Nuclide	Activity (μCi/cm^3)
Kr-83m	8.6×10^{-2}
Kr-85m	4.5×10^{-1}
Kr-85	2.0
Kr-87	2.4×10^{-1}
Kr-88	7.4×10^{-1}
Xe-131m	7.3×10^{-1}
Xe-133m	9.4×10^{-1}
Xe-133	6.7×10^{1}
Xe-135	2.0
Xe-138	1.2×10^{-1}

Note:
(a) Includes 80 kev Xe-133

Table 12.2-10 (Sheet 2 of 2)

GASEOUS RADWASTE SYSTEM
COMPONENT SOURCE TERMS

B. Charcoal guard and delay beds (8 ft^3 guard bed and 80 ft^3 delay beds)

	Source Strength (Mev/cm^3-sec)	
Energy Group (Mev/gamma)	**Guard Bed**	**Delay Beds**
0.2 - 0.4	$8.6 \times 10^{7(a)}$	$8.0 \times 10^{6(a)}$
0.4 - 0.9	5.2×10^{6}	4.9×10^{5}
0.9 - 1.35	1.2×10^{6}	1.1×10^{5}
1.35 - 1.8	3.6×10^{6}	3.4×10^{5}
1.8 - 2.2	6.4×10^{6}	6.0×10^{5}
2.2 - 2.6	1.4×10^{7}	1.3×10^{6}
2.6 - 3.0	7.0×10^{4}	6.5×10^{3}
3.0 - 4.0	2.8×10^{4}	2.6×10^{3}
4.0 - 5.0	1.8×10^{2}	1.6×10^{1}
Total	1.2×10^{8}	1.1×10^{7}

	Activity ($\mu Ci/cm^3$)	
Nuclide	**Guard Bed**	**Delay Beds**
Kr-83m	2.5×10^{1}	2.4
Kr-85m	3.2×10^{2}	3.0×10^{1}
Kr-85	1.6×10^{3}	1.5×10^{2}
Kr-87	4.8×10^{1}	4.5
Kr-88	3.3×10^{2}	3.1×10^{1}
Xe-131m	5.6×10^{2}	5.3×10^{1}
Xe-133m	7.3×10^{2}	6.9×10^{1}
Xe-133	5.2×10^{4}	4.8×10^{3}
Xe-135	3.0×10^{3}	2.8×10^{2}

Note:
(a) Includes 80 kev Xe-133

Table 12.2-11

SPENT DEMINERALIZER RESIN SOURCE STRENGTHS AND SPECIFIC ACTIVITIES

Energy Group (Mev/gamma)		Spent Resin Source Strength (Mev/cm^3-sec) Initial	After 30 Days
0.2 - 0.4		1.6×10^7	1.5×10^6
0.4 - 0.9		1.6×10^8	1.4×10^8
0.9 - 1.35		1.6×10^7	1.1×10^7
1.35 - 1.8		4.4×10^6	2.9×10^6
1.8 - 2.2		6.2×10^5	-
2.2 - 2.6		1.2×10^5	-
2.6 - 3.0		4.1×10^4	-
3.0 - 4.0		1.1×10^4	-
4.0 - 5.0		7.2×10^2	-
	TOTAL	2.0×10^8	1.6 x 10

Nuclide	Spent Resin Activity ($\mu Ci/cm^3$) Initial	After 30 Days
Br-84	9.7×10^{-2}	-
Y-90	(a)	5.0
I-131	1.2×10^3	9.4×10^1
I-135	4.9×10^1	-
Rb-88	3.6	-
Cs-134	1.7×10^3	1.6×10^3
Cs-136	7.4×10^1	-
Cs-137	2.1×10^3	2.1×10^3
Ba-137m	2.0×10^3	2.0×10^3
Cs-138	2.0	-
Co-60	8.6×10^1	8.5×10^1
La-140	(a)	6.5×10^{-1}

Note:
(a) Not included in list because contribution to total source strength is not significant.

Table 12.2-12

NORMAL RESIDUAL HEAT REMOVAL SYSTEM SOURCE STRENGTHS AND SPECIFIC ACTIVITIES

Energy Group	Source Strength (Mev/gram-sec)	
Mev/gamma	**4 Hours After Shutdown**	**8 Hours After Shutdown**
0.2 - 0.4	9.8×10^{4} [(a)]	9.0×10^{4} [(a)]
0.4 - 0.9	3.4×10^{5}	3.2×10^{5}
0.9 - 1.35	2.9×10^{5}	2.0×10^{4}
1.35 - 1.8	6.9×10^{3}	2.6×10^{3}
1.8 - 2.2	1.2×10^{4}	4.2×10^{3}
2.2 - 2.6	1.2×10^{4}	4.3×10^{3}
2.6 - 3.0	8.9×10^{2}	3.2×10^{2}
3.0 - 4.0	3.5×10^{2}	1.2×10
4.0 - 5.0	5.7×10^{1}	2.1×10^{1}
TOTAL	5.0×10^{5}	4.4×10^{5}

	Activity (μCi/gram)	
Nuclide	**4 Hours After Shutdown**	**8 Hours After Shutdown**
Kr-88	2.8×10^{-1}	1.1×10^{-1}
Xe-133	6.8×10^{1}	6.6×10^{1}
Xe-135	1.6	1.2
I-132	1.0×10^{-1}	3.5×10^{-2}
I-133	3.0×10^{-1}	1.6×10^{-1}
I-135	1.3×10^{-1}	5.0×10^{-2}
Rb-88	3.0×10^{-1}	1.4×10^{-1}
Cs-134	1.4×10^{-1}	9.2×10^{-2}
Cs-136	3.1×10^{-1}	2.1×10^{-1}
Co-58	1.0×10^{1}	1.0×10^{1}
Co-60	1.0×10^{-1}	1.0×10^{-1}

<u>Note:</u>
(a) Includes 80 kev Xe-133

Table 12.2-13

CORE AVERAGE AND SPENT FUEL NEUTRON SOURCE STRENGTHS AT VARIOUS TIMES AFTER SHUTDOWN

Time After Shutdown	Core Average (n/watt-sec)	Spent Fuel (n/watt-sec)
12 hours	27	62
24 hours	27	62
100 hours	27	62
1 week	27	61
1 month	26	59
3 months	23	54
6 months	20	48
1 year	17	42
5 years	13	31

Table 12.2-14

SPENT FUEL GAMMA RAY SOURCE STRENGTHS

Energy Group	Source Strength at Time After Shutdown (Mev/watt-sec)				
Mev/gamma	12 Hours	24 Hours	100 Hours	1 Week	1 Month
<0.15	2.3×10^{9}	2.0×10^{9}	9.8×10^{8}	5.6×10^{8}	1.1×10^{8}
0.15 - 0.45	3.1×10^{9}	2.7×10^{9}	1.2×10^{9}	7.3×10^{8}	8.7×10^{7}
0.45 - 1.0	1.2×10^{10}	1.0×10^{10}	6.7×10^{9}	5.8×10^{9}	3.6×10^{9}
1.0 - 1.5	2.0×10^{9}	1.3×10^{9}	6.3×10^{8}	4.6×10^{8}	1.5×10^{8}
1.5 - 2.0	3.1×10^{9}	2.9×10^{9}	2.4×10^{9}	2.1×10^{9}	5.9×10^{8}
2.0 - 2.5	3.4×10^{8}	2.5×10^{8}	1.9×10^{8}	1.6×10^{8}	6.5×10^{7}
2.5 - 3.0	1.7×10^{8}	1.6×10^{8}	1.4×10^{8}	1.2×10^{8}	3.5×10^{7}
3.0 - 4.0	4.6×10^{6}	1.8×10^{6}	1.5×10^{6}	1.3×10^{6}	4.1×10^{5}
4.0 - 6.0	2.7×10^{5}	1.4×10^{4}	1.3×10^{1}	1.3×10^{1}	1.2×10^{1}

	3 Months	6 Months	1 Year	5 Years
<0.15	4.5×10^{7}	2.4×10^{7}	1.5×10^{7}	2.7×10^{6}
0.15 - 0.45	8.8×10^{6}	4.8×10^{6}	3.7×10^{6}	1.4×10^{6}
0.45 - 1.0	2.2×10^{9}	1.3×10^{9}	7.0×10^{8}	2.3×10^{8}
1.0 - 1.5	7.4×10^{7}	6.1×10^{7}	4.9×10^{7}	1.8×10^{7}
1.5 - 2.0	2.8×10^{7}	4.7×10^{6}	3.2×10^{6}	6.2×10^{5}
2.0 - 2.5	2.2×10^{7}	1.6×10^{7}	1.0×10^{7}	3.3×10^{5}
2.5 - 3.0	1.5×10^{6}	2.4×10^{5}	1.0×10^{5}	1.0×10^{4}
3.0 - 4.0	6.4×10^{4}	4.3×10^{4}	3.0×10^{4}	1.9×10^{3}
4.0 - 6.0	1.1×10^{1}	1.0×10^{1}	8.9	6.8

Table 12.2-15

IRRADIATED SILVER-INDIUM-CADMIUM CONTROL ROD SOURCE STRENGTHS

Energy Group	Source Strength at Time After Shutdown (Mev/cm^3-sec)		
Mev/gamma	**1 Day**	**1 Week**	**1 Month**
0.20 - 0.40	2.3×10^8	2.3×10^8	2.2×10^8
0.40 - 0.90	1.1×10^{12}	1.1×10^{12}	1.0×10^{12}
0.90 - 1.35	2.0×10^{11}	1.9×10^{11}	1.8×10^{11}
1.35 - 1.80	3.7×10^{11}	3.7×10^{11}	3.4×10^{11}
Mev/gamma	**6 Months**	**1 Year**	**5 Years**
0.20 - 0.40	1.4×10^8	8.5×10^7	1.5×10^6
0.40 - 0.90	6.6×10^{11}	4.0×10^{11}	7.1×10^9
0.90 - 1.35	1.2×10^{11}	7.2×10^{10}	1.3×10^9
1.35 - 1.80	2.3×10^{11}	1.4×10^{11}	2.5×10^9

<u>Note:</u>
The absorber cross-sectional area is 0.589 square centimeters per rod and the absorber material density is 10.2 grams per cubic centimeter.

Table 12.2-16

**IRRADIATED SB-BE SECONDARY SOURCE ROD
GAMMA RAY SOURCE STRENGTHS**

Energy Group	Source Strength at Time After Shutdown (Mev/watt-sec)		
Mev/gamma	**1 Day**	**1 Week**	**1 Month**
0.20 - 0.40	3.0×10^{10}	2.9×10^{10}	2.5×10^{10}
0.40 - 0.90	1.1×10^{13}	7.0×10^{12}	4.6×10^{12}
0.90 - 1.35	6.7×10^{11}	4.8×10^{11}	3.4×10^{11}
1.35 - 1.80	7.6×10^{12}	7.1×10^{12}	5.5×10^{12}
1.80 - 2.20	9.8×10^{11}	9.1×10^{11}	7.0×10^{11}

Mev/gamma	6 Months	1 Year	5 Years
0.20 - 0.40	1.1×10^{10}	3.7×10^{9}	2.2×10^{7}
0.40 - 0.90	8.1×10^{11}	9.7×10^{10}	1.8×10^{8}
0.90 - 1.35	6.0×10^{10}	7.0×10^{9}	0
1.35 - 1.80	9.7×10^{11}	1.2×10^{11}	0
1.80 - 2.20	1.2×10^{11}	1.5×10^{10}	0

Notes:
- The Sb-Be material density is 3.38 grams per cubic centimeter.
- The secondary source rod cross-sectional area is 0.582 square centimeter per rod.
- The average neutron energy is 30 kev.

Table 12.2-17

IRRADIATED SB-BE SECONDARY SOURCE ROD NEUTRON SOURCE STRENGTHS

Time After Shutdown	Sb-124 Concentration (curies/cm^3)	Neutron Source Strength (n/cm^3-sec)
1 day	230	4.5×10^8
1 week	210	4.2×10^8
1 month	160	3.2×10^8
6 months	29	5.8×10^7
1 year	3.4	6.8×10^6
5 years	0	0

Note:
- The Sb-Be material density is 3.38 grams per cubic centimeter.
- The secondary source rod cross-sectional area is 0.582 square centimeter per rod.
- The average neutron energy is 30 kev.

Table 12.2-18

IRRADIATED TYPE 304 STAINLESS STEEL SOURCE STRENGTHS (0.12 WEIGHT PERCENT COBALT)

Energy Group	Source Strength at Time After Shutdown (Mev/cc-sec)		
Mev/gamma	1 Day	1 Week	1 Month
0.20 - 0.40	7.1×10^{9}	6.1×10^{9}	3.4×10^{9}
0.40 - 0.90	3.1×10^{10}	2.9×10^{10}	2.6×10^{10}
0.90 - 1.35	2.4×10^{11}	2.3×10^{11}	2.3×10^{11}
1.35 - 1.80	1.9×10^{8}	1.8×10^{8}	1.4×10^{8}

Mev/gamma	6 Months	1 Year	5 Years
0.20 - 0.40	8.3×10^{7}	9.9×10^{5}	0
0.40 - 0.90	1.2×10^{11}	6.4×10^{9}	2.3×10^{8}
0.90 - 1.35	2.1×10^{7}	2.0×10^{11}	1.2×10^{11}
1.35 - 1.80	3.3×10^{7}	5.4×10^{6}	0

Notes:
The various cross-section areas per rod are as follows:
- Ag-In-Cd control rod cladding - 0.136 cm^2
- Sb-Be secondary source rod cladding - 0.136 cm^2
- Gray rod cladding - 0.136 cm^2
- Gray rod pellet - 0.589 cm^2

Table 12.2-19

IRRADIATED FLUX THIMBLE SOURCE STRENGTHS

Energy Group	Source Strength at Time After Shutdown (Mev/cc-sec)			
Mev/gamma	12 Hours	1 Day	70 Hours	1 Week
<0.15	8.6×10^8	7.9×10^8	7.6×10^8	7.1×10^8
0.15 - 0.45	9.4×10^9	9.2×10^9	8.8×10^9	7.9×10^9
0.45 - 1.0	9.6×10^{10}	9.4×10^{10}	9.2×10^{10}	8.8×10^{10}
1.0 - 1.5	2.5×10^{10}	2.5×10^{10}	2.5×10^{10}	2.5×10^{10}
1.5 - 2.0	1.8×10^9	8.6×10^8	8.1×10^8	7.6×10^8
2.0 - 2.5	6.0×10^8	2.4×10^7	2.4×10^5	2.4×10^5
2.5 - 3.0	1.0×10^8	4.1×10^6	-	-
3.0 - 4.0	1.1×10^7	4.4×10^5	-	-

Mev/gamma	1 Month	6 Months	1 Year	5 Years
<0.15	5.0×10^8	$9.5\ 10^7$	2.9×10^7	9.6×10^6
0.15 - 0.45	4.4×10^9	1.3×10^8	7.3×10^6	5.0×10^5
0.45 - 1.0	7.0×10^{10}	1.6×10^{10}	3.3×10^9	2.7×10^7
1.0 - 1.5	2.5×10^{10}	2.3×10^{10}	2.2×10^{10}	1.3×10^{10}
1.5 - 2.0	6.2×10^8	1.4×10^8	2.3×10^7	-
2.0 - 2.5	2.4×10^5	2.2×10^5	2.1×10^5	1.2×10^5
2.5 - 3.0	-	-	-	-
3.0 - 4.0	-	-	-	-

Note:
The flux thimble and mandrel cross-sectional area is 0.574 square centimeter.

Table 12.2-20

CORE MELT ACCIDENT SOURCE STRENGTHS IN CONTAINMENT ATMOSPHERE AS A FUNCTION OF TIME

Energy Group Mev/gamma	Source Strength at Time After Release (Mev/watt-sec)				
	10 Min.	**40 Min**	**1.97 Hours**	**3.97 Hours**	**5 Hours**
<0.15	3.7×10^6	5.8×10^6	1.1×10^8	1.1×10^8	1.0×10^8
0.15 - 0.45	3.6×10^7	4.6×10^7	5.0×10^8	4.1×10^8	3.9×10^8
0.45 - 1.0	2.9×10^8	3.9×10^8	2.5×10^9	1.5×10^9	1.2×10^9
1.0 - 1.5	2.1×10^8	2.4×10^8	1.1×10^9	7.0×10^8	6.0×10^8
1.5 - 2.0	7.3×10^7	8.7×10^7	6.6×10^8	4.4×10^8	3.6×10^8
2.0 - 2.5	8.0×10^7	8.4×10^7	7.7×10^8	4.5×10^8	3.5×10^8
2.5 - 3.0	2.8×10^7	2.5×10^7	1.2×10^8	5.0×10^7	3.3×10^7
3.0 - 4.0	9.8×10^6	5.2×10^6	1.8×10^7	7.7×10^6	5.5×10^6
4.0 - 6.0	3.1×10^6	3.9×10^5	3.6×10^6	2.5×10^6	1.9×10^6
6.0 - 11.0	-	-	-	-	-
Beta	3.9×10^8	4.0×10^8	3.3×10^9	2.3×10^9	2.0×10^9

Mev/gamma	10 Hours	1 Day	1 Week	1 Month	1 Year
<0.15	1.0×10^8	9.4×10^7	4.4×10^7	2.5×10^6	1.3×10^5
0.15 - 0.45	3.1×10^8	2.1×10^8	7.8×10^7	1.1×10^7	9.9×10^4
0.45 - 1.0	8.0×10^8	5.2×10^8	2.0×10^8	1.3×10^8	9.3×10^7
1.0 - 1.5	3.5×10^8	1.2×10^8	2.4×10^7	8.8×10^6	3.4×10^6
1.5 - 2.0	1.7×10^8	4.7×10^7	3.9×10^7	1.2×10^7	3.9×10^3
2.0 - 2.5	1.1×10^8	9.3×10^6	1.2×10^6	1.9×10^5	6.4×10^3
2.5 - 3.0	7.2×10^6	1.3×10^6	2.3×10^6	7.2×10^5	2.7×10^2
3.00 - 4.00	1.5×10^6	5.7×10^4	2.4×10^4	7.6×10^3	5.1×10^1
4.0 - 6.0	5.7×10^5	1.9×10^4	-	-	-
6.0 - 11.0	-	-	-	-	-
Beta	1.2×10^9	7.3×10^8	2.5×10^8	6.0×10^8	2.5×10^7

Note:
No release from core until 10 minutes after incident (see subsection 15.6.5.3).

Table 12.2-21

CORE MELT ACCIDENT INTEGRATED SOURCE STRENGTHS IN CONTAINMENT ATMOSPHERE

Energy Group Mev/gamma	Source Strength at Time After Release (Mev/watt) 10 Min.	40 Min.	1.97 Hours	5 Hours
<0.15	3.7×10^{6}	8.4×10^{9}	3.5×10^{11}	1.5×10^{12}
0.15 - 0.45	3.6×10^{7}	7.3×10^{10}	1.6×10^{12}	6.4×10^{12}
0.45 - 1.0	2.9×10^{8}	6.1×10^{11}	8.1×10^{12}	2.7×10^{13}
1.0 - 1.5	2.1×10^{8}	4.0×10^{11}	4.1×10^{12}	1.3×10^{13}
1.5 - 2.0	7.3×10^{7}	1.4×10^{11}	2.2×10^{12}	7.6×10^{12}
2.0 - 2.5	8.0×10^{7}	1.5×10^{11}	2.9×10^{12}	8.7×10^{12}
2.5 - 3.0	2.8×10^{7}	4.8×10^{10}	5.6×10^{11}	1.3×10^{12}
3.0 - 4.0	9.8×10^{6}	1.3×10^{10}	8.6×10^{10}	2.0×10^{11}
4.0 - 6.0	3.1×10^{6}	2.4×10^{9}	1.4×10^{10}	4.4×10^{10}
6.0 - 11.0	-	-	-	-
Beta	3.9×10^{8}	7.1×10^{11}	1.1×10^{13}	3.9×10^{13}

Mev/gamma	10 Hours	1 Day	1 Week	1 Month	1 Year
<0.15	3.4×10^{12}	8.3×10^{12}	4.3×10^{13}	7.2×10^{13}	9.0×10^{13}
0.15 - 0.45	1.3×10^{13}	2.6×10^{13}	8.4×10^{13}	1.5×10^{14}	2.2×10^{14}
0.45 - 1.0	4.5×10^{13}	7.7×10^{13}	2.2×10^{14}	5.5×10^{14}	3.7×10^{15}
1.0 - 1.5	2.1×10^{13}	3.2×10^{13}	5.4×10^{13}	8.4×10^{13}	2.5×10^{14}
1.5 - 2.0	1.2×10^{13}	1.7×10^{13}	3.7×10^{13}	8.3×10^{13}	1.3×10^{14}
2.0 - 2.5	1.2×10^{13}	1.4×10^{13}	1.6×10^{13}	1.7×10^{13}	1.8×10^{13}
2.5 - 3.0	1.6×10^{12}	1.8×10^{12}	2.8×10^{12}	5.6×10^{12}	3.2×10^{12}
3.0- 4.0	2.5×10^{11}	2.7×10^{11}	2.9×10^{11}	3.2×10^{11}	3.6×10^{11}
4.0 - 6.0	6.4×10^{10}	7.2×10^{10}	7.2×10^{10}	7.2×10^{10}	7.2×10^{10}
6.0 - 11.0	-	-	-	-	-
Beta	6.8×10^{13}	1.2×10^{14}	3.2×10^{14}	5.8×10^{14}	1.7×10^{15}

Note:
No release from core until 10 minutes after incident (see subsection 15.6.5.3)

Table 12.2-22

PARAMETERS AND ASSUMPTIONS USED FOR CALCULATING CONTAINMENT AIRBORNE RADIOACTIVITY CONCENTRATIONS

Parameter/Assumption	Value
Reactor coolant leakage rate	30 lb/day
Time used to estimate equilibrium concentration	100 days
Containment free air volume	1.83E6 cu. ft
Flashing fraction	0.40
Fuel defects	0.250%
Reactor coolant tritium concentration	3.5 μCi/g
Normal operation purge flow rate	4,000 cfm[1]
Normal operation purge duration	20 hrs/week
Shutdown purge flow rate	8,000 cfm[1]

Table 12.2-23 (Sheet 1 of 3)

CONTAINMENT AIRBORNE RADIOACTIVITY CONCENTRATIONS
($\mu Ci/cm^3$)

Isotope	Equilibrium Activity (no purge)	Maximum Activity (with normal purge)	Shutdown Activity (shutdown purge for 24 hrs)
Cr-51	5.68E-12	5.08E-12	1.14E-13
Mn-54	2.93E-12	2.62E-12	6.04E-14
Mn-56	5.86E-10	5.36E-10	2.12E-14
Fe-55	2.19E-12	1.95E-12	4.51E-14
Fe-59	5.68E-13	5.08E-13	1.16E-14
Co-58	8.30E-12	7.43E-12	1.70E-13
Co-60	9.62E-13	8.60E-13	1.99E-14
Br-83	5.09E-11	4.66E-11	1.11E-15
Br-84	1.50E-11	1.42E-11	9.47E-27
Br-85	2.71E-13	2.69E-13	-
Kr-83m	5.82E-09	4.43E-09	3.49E-13
Kr-85m	3.33E-08	1.89E-08	4.70E-10
Kr-85	5.46E-05	5.48E-07	9.76E-08
Kr-87	5.03E-09	4.13E-09	1.61E-14
Kr-88	3.47E-08	2.34E-08	8.79E-11
Kr-89	1.42E-11	1.41E-11	-
Rb-88	9.95E-10	9.61E-10	1.19E-35
Rb-89	4.09E-11	3.96E-11	2.90E-41
Sr-89	1.79E-12	1.60E-12	3.65E-14
Sr-90	1.09E-13	9.78E-14	2.26E-15
Sr-91	3.99E-12	3.60E-12	1.47E-14
Sr-92	6.96E-13	6.36E-13	3.42E-17
Y-90	2.81E-14	2.52E-14	4.50E-16
Y-91m	1.24E-12	1.16E-12	6.03E-23
Y-91	2.36E-13	2.11E-13	4.82E-15
Y-92	6.58E-13	5.99E-13	1.34E-16
Y-93	2.01E-13	1.81E-13	8.49E-16

Table 12.2-23 (Sheet 2 of 3)

CONTAINMENT AIRBORNE RADIOACTIVITY CONCENTRATIONS ($\mu Ci/cm^3$)

Isotope	Equilibrium Activity (no purge)	Maximum Activity (with normal purge)	Shutdown Activity (shutdown purge for 24 hrs)
Zr-95	2.80E-13	2.50E-13	5.71E-15
Nb-95	2.80E-13	2.50E-13	5.66E-15
Mo-99	3.37E-10	3.02E-10	5.44E-12
Tc-99m	2.82E-10	2.55E-10	3.83E-13
Ru-103	2.40E-13	2.15E-13	4.88E-15
Ag-110m	7.87E-13	7.04E-13	1.62E-14
Te-127m	1.35E-12	1.21E-12	2.78E-14
Te-129m	4.37E-12	3.1E-12	8.84E-14
Te-129	4.38E-12	4.08E-12	6.6E-20
Te-131m	1.15E-11	1.03E-11	1.38E-13
Te-131	3.28E-12	3.14E-12	4.18E-31
Te-132	1.34E-11	1.20E-11	2.25E-13
Te-134	1.10E-11	1.03E-11	1.23E-23
I-129	2.93E-17	2.62E-17	2.40E-18
I-130	1.66E-11	1.49E-11	3.62E-13
I-131	1.22E-09	1.09E-09	9.18E-11
I-132	1.61E-09	1.48E-09	1.01E-13
I-133	2.45E-09	2.20E-09	9.20E-11
I-134	2.44E-10	2.29E-10	1.37E-19
I-135	1.27E-09	1.14E-09	8.75E-12
Xe-131m	3.33E-06	1.64E-07	3.28E-08
Xe-133m	8.12E-07	1.28E-07	3.28E-08
Xe-133	1.37E-04	1.25E-05	2.80E-06
Xe-135m	4.11E-10	3.94E-10	2.40E-37
Xe-135	3.01E-07	1.22E-07	1.47E-08
Xe-137	3.41E-11	3.38E-11	-
Xe-138	4.47E-10	4.30E-10	3.39E-40

Table 12.2-23 (Sheet 3 of 3)

CONTAINMENT AIRBORNE RADIOACTIVITY CONCENTRATIONS ($\mu Ci/cm^3$)

Isotope	Equilibrium Activity (no purge)	Maximum Activity (with normal purge)	Shutdown Activity (shutdown purge for 24 hrs)
Cs-134	1.01E-09	8.99E-10	2.07E-11
Cs-136	2.31E-09	2.07E-09	4.53E-11
Cs-137	9.18E-10	8.21E-10	1.90E-11
Cs-138	3.43E-10	3.27E-10	3.20E-25
Ba-137m	5.05E-11	5.02E-11	-
Ba-140	1.79E-12	1.60E-12	3.50E-14
La-140	4.00E-12	3.58E-12	5.50E-14
Ce-141	2.80E-13	2.50E-13	5.65E-15
Ce-143	2.27E-13	2.03E-13	2.86E-15
Pr-143	2.57E-13	2.30E-13	5.06E-15
Ce-144	2.10E-13	1.88E-13	4.32E-15
Pr-144	6.17E-14	5.96E-14	1.56E-40
H-3	3.64E-05	3.65E-07	4.88E-09
Ar-41	1.05E-05	8.03E-06	3.08E-12
Total	2.43E-04	2.19E-05	2.98E-06
Iodines	6.81E-09	6.16E-09	1.93E-10
Particulates	7.02E-09	6.40E-09	9.20E-11
Noble Gases	2.07E-04	2.16E-05	2.97E-06

Table 12.2-24

PARAMETERS AND ASSUMPTIONS USED FOR CALCULATING FUEL HANDLING AREA AIRBORNE RADIOACTIVITY CONCENTRATIONS

Parameter/Assumption	Value
Ventilation flow through fuel handling area[1]	17,000 cfm[2]
Iodine filter efficiency	0
Particulate filter efficiency	0.99
Fuel handling area free air volume	200,000 ft^3
Fuel defects	0.25%
Time from shutdown to reactor vessel head removal	100 hours
Refueling time	10 days
Decontamination factors of mixed-bed demineralizer for spent fuel pool purification system:	
Iodines	100
Cs and Rb	2
Others	50
Spent fuel pool temperature	120°F
Evaporation rate of spent fuel pool water	486 lbs/hr
Spent fuel pool tritium concentration	1.0 µCi/g

(1 This flow rate is defined as the sum of the fuel area exhaust fan flows minus the rail car bay/solid radwaste system exhaust flow.

(2 This is the nominal expected ventilation flow rate. For conservatism, the calculated airborne radioactivity concentrations are based on a 10% lower flow rate.

Table 12.2-25 (Sheet 1 of 2)

FUEL HANDLING AREA AIRBORNE RADIOACTIVITY CONCENTRATIONS
($\mu Ci/cm^3$)

Isotope	Activity
Cr-51	3.40E-12
Mn-54	1.93E-12
Mn-56	5.91E-22
Fe-55	1.45E-12
Fe-59	3.54E-13
Co-58	5.30E-12
Co-60	6.39E-13
Br-83	5.88E-24
Br-84	2.15E-69
Kr-83m	2.48E-26
Kr-85m	4.42E-16
Kr-85	1.62E-10
Kr-87	4.36E-33
Kr-88	1.58E-19
Sr-89	1.13E-12
Sr-90	7.27E-14
Sr-91	1.62E-15
Sr-92	2.59E-24
Y-90	6.26E-15
Y-91	1.49E-13
Y-92	1.07E-21
Y-93	1.47E-16
Zr-95	1.78E-13
Nb-95	1.71E-13
Mo-99	7.76E-11
Tc-99m	1.56E-15
Ru-103	1.48E-13
Ag-110m	5.18E-13
Te-127m	8.78E-13
Te-129m	2.66E-12
Te-131m	7.41E-13
Te-131	9.00E-86
Te-132	3.65E-12

Table 12.2-25 (Sheet 2 of 2)

FUEL HANDLING AREA AIRBORNE RADIOACTIVITY CONCENTRATIONS
(µCi/cm³)

Isotope	Activity
I-129	1.95E-16
I-130	3.78E-13
I-131	5.64E-09
I-132	4.80E-22
I-133	5.69E-10
I-135	2.07E-13
Xe-131m	9.81E-11
Xe-133m	1.93E-10
Xe-133	1.41E-08
Xe-135	3.15E-12
Cs-134	6.84E-10
Cs-136	1.26E-09
Cs-137	6.27E-10
Ba-140	9.47E-13
La-140	4.66E-13
Ce-141	1.70E-13
Ce-143	1.80E-14
Pr-143	1.38E-13
Ce-144	1.38E-13
H-3	1.07E-05
Total (excluding tritium)	2.35E-08
Iodines	6.21E-09
Particulates	2.67E-09
Noble Gases	1.46E-08

Table 12.2-26

PARAMETERS AND ASSUMPTIONS USED FOR CALCULATING AUXILIARY BUILDING AIRBORNE RADIOACTIVITY CONCENTRATIONS

Parameter/Assumption	Value
Ventilation exhaust flow[(1)]	25,000 cfm[(2)]
Free air volume	365,400 ft^3
Primary coolant leakage to auxiliary building	20 lb/day
Flashing fraction	0.4
Primary coolant source term	See Table 11.1-2
Fuel defects	0.25%

(1 This flow rate is defined as the sum of the aux/annex exhaust fan flow minus the annex building exhaust flow minus room 12555 (VES, containment access) exhaust flow.

(2 This is the nominal expected ventilation flow rate. For conservatism, the calculated airborne radioactivity concentrations are based on a 10% lower flow rate.

Table 12.2-27 (1 of 3)

AUXILIARY BUILDING AIRBORNE RADIOACTIVITY CONCENTRATIONS
(μCi/cm³)

Isotope	Activity
Cr-51	5.14E-12
Mn-54	2.65E-12
Mn-56	6.73E-10
Fe-55	1.98E-12
Fe-59	5.14E-13
Co-58	7.52E-12
Co-60	8.70E-13
Br-83	5.94E-11
Br-84	3.13E-11
Br-85	3.80E-12
Kr-83m	8.80E-10
Kr-85m	4.65E-09
Kr-85	2.08E-08
Kr-87	2.47E-09
Kr-88	7.62E-09
Kr-89	1.68E-10
Rb-88	3.01E-09
Rb-89	1.38E-10
Sr-89	1.62E-12
Sr-90	9.89E-14
Sr-91	3.88E-12
Sr-92	7.91E-13
Y-90	2.57E-14
Y-91m	2.06E-12
Y-91	2.14E-13
Y-92	7.12E-13

Table 12.2-27 (2 of 3)

AUXILIARY BUILDING AIRBORNE RADIOACTIVITY CONCENTRATIONS
($\mu Ci/cm^3$)

Isotope	Activity
Y-93	1.94E-13
Zr-95	2.53E-13
Nb-95	2.53E-13
Mo-99	3.09E-10
Tc-99m	2.85E-10
Ru-103	2.18E-13
Ag-110m	7.12E-13
Te-127m	1.23E-12
Te-129m	3.96E-12
Te-129	6.33E-12
Te-131m	1.07E-11
Te-131	7.91E-12
Te-132	1.23E-11
Te-134	1.98E-11
I-129	2.65E-17
I-130	1.58E-11
I-131	1.11E-09
I-132	1.90E-09
I-133	2.29E-09
I-134	3.96E-10
I-135	1.27E-09
Xe-131m	7.42E-09
Xe-133m	9.69E-09
Xe-133	6.83E-07

Table 12.2-27 (3 of 3)

AUXILIARY BUILDING AIRBORNE RADIOACTIVITY CONCENTRATIONS
($\mu Ci/cm^3$)

Isotope	**Activity**
Xe-135m	9.89E-10
Xe-135	2.08E-08
Xe-137	3.36E-10
Xe-138	1.19E-09
Cs-134	9.10E-10
Cs-136	2.10E-09
Cs-137	8.31E-10
Cs-138	7.12E-10
Ba-137m	7.91E-10
Ba-140	1.62E-12
La-140	3.68E-12
Ce-141	2.53E-13
Ce-143	2.10E-13
Pr-143	2.33E-13
Ce-144	1.90E-13
Pr-144	1.90E-13
H-3	1.38E-08
Total	7.90E-07
Iodines	6.98E-09
Particulates	9.95E-09
Noble Gases	7.59E-07