12.2 Radiation Sources

This section describes the key component sources of radioactivity present in the U.S. EPR, in accordance with Section 12 of the NUREG-0800 SRP (Reference 1), that are used as input to:

- Perform shield design calculations (see Section 12.3.2).
- Design the ventilation systems.

Source terms are presented here for both contained and airborne sources of radioactivity.

12.2.1 Contained Sources

The U.S. EPR component source terms for contained sources are based on the shielding design basis primary coolant source term described in Section 11.1.2, Table 11.1-2, which is based on U.S. EPR specific design inputs and a conservative 0.25 percent failed fuel fraction. Plan scale drawings of each floor of the plant, showing the location of these contained sources, are included in the radiation zone maps (see Section 12.3.2.3).

12.2.1.1 Reactor Core

During normal operation, radiation within the containment consists of neutrons and gamma radiation emanating from the reactor core. The model dimensions for the reactor vessel are shown in Table 12.2-1 – Reactor Vessel Model Dimensions. Table 12.2-2—Neutron and Gamma Fluxes at Primary Shield Concrete lists neutron and gamma multigroup fluxes at the inside surface of the primary shield concrete, core midplane elevation. These fluxes are further reduced by shielding provided by the reactor vessel and reactor internals. See Section 12.3.1.1 for features that reduce neutron and gamma streaming in the service area of the Containment Building.

Table 12.2-3—Reactor Photon Spectra at Selected Times Following Shutdown lists the photon spectra for the reactor core as a function of time following shutdown. This information is used for determining shielding requirements during shutdown and inservice inspection.

12.2.1.2 Reactor Coolant System

Sources of radiation in the RCS are fission products released from fuel cladding defects and activated corrosion products. Each of these radiological sources is continuously transported through most of the RCS; the pressurizer and its associated surge line do not normally experience large continuous flows. These sources are listed in Table 11.1-2, and their bases are described in Section 11.1.

During operation, nitrogen-16 is the largest source of radioactivity in the RCPs, SGs, and reactor coolant piping, and consequently has the most impact on shielding design in the Reactor Building. Because of the short half-life of nitrogen-16 (7.11 s) and reactor coolant transport times, nitrogen-16 activity in the RCS varies considerably by location. Table 12.2-4—Nitrogen-16 Concentration Along Reactor Coolant Loop and Figure 12.2-1—Nitrogen-16 Concentration Along Reactor Coolant Loop present bounding values of nitrogen-16 concentrations as a function of transport time within the RCS.

The radiation sources originating within the pressurizer consist of the reactor coolant source term without the nitrogen-16 contribution. The pressurizer source term spectrum is shown in Table 12.2-5—Photon Spectra for Pressurizer.

During plant operation, radioactive corrosion products deposit on the inner surface of pipes and components and build up a layer of contamination. This build-up of contamination is a continuous process, which is mainly dependent on physical and chemical conditions of the RCS in the different states of the reactor (full power, shutdown, and startup). Bounding values of fixed corrosion products for the U.S. EPR are presented in Table 12.2-6—Corrosion Product Deposits on the Main Coolant Loops for selected radionuclides based upon operating reactor data for plants with low-cobalt alloys. This information is used for shielding requirements during shutdown and inservice inspection.

12.2.1.3 Chemical and Volume Control System

The chemical and volume control system (CVCS) extracts reactor coolant from the RCS for purification, degassing, and treatment. The extracted reactor coolant is then re-injected into the primary coolant system. The CVCS operates continuously when the reactor is operating. The CVCS components are located outside of containment. The volume control tank (VCT), located in the Fuel Building, is the largest radiological source in the CVCS. During normal operation, both purified and unpurified nondegasified reactor coolant flows continuously through the VCT. Within the VCT, reactor water is partly degasified because of the gas phase above the water level. The gas phase of the VCT is connected to the purge gas circuit of the gaseous waste processing system. For surge gas, the degasified noble gas is transferred to the gaseous waste processing system. Figure 12.2-2—Simplified Flow Diagram for Volume Control Tank shows a simplified flow diagram for this process, with flow rates, for the VCT.

The CVCS source term activity is based on the shielding design basis primary source term for the RCS described in Section 11.1. Nitrogen-16 reactor coolant activity is not significant for this system because the half-life of nitrogen-16 is significantly less than the transport time required for CVCS water to exit the reactor containment. The CVCS VCT liquid and gaseous radiological source terms are provided in Table 12.2-7—Photon Spectra for Water Phase of Volume Control Tank and Table 12.2-8—Photon Spectra for Gas Phase of Volume Control Tank.

12.2.1.4 Primary Coolant Purification System

The following functions are performed by the primary coolant purification system (CPS):

- Maintain the reactor coolant water quality in accordance with the water specifications.
- Remove suspended and dissolved fission and activation products from the reactor coolant.
- Remove the surplus of lithium-7 which builds up because of the nuclear reaction: $^{10}B(n,\alpha)^{7}Li$.
- Maintain cesium activity at acceptable levels.

The system consists of three parallel coolant filters, followed by two parallel mixed-bed ion exchangers, which are followed by two parallel resin traps. These components are located in the Nuclear Auxiliary Building. The normal flow path is from the CVCS letdown, through the filter and ion exchanger, to the CVCS upstream of the high pressure charging pumps for return to the RCS. The filters and mixed-bed ion exchangers represent the largest radiological source for this system.

Similar to the CVCS, the CPS source term activity is based on the shielding design basis primary source term for the RCS described in Section 11.1. Nitrogen-16 reactor coolant activity is not significant for this system because the half-life of nitrogen-16 is significantly less than the transport time required for CPS water to exit the Reactor Building. Table 12.2-9—CPS Design Inputs includes the values used to determine the source term for this system.

The CPS source term is bounded by the values in Table 12.2-10—Photon Spectra of CPS Mixed Bed Demineralizers after Operation Period of 1 Year. A one-year operation period was selected for determining shielding adequacy. The mixed-bed demineralizer source analysis does not consider the effects of mechanical filters in the analysis. Table 12.2-11—Activity Inventory on CPS Coolant Filters after Operation Period of 1 Year provides the CPS source term for a separate mechanical filter.

12.2.1.5 Primary Coolant Degasification System

The primary coolant degasification system (CDS) reduces the noble gas in the primary coolant before shutdown. The degasified noble gas is transferred to the gaseous waste processing system. A simplified flow diagram for the degasifier, with flow rates, is shown in Figure 12.2-3—Simplified Flow Diagram for the Primary Coolant Degasification System Degasifier. The degasifier constitutes the largest radiological source for this system.

The degasifier includes both a liquid and a gaseous source. The liquid source consists of reactor coolant that has been purified (filtered and demineralized). The gaseous source consists of noble gas and iodines. The CDS source term activity is based on the shielding design basis primary source term for the RCS described in Section 11.1. Nitrogen-16 reactor coolant activity is not significant for this system because the half-life of nitrogen-16 is significantly less than the transport time required for CDS water to exit the containment. The CDS source terms are provided in Table 12.2-12—Photon Spectra for Water Phase of Degasifier and Table 12.2-13—Photon Spectra for Gas Phase of Degasifier.

12.2.1.6 Secondary Coolant Cycle

Under normal operating conditions, insignificant radioactivity is present within the steam and power conversion system. SG tube defects cause the introduction of reactor coolant into the secondary coolant system. The resulting radionuclide concentrations in the secondary coolant depend upon the primary-to-secondary leak rate, the nuclide decay constant, and the SG blowdown rate. A design basis secondary coolant source resulting from a defined SG tube leak is presented and described in Sections 11.1 and 15.0.3.6. For shielding and dose assessment purposes, the steam and power conversion system is assumed to be nonradioactive.

12.2.1.7 Component Cooling Water and Essential Service Water Systems

Under normal operating conditions, the component cooling water system and essential service water system work together to transfer heat from safety-related systems and operational cooling loads to the heat sink. Heat transfer between components and systems occurs via heat exchangers. For shielding and dose assessment purposes, the component cooling water and essential service water systems are assumed to be nonradioactive.

12.2.1.8 Fuel Pool Cooling and Purification System

Radioactive impurities in the fuel pool water or in the fuel pool cooling system result from:

- Release of fission products from breaches in fuel rod cladding.
- Release of activated corrosion products located on the surfaces of fuel rods stored in the fuel pool.
- Intermixing of minimal amounts of reactor coolant with fuel pool water via the transfer channel during fuel assembly transfer.

The fuel pool cooling and purification system (FPCPS) uses mechanical filters and mixed-bed demineralizers, which are operated continuously to remove impurities. The mechanical prefilters, upstream of the mixed bed demineralizer, are used to trap undissolved corrosion products, preventing them from entering the mixed bed demineralizer. The activity on the mechanical pre-filter and post-filters is bounded by the activity on the mixed bed demineralizer. The source term for the FPCPS mixed bed demineralizer is presented in Table 12.2-14—Photon Spectra for FPCPS Mixed-Bed Demineralizer after Operation Period of 1 Year. A one-year operation period was selected for determining shielding adequacy.

12.2.1.9 Liquid Waste Management System

The radiation sources in the liquid waste storage system (LWSS) and in the liquid waste processing system (LWPS) include fission and activation products present in the reactor coolant. Table 12.2-15—Photon Spectra for Liquid Waste Storage System Group I Waste Storage Tank and Table 12.2-16—Photon Spectra for Liquid Waste

Processing System Evaporator After 3 Months Operating provide the source terms for the components of the LWSS and LWPS.

12.2.1.10 Gaseous Waste Processing System

Radioactive fission product gases that are generated in the reactor core are released into the reactor coolant through the fuel rod cladding and are transported to auxiliary systems within the plant. These gases are collected and processed by the gaseous waste processing system (GWPS). The radiation shielding source terms for the components of the GWPS are listed in Table 12.2-17—Photon Spectra for Gaseous Waste Processing System.

12.2.1.11 Solid Waste Management System

During operation, solid radioactive waste is generated from processes such as maintenance, repair, exchange of components, decontamination, and cleaning. The U.S. EPR layout physically separates radioactive waste collection, processing, handling, and storage. This arrangement minimizes the dose contribution from activities in which the operator is not immediately involved. To further minimize exposure, operators use remote control equipment to move solid radioactive wastes into and out of storage.

The wastes associated with this system range in activity from relatively low activity materials to high activity spent resins and filter cartridges. Tables 11.4-2 through 11.4-10 provide the shielding source terms for the components of the solid waste management system.

12.2.1.12 Post-LOCA ESF Filters

The radiation shielding source terms for the ESF filters post-LOCA are listed in Table 12.2-18—Photon Spectra for ESF Filters Post-LOCA.

12.2.1.13 Miscellaneous Sources

A combined license (COL) applicant that references the U.S. EPR design certification will provide site-specific information for required radiation sources containing byproduct, source, and special nuclear material that may warrant shielding design considerations. This site-specific information will include a listing of isotope, quantity, form, and use of all sources in this latter category that exceed 100 millicuries.

12.2.2 Airborne Radioactive Material Sources

Airborne radioactive material sources in the plant are considered in the design of the ventilation systems. Airborne radioactivity is monitored inside the plant, as described in Section 12.3.4, and in process equipment and effluents, as described in Section 11.5.

12.2.2.1 Normal Operations

Airborne radioactivity concentrations can occur in the Reactor Building, both during power operation (coolant leakage) and refueling (evaporation of the refueling pool). The normal airborne radioactivity concentrations within the Containment Building are based on continuous RCS leakage into the equipment area of the Reactor Building and activation of naturally-occurring argon in the Reactor Building air that is exposed to high neutron flux level, with subsequent leakage to the service area. The assumptions and parameters listed in Table 12.2-19—Parameters and Assumptions for Calculating Airborne Radioactive Concentrations were used to evaluate the airborne radionuclide concentrations in the Reactor Building.

The spent fuel pool water contains radionuclides from defects in spent fuel and corrosion products released from fuel assemblies. The evaporation of the spent fuel pool water then leads to airborne radioactivity concentrations in the Fuel Building, both during power operation and refueling. The airborne radioactivity in the Fuel Building is primarily because of tritium, since the continuous operation of the FPCPS effectively removes other isotopes from the pool. The assumptions and parameters listed in Table 12.2-19 were used to evaluate the airborne radionuclide concentrations in the Fuel Building. The concentrations in the Reactor and Fuel Buildings are listed in Table 12.2-20—Airborne Radioactivity Concentrations.

Equipment leakage is the primary source of airborne radioactivity concentrations within the Nuclear Auxiliary Building and Radioactive Waste Processing Building. This equipment is located in normally unoccupied areas. The ventilation systems in the Nuclear Auxiliary Building and Radioactive Waste Processing Building are designed so that the airflow is from regions of lower potential for contamination to those with higher potential for contamination, and then exhausted from the building. As a result, negligible airborne radioactivity concentrations are expected in those areas of the Nuclear Auxiliary and Radioactive Waste Processing Buildings which are normally occupied.

As discussed in Section 12.2.1.6, components within the Turbine Building are considered to be nonradioactive under normal operating conditions (no primary-to-secondary leaks). Thus, airborne radioactivity concentrations in the Turbine Building are also expected to be negligible.

12.2.3 References

1. NUREG-0800, "U.S. NRC Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," NRC, March 2007.

2. NUREG-0017, "Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors PWR-GALE Code," Revision 1, NRC, April 1985.

Table 12.2-1—Reactor Vessel Model Dimensions (cm)

Zone	R min	R max	Z min	Z max
Lower Plenum	118.338	243.5	0	30
Lower Support Plate	118.338	188.34	30	71.5
Lower End Fitting	118.338	188.34	71.5	79.5
Lower Gas Plenum	118.338	188.34	79.5	93.2
Core	118.338	188.34	93.2	513
Upper Gas Plenum	118.338	188.34	513	534.5
Upper End Fitting	118.338	188.34	534.5	554
Upper Internals	118.338	188.34	554	560
Upper Plenum	118.338	208	560	601.5
HR Support Plate	118.338	216.25	30	71.5
Heavy Reflector	118.338	208.3	71.5	554
Water	188.34	208.3	554	560
Core Barrel	208	214.5	71.5	601.5
Downcomer	214.5	243.5	30/71.5	601.5
RPV Liner	243.5	244.3	0	601.5
RPV	244.3	269.25	0	601.5
Air	269.25	307.5	0	601.5
Concrete	307.5	337.5	0	601.5

Table 12.2-2—Neutron and Gamma Fluxes at Primary Shield Concrete

Energy	Flux (n/cm^2-s)
≥1 MeV	1.51E+08
≥0.1 MeV	2.08E+09
≤0.414 eV	8.55E+08
Total neutron flux	6.00E+09
Total gamma flux (photon/cm^2-s)	1.96E+09

Table 12.2-3—Reactor Photon Spectra at Selected Times Following Shutdown

Energy (MeV)	Photon Spectra (MeV/s) as a Function of Shutdown Time (hours)						
	0.0833 hr (5 min)	1 hr	10 hr	100 hr (4.2 d)	1000 hr (42 d)	10000 hr (1.1 y)	100000 hr (11 y)
0.01	1.76E+18	1.44E+18	1.22E+18	4.34E+17	5.35E+15	1.04E+15	4.53E+14
0.025	4.15E+17	3.22E+17	2.34E+17	1.14E+17	1.54E+16	1.87E+15	1.47E+14
0.0375	1.11E+18	7.58E+17	6.15E+17	3.23E+17	5.99E+16	1.41E+16	2.32E+15
0.0575	5.26E+17	4.76E+17	4.36E+17	2.14E+17	6.45E+15	9.02E+14	5.11E+14
0.085	7.54E+18	3.65E+18	2.36E+18	1.00E+18	2.91E+16	6.74E+15	5.69E+14
0.125	1.16E+19	1.10E+19	9.70E+18	3.81E+18	3.36E+17	4.10E+16	3.24E+15
0.225	2.24E+19	1.73E+19	1.39E+19	4.45E+18	4.37E+16	3.89E+15	1.12E+15
0.375	2.19E+19	9.79E+18	5.36E+18	2.80E+18	2.11E+17	1.75E+16	1.35E+15
0.575	6.41E+19	4.64E+19	3.05E+19	1.44E+19	5.81E+18	2.19E+18	4.37E+17
0.85	1.06E+20	6.95E+19	3.71E+19	2.26E+19	1.22E+19	1.55E+18	6.11E+16
1.25	8.23E+19	4.35E+19	1.39E+19	4.19E+18	8.13E+17	2.77E+17	4.01E+16
1.75	4.50E+19	2.94E+19	1.76E+19	1.34E+19	1.85E+18	2.02E+16	1.53E+15
2.25	3.13E+19	1.59E+19	2.73E+18	1.42E+18	3.14E+17	4.45E+16	9.48E+12
2.75	1.45E+19	6.98E+18	9.75E+17	7.66E+17	1.04E+17	9.49E+14	1.00E+12
3.5	7.09E+18	2.24E+18	4.87E+16	8.35E+15	1.44E+15	1.80E+14	3.83E+11
5	2.28E+18	4.07E+16	3.52E+15	2.33E+11	2.30E+11	2.08E+11	1.39E+11
7	3.77E+10	3.77E+10	3.77E+10	3.76E+10	3.70E+10	3.36E+10	2.25E+10
9.5	5.88E+09	5.88E+09	5.88E+09	5.87E+09	5.78E+09	5.24E+09	3.51E+09
Total	4.20E+20	2.59E+20	1.37E+20	6.99E+19	2.18E+19	4.17E+18	5.49E+17

Table 12.2-4—Nitrogen-16 Concentration Along Reactor Coolant Loop

Time (s)	Location	N-16 Concentration (Ci/g)
0	---	6.94E-05
1.3585	Active Fuel Region Inlet	6.08E-05
2.373	Active Fuel Region Outlet	1.54E-04
4	SG Inlet Nozzle Diffuser	1.31E-04
6	---	1.08E-04
8	---	8.89E-05
9.93	RCP Outlet	6.94E-05

Table 12.2-5—Photon Spectra for Pressurizer

Energy (MeV)	Photon Spectra (Mev/s-m^3)
0.01	7.18E+08
0.025	9.21E+08
0.0375	3.67E+10
0.0575	2.00E+07
0.085	7.42E+10
0.125	2.58E+08
0.225	2.59E+10
0.375	1.08E+10
0.575	4.08E+10
0.85	3.79E+10
1.25	4.30E+10
1.75	2.97E+10
2.25	4.41E+10
2.75	9.52E+09
3.5	1.43E+09
5	4.50E+08
7	6.77E-04
9.5	1.06E-04
Total	3.56E+11

Note:

1. The above photon spectrum is associated with a reactor coolant density of 0.699 g/cm^3.

Table 12.2-6—Corrosion Product Deposits on the Main Coolant Loops

Nuclide	Hot Leg/Cold Leg (µCi/cm^2)	SGs (µCi/cm^2)
Mn-54	1.1E+00	3.5E-01
Co-58	1.4E+01	7.0E+00
Co-60	2.6E+00	1.4E+00
Fe-59	5.4E-01	3.2E-01

Table 12.2-7—Photon Spectra for Water Phase of Volume Control Tank

Photon Energy (MeV)	Photon Spectra (MeV/s-m^3)
0.01	3.64E+06
0.025	2.84E+07
0.0375	2.57E+07
0.0575	1.69E+07
0.085	3.49E+07
0.125	1.53E+08
0.225	7.66E+08
0.375	4.52E+09
0.575	2.18E+10
0.85	1.88E+10
1.25	2.14E+10
1.75	1.67E+10
2.25	2.16E+09
2.75	3.97E+09
3.5	6.62E+08
5	2.26E+08
7	4.37E-04
9.5	6.83E-05
Total	9.12E+10

Table 12.2-8—Photon Spectra for Gas Phase of Volume Control Tank

Photon Energy (MeV)	Photon Spectra (MeV/s-m^3)
0.01	2.56E+09
0.025	3.14E+09
0.0375	1.36E+11
0.0575	5.43E+04
0.085	2.75E+11
0.125	3.30E+07
0.225	7.35E+10
0.375	5.95E+09
0.575	7.90E+09
0.85	1.62E+10
1.25	8.77E+09
1.75	3.51E+10
2.25	8.41E+10
2.75	8.94E+09
3.5	1.25E+09
5	3.96E+08
7	0.00E+00
9.5	0.00E+00
Total	6.59E+11

Table 12.2-9—CPS Design Input

Parameter	Value
RCS letdown flow rate for purification	79,366 lb/hr (10 kg/s)
Coolant filter decontamination factor for corrosion products	1.1
Coolant filter efficiency for corrosion products	0.091
Mixed-bed filter decontamination factors, based on NUREG-0017 (Reference 2)	Iodine, Bromine: 100 Cesium, Rubidium: 2 Tritium, Noble Gases: 1 Others: 50
Mixed bed filter efficiencies, based on NUREG-0017 (Reference 2)	Iodine, Bromine: 0.99 Cesium, Rubidium: 0.50 Tritium, Noble Gases: 0 Others: 0.98

Table 12.2-10—Photon Spectra of CPS Mixed Bed Demineralizers after Operation Period of 1 Year

Photon Energy (MeV)	Photon Spectra (MeV/s) at Two Times	
	0 days	½ year
0.01	1.03E+11	4.48E+10
0.025	4.68E+11	6.39E+09
0.0375	1.87E+12	1.60E+12
0.0575	1.79E+11	9.24E+07
0.085	6.66E+11	8.22E+08
0.125	1.69E+12	5.44E+09
0.225	7.86E+12	3.73E+10
0.375	8.47E+13	3.86E+10
0.575	1.02E+15	8.68E+14
0.85	6.81E+14	5.43E+14
1.25	1.06E+14	6.15E+13
1.75	5.40E+12	1.42E+10
2.25	9.73E+11	6.16E+09
2.75	2.97E+12	6.50E+07
3.5	2.02E+10	1.17E+07
5	2.93E+09	1.14E+03
7	2.26E+02	1.84E+02
9.5	3.54E+01	2.88E+01
Total	1.91E+15	1.47E+15

Table 12.2-11—Activity Inventory on CPS Coolant Filters after Operation Period of 1 Year

Nuclide	Activity (Ci)	Activity (Ci) after 6 months decay
Na-24	2.6E+00	0.00E+00
Cr-51	6.3E+00	6.52E-02
Mn-54	2.0E+01	1.31E+01
Fe-55	1.9E+01	1.68E+01
Fe-59	9.7E-01	5.80E-02
Co-58	2.3E+01	3.78E+00
Co-60	9.1E+00	8.56E+00
Zn-65	5.7E+00	3.40E+00
W-187	2.0E-01	0.00E+00
Total	8.6E+01	4.57E+01

Table 12.2-12—Photon Spectra for Water Phase of Degasifier

Photon Energy (MeV)	Photon Spectra (MeV/s-m^3)
0.01	4.77E+05
0.025	1.02E+06
0.0375	1.02E+07
0.0575	8.31E+06
0.085	5.99E+06
0.125	1.75E+07
0.225	1.23E+08
0.375	3.52E+08
0.575	4.02E+09
0.85	6.02E+09
1.25	8.44E+09
1.75	7.09E+09
2.25	1.75E+09
2.75	2.19E+09
3.5	5.18E+08
5	2.27E+08
7	1.91E-05
9.5	2.99E-06
Total	3.08E+10

Table 12.2-13—Photon Spectra for Gas Phase of Degasifier

Photon Energy (MeV)	Photon Spectra (MeV/s-m^3)
0.01	7.24E+08
0.025	8.87E+08
0.0375	3.73E+10
0.0575	1.19E+05
0.085	7.55E+10
0.125	1.31E+07
0.225	2.49E+10
0.375	3.37E+09
0.575	4.33E+09
0.85	4.70E+09
1.25	3.09E+09
1.75	7.91E+09
2.25	3.95E+10
2.75	3.53E+09
3.5	2.66E+08
5	1.27E+07
7	0.00E+00
9.5	0.00E+00
Total	2.06E+11

Table 12.2-14—Photon Spectra for FPCPS Mixed-Bed Demineralizer after Operation Period of 1 Year

Photon Energy (MeV)	Photon Spectra (MeV/s)
0.01	3.72E+08
0.025	2.50E+08
0.0375	2.83E+09
0.0575	2.45E+08
0.085	3.83E+08
0.125	7.26E+08
0.225	4.85E+09
0.375	3.98E+10
0.575	2.04E+12
0.85	1.69E+12
1.25	2.66E+11
1.75	1.29E+09
2.25	1.54E+08
2.75	2.55E+08
3.5	5.22E+05
5	2.91E+03
7	4.45E+00
9.5	6.94E-01
Total	4.04E+12

Table 12.2-15—Photon Spectra for Liquid Waste Storage System Group I Waste Tank

Photon Energy (MeV)	Photon Spectra (MeV/s-m^3)
0.01	9.23E+06
0.025	6.89E+07
0.0375	7.02E+07
0.0575	2.75E+07
0.085	1.03E+08
0.125	3.51E+08
0.225	2.91E+09
0.375	9.15E+09
0.575	3.48E+10
0.85	1.66E+10
1.25	2.39E+10
1.75	7.53E+09
2.25	1.20E+09
2.75	3.00E+09
3.5	3.35E+06
5	6.06E+04
7	9.68E-04
9.5	1.51E-04
Total	9.98E+10

Table 12.2-16—Photon Spectra for Liquid Waste Processing System Evaporator After 3 Months Operations

Photon Energy (MeV)	Photon Spectra (MeV/s)
0.01	2.36E+10
0.025	1.51E+11
0.0375	3.81E+11
0.0575	1.03E+11
0.085	2.50E+11
0.125	5.60E+11
0.225	3.00E+12
0.375	2.90E+13
0.575	1.89E+14
0.85	1.35E+14
1.25	2.78E+13
1.75	1.16E+12
2.25	2.09E+11
2.75	7.98E+11
3.5	8.13E+08
5	1.03E+07
7	2.33E+01
9.5	3.64E+00
Total	3.88E+14

Table 12.2-17—Photon Spectra for Gaseous Waste Processing System

Photon Energy (MeV)	Photon Spectra ($MeV/s\text{-}m^3$)	
	Purge Gas Circuit	Delay Bed after Degasification Flow Termination
0.01	6.92E+08	2.27E+10
0.03	8.49E+08	2.84E+10
0.04	3.68E+10	1.22E+12
0.06	1.47E+04	3.21E+05
0.09	7.44E+10	2.46E+12
0.13	8.92E+06	2.73E+08
0.23	1.98E+10	5.79E+11
0.38	1.61E+09	4.16E+10
0.58	2.13E+09	9.73E+10
0.85	4.36E+09	1.23E+11
1.25	2.37E+09	9.16E+10
1.75	9.48E+09	2.76E+11
2.25	2.27E+10	5.82E+11
2.75	2.41E+09	6.95E+10
3.50	3.36E+08	1.06E+10
5.00	1.07E+08	3.47E+09
7.00	0.00E+00	0.00E+00
9.50	0.00E+00	0.00E+00
Total	1.78E+11	5.61E+12

Table 12.2-18—Photon Spectra for ESF Filters Post-LOCA
Sheet 1 of 2

Photon Energy (MeV)	Photon Spectra (MeV/s) at Various Times (hr) Post-LOCA						
	1	2	8	24	96	720	8766
Annulus Ventilation							
0.01	1.21E+10	9.43E+10	5.17E+11	7.37E+11	4.57E+11	6.44E+10	1.68E+10
0.025	1.54E+11	9.90E+11	4.96E+12	7.33E+12	5.20E+12	5.75E+11	9.72E+10
0.0375	7.90E+10	4.45E+11	2.26E+12	3.51E+12	3.02E+12	1.22E+12	8.10E+11
0.0575	5.83E+10	3.82E+11	2.12E+12	3.21E+12	2.36E+12	3.24E+11	1.71E+08
0.085	1.39E+11	7.05E+11	3.29E+12	5.10E+12	4.22E+12	5.72E+11	2.63E+09
0.125	5.19E+11	1.87E+12	5.34E+12	7.34E+12	3.83E+12	2.72E+11	2.17E+10
0.225	4.10E+12	2.11E+13	8.67E+13	1.11E+14	7.48E+13	6.80E+12	1.03E+11
0.375	1.80E+13	8.41E+13	3.80E+14	5.62E+14	4.81E+14	6.20E+13	7.96E+11
0.575	1.22E+14	5.25E+14	1.73E+15	1.91E+15	1.06E+15	7.17E+14	5.43E+14
0.85	1.44E+14	5.01E+14	9.68E+14	1.10E+15	8.92E+14	5.90E+14	3.96E+14
1.25	1.73E+14	5.59E+14	1.23E+15	6.82E+14	2.69E+14	9.38E+13	3.87E+13
1.75	5.94E+13	2.22E+14	4.42E+14	2.19E+14	2.07E+14	6.58E+13	2.93E+10
2.25	2.46E+13	5.49E+13	6.81E+13	2.98E+13	9.26E+12	9.94E+11	3.89E+10
2.75	1.41E+13	2.41E+13	3.75E+12	5.41E+12	1.22E+13	3.94E+12	2.64E+09
3.5	3.24E+12	5.72E+12	6.97E+11	6.80E+10	1.26E+11	4.21E+10	5.07E+08
5	4.09E+11	1.05E+12	2.67E+11	5.52E+09	4.57E+04	4.63E+04	4.22E+04
7	7.45E+01	6.43E+02	3.89E+03	6.56E+03	7.37E+03	7.48E+03	6.80E+03
9.5	1.16E+01	1.00E+02	6.07E+02	1.02E+03	1.15E+03	1.17E+03	1.06E+03
Safeguard Building (Controlled Area)							
0.01	9.78E+06	1.31E+08	1.10E+10	7.77E+10	2.74E+11	1.45E+11	2.36E+08
0.025	4.91E+08	6.57E+09	5.60E+11	3.94E+12	1.38E+13	5.95E+12	6.42E+09
0.0375	1.26E+08	1.68E+09	1.45E+11	1.02E+12	3.54E+12	1.43E+12	1.19E+09
0.0575	7.75E+07	1.59E+09	1.63E+11	1.14E+12	3.48E+12	1.03E+11	4.50E-20
0.085	4.05E+08	4.07E+09	2.92E+11	2.18E+12	9.60E+12	7.59E+12	1.67E+05
0.125	1.30E+09	8.17E+09	2.10E+11	1.24E+12	2.87E+12	9.51E+10	1.06E+08
0.225	1.25E+10	1.38E+11	9.46E+12	5.59E+13	1.84E+14	6.78E+13	1.42E+09
0.375	6.46E+10	6.23E+11	4.53E+13	3.16E+14	1.36E+15	1.08E+15	8.57E+07
0.575	3.90E+11	3.43E+12	1.67E+14	7.46E+14	9.77E+14	2.01E+14	3.31E+10
0.85	4.80E+11	3.21E+12	7.17E+13	2.78E+14	5.74E+14	6.21E+13	5.57E+09
1.25	3.80E+11	3.28E+12	1.35E+14	2.78E+14	1.85E+14	5.22E+12	3.59E+09
1.75	1.63E+11	1.34E+12	5.11E+13	8.01E+13	2.00E+13	5.65E+11	2.47E-19
2.25	2.86E+10	2.31E+11	8.53E+12	1.73E+13	2.03E+13	5.79E+11	2.53E-19

Table 12.2-18—Photon Spectra for ESF Filters Post-LOCA
Sheet 2 of 2

Photon Energy (MeV)	Photon Spectra (MeV/s) at Various Times (hr) Post-LOCA						
	1	2	8	24	96	720	8766
2.75	1.75E+09	8.06E+09	4.96E+10	1.91E+11	5.81E+11	1.72E+10	7.51E-21
3.5	5.50E+09	1.58E+10	5.37E+08	3.49E+00	2.58E-40	0.00E+00	0.00E+00
5	1.23E+08	3.52E+08	1.20E+07	7.78E-02	5.75E-42	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9.5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Main Control Room (Intake and Recirculation Filters)							
0.01	1.22E+05	8.76E+05	4.79E+06	5.19E+06	3.25E+06	6.19E+05	1.10E+05
0.025	1.93E+06	9.57E+06	4.74E+07	5.58E+07	4.88E+07	1.40E+07	6.14E+05
0.0375	1.28E+06	4.65E+06	2.17E+07	2.61E+07	2.39E+07	1.07E+07	5.33E+06
0.0575	8.56E+05	3.84E+06	1.98E+07	2.25E+07	1.55E+07	2.13E+06	1.08E+03
0.085	2.21E+06	7.48E+06	3.37E+07	4.50E+07	5.52E+07	2.24E+07	1.66E+04
0.125	8.52E+06	2.10E+07	4.92E+07	5.06E+07	2.46E+07	1.72E+06	1.37E+05
0.225	6.57E+07	2.23E+08	8.53E+08	8.68E+08	7.24E+08	2.03E+08	6.60E+05
0.375	3.38E+08	9.62E+08	4.03E+09	5.28E+09	7.06E+09	3.04E+09	5.03E+06
0.575	2.31E+09	6.02E+09	1.78E+10	1.61E+10	8.47E+09	5.16E+09	3.59E+09
0.85	2.83E+09	8.76E+09	1.63E+10	8.45E+09	6.25E+09	4.01E+09	2.62E+09
1.25	3.56E+09	8.08E+09	1.35E+10	5.81E+09	1.90E+09	6.19E+08	2.55E+08
1.75	1.69E+09	1.26E+10	2.55E+10	2.03E+09	1.33E+09	4.15E+08	1.84E+05
2.25	5.49E+08	1.10E+09	9.38E+08	2.58E+08	6.14E+07	6.28E+06	2.46E+05
2.75	4.01E+08	2.03E+09	3.17E+09	6.59E+07	7.81E+07	2.48E+07	1.67E+04
3.5	9.27E+07	5.70E+08	1.01E+09	9.59E+06	8.10E+05	2.65E+05	3.20E+03
5	1.90E+07	2.07E+08	4.03E+08	3.68E+06	3.25E-01	2.92E-01	2.66E-01
7	6.16E-04	5.83E-03	3.57E-02	4.52E-02	4.72E-02	4.72E-02	4.29E-02
9.5	9.61E-05	9.09E-04	5.57E-03	7.04E-03	7.37E-03	7.36E-03	6.69E-03

Table 12.2-19—Parameters and Assumptions for Calculating Airborne Radioactive Concentrations

Parameter/Assumption	Value
Containment Building	
Reactor coolant leakage rate	1 gpm (continuous), in equipment area
Time used to estimate airborne concentration	24 hours
Containment free air volume	5.68E+05 ft^3 Equipment area 2.25E+06 ft^3 Service area 2.82E+06 ft^3 Total
Flashing fraction	43.8%
Fuel defects	0.25%
Reactor coolant tritium concentration	1 μCi/gm
Normal operation purge flow rate	3210 (initiated after equilibrium conditions have been achieved) Service area purged via equipment area
Primary containment configuration	Isolated equipment area, with 1% per day leakage rate to service area
Equipment area filtered recirculation flow and filtration efficiencies (continuous)	4100 cfm 90% for all nuclides except noble gases and N-16
Fuel Building	
Spent fuel pool evaporation rate	1 gpm
Fuel Building air volume	2.11E+05 ft^3
Ventilation flow through area	35,450 cfm
Fuel Building air release rate	241.9 per day

Table 12.2-20—Airborne Radioactivity Concentrations

Nuclide	Reactor Building Concentration – Service Area (µCi/ml)	Fuel Building Concentration (µCi/ml)	10 CFR Part 20, Appendix B Inhalation DAC (µCi/ml)
H-3	9.26E-07	2.67E-06	2E-05
Ar-41	< 3.0E-06	N/A	3E-06
Br-83	1.27E-14	1.07E-22	3E-05
Kr-83m	7.13E-14	2.13E-21	1E-02
Kr-85m	1.11E-10	5.28E-16	2E-05
Kr-85	5.65E-03	1.96E-08	1E-04
Kr-87	4.37E-16	1.60E-31	5E-06
Kr-88	9.41E-12	2.98E-19	2E-06
Rb-88	1.05E-11	3.06E-19	3E-05
I-129	4.37E-14	4.87E-17	4E-09
I-130	4.33E-11	2.74E-13	3E-07
I-131	4.04E-08	5.72E-10	2E-08
I-132	1.08E-13	1.27E-10	3E-06
I-133	3.33E-09	5.83E-11	1E-07
I-134	1.24E-19	7.03E-41	2E-05
I-135	1.03E-10	4.96E-14	7E-07
Xe-131m	2.83E-05	1.27E-09	4E-04
Xe-133	1.05E-06	6.30E-10	1E-04
Xe-133	4.91E-04	7.54E-08	1E-04
Xe-135m	1.65E-11	1.37E-14	9E-06
Xe-135	1.97E-08	2.11E-11	1E-05
Cs-134	1.48E-07	7.44E-10	4E-08
Cs-136	4.87E-09	1.43E-10	3E-07
Cs-137	1.01E-07	2.85E-10	6E-08

Figure 12.2-1—Nitrogen-16 Concentration Along Reactor Coolant Loop

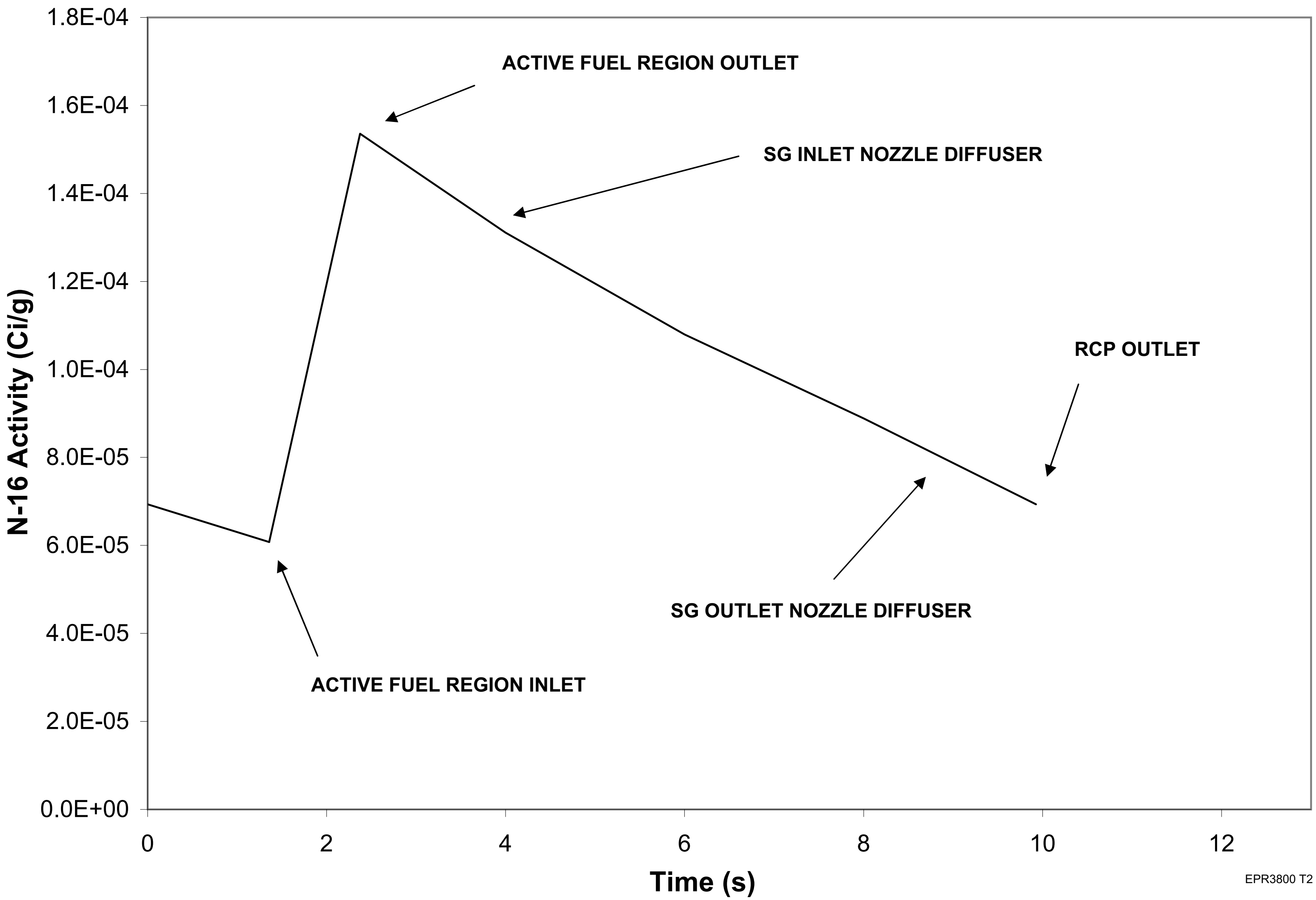

Figure 12.2-2—Simplified Flow Diagram for Volume Control Tank

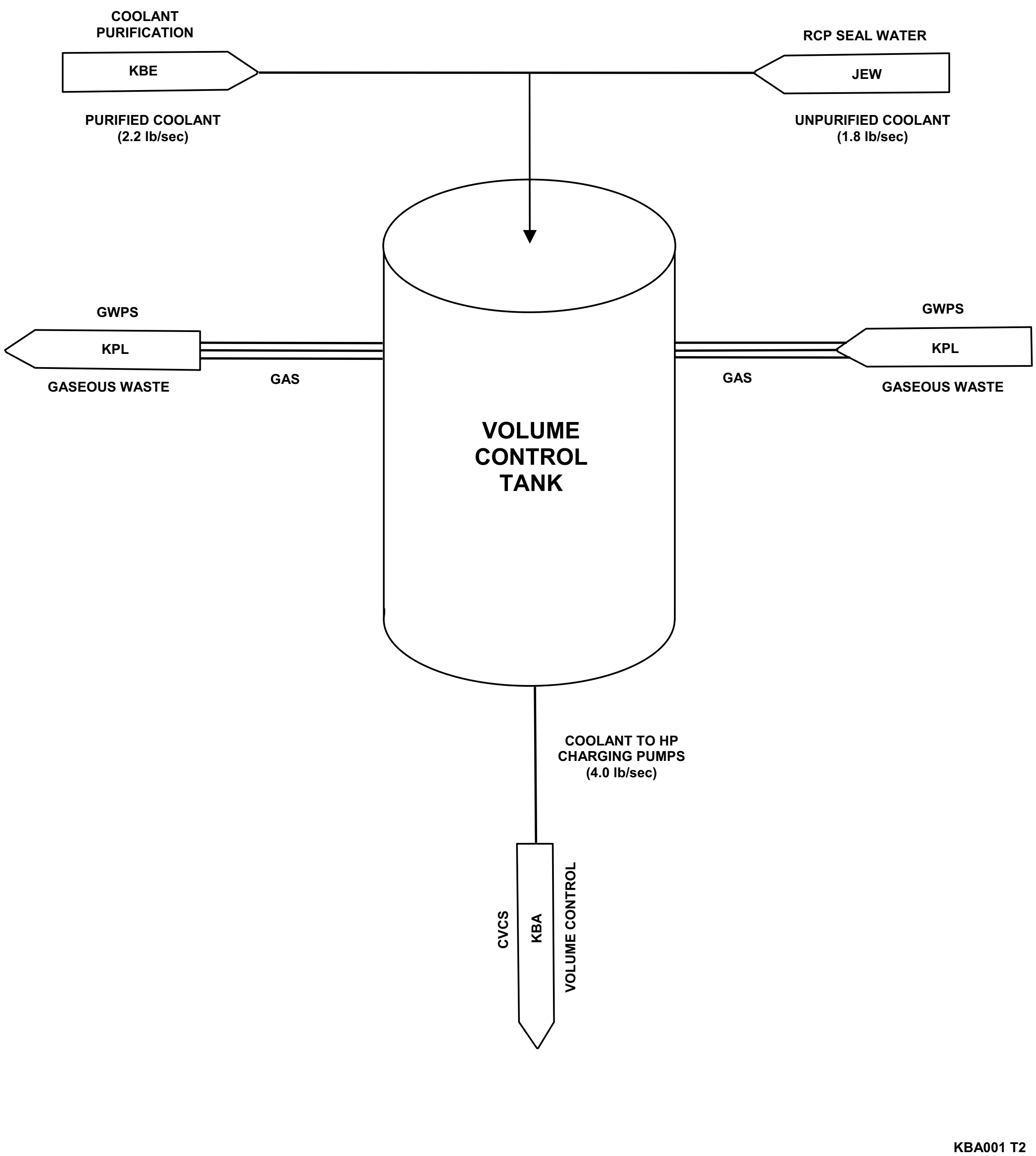

Figure 12.2-3—Simplified Flow Diagram for the Primary Coolant Degasification System Degasifier