ArevaEPRDCPEm Resource

From: BRYAN Martin (EXT) [Martin.Bryan.ext@areva.com]
Sent: Thursday, May 13, 2010 4:02 PM
To: Tesfaye, Getachew
Cc: DELANO Karen V (AREVA NP INC); ROMINE Judy (AREVA NP INC); BENNETT Kathy A (OFR) (AREVA NP INC); WILLIFORD Dennis C (AREVA NP INC)
Subject: Response to U.S. EPR Design Certification Application RAI No. 280, FSAR Ch 12, Supplement 2
Attachments: RAI 280 Supplement 2 Response US EPR DC.pdf

Getachew,

AREVA NP Inc. provided a schedule for a technically correct and complete response to RAI No. 280 on February 26, 2010. To allow time for AREVA to discuss proposed responses to the questions with the NRC staff (which was performed during the Chapter 12 audit on April 23, 2010), a revised schedule was provided in RAI 280 Supplement 1. The attached file, "RAI 280 Supplement 2 Response US EPR DC.pdf" provides technically correct and complete responses to 2 of the remaining 3 questions.

A revised schedule to complete the remaining response is required in order to address NRC reviewer concerns discussed during the Chapter 12 audit on April 23, 2010 and during the follow-up telecon on April 28, 2010.

Appended to this file are affected pages of the U.S. EPR Final Safety Analysis Report in redline-strikeout format which support the response to RAI 280 Question 12.02-5.

The following table indicates the respective pages in the response document, "RAI 280 Supplement 2 Response US EPR DC.pdf," that contain AREVA NP's response to the subject questions.

Question #	Start Page	End Page
12.02-5	2	2
12.02-6	3	4

The schedule for a technically correct and complete response to the remaining question has been changed and is provided below:

Question #	Response Date
12.03-12.04-17	**July 29, 2010**

Martin (Marty) C. Bryan
U.S. EPR Design Certification Licensing Manager
AREVA NP Inc.
Tel: (434) 832-3016
702 561-3528 cell
Martin.Bryan.ext@areva.com

From: WELLS Russell D (AREVA NP INC)
Sent: Tuesday, April 20, 2010 10:55 AM
To: 'Getachew Tesfaye'
Cc: BRYAN Martin (EXT); BENNETT Kathy A (OFR) (AREVA NP INC); DELANO Karen V (AREVA NP INC); ROMINE Judy

(AREVA NP INC)
Subject: Response to U.S. EPR Design Certification Application RAI No. 280, FSAR Ch 12, Supplement 1

Getachew,

AREVA NP Inc. provided a schedule for a technically correct and complete response to RAI No. 280 on February 26, 2010. To allow time for AREVA to discuss proposed responses to the remaining 3 questions with the NRC staff (scheduled for April 23, 2010), a revised schedule is provided in this e-mail.

The schedule for technically correct and complete responses to the remaining 3 questions has been changed as provided below:

Question #	Response Date
RAI 280 — 12.02-5	May 13, 2010
RAI 280 — 12.02-6	May 13, 2010
RAI 280 — 12.03-12.04-17	May 13, 2010

Sincerely,

(Russ Wells on behalf of)
Martin (Marty) C. Bryan
Licensing Advisory Engineer
AREVA NP Inc.
Tel: (434) 832-3016
Martin.Bryan.ext@areva.com

From: BRYAN Martin (EXT)
Sent: Friday, February 26, 2010 4:29 PM
To: 'Tesfaye, Getachew'
Cc: DELANO Karen V (AREVA NP INC); BENNETT Kathy A (OFR) (AREVA NP INC); ROMINE Judy (AREVA NP INC); WILLIFORD Dennis C (AREVA NP INC)
Subject: Response to U.S. EPR Design Certification Application RAI No. 280, FSAR Ch. 12

Getachew,

Attached please find AREVA NP Inc.'s response to the subject request for additional information (RAI). The attached file, "RAI 280 Response US EPR DC.pdf" provides a schedule since a technically correct and complete response to the 3 questions is not provided.

The following table indicates the respective pages in the response document, "RAI 280 Response US EPR DC.pdf," that contain AREVA NP's response to the subject questions.

Question #	Start Page	End Page
RAI 280 — 12.02-5	2	2
RAI 280 — 12.02-6	3	3
RAI 280 — 12.03-12.04-17	4	5

A complete answer is not provided for the 3 questions. The schedule for a technically correct and complete response to these questions is provided below.

Question #	Response Date

RAI 280 — 12.02-5	April 21, 2010
RAI 280 — 12.02-6	April 21, 2010
RAI 280 — 12.03-12.04-17	April 21, 2010

Martin (Marty) C. Bryan
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Tel: (434) 832-3016
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From: Tesfaye, Getachew [mailto:Getachew.Tesfaye@nrc.gov]
Sent: Thursday, August 27, 2009 3:10 PM
To: ZZ-DL-A-USEPR-DL
Cc: Bernal, Sara; Hinson, Charles; Frye, Timothy; Jennings, Jason; Colaccino, Joseph; ArevaEPRDCPEm Resource
Subject: U.S. EPR Design Certification Application RAI No. 280 (3307, 3554),FSAR Ch. 12

Attached please find the subject requests for additional information (RAI). A draft of the RAI was provided to you on August 25, 2009, and discussed with your staff on August 27, 2009. No changes were made to the draft RAI questions as a result of that discussion. The questions in this RAI are considered potential open items for Phases 2 and 3 reviews. As such, the schedule we have established for your application assumes technically correct and complete responses prior to the start of Phase 4 review. For any RAI question that cannot be answered prior to the start of Phase 4 review, it is expected that a date for receipt of this information will be provided so that the staff can assess how this information will impact the published schedule.

Thanks,
Getachew Tesfaye
Sr. Project Manager
NRO/DNRL/NARP
(301) 415-3361

Hearing Identifier: AREVA_EPR_DC_RAIs
Email Number: 1416

Mail Envelope Properties (BC417D9255991046A37DD56CF597DB7106219E64)

Subject: Response to U.S. EPR Design Certification Application RAI No. 280, FSAR Ch 12, Supplement 2
Sent Date: 5/13/2010 4:01:45 PM
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From: BRYAN Martin (EXT)

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Files	**Size**	**Date & Time**
MESSAGE	5402	5/13/2010 4:01:48 PM
RAI 280 Supplement 2 Response US EPR DC.pdf		174902

Options
Priority: Standard
Return Notification: No
Reply Requested: No
Sensitivity: Normal
Expiration Date:
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Response to

Request for Additional Information No. 280, Supplement 2

8/27/2009

U.S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 12.02 - Radiation Sources
SRP Section: 12.03-12.04 - Radiation Protection Design Features

Application Section: FSAR Ch. 12

QUESTIONS for Health Physics Branch (CHPB)

Question 12.02-5:

POTENTIAL OPEN ITEM

RG 1.206, Section C.I.12.2.1, "Contained Sources," states that the applicant should describe the sources of radiation during normal and accident conditions, that are the basis for the radiation protection design. Sources should be tabulated by isotopic composition or gamma ray energy groups, strength (becquerel or curie content), and geometry. The basis for these values should also be provided.

In response to RAI 150 (1656) Question 12.02-3 and RAI 150 (1606) Question 12.03-12.04-4, the applicant provided information on radiation sources which constitute a radiation protection and shielding concern, including spent fuel, the safety injection system (post-LOCA), the residual heat removal system (after shutdown) and the movable in-core flux mapping system (or aeroball system). The response provided was acceptable, however the applicant did not incorporate any changes into the EPR FSAR. Please update Section 12.2 of the EPR FSAR to include, for each of the above systems, the source term information (i.e., photon spectra) and basis for those values provided in the applicant's response to RAI 150 (1656) Question 12.02-3 and Question 12.03-12.04-3, in accordance with the guidance provided in RG 1.206.

Response to Question 12.02-5:

U. S. EPR FSAR Tier 2, Section 12.2.1 will be revised to include separate subsections for the photon energy spectra for the safety injection system, the normal residual heat removal system, and the aeroball measurement system. U.S. EPR FSAR Tier 2, Table 12.2-3 will be revised based on the response to RAI 150, Question 12.02-3 (Part i) to include the spent fuel gamma ray source strengths at additional decay times following reactor shutdown. U.S. EPR FSAR Tier 2, Table 12.2-21 will be added based on the response to RAI 150, Question 12.02-3 (Part ii) to include safety injection system source strengths at various times following a loss of coolant accident. U.S. EPR FSAR Tier 2, Table 12.2-22 will be added based on the response to RAI 150, Question 12.02-3 (Part iii) to include the normal residual heat removal system source strengths at various decay times following a reactor shutdown. U.S. EPR FSAR Tier 2, Table 12.2-23 will be added based on the response to RAI 150, Question 12.03-12.04-4 (Part iii) to include the total activity of the aeroballs as a function of the decay time. In addition, a footnote will be added to U.S. EPR FSAR Tier 2, Table 12.2-23 based on the response to RAI 150, Question 12.03-12.04-4 (Part iii) to state:

> "The bounding total activity for the Aeroballs was established by considering 34 consecutive irradiation cycles with each cycle consisting of a 4 minute irradiation followed by a 10 minute decay period after the irradiation."

FSAR Impact:

U. S. EPR FSAR Tier 2, Section 12.2.1 and Table 12.2-3 will be revised as described in the response and indicated on the enclosed markup. U.S. EPR FSAR Tier 2, Table 12.2-21, Table 12.2-22 and Table 12.2-23 will be added as described in the response and indicated on the enclosed markup.

Question 12.02-6:

POTENTIAL OPEN ITEM

In order to demonstrate the EPR design's compliance with the occupational dose limits of 10 CFR 20.1201 the applicant provided airborne concentrations for the reactor building and the fuel building in Section 12.2 of the EPR FSAR. An overview of the methodology used to calculate these airborne concentrations was provided in response to RAI 150 (1656) Question 12.02-2. However, the staff has some additional questions regarding the following points:

1. The EPR FSAR Table 12.2-19, "Parameters and Assumptions for Calculating Airborne Radioactive Concentrations," states that the containment building equipment area filtered recirculation filtration efficiencies is 90% for all nuclides except for noble gases and N-16." Please also provide information on the filtration efficiency (or lack thereof) for tritium.
2. The applicant's response to RAI 150 (1656) Question 12.02-2 includes the equation used to calculate the evaporation rate from the spent fuel pool. Please provide the source and basis for this equation.
3. The response to RAI 150 (1656) Question 12.02-2 states that "the multiplier used for tritium was based on a 1 percent diffusion rate from the design basis activity calculation." Please provide the basis for selecting the 1 percent diffusion rate.
4. In order to calculate the airborne calculations for the service compartments a 1% per day leakage rate from the equipment area to the service area was assumed. Provide the basis for this assumption.

Response to Question 12.02-6:

1. There is no filtration removal of tritium.

2. The response to RAI 150, Question 12.02-2 included the following equation for spent fuel pool evaporation:

   $$E = 0.771(1.465 - 0.0186\ B)\ (0.44 + 0.118\ W)\ (e_s - e_d)$$

   where:

   E = Evaporation (inches per day)

   B = barometric reading (inches of Hg)

   W = water surface wind (miles per hour)

   e_s = mean vapor pressure at temperature of water surface (inches of Hg)

   e_d = mean vapor pressure of saturated air (inches of Hg)

   This equation is used to determine the evaporation of water from tanks and reservoirs. It is provided on page 3-81, under "Evaporators and Evaporation", from the following reference:

Kent's Mechanical Engineer's Handbook, J. Salisbury, 12th Edition, Wiley Engineering.

3. The 1 per cent diffusion tritium rate from the fuel, as stated in the response to RAI 150 , Question 12.02-2, is based on the one per cent values reported in the following references:

   J. E. Phillips and C. E. Easterly, "Sources of Tritium", Nuclear Safety, Vol. 22, No. 5, September - October, 1981.

   J. Locante, "Tritium in Pressurized Water Reactors", Trans. American Nuclear Society 14: No. 1, 161-2, June 1971.

4. The Reactor Building service and mechanical areas are segregated compartments that prevent contamination of the service area. The analysis assumed a 1 percent per day transfer of radioactivity from the mechanical area to the service area. This is a conservative assumption because without any incoming or outgoing air flows during normal operation, no leakage is expected during equilibrium conditions. The leakage rate to the service area is terminated at the start of purging because purging of the service area occurs via the equipment area.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

U.S. EPR Final Safety Analysis Report Markups

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 (cm). 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.

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~~Table—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.~~ The spent fuel gamma ray source strengths, as a function of time after shutdown, are presented in Table 12.2-3. The spectra are based on the radionuclide mix containing the bounding core inventory for each individual radionuclide of importance for the following core parameters:

- Power level: 4612 MW_t.
- U-235 fuel enrichment: 2 to 5 $^w/_o$.
- Fuel burn-up: 5 to 62 GWD/MTU.

12.02-5

- Core loading: 129 MTU (metric tons of uranium).

The 18-group spectral structure corresponds to that of ORIGEN-2, and the tabulation includes 18 decay times covering the interval from 5 minutes to approximately 23 years.

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

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.

12.2.1.14 Safety Injection System

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The U.S. EPR safety injection system (SIS) source strengths at various times following a loss of coolant accident (LOCA) are presented in Table 12.2-21. The tabulated spectra are based on the following:

1. A radionuclide mix at the time of the postulated LOCA containing the bounding core inventory for each individual radionuclide of importance for the following core parameters:

Power level:	4612 MW_t
U-235 fuel enrichment:	2 to 5 w/o
Fuel burn-up:	5 to 62 GWD/MTU
Core loading:	129 MTU (metric tons of uranium)

2. Core release fractions as defined in RG 1.183 for the alternative source term methodology.

3. Instantaneous transfer from the core of all released halogens and other particulates directly into the post-LOCA liquids in the in-containment refueling water storage tank (IRWST), which is the supply source for the SIS (i.e., combined gap and early in-vessel releases to the IRWST at t=0 hr, a conservative assumption).

12.02-5

4. Instantaneous evolution of all noble gases generated within the IRWST from halogen decay directly to the containment atmosphere.

5. 17 decay times spanning the range from 0 hours to 1 year.

12.2.1.15 Normal Residual Heat Removal System

The normal residual heat removal (RHR) system source strength is presented in Table 12.2-22 for a series of decay times after shutdown. The tabulated spectra are based on the following:

1. The initial (un-decayed) RCS coolant inventory is assumed to correspond to the design-basis source term listed in Table 11.1-2.

2. No dilution credit is considered for the extra coolant injected into the RCS to compensate for the coolant volume reduction induced by the cool-down.

3. The RCS coolant is assumed to be degasified prior to shutdown. Specifically, the noble gas concentrations in the RHR piping are assumed to correspond to 1 percent of those during operation.

4. The coolant density is assumed to be 1 g/cc during the entire cool-down process by the RHR.

5. The time array for the post-shutdown decay is assumed to include the following time steps: 3, 6, 9, 12, 15 and 18 hours. The typical time for RHR cool-down startup (based on a cool-down rate of 90°F per hour and coolant temperature reduction from 594°F at full power to 250°F) is about 4 hours.

12.2.1.16 Aeroball Measurement System

Each Aeroball is 1.7 mm in diameter and the typical composition of each Aeroball is:

weight % Cr-50 in Aeroball: 14.5

weight % Fe-56 in Aeroball: 83.36

weight % V-51 in Aeroball: 1.54

weight % C-12 in Aeroball: 0.6

12.02-5

The neutron capture reactions include:

$$^{51}_{23}V \xrightarrow{(n,\gamma)} {}^{52}_{23}V \xrightarrow[3.76\,\text{min}]{\beta,\gamma} {}^{52}_{24}Cr \quad (\gamma = 1434.1\,keV)$$

$$^{50}_{24}Cr \xrightarrow{(n,\gamma)} {}^{51}_{24}Cr \xrightarrow[27.7\,day]{\varepsilon,\gamma} {}^{51}_{23}V \quad (\gamma = 320.1\,keV)$$

$$^{56}_{26}Fe \xrightarrow{n} {}^{57}_{26}Fe$$

$$^{12}_{6}C \xrightarrow{n} {}^{13}_{6}C$$

$$^{55}_{25}Mn \xrightarrow{(n.\gamma)} {}^{56}_{25}Mn \xrightarrow[2.578\,hr]{\beta,\gamma} {}^{56}_{26}Fe \quad (\gamma = 846.8,\ 1810.8,\ 2113.1\,keV)$$

The V-52 activity decays away after 45 minutes. The Mn-56 activity decays away after 24 hours.

The content of the alloy elements with their tolerances are specified in detail and verified after fabrication by chemical analysis. During commissioning, two ball stacks will be activated so that they reach saturation. Their activity will then be measured to establish time dependence and decay constants of the material components.

The bounding total activity for the Aeroballs was established by considering 34 consecutive irradiation cycles with each cycle consisting of a 4 minute irradiation followed by a 10 minute decay period after the irradiation. The conservative action of applying this minimal 10 minute decay time between irradiations 34 consecutive times will bound all conceivable future use of this system. Note that the typical decay period between irradiations is expected to be 14 days. Table 12.2-23 presents the total activity of the Aeroballs as a function of decay time after the application of these 34 irradiation cycles.

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

~~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)~~	~~10,000 hr (1.1 y)~~	~~100,000 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~~

12.02-5

Table 12.2-3—Full-Core Bounding Photon Spectra at 4612 MW_t
Sheet 1 of 3

Energy (MeV)	Photon Spectra (MeV/sec) as a Function of Shutdown Time (hrs)					
	0.0833 (5 min)	1	2	5	10	20
0.01	1.76E+18	1.44E+18	1.36E+18	1.30E+18	1.22E+18	1.08E+18
0.025	4.15E+17	3.22E+17	2.92E+17	2.59E+17	2.34E+17	2.03E+17
0.0375	1.11E+18	7.58E+17	6.93E+17	6.49E+17	6.15E+17	5.61E+17
0.0575	5.26E+17	4.76E+17	4.71E+17	4.57E+17	4.36E+17	3.98E+17
0.085	7.54E+18	3.65E+18	2.81E+18	2.52E+18	2.36E+18	2.12E+18
0.125	1.16E+19	1.10E+19	1.07E+19	1.03E+19	9.70E+18	8.70E+18
0.225	2.24E+19	1.73E+19	1.62E+19	1.50E+19	1.39E+19	1.19E+19
0.375	2.19E+19	9.79E+18	7.41E+18	6.00E+18	5.36E+18	4.75E+18
0.575	6.41E+19	4.64E+19	4.11E+19	3.49E+19	3.05E+19	2.54E+19
0.85	1.06E+20	6.95E+19	5.66E+19	4.28E+19	3.71E+19	3.24E+19
1.25	8.23E+19	4.35E+19	3.18E+19	2.04E+19	1.39E+19	9.21E+18
1.75	4.5E+19	2.94E+19	2.50E+19	2.01E+19	1.76E+19	1.59E+19
2.25	3.13E+19	1.59E+19	1.06E+19	5.12E+18	2.73E+18	1.90E+18
2.75	1.45E+19	6.98E+18	4.25E+18	1.70E+18	9.75E+17	8.64E+17
3.5	7.09E+18	2.24E+18	1.27E+18	3.27E+17	4.87E+16	1.05E+16
5	2.28E+18	4.07E+16	2.71E+16	1.20E+16	3.52E+15	3.07E+14
7	3.77E+10	3.77E+10	3.77E+10	3.77E+10	3.77E+10	3.77E+10
9.5	5.88E+09	5.88E+09	5.88E+09	5.88E+09	5.88E+09	5.88E+09
Total	4.20E+20	2.59E+20	2.11E+20	1.62E+20	1.37E+20	1.15E+20

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Table 12.2-3—Full-Core Bounding Photon Spectra at 4612 MW_t
Sheet 2 of 3

Energy (MeV)	Photon Spectra (MeV/sec) as a Function of Shutdown Time (hrs)					
	50 (2.08 days)	100 (4.17 days)	200 (8.33 days)	500 (20.8 days)	1000 (41.7 days)	2000 (83.3 days)
0.01	7.64E+17	4.34E+17	1.52E+17	1.89E+16	5.35E+15	2.53E+15
0.025	1.55E+17	1.14E+17	7.08E+16	3.10E+16	1.54E+16	6.90E+15
0.0375	4.41E+17	3.23E+17	2.11E+17	1.05E+17	5.99E+16	3.62E+16
0.0575	3.09E+17	2.14E+17	1.17E+17	3.11E+16	6.45E+15	1.98E+15
0.085	1.58E+18	1.00E+18	4.51E+17	9.84E+16	2.91E+16	1.42E+16
0.125	6.31E+18	3.81E+18	1.63E+18	5.40E+17	3.36E+17	1.81E+17
0.225	7.94E+18	4.45E+18	1.59E+18	1.91E+17	4.37E+16	1.27E+16
0.375	3.77E+18	2.80E+18	1.80E+18	7.12E+17	2.11E+17	4.61E+16
0.575	1.85E+19	1.44E+19	1.12E+19	7.83E+18	5.81E+18	4.16E+18
0.85	2.66E+19	2.26E+19	1.90E+19	1.50E+19	1.22E+19	8.77E+18
1.25	5.77E+18	4.19E+18	2.81E+18	1.47E+18	8.13E+17	4.76E+17
1.75	1.46E+19	1.34E+19	1.09E+19	5.58E+18	1.85E+18	2.38E+17
2.25	1.62E+18	1.42E+18	1.14E+18	6.60E+17	3.14E+17	1.29E+17
2.75	8.32E+17	7.66E+17	6.23E+17	3.19E+17	1.04E+17	1.25E+16
3.5	9.02E+15	8.35E+15	6.88E+15	3.69E+15	1.44E+15	4.50E+14
5	4.35E+11	2.33E+11	2.33E+11	2.32E+11	2.30E+11	2.26E+11
7	3.77E+10	3.76E+10	3.76E+10	3.74E+10	3.70E+10	3.65E+10
9.5	5.88E+09	5.87E+09	5.86E+09	5.83E+09	5.78E+09	5.69E+09
Total	8.92E+19	6.99E+19	5.16E+19	3.26E+19	2.18E+19	1.41E+19

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Table 12.2-3—Full-Core Bounding Photon Spectra at 4612 MW_t
Sheet 3 of 3

Energy (MeV)	Photon Spectra (MeV/sec) as a Function of Shutdown Time (hrs)					
	5.0E+03 (0.57 yrs)	1.0E+04 (1.14 yrs)	2.0E+04 (2.28 yrs)	5.0E+04 (5.7 yrs)	1.0E+05 (11.4 yrs)	2.0E+05 (22.8 yrs)
0.01	1.49E+15	1.04E+15	7.36E+14	5.50E+14	4.53E+14	3.40E+14
0.025	2.68E+15	1.87E+15	1.36E+15	5.78E+14	1.47E+14	2.18E+13
0.0375	2.12E+16	1.41E+16	7.67E+15	3.41E+15	2.32E+15	1.48E+15
0.0575	1.15E+15	9.02E+14	7.14E+14	5.61E+14	5.11E+14	5.28E+14
0.085	9.96E+15	6.74E+15	3.55E+15	1.28E+15	5.69E+14	1.50E+14
0.125	6.99E+16	4.10E+16	1.92E+16	5.93E+15	3.24E+15	1.23E+15
0.225	5.31E+15	3.89E+15	3.19E+15	2.04E+15	1.12E+15	4.46E+14
0.375	2.21E+16	1.75E+16	1.25E+16	5.09E+15	1.35E+15	1.64E+14
0.575	2.80E+18	2.19E+18	1.53E+18	7.39E+17	4.37E+17	3.04E+17
0.85	3.66E+18	1.55E+18	9.00E+17	3.00E+17	6.11E+16	9.72E+15
1.25	3.52E+17	2.77E+17	1.88E+17	8.57E+16	4.01E+16	1.46E+16
1.75	3.21E+16	2.02E+16	9.85E+15	2.92E+15	1.53E+15	6.07E+14
2.25	7.32E+16	4.45E+16	1.67E+16	9.19E+14	9.48E+12	1.87E+11
2.75	1.42E+15	9.49E+14	4.32E+14	4.11E+13	1.00E+12	1.31E+11
3.5	2.67E+14	1.80E+14	8.25E+13	8.09E+12	3.83E+11	1.50E+11
5	2.17E+11	2.08E+11	1.97E+11	1.72E+11	1.39E+11	9.16E+10
7	3.51E+10	3.36E+10	3.17E+10	2.78E+10	2.25E+10	1.48E+10
9.5	5.47E+09	5.24E+09	4.95E+09	4.34E+09	3.51E+09	2.31E+09
Total	7.05E+18	4.17E+18	2.70E+18	1.15E+18	5.49E+17	3.34E+17

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Table 12.2-21—Post-LOCA Photon Spectra for Waterborne Sources Sheet 1 of 3

Energy (MeV)	Photon Spectra (MeV/sec-m^3) as a Function of Post-LOCA Time (hrs)					
	0	0.1	0.2	0.5	1	2
0.01	9.75E+11	8.02E+11	7.22E+11	6.20E+11	5.58E+11	5.16E+11
0.025	1.23E+13	8.28E+12	7.13E+12	6.13E+12	5.46E+12	4.78E+12
0.0375	6.91E+12	4.71E+12	3.99E+12	3.36E+12	2.96E+12	2.54E+12
0.0575	1.87E+12	1.84E+12	1.83E+12	1.82E+12	1.81E+12	1.80E+12
0.085	8.61E+12	7.84E+12	7.20E+12	5.83E+12	4.53E+12	3.40E+12
0.125	3.38E+13	3.14E+13	2.98E+13	2.54E+13	1.85E+13	1.03E+13
0.225	3.12E+14	1.97E+14	1.77E+14	1.50E+14	1.25E+14	1.00E+14
0.375	8.16E+14	5.73E+14	5.48E+14	4.92E+14	4.31E+14	3.68E+14
0.575	3.72E+15	3.62E+15	3.54E+15	3.27E+15	2.85E+15	2.29E+15
0.85	6.89E+15	5.81E+15	5.38E+15	4.55E+15	3.56E+15	2.34E+15
1.25	8.05E+15	6.64E+15	6.41E+15	5.46E+15	4.02E+15	2.46E+15
1.75	2.03E+15	1.87E+15	1.85E+15	1.79E+15	1.63E+15	1.29E+15
2.25	1.54E+15	1.23E+15	1.15E+15	9.10E+14	5.78E+14	2.51E+14
2.75	1.08E+15	7.77E+14	7.22E+14	5.62E+14	3.57E+14	1.58E+14
3.5	1.10E+15	4.49E+14	2.54E+14	1.43E+14	8.75E+13	4.16E+13
5	1.24E+15	3.06E+14	7.57E+13	1.57E+13	1.39E+13	1.08E+13
7	3.18E+03	3.18E+03	3.18E+03	3.18E+03	3.18E+03	3.18E+03
9.5	4.95E+02	4.95E+02	4.95E+02	4.96E+02	4.96E+02	4.96E+02
Total	2.68E+16	2.15E+16	2.02E+16	1.74E+16	1.37E+16	9.33E+15

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Table 12.2-21—Post-LOCA Photon Spectra for Waterborne Sources Sheet 2 of 3

Energy (MeV)	Photon Spectra (MeV/sec-m^3) as a Function of Post-LOCA Time (hrs)					
	5	10	20	24	50	100
0.01	4.72E+11	4.32E+11	3.85E+11	3.70E+11	2.94E+11	2.00E+11
0.025	4.21E+12	3.94E+12	3.62E+12	3.52E+12	2.95E+12	2.16E+12
0.0375	2.07E+12	1.85E+12	1.71E+12	1.68E+12	1.51E+12	1.26E+12
0.0575	1.76E+12	1.71E+12	1.60E+12	1.56E+12	1.33E+12	1.00E+12
0.085	2.75E+12	2.63E+12	2.49E+12	2.44E+12	2.17E+12	1.76E+12
0.125	5.21E+12	4.33E+12	3.75E+12	3.58E+12	2.68E+12	1.61E+12
0.225	7.71E+13	6.57E+13	5.53E+13	5.27E+13	4.24E+13	3.08E+13
0.375	3.15E+14	2.93E+14	2.71E+14	2.64E+14	2.36E+14	1.98E+14
0.575	1.64E+15	1.27E+15	9.82E+14	9.08E+14	6.22E+14	4.39E+14
0.85	1.11E+15	7.20E+14	5.53E+14	5.26E+14	4.39E+14	3.73E+14
1.25	1.33E+15	8.22E+14	4.05E+14	3.27E+14	1.60E+14	1.13E+14
1.75	7.26E+14	3.56E+14	1.36E+14	1.06E+14	7.40E+13	8.88E+13
2.25	8.26E+13	4.45E+13	1.87E+13	1.43E+13	5.85E+12	3.98E+12
2.75	4.28E+13	1.31E+13	3.26E+12	2.94E+12	4.03E+12	5.20E+12
3.5	1.32E+13	3.75E+12	3.45E+11	1.47E+11	4.16E+10	5.40E+10
5	5.03E+12	1.48E+12	1.29E+11	4.85E+10	8.49E+07	2.01E+04
7	3.18E+03	3.18E+03	3.18E+03	3.18E+03	3.17E+03	3.17E+03
9.5	4.96E+02	4.95E+02	4.95E+02	4.95E+02	4.95E+02	4.95E+02
Total	5.36E+15	3.61E+15	2.44E+15	2.21E+15	1.59E+15	1.26E+15

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Table 12.2-21—Post-LOCA Photon Spectra for Waterborne Sources Sheet 3 of 3

Energy (MeV)	Photon Spectra (MeV/sec-m^3) as a Function of Post-LOCA Time (hrs)				
	200	500	720	4320	8766
0.01	1.09E+11	4.17E+10	2.74E+10	7.44E+09	6.86E+09
0.025	1.26E+12	4.12E+11	2.44E+11	5.07E+10	4.02E+10
0.0375	9.61E+11	6.03E+11	5.02E+11	3.49E+11	3.31E+11
0.0575	6.18E+11	2.30E+11	1.34E+11	2.86E+08	1.22E+08
0.085	1.21E+12	4.49E+11	2.27E+11	1.97E+09	1.28E+09
0.125	6.80E+11	1.71E+11	1.17E+11	1.69E+10	9.64E+09
0.225	1.79E+13	5.35E+12	2.71E+12	5.09E+10	4.29E+10
0.375	1.40E+14	5.02E+13	2.41E+13	3.77E+11	3.27E+11
0.575	3.57E+14	3.05E+14	2.93E+14	2.53E+14	2.22E+14
0.85	3.17E+14	2.58E+14	2.42E+14	1.92E+14	1.62E+14
1.25	8.29E+13	4.95E+13	3.84E+13	1.88E+13	1.58E+13
1.75	8.49E+13	4.50E+13	2.75E+13	8.02E+10	1.88E+10
2.25	2.35E+12	7.99E+11	4.82E+11	3.24E+10	1.70E+10
2.75	5.02E+12	2.67E+12	1.62E+12	2.03E+09	1.09E+09
3.5	5.26E+10	2.83E+10	1.74E+10	3.00E+08	2.09E+08
5	1.96E+04	1.95E+04	1.94E+04	1.85E+04	1.77E+04
7	3.17E+03	3.15E+03	3.14E+03	2.98E+03	2.86E+03
9.5	4.94E+02	4.91E+02	4.89E+02	4.65E+02	4.45E+02
Total	1.01E+15	7.18E+14	6.31E+14	4.65E+14	4.01E+14

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Table 12.2-22—Photon Spectra for Residual Heat Removal System

Energy (MeV)	Photon Spectra (MeV/sec-m^3) as a Function of Post-Shutdown Time (hrs) – Coolant at 1 g/cc					
	3	6	9	12	15	18
0.01	1.87E+07	1.84E+07	1.80E+07	1.77E+07	1.74E+07	1.72E+07
0.025	8.37E+07	7.89E+07	7.57E+07	7.32E+07	7.11E+07	6.93E+07
0.0375	5.76E+08	5.78E+08	5.79E+08	5.77E+08	5.74E+08	5.70E+08
0.0575	2.78E+07	2.73E+07	2.68E+07	2.64E+07	2.60E+07	2.56E+07
0.085	1.13E+09	1.13E+09	1.13E+09	1.13E+09	1.12E+09	1.12E+09
0.125	3.29E+08	3.59E+08	3.81E+08	3.92E+08	3.97E+08	3.96E+08
0.225	2.82E+09	3.23E+09	3.35E+09	3.29E+09	3.12E+09	2.90E+09
0.375	9.38E+09	9.04E+09	8.80E+09	8.60E+09	8.43E+09	8.28E+09
0.575	3.91E+10	3.31E+10	2.95E+10	2.69E+10	2.48E+10	2.30E+10
0.85	2.05E+10	1.55E+10	1.34E+10	1.23E+10	1.16E+10	1.10E+10
1.25	2.91E+10	2.19E+10	1.72E+10	1.38E+10	1.13E+10	9.44E+09
1.75	9.61E+09	6.79E+09	4.92E+09	3.60E+09	2.64E+09	1.94E+09
2.25	1.85E+09	1.18E+09	8.19E+08	5.88E+08	4.32E+08	3.25E+08
2.75	3.34E+09	2.86E+09	2.48E+09	2.16E+09	1.88E+09	1.64E+09
3.5	1.73E+07	4.66E+06	3.09E+06	2.33E+06	1.85E+06	1.53E+06
5	2.12E+06	7.92E+05	3.93E+05	2.01E+05	1.08E+05	6.12E+04
7	9.65E-04	9.65E-04	9.65E-04	9.64E-04	9.64E-04	9.64E-04
9.5	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04
Total	1.18E+11	9.57E+10	8.26E+10	7.34E+10	6.63E+10	6.08E+10

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Table 12.2-23—Photon Release Rates for Aeroballs

Photon Energy Group (MeV)	Photon Release Rate (photon/m³-sec)								
	Discharge	1 Hour	2 Hours	4 Hours	8 Hours	1 Day	2 Days	1 Week	1 Month
0.01	5.56E+15	1.32E+15	1.25E+15	1.16E+15	1.07E+15	1.02E+15	9.90E+14	8.74E+14	4.91E+14
0.025	1.00E+15	6.07E+13	4.64E+13	2.71E+13	9.25E+12	1.25E+11	2.08E+08	1.47E+06	2.37E+02
0.0375	6.70E+14	4.07E+13	3.11E+13	1.82E+13	6.20E+12	8.40E+10	1.39E+08	9.21E+05	1.48E+02
0.0575	1.01E+15	6.06E+13	4.63E+13	2.71E+13	9.23E+12	1.25E+11	2.06E+08	1.22E+06	1.97E+02
0.085	6.43E+14	3.86E+13	2.95E+13	1.72E+13	5.87E+12	7.96E+10	1.30E+08	6.46E+05	1.04E+02
0.125	4.42E+14	2.64E+13	2.02E+13	1.18E+13	4.02E+12	5.45E+10	8.86E+07	3.62E+05	5.83E+01
0.225	6.57E+14	3.88E+13	2.97E+13	1.73E+13	5.91E+12	8.05E+10	4.07E+08	4.19E+07	6.80E+03
0.375	1.11E+15	7.96E+14	7.90E+14	7.82E+14	7.73E+14	7.57E+14	7.39E+14	6.52E+14	3.67E+14
0.575	2.41E+14	1.20E+13	9.15E+12	5.34E+12	1.82E+12	2.47E+10	3.91E+07	2.70E+03	4.34E-01
0.85	8.29E+15	6.21E+15	4.75E+15	2.77E+15	9.46E+14	1.28E+13	2.58E+10	8.28E+08	1.33E+05
1.25	8.47E+16	1.20E+13	8.16E+12	4.77E+12	1.64E+12	3.51E+10	8.99E+09	1.34E+09	2.16E+05
1.75	2.38E+15	1.77E+15	1.35E+15	7.90E+14	2.70E+14	3.66E+12	5.78E+09	5.66E-05	4.09E-13
2.25	1.11E+15	8.50E+14	6.50E+14	3.80E+14	1.30E+14	1.76E+12	2.78E+09	2.72E-05	0.00E+00
2.75	1.56E+14	1.19E+14	9.10E+13	5.32E+13	1.81E+13	2.46E+11	3.89E+08	3.81E-06	0.00E+00
3.5	1.34E+13	1.02E+13	7.80E+12	4.55E+12	1.55E+12	2.11E+10	3.33E+07	3.26E-07	0.00E+00
5	1.55E-03	8.21E-21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	7.98E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9.5	5.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total (photon/m³-sec)	1.08E+17	1.14E+16	9.11E+15	6.07E+15	3.26E+15	1.79E+15	1.73E+15	1.53E+15	8.58E+14
Total (MeV/m³-sec)	1.21E+17	1.10E+16	8.48E+15	5.08E+15	1.93E+15	3.16E+14	2.87E+14	2.53E+14	1.42E+14