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Our ref: DCP/NRC1565

April 4, 2003

SUBJECT: Transmittal of Westinghouse Responses to US NRC Requests for Additional Information on the AP1000 Application for Design Certification

This letter transmits the Westinghouse responses to NRC Requests for Additional Information (RAI) regarding our application for Design Certification of the AP1000 Standard Plant. A list of the RAI responses that are transmitted with this letter is provided in Attachment 1. Attachment 2 provides the RAI responses.

Please contact me if you have questions regarding this submittal.

Very truly yours,

M. M. Corletti
Passive Plant Projects & Development
AP600 & AP1000 Projects

/Attachments

1. Table 1, "List of Westinghouse's Responses to RAIs Transmitted in DCP/NRC1565"
2. Westinghouse Non-Proprietary Response to US Nuclear Regulatory Commission Requests for Additional Information dated April 2003

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			Attachment
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	M. M. Corletti	- Westinghouse, Pittsburgh, PA	2
	Doc Control	- US NRC, Rockville, MD	Original
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Attachment 1

"List of Westinghouse's Responses to RAIs Transmitted in DCP/NRC1565"

Attachment 1

Table 1 **"List of Westinghouse's Responses to RAIs Transmitted in DCP/NRC1565"**
251.002, Rev. 0 260.004, Rev. 0 260.005, Rev. 0 471.011, Rev. 0 720.039, Rev. 2 720.056, Rev. 1 720.070, Rev. 1

Attachment 2

Westinghouse Non-Proprietary Response to US Nuclear Regulatory Commission
Requests for Additional Information dated March 2003

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

RAI Number: 251.002

Original Question:

Address questions 2.a to 2.f if the modifications mentioned in question 251.001 affect the subject of each of these six questions. (DCD Section 3.5.1.3)

a. Provide the probability distributions for both undetected and reported indications for the probabilistic burst and missile analysis and the bases for the selection. How are they used in the Monte-Carlo simulations?

b. Explain how stress corrosion crack growth and fatigue crack growth were considered in your turbine missile analysis. Assess the impact of crack growth due to low cycle fatigue (associated with turbine unit startups and shutdowns) on your missile probability analysis. Also, please demonstrate that the vibratory stresses of the turbine disks due to various excitations are negligible.

c. Was the stress corrosion crack growth rate independent of the level of stress intensity factor? Plot data from tests and operating plants to support your conclusion. If any variables related to stress corrosion crack initiation were included in your current turbine missile probability analysis, please provide detailed information regarding the use of the stress corrosion crack initiation parameters in your analysis.

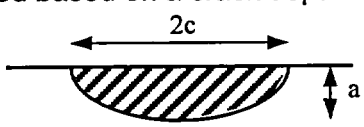
d. Provide all random variables, their distributions, and suggested number of standard deviations that were used in your Monte-Carlo simulations. Explain the need for distributions other than the normal distribution for any of the variables, and justify the use of the suggested number of standard deviations for all variables. Comment on the convergence of the calculated P_1 value for your Monte-Carlo simulation involving this many random variables. Further, how do were the mean values for these variables determined, especially for the mass of bladed disk fragments and fragments from other rotating parts? How do they correlate with industry experience on turbine missile events? Are values for these variables dependent upon the specific design or model of a turbine? Please use a typical turbine model to be used in the AP1000 application as an example and illustrate how these values were established. How were the degree of blade crushing, blade bending, and deformation of stationary blades considered in your calculation of the probability of casing penetration?

e. Assess the contributions due to these modifications to the turbine missile probability reported in the submittal.

Westinghouse Response:

a. In WCAP15783, the missile generation probability was not analyzed utilizing Monte Carlo simulation nor did it use the distributions for undetected and reported indications. The size of the initial crack depth, a_{i_max}, is assumed to be the maximum one which can not be detected by inspection.

Since the inspection procedures used for fully integral rotor forgings will reliably detect a flaw length more than 1.50 mm [0.0591in], a maximum crack depth of 0.375mm [0.0148in] was assumed based on a crack depth to length ratio of 1:4 .



a_{i_max}:	0.375 mm	[0.0148in]
$c_{_max}$:	1.50/2 mm	[0.0591/2in]

b. Stress corrosion crack growth and fatigue crack growth are included in the turbine missile analysis as explained in WCAP 15783. Note that cracks due to stress corrosion cracking (SCC) begin from the rim of the disk and cracks due to low cycle fatigue (LCF) begin at the surface of the center bore under the disk of the last blades. Because the shrunk-on disk bore has been eliminated, the rotor center bore surface will never get in contact with steam in the AP1000 LP turbine rotor structure. Crack initiation by SCC and LCF begin at different positions, so the interaction between SCC and LCF is not considered in our turbine missile analysis.

c. Yes, the stress corrosion crack growth rate is independent of the level of stress intensity factor. Figure 251.002-1 shows the crack growth rate test results using pre-cracked specimens in actual PWR steam conditions. The crack propagation data shows a plateau with some scatter but the upper limit of crack propagation is almost constant and independent of the level of stress intensity factor. The probability of reaching a critical crack size was analyzed by the modified Clark equation accompanied by uncertainty term, ε. The crack growth rate, γ, model used is as follows:

$$\ln\gamma = a + \frac{b}{T} + c \cdot \sigma_{ys} + \varepsilon$$

The stress corrosion crack initiation is conservatively assumed to exist when the rotor is installed.

d. Monte Carlo simulation is not used in calculating missile generation probability.

e. Monte Carlo simulation is not used in calculating missile generation probability.

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

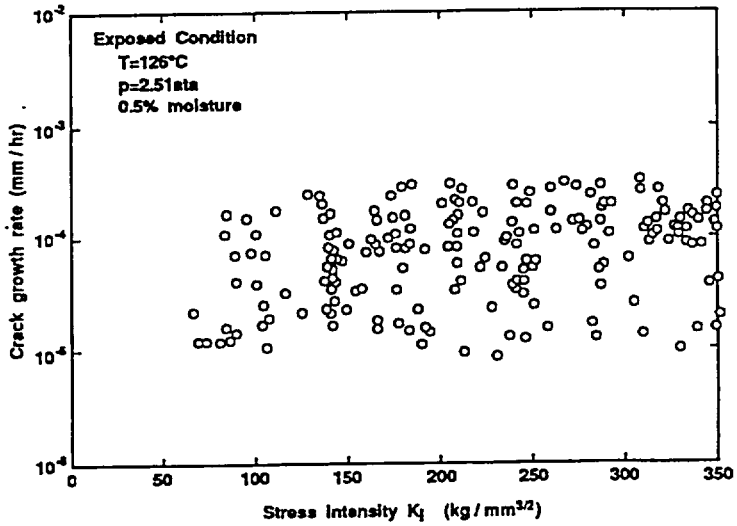
Design Control Document (DCD) Revision:

None

PRA Revision:

None

Figure 251.002-1: Crack Growth Rates of Specimens



PWR-Vol.21 ASME 1993; T. Endo, H. Itoh, Y. Kondo, "MATERIAL ASPECT FOR THE PREVENTION OF ENVIRONMENTALLY-ASSISTED CRACKING IN LOW PRESSURE STEAM TURBINE" Fig.14

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

Additional NRC Question:

(a) Substantiate the statement that the inspection procedures, equipment, and personnel will allow the owner to reliably detect a flaw with a length of 1.5 mm and a depth of 0.375 mm.

(b) The applicant has answered this question partially. The crack growth rate that was approved in 1987 was based on a database of 60 keyway cracks and 9 bore cracks. What is the basis for the new corrosion crack growth rate in WCAP-15783? Does the mean and the standard deviation of the error term, ε, which appears in the crack growth equation, reflects the statistical characteristics of the new database?

Westinghouse Response: (Revision 1)

(a) The stated detection is for flaws with a length of 1.5 mm, with a depth "assumed based on a crack depth to length ratio of 1:4."

In response to this issue, the turbine supplier has advised that trained personnel perform ultrasonic testing (UT) inspection on the rotor after tempering and finish center bore machining (if present). The testing is performed on the outer surface and center bore (if present). The testing device is calibrated by test specimens of the same material with a 1.6 mm diameter hole, so as to be able to clearly distinguish imperfections from reflected echo. In addition, magnetic particle examination (MT inspection) is performed on the rotor outer surface and on the surface of center bore (if present). No magnetic particle flaw indications are permissible in bores (if present) or in highly stressed regions. Thus, Westinghouse is confident that the turbine manufacturer can reliably detect flaws with a length of 1.5 mm or more as previously stated.

(b) The corrosion crack growth rate in WCAP-15783 was established based on measured crack growth rates of test specimens installed in the extraction steam of an actual nuclear steam turbine. Comparisons were made between the calculated crack growth rate (using the Clark equation) and actual measured crack growth rate (in steam turbine test specimens). Using these calculated and measured data, the uncertainty term ε was derived. The mean and the standard deviation of the uncertainty term, ε, which appears in the crack growth equation does reflect the statistical characteristics of the new database.

Additional Design Control Document (DCD) Revision: (Revision 1)

None

Additional PRA Revision: (Revision 1)

None

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

RAI Number: 260.004

Question:

In the AP1000 Design Control Document (DCD) Section 17.4.1, Revision 0, Westinghouse stated that the design reliability assurance program (D-RAP), as shown in Figure 17.4-1, is implemented in three phases. The first phase, the Design Certification phase, defines the overall structure of the AP1000 D-RAP, and implements those aspects of the program which are applicable to the design process. During this phase, risk-significant systems, structures, and components (SSCs) are identified for inclusion in the program using probabilistic, deterministic, and other methods. Phase II, the post-design certification process, develops component maintenance recommendations for the plant's operations and maintenance activities for identified SSCs. The third phase is the site-specific phase, which introduces the plant's site-specific SSCs to the D-RAP process. Phases I and II are performed by the designer. Phase III is the responsibility of the Combined License applicant.

The NRC determined that it is not acceptable for Westinghouse to complete Phase II following issuance of a design certification for the AP1000 design. Current NRC staff policy does not allow the design certification applicant to carry open items to the post design certification phase. In accordance with the acceptance criteria for Standard Review Plan Section 17.4, RAP, Westinghouse should not have post design certification issues in the DCD for the AP1000 design. Westinghouse may complete this activity prior to issuance of a design certification or the COL applicant may complete this activity. Clarification of this Phase II activity is necessary.

Westinghouse Response:

DCD Chapter 17 will be revised to assign responsibility for developing the maintenance assessment and recommendations for the risk-significant plant components in Phase II of the D-RAP to the COL applicant.

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

Design Control Document (DCD) Revision:

DCD 17.4.1, Paragraph 2

The D-RAP, as shown in Figure 17.4-1, is implemented in three phases. The first phase, the Design Certification phase, defines the overall structure of the AP1000 D-RAP, and implements those aspects of the program which are applicable to the design process. During this phase, risk-significant SSCs are identified for inclusion in the program using probabilistic, deterministic, and other methods. Phase II, the post-design certification process, develops component maintenance recommendations for the plant's operations and maintenance activities for the identified SSCs. The third phase is the site-specific phase, which introduces the plant's site-specific SSCs to the D-RAP process. Phases I **is**~~and II are~~ performed by the designer. Phases **II and** III **are**~~is~~ the responsibility of the Combined License applicant.

DCD 17 4.6, Paragraph 2

Development of maintenance assessments and recommendations for the D-RAP (Phase II) and ~~T~~the site-specific portion of the D-RAP (Phase III) **are**~~is~~ the responsibility of the Combined License applicant.

The Combined License applicant is responsible for submitting its **maintenance recommendations (Phase II) and** site-specific (Phase III) D-RAP organization description to the NRC.

DCD 17.4.7.2.1, First Sentence

To support the Combined License applicant's D-RAP Phase **II and** III and O-RAP, the following information is provided:

DCD 17.4.7.4, First Paragraph (last sentence modified by RAI 260.005)

The following is an example of a system that was reviewed and modified under the D-RAP, Phases I~~ and II~~. The design and analytical results presented here are intended as an example ~~and do not reflect the current AP1000 design~~.

PRA Revision:

None

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

RAI Number: 260.005

Question:

a. In DCD Section 17.4.7.2.1, Information Available to Combined License Applicant, Revision 0, Westinghouse states:

To support the Combined License applicant's D-RAP Phase III and O-RAP, the following information is provided:

1. The list of risk-significant SSCs identified during the design phase
2. The PRA [Probabilistic Risk Assessment] assumptions for component unavailability and failure data
3. The analyses performed for components identified as major contributors to total risk, with the dominant failure modes identified and prioritized. The suggested means for prevention and mitigation of these failure modes forms the basis for the plant surveillance, testing, and maintenance programs.

The NRC staff cannot find some of this information in Table 17.4-1. The staff is requesting that Westinghouse add appropriate cross-references to DCD Section 17.4.7.2.1 for items 2 and 3 noted above. In addition, the staff is requesting that Westinghouse add the appropriate cross-references in the AP1000 DCD or PRA to DCD Section 17.4.7.2.1 on component unavailability and failure data and the dominant failure modes for SSCs included in the D-RAP.

b. In DCD Section 17.4.7.4, Westinghouse provided an example of D-RAP implementation with the automatic depressurization system (ADS) for a selection of components that are in the D-RAP for the AP1000 design. In DCD Section 17.4.7.4, Westinghouse states that "the design and analytical results presented here are intended as an example and do not reflect the current AP1000 design." The NRC staff determined that this wording is confusing.

Westinghouse Response:

a. DCD Section 17.4.7.2.1 will be revised as shown below to provide cross-references to DCD Table 17.4-1 for Item 1 and to the appropriate sections of the AP1000 PRA for Items 2 and 3.

In the response to RAI 720.038, Section 59.10 was added to the AP1000 PRA to describe the process for providing PRA-based in-sights to the D-RAP. Table 59-18 of the AP1000 PRA provides specific cross references to DCD 17.4 for risk-significant SSCs. Item 44 of Table 59-18 specifically confirms that a list of risk-significant SSCs are included in the D-RAP.

b The last sentence of the first paragraph in DCD Section 17.4.7.4 will be revised as shown below to eliminate the confusing wording.

Design Control Document (DCD) Revision:

DCD Section 17.4.7.2.1

To support the Combined License applicant's D-RAP Phase III and O-RAP, the following information is provided:

- The list of risk-significant SSCs identified during the design phase **(Table 17.4-1)**
- The PRA assumptions for component unavailability and failure data **(Chapter 32 of the AP1000 PRA)**
- The analyses performed for components identified as major contributors to total risk, with the dominant failure modes identified and prioritized. **(Chapter 50 of the AP1000 PRA identifies major contributors to total risk and Chapters 8 to 28 of the AP1000 PRA describes the analyses of the respective systems and associated components in Table 17.4-1.)** The suggested means for prevention or mitigation of these failure modes forms the basis for the plant surveillance, testing, and maintenance programs.

DCD Section 17.4.7.4, First Paragraph (first sentence modified by RAI 260.004)

The following is an example of a system that was reviewed and modified under the D-RAP, Phases I ~~and II~~. The design and analytical results presented here are intended as an example ~~and do not reflect the current AP1000 design~~.

PRA Revision:

None

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

RAI Number: 471.011

Question:

Regulatory Guide (RG) 8.12 (regarding criticality monitors) has been withdrawn. References to this RG were deleted in Section 1.9.1.4 of the DCD but not in Section 11.5.6. Section 11.5.6 also references 10 CFR 70.24. Since issuance of the AP600 SE, there has been new guidance on criticality monitors (namely 10 CFR 50.68).

Please provide the applicable guidance that the AP1000 design is using for criticality monitors (i.e. are you still complying with 70.24 or 50.68?).

Westinghouse Response:

The references to RG 8.12 will be deleted as shown in the attached DCD pages.

The AP1000 is designed for compliance with 10 CFR 70.24. Meeting 10 CFR 70.24 is cited in 10 CFR 50.68 paragraph (a) as an acceptable method for compliance with 10 CFR 50.68.

Design Control Document (DCD) Revision:

Delete references to Regulatory Guide 8.12 from Section 11.5 as shown on the attached pages.

PRA Revision:

None

11.5.4 Process and Airborne Monitoring and Sampling

Radiation monitors are used to initiate automatic closure of isolation valves and dampers in liquid and gaseous process systems as described in subsection 11.5.2.3. These radiation monitors address the requirement of General Design Criterion 60 to suitably control the release of radioactive materials in gaseous and liquid effluents.

Radiation monitors are used in the radioactive waste processing systems as described in subsection 11.5.2.3. These radiation monitors address the requirement of General Design Criterion 63 to monitor radiation levels in radioactive waste systems.

Radiation monitors are used in the ventilation systems as described in subsection 11.5.2.3 to ensure that airborne concentrations within the plant are within the limits of 10 CFR 20.

11.5.5 Post-Accident Radiation Monitoring

The radiation monitors listed below meet the guidelines of Regulatory Guide 1.97 and are described in subsections 11.5.2.3 and 11.5.6.2. For further Regulatory Guide 1.97 information refer to Appendix 7A and Section 7.5.

- Main steam line radiation monitors
- Steam generator blowdown radiation monitor
- Main control room supply air duct radiation monitors
- Plant vent radiation monitor
- Turbine island vent discharge radiation monitor
- Containment high range radiation monitors
- Primary sampling room area monitor
- Technical support center area monitor

The post-accident sampling system is described in subsection 9.3.3 and is used to obtain samples for onsite laboratory analysis, including radioisotopic analysis, after a postulated accident.

11.5.6 Area Radiation Monitors

The area radiation monitors are provided to supplement the personnel and area radiation survey provisions of the AP1000 health physics program described in Section 12.5 and to comply with the personnel radiation protection guidelines of 10 CFR 20, 10 CFR 50, 10 CFR 70, and Regulatory Guides 1.97, 8.2, ~~8.8, and 8.12.~~and 8.8.

During refueling operations in containment and the fuel handling area, criticality monitoring functions, as stated in 10 CFR 70.24~~ and Regulatory Guide 8.12~~, are performed by the area radiation monitors in combination with portable bridge monitors.

11.5.6.1 Design Objectives

The design objectives of the area radiation monitors during normal operating plant conditions and anticipated operational occurrences are to:

- Measure the radiation intensities in specific areas of AP1000
- Warn of uncontrolled or inadvertent movement of radioactive material in AP1000
- Provide local and remote indication of ambient gamma radiation and local and remote alarms at key points where substantial changes in radiation flux might be of immediate importance to personnel
- Annunciate and warn of possible equipment malfunctions and leaks in specific areas of AP1000
- Furnish information for radiation surveys
- Minimize the time, effort, and radiation received by operating personnel during routine maintenance and calibration
- Incorporate modular design concepts throughout, to provide easy maintenance

By meeting the above objectives, the radiation monitoring system aids health physics personnel in keeping radiation exposures as-low-as-reasonably-achievable (ALARA).

Locations of area monitor detectors are based on the following criteria:

- Area monitors are located in areas that are normally accessible and where changes in normal plant operating conditions can cause significant increases in exposure rates above those expected for the areas.
- Area monitors are located in areas that are normally or occasionally accessible where significant increases in exposure rates might occur because of operational transients or maintenance activities.
- Area monitors are located to best measure the increase in exposure rates within a specific area and to avoid shielding of the detector by equipment or structural materials.
- In the selection of area monitors, consideration is given to the environmental conditions under which the monitor operates.

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

RAI Number: 720.039 (Response Revision 2)

Question:

An important objective of the AP600 PRA was to provide input to the design certification process regarding the need for regulatory oversight of certain non-safety-related systems. The process used to identify SSCs for regulatory oversight as well as the type and level of such oversight was called Regulatory Treatment of Non-Safety-Related Systems (RTNSS) in the AP600 certification. The end results of this process were the "availability controls" documented in Section 16.3 of the DCD. Please provide similar information for AP1000 This information should account for uncertainties in the AP1000 PRA so that it can be used by the staff to make similar conclusions, about the need for non-safety-system oversight, as were made for the AP600 design (e.g., as documented in the AP600 FSER Chapter 19.1.7 "PRA input to the RTNSS Process.)"

Additional Question:

The staff requested Westinghouse to provide all important steps in the process of using PRA results to identify systems, structures and components (SSCs) for regulatory oversight as well as the type and level of such oversight for non-safety-related systems. This information should account for uncertainties in the AP1000 PRA so that it can be used by the staff to make similar conclusions, about the need for non-safety-system oversight, to those made for the AP600 design (e.g., as documented in the AP600 FSER Chapter 19.1.7 "PRA input to the RTNSS Process.)" Westinghouse did not provide this information with its response.

The following are additional comments on WCAP-15985 "AP1000 Implementation of the Regulatory Treatment of Nonsafety-Related Systems Process".

1. Table 1.1 (P.1.6):

   The table lists non-safety systems evaluated in AP1000 RTNSS process in alphabetical order. It ends at steam generator. Are there other non-safety systems after steam generator evaluated with the RTNSS process?

2. Table 2-1 (p. 2-4):

   Table 2-1 lists only 5 non-safety systems and functions failed in PRA sensitivity studies, i.e., CVS, RNS, ECS, DAS and hydrogen ignitors. Does that mean other non-safety systems (such as the plant control system, component cooling water system, etc.) not on this list are assumed to be operational in the PRA sensitivity studies? If so, are they RTNSS important? Would they be subject to Technical Specifications or short-term

availability administrative control? If front-line systems are deemed important, then their supporting systems are also deemed RTNSS-important.

3. Section 2 states that the PRA sensitivity studies are based on the AP1000 baseline PRA, and that they include an evaluation of internal events that occur at-power. Are external events and low power/ shut-down internal events included in the sensitivity studies?

4. Section 2.2 states that the PRA CDF and LRF - with assumed failure of the nonsafety-related mitigation functions of the nonsafety-related SSCs - are reported in Chapter 50 of the AP1000 PRA report. However, Chapter 50 provides the importance and sensitivity analysis on CDF only. Clarify where in Chapter 50 describes the sensitivity studies for LRF?

5. Table 2-2 lists AP600/AP1000 PRA results for "baseline" and "without non-nuclear safety SSCs." The AP1000 shutdown, internal event, baseline PRA CDFs are listed as 1.2E-7 and 1.2E-8 in columns 2 and 3 for the shutdown internal events without and with manual DAS controls, respectively. Explain why the CDF for shutdown internal events without manual DAS controls is 10 times higher with manual DAS controls, whereas the LRF are the same for both cases.

6. Several places in Section 3, quote section 59 of the PRA as the source of various initiating event contributions to the LRF, e.g., Sections 3.2 and 3.4 states both the RCS leak initiating and main steamline break event contributes only 1.5% to the LRF, Section 3.5 lists LRF for various events, etc. Clarify where in Chapter 59 these LRFs for various events are provided.

7. Section 6 describes Post-72 hour Actions. Is the design of onsite equipment needed for post-72-hour support actions consistent with GDC 2 requirement for protection against natural phenomena? Where is this documented?

8. Section 10.2.2 describes the missions of various nonsafety-related plant systems, including the RNS for providing shutdown decay heat removal during RCS open shutdown conditions. Where is the RNS injection function to provide injecting cask loading pit water into the RCS following ADS actuation described?

9. Table 10-2, Investment Protection Short-term Availability Controls:

A. 2.5 PCCWST and Spent Fuel Pool Makeup - Long-term Shutdown (P. 10-35):

The "Operability" for Item 2.5 states that Long-term makeup to the PCCWST should be operable. Since the PCS recirculation pumps provide the capability to transfer water from the PCS ancillary water storage tank to the PCS water storage tank and spent fuel pool for post-72 hour support actions, why does the "Operability" requires only the

makeup to the PCCWST, but not SFP, to be operable? Clarify the basis for the PCS ancillary tank water volume of 725,000 gal in SR 2.5.1 (whether it is for 7 days or 3 days supply).

B. BASES for 3.3 AC power supplies - long-term shutdown (P. 10-56):

Clarify the basis for the ancillary fuel tank fuel volume of 600 gal in SR 3.3.1 (3 or 7 days supply?).

Westinghouse Response to Additional Question: < The following response is to the additional question; the original response is shown afterwards. **The main change for Revision 2 is the addition of a markup section 2.3 in the WCAP that was omitted from the Revision 1 response.** >

WCAP-15985 "AP1000 Implementation of the Regulatory Treatment of Nonsafety-Related Systems Process" provides a discussion of the PRA uncertainties in section 2.3. This discussion is the same as that provided for AP600. It addresses each identified PRA uncertainty and discusses nonsafety features that are able to compensate for them. The issues addressed include T&H uncertainty, equipment failure rates (IRWST check valves, squib valves, reactor coolant pump breakers), and importance of nonsafety equipment to PRA initiating event frequencies.

It is proposed that additional discussion be added to this section for each of these uncertainties and that the large LOCA initiating event frequency be added as another uncertainty. A revised version of this section is attached to this RAI response.

1. WCAP-15985, Table 1-1, is missing 7 systems. The following systems were inadvertently omitted and will be added to the end of this table:

   Storm Drainage
   Transmission Switchyard and Offsite Power
   Turbine Building Closed Cooling Water
   Turbine Building Ventilation
   Turbine Island Chemical Feed
   Turbine Island Vents, Drains and Relief
   Waste Water

2. Failing the front line nonsafety systems is a simple way of removing the mitigation capabilities of all the nonsafety systems from the AP1000 PRA. Once the front line systems have been removed the support systems have no capability of mitigating accidents. The Startup Feedwater System (SFWS) was also failed in this study. It was

inadvertently omitted from Table 2-1; it will be added to this table in revision 1 of the WCAP.

Note that when a front line systems is captured as RTNSS important, then any support systems that are required to allow the front line systems to meet its RTNSS important mission are also considered RTNSS important.

3. The PRA sensitivity studies performed without nonsafety mitigating systems were not performed for external events because their contribution to CDF and LRF are small.

The AP1000 PRA, revision 1, shows the following at power, core damage frequencies:

Internal Events	2.4E-7/yr
Internal Floods	8.8E-10/yr
Internal Fire	5.6E-8/yr

From this information, it is concluded that it is not necessary for RTNSS to consider internal floods or fires.

The AP1000 RTNSS evaluation did consider shutdown, internal events as shown in Table 2-1.

A sentence will be added to section 2.0, second paragraph. The sentence will say, "Internal fire and flood events are not included in this evaluation because the AP1000 PRA quantification has shown them to have a much lower risk".

4. Chapter 50 of the PRA, revision 1, only includes CDF without nonsafety systems. Westinghouse has performed a sensitivity to determine the LRF with failure of the front line nonsafety features. This study will be added to the PRA chapter 50 in the next PRA revision.

5. As agreed with the staff, we will refer to the PRA sensitivity studies with credit removed for standby nonsafety systems as a focused PRA. The baseline PRA CDF and LRF for should not change between columns 2 and 3 since the only difference is due to what nonsafety features are included in the Focused PRA. The CDF in column 2 is correct. The CDF in column 3 will be changed to 1.2E-7. The total CDF for column 3 is affected; it will change from 2.5E-7 to 3.6E-7.

6. The importance of initiating events to LRF was presented in the response to 720.057. This table will be added to the next revision of the PRA in Chapter 59.

7. The approach used for AP1000 is the same as was used for AP600, which is consistent with SECY-95-132. WCAP-15985, section 10.3.2, says that the long-term shutdown equipment should be available following seismic and high winds. This section also

references DCD Table 3.2-3 and says that the supports for this equipment are Seismic II. DCD sections 1.9.5.3.1 (RTNSS) and 1.9.5.4 (Post-72 Hour Support Actions) provide additional information.

8. In section 10.2.2, the following will be added:

"RNS (RCS intact)

The RNS provides low pressure injection during accidents with ADS actuation."

9.A The OPERABILITY statement under availability control 2.5 will be changed as follows in both the WCAP and the DCD:

"Long-term makeup to the PCCWST and the Spent Fuel Pool should be operable."

The BASES for the capacity of the PCS ancillary tank will be clarified as follows in both the WCAP and the DCD:

"The PCS recirculation pumps provide long-term shutdown support by transferring water from the PCS ancillary tank to the PCCWST and the spent fuel pool. The specified PCS ancillary water tank volume is sufficient ~~This water is used~~ to maintain PCS and spent fuel pool cooling during the 3- to 7-day time period following an accident. After 7 days, water brought in from offsite allows the PCCWST to continue to provide PCS cooling and makeup to the spent fuel pit. This PCCWST makeup function is important because it supports long-term shutdown operation. A minimum availability of 90 percent is assumed for this function during the MODES of applicability, considering both maintenance unavailability and failures to operate."

9.B The BASES for the availability control 3.3 will be changed as follows in both the WCAP and in the DCD,

"The long-term AC power supply function involves the use of two ancillary diesel generators and an ancillary diesel generator fuel oil storage tank. The specified ancillary fuel oil storage tank volume is based on operation of both ancillary diesel-generators for four days. DCD subsection 8.3.1 contains additional information on the long-term AC power supply function."

Design Control Document (DCD) Revision:

The changes shown above in response 9A/B will be incorporated into DCD Table 16.3-2 in availability controls 2.5 and 3.3.

PRA Revision:

Add Table 50-26:

Table 50-26
CONTRIBUTION OF INIATING EVENTS TO LARGE RELEASE

	Initiating Event Category	% Contribution to LRF	LRF Contribution	Initiating Event Frequency
1	IEV-ATWS	17.11%	3.27E-09	4.81E-01
2	IEV-SGTR	15.87%	3.04E-09	3.88E-03
3	IEV-SPADS	13.14%	2.51E-09	5.40E-05
4	IEV-SI-LB	9.82%	1.88E-09	2.12E-04
5	IEV-TRANS	7.49%	1.43E-09	1.40E+00
6	IEV-SLOCA	5.94%	1.14E-09	5.00E-04
7	IEV-RV-RP	5.37%	1.03E-09	1.00E-08
8	IEV-MLOCA	4.71%	9.02E-10	4.36E-04
9	IEV-ATW-T	3.72%	7.12E-10	1.17E+00
10	IEV-LCOND	2.73%	5.22E-10	1.12E-01
11	IEV-LOSP	2.46%	4.70E-10	1.20E-01
12	IEV-LMFW	1.98%	3.80E-10	3.35E-01
13	IEV-LLOCA	1.65%	3.16E-10	5.00E-06
14	IEV-RCSLK	1.53%	2.93E-10	6.20E-03
15	IEV-SLB-V	1.22%	2.33E-10	2.39E-03
16	IEV-LMFW1	1.11%	2.12E-10	1.92E-01
17	IEV-CMTLB	1.03%	1.98E-10	9.31E-05
18	IEV-LCCW	0.72%	1.37E-10	1.44E-01
19	IEV-ATW-S	0.53%	1.01E-10	1.48E-02
20	IEV-LCAS	0.52%	1.00E-10	3.48E-02
21	IEV-POWEX	0.50%	9.49E-11	4.50E-03
22	IEV-PRSTR	0.45%	8.64E-11	1.34E-04
23	IEV-SLB-U	0.26%	4.97E-11	3.72E-04
24	IEV-LRCS	0.08%	1.58E-11	1.80E-02
25	IEV-SLB-D	0.05%	9.07E-12	5.96E-04
26	IEV-ISLOC	0.00%	4.74E-13	5.00E-11
	Totals	100.00%	1.91E-08	2.38E+00

PRA, Chapter 50.5.5:

Results

The calculations are performed on a personal computer using the SEN code for sensitivity analysis. The input file is taken from the AP1000 PRA CDF analysis. This file is CMTOT.OUT. The results of the sensitivity analysis are given in Tables 50-20 and 50-21.

Table 50-20 shows the contribution of the initiating events when no credit is taken for the above standby systems.

The output file contains 7269 cutsets. The top 50 of these cutsets are shown in Table 50-23.

This sensitivity analysis estimates that the CDF increases from 2.41E-07/year to 7.41E-06/year when no credit is taken for the standby systems CVS, SFS, RNS, DAS, and DGs.

A similar sensitivity study was performed to estimate the LF increase when no credit is taken for nonsafety standby systems. This study removed the hydrogen ignitors in addition to the CVS, SFS, RNS, DAS, and DGs. In this case, the LRF increases from 1.9E-8/year to 5.2E-6/year.

These results are limited by the way the sensitivity analysis is performed. Namely, if a CDF cutset does not appear in the CMTOT.OUT file due to cutoff probability, then it is resurrected in the present analysis.

Revision to WCAP-15985 "AP1000 Implementation of the Regulatory Treatment of Nonsafety-Related Systems Process":

WCAP-15985, Table 1-1:

Table 1-1 (cont.)	**Nonsafety-Related Systems Evaluated in AP1000 RTNSS Process**
	Radiation Monitoring
	Radioactive Waste Drain
	Radiologically Controlled Area Ventilation
	Radwaste Building HVAC
	Raw Water
	Sanitary Drainage
	Secondary Sampling
	Security Lighting
	Seismic Monitoring
	Service Water
	Solid Radwaste
	Special Monitoring
	Special Process Heat Tracing
	Spent Fuel Pit Cooling
	Standby Diesel and Auxiliary Boiler Fuel Oil
	Stator Cooling
	Steam Generator
	Storm Drainage
	Transmission Switchyard and Offsite Power
	Turbine Building Closed Cooling Water
	Turbine Building Ventilation
	Turbine Island Chemical Feed
	Turbine Island Vents, Drains and Relief
	Waste Water

WCAP-15985, Section 2.0:

2 PROBABILISTIC RISK ASSESSMENT EVENT MITIGATION EVALUATION

PRA sensitivity studies were performed to quantify the importance of nonsafety-related systems in mitigating PRA events. These sensitivity studies, **refered to as the focused PRA sensitivity study,** calculate the CDF and LRF without reliance on nonsafety-related SSC mitigation. Nonsafety-related SSCs are considered not important for PRA mitigation if the resulting CDF is less than the NRC safety goal of 1×10^{-4} events per year and the resulting LRF is less than 1×10^{-6} per year. If nonsafety-related SSC mitigation functions are relied upon in these **focused** PRA sensitivity study~~ies~~ to meet the safety goals, they will be assigned reliability/unavailability missions as appropriate and will be subject to additional regulatory oversight.

The **focused** PRA sensitivity study~~ies~~ ~~are~~**is** based on the AP1000 baseline PRA. They include an evaluation of internal events that occur at-power. **Internal fire and flood events are not included in this evaluation because the AP1000 PRA quantification has shown them to have a much lower risk.** Seismic margins are used to evaluate seismic events (section 9).

For these **focused** PRA sensitivity study~~ies~~, the initiating event frequencies remain the same as in the baseline PRA. The mitigation functions of the nonsafety-related systems are failed, and then the CDF and LRF are calculated. If the CDF and LRF calculated in this **focused** PRA sensitivity study are acceptable and no mitigation credit is taken for nonsafety-related SSCs, then no additional regulatory oversight is necessary for the nonsafety-related SSCs.

Table 2-1 lists the AP1000 nonsafety-related systems modeled in the baseline PRA and assumed to fail to provide mitigation. Table 2-1 also contains a list of the safety-related systems modeled in the PRA.

2.1 EVALUATION

The **focused** PRA sensitivity study is performed using the same methodology as the baseline PRA. In the quantification of the CDF and LRF, the failure probability of each nonsafety SSC is set to 1. The **focused PRA** sensitivity study for CDF and LRF **is**~~are~~ described in Chapter 50 of the AP1000 PRA report. In addition, the improvement to these results, due to crediting manual Diverse Actuation System (DAS) controls, was estimated by evaluating the cutsets associated with these results.

2.2 RESULTS

The PRA CDF and LRF with assumed failure of the nonsafety-related mitigation functions of the nonsafety-related SSCs are reported in Chapter 50 of the AP1000 PRA report. Summary results from the sensitivity studies and a comparison with the AP1000 and AP600 baseline CDF and LRF are also found in Table 2-2.

Table 2-2 shows that use of these **focused PRA** sensitivity study~~ies~~ results in higher CDF/LRF than obtained in the AP600 focused PRA. This result is caused by not having all events lose offsite ac power upon reactor trip. As a result, the Protection and Safety Monitoring System (PMS) is required to actuate passive safety features, such as the rods, PRHR heat exchanger (PRHR HX), and containment isolation. These **AP1000 focused PRA** sensitivity study~~ies~~ indicates that the LRF will be above the safety goal. By crediting the manual DAS controls, the LRF as well as the CDF are reduced so that the PRA safety goals are met.

As a result, the following DAS manual controls need to be credited for PRA mitigation:

- Reactor trip
- PRHR HX and in-containment refueling water storage tank (IRWST) gutter valves
- Core makeup tank (CMT) isolation valves
- Automatic Depressurization System (ADS) stages 1, 2, 3, and 4
- IRWST injection isolation valves
- Containment recirculation isolation valves
- PCS water drain valves
- Containment isolation valves

Since the DAS manual controls are credited to meet the LRF safety goal, it was concluded that these DAS manual controls should be included in the AP1000 Technical Specifications. (See section 10.4 for a draft of the DAS manual control Technical Specification.)

2.3 UNCERTAINTY

For resolving the RTNSS issue with the NRC, several additional nonsafety-related SSCs are designated as RTNSS-important. These additional SSCs are selected using insights from the AP1000 PRA to compensate for potential uncertainties identified by the NRC. These areas of potential uncertainty include the following:

- Thermal/hydraulic uncertainty – The thermal/hydraulic calculations used to justify the PRA success criteria may have uncertainty. Some low-margin, high-risk accident sequences have been identified for both short-term and long-term conditions. These low-margin, high-risk sequences include large loss-of-coolant accidents (LOCAs), direct vessel injection (DVI) line breaks, and long-term cooling. A thermal/hydraulic uncertainty evaluation was performed as described in the AP1000 PRA, Appendix A. The result of the evaluation confirms that the majority of the success criteria specified in the AP1000 PRA for passive-only accident sequences leads to successful core cooling, even when conservatisms consistent with design basis methodology are applied. The effect of thermal/hydraulic uncertainty on the PRA is small. In the PRA sensitivity study without nonsafety SSC mitigation, total CDF and LRF remain within the goals established in SECY-94-084.

- Equipment failure rate uncertainty – The equipment failure rates used for the **PXS**~~IRWST~~ check valves **(IRWST injection, Containment Recirculation)**, squib valves **(ADS Stage 4, IRWST injection, Containment Recirculation)**, and the reactor ~~coolant pump (RCP)~~ trip breakers may have **more** uncertainty **than other equipment**. An uncertainty analysis was performed for equipment failure rates, human error probabilities, and initiating event frequencies. The results of the uncertainty analysis are reported in AP1000 PRA Chapter 51. The result of the uncertainty analysis confirmed that the results are within the required safety goals.

~~□Nonsafety-related SSC importance in an initiating event frequency—The evaluation of the importance of nonsafety-related SSCs with respect to initiating events may have some uncertainty. One issue is what is an appropriate measure of risk importance; that is, is an initiating event significant if the CDF or LRF from it is 1 percent or 10 percent of the total?~~

- **Initiating event frequency uncertainty – The large pipe break LOCA and the SG tube rupture initiating event frequencies may have more uncertainty than other events. The uncertainty with the large LOCA frequency is a result of events that have occurred in operating plants; these events have affected portions of the RCS that operate at or near the hot leg temperature. Since hot leg side large LOCAs are much less severe, the success criteria used in the PRA is overly conservative for these breaks. For example, the spurious LOCA (ADS stage 4) is a large hot leg LOCA that requires only one accumulator. Another factor is the use of Inconel 600 in welds. AP1000 uses Inconel 690, which is recognized to be mush less seceptable to cracking.**

  The SGTR frequency is based on plant operating experience form more recent plants that are using SGs with similar design features and materials.

  As a result, neither of these uncertainties is considered significant enough to warrant compensation by the addition of short-term availability controls.

- **Hydrogen standing flames uncertainty – In case of a core damage with failure of all ADS stage 4 valves, there was a concern with the ability of the AP600 containment to withstand standing hydrogen flames located at the IRWST vents. For the AP600, Westinghouse performed analysis that showed that the containment could withstand such flames. To address potential certainty with this analysis for the AP1000, Westinghouse has introduced design features that prevent such flames from being located close to the containment. These design features are safety related spring loaded dampers on the IRWST vents located close to the containment and no spring loading on the IRWST vents located well away from the containment. As a result, the vents located close to the containment will not open during such a serve accident and any standing flames would be located well away from the containment.**

The objective of this PRA uncertainty evaluation is to determine which nonsafety-related SSCs should be identified to compensate for the PRA uncertainties. The approach is to identify SSCs that directly compensate for the uncertainty. It is recognized that for some of these uncertainties, there are no nonsafety-related SSCs that can directly compensate for these uncertainties. In such situations, margin is provided in the PRA by adding regulatory oversight on nonsafety-related SSCs that improve the PRA sensitivity study results for other sequences. For example, there are no nonsafety-related SSCs that can improve the PRA sensitivity study results associated with DVI line breaks. During a DVI line break, the Normal Residual Heat Removal System (RNS) injection flow spills out the break and does not inject water into the RCS. Providing short-term availability controls on a system such as the DAS for ATWS events is a way to add margin to the PRA sensitivity study by improving the overall PRA sensitivity study results, even though it does not add margin to DVI line break events.

The result of this PRA uncertainty evaluation ~~for the AP600 was~~ **is** that a few additional nonsafety-related SSCs **are**~~were~~ designated as RTNSS-important to add margin to compensate for **these** potential uncertainties. The nonsafety-related SSCs in the AP600 designated by this process include the following:

- Automatic DAS ATWS and engineered safety feature (ESF) actuation (provides margin for **reactor trip breaker uncertainty,** thermal/hydraulic **analysis** uncertainty**, and for PMS software uncertainty). Note that the Technical Specification added for DAS manual controls (Table 10-3) provides additional margin.**

- RNS **injection** capability (provides margin for ADS **Stage 4 squib valves,** ~~/~~IRWST injection/containment recirculation **check and squib** valve reliability uncertainty, and long-term cooling thermal/hydraulic **analysis** uncertainty)

- Onsite ac power supplies (provide margin for ADS/IRWST injection/containment recirculation valve reliability certainty, and long-term cooling thermal/hydraulic uncertainty)

- Hydrogen ignitors (provide margin for uncertainty in hydrogen burn consequences)

~~As a result of the AP1000 evaluation, these nonsafety-related SSCs were retained as RTNSS-important in the AP1000.~~

Section 10 provides a list of the RTNSS-important SSCs, a description of the functions they perform, and the proposed short-term availability control regulatory oversight for these SSCs. **Note that the short-term availability controls identified for these RTNSS-important SSCs in Table 10-2, indicate that an availability of 90% is expected for these functions during the specified MODES considering both maintenance unavailability and failures.**

WCAP-15985, Table 2-1:

Table 2-1	**Systems and Functions Credited in Focused PRA ~~Probabilistic Risk Assessment~~ Sensitivity Studyies**
Nonsafety-Related Systems and Functions Failed in Focused PRA Sensitivity Studyies	
Chemical and Volume Control System (CVS)	
Normal Residual Heat Removal System (RNS)	
Startup Feedwater System (SFWS)	
Main AC Power System (ECS) (diesel only)	
Diverse Actuation System (DAS)	
Hydrogen ignitors	
Safety-Related Systems and Functions Credited in Focused PRA Sensitivity Studyies	
• Passive Core Cooling System (PXS)	
– IRWST injection/containment recirculation	
– Core makeup tank (CMT)	
– Accumulator	
– Passive residual heat removal (PRHR)	
– Automatic depressurization	
• Passive Containment Cooling (PCS)	
• Containment Isolation	
• Class 1E DC and UPS System (IDS)	
• Protection and Safety Monitoring System (PMS)	
• Steam Generator Isolation	

WCAP-15985, Table 2-2:

Table 2-2 AP600/AP1000 PRA Results for Baseline and Without Non-Nuclear Safety SSCs			
	AP1000[1]	AP1000[2]	AP600
CDF, At-Power, Internal			
Baseline	2.4 E-7	2.4 E-7	1.7 E-7
~~Without NNS SSCs~~	7.4 E-6	2.3 E-6	~~N/A~~
Focused[6]	~~N/A~~	~~N/A~~	7.7 E-6
CDF, Shutdown, Internal			
Baseline	1.2 E-7	1.2 E-7~~8~~	1.0 E-7
~~Without NNS SSCs~~	(3)	(3)	~~N/A~~
Focused[6]	~~N/A~~	~~N/A~~	4.1 E-7
CDF, Total Internal			
Baseline	3.6 E-7	3.6~~2.5~~ E-7	2.7 E-7
~~Without NNS SSCs~~	< 1 E-4 [3]	<< 1 E-4 [3]	~~N/A~~
Focused[6]	~~N/A~~	~~N/A~~	8.1 E-6
Safety goal	1.0 E-4	1.0 E-4	1.0 E-4
LRF, At-Power, Internal			
Baseline	1.9 E-8	1.9 E-8	1.8 E-8
~~Without NNS SSCs~~	5.2 E-6	4.3 E-7	~~N/A~~
Focused[6]	~~N/A~~	~~N/A~~	5.5 E-7
LRF, Shutdown, Internal			
Baseline	2.0 E-8	2.0 E-8	1.5 E-8
Without NNS SSCs	(4)	(5)	N/A
Focused[6]	N/A	N/A	2.6 E-7
LRF, Total Internal			
Baseline	3.9 E-8	3.9 E-8	3.3 E-8
~~Without NNS SSCs~~	> 1 E-6 [4]	< 1 E-6 [5]	~~N/A~~
Focused[6]	~~N/A~~	~~N/A~~	8.2 E-7
Safety goal	1.0 E-6	1.0 E-6	1.0 E-6

Notes:

1. Assumes NNS SSCs in Table 2-1 fail.
2. Assumes NNS SSCs in Table 2-1 fail, except for manual DAS controls listed in section 2.2
3. Based on AP600/AP1000 results, the AP1000 CDF during shutdowns without NNS SSCs is estimated to be an order of magnitude less than the CDF at-power without NNS SSCs.
4. The base AP1000 LRF at-power without NNS SSCs exceeds the safety goal without including the shutdown LRF.
5. Based on AP600/AP1000 results, the AP1000 LRF during shutdowns without NNS SSCs is estimated to be about the same as the LRF at-power without NNS SSCs
6. **As discussed in section 2.2, the focused PRA sensitivity study for AP1000 was calculated in a slightly different manner than for the AP600. As a result, the frequencies are not directly comparable.**

Definitions:

N/A = not applicable

NNS = non-nuclear safety

WCAP-15985, Section 10.2.2:

- RNS (RCS Open)

  The RNS provides shutdown decay heat removal during RCS open shutdown conditions.

- **RNS (RCS Intact)**

  The RNS provides low pressure injection during accidents with ADS actuation.

- CCS (RCS Open)

  The CCS provides cooling to support RNS shutdown decay heat removal operation during RCS open shutdown conditions.

WCAP-15985, Table 10-2, Availability Controls 2.5 and 3.3:

The word changes shown in response 9A/B will be implemented in these availability controls.

Westinghouse Response: < This is the original (unchanged) response. >

WCAP-15985 "AP1000 Implementation of the Regulatory Treatment of Nonsafety-Related Systems Process" provides the basis for the implementation of the RTNSS policy statement. The AP1000 implementation of the RTNSS policy statement is consistent with the approach that was taken for the AP600. Note that PRA sensitivity studies with nonsafety systems failed were used to evaluate the importance of nonsafety features in PRA accident mitigation, instead of the focused PRA sensitivity study. The AP1000 PRA, revision 0, includes the CMF sensitivity study; the LRF sensitivity study was performed recently based on the response to RAI 720.057 and will be added to the PRA in revision 1.

Use of these sensitivity studies increases the need for passive safety feature actuation signals since non-safety AC power is assumed to be available after each accident except for loss of offsite power. As a result, some non-safety manual Diverse Actuation System (DAS) controls are required to meet the licensing PRA safety goals. These manual DAS controls are captured as RTNSS important and additional regulatory oversight is provided. Since these manual DAS controls meet the technical specification screening criteria for PRA importance, a Technical Specification is added on these manual DAS controls. The additional Technical Specification is included in the revised AP1000 Technical Specifications that are submitted as part of the response to RAI 630.001.

These DAS manual controls were the only additional non-safety featured captured in the AP1000 RTNSS evaluation. The list of non-safety features that have short-term availability controls is the same for AP1000 and AP600.

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

Design Control Document (DCD) Revision:

See the attached Technical Specification for DAS that is included in the revised AP1000 Technical Specifications.

PRA Revision:

None

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

RAI Number: 720.056 (Response Revision 1)

Question:

The offsite consequences for release categories CFI and CI for the AP1000 are similar to or less than the corresponding values for AP600. This is unexpected since the fission product inventories for AP1000 are larger than for AP600, and the same release fractions were assumed. Please explain the reasons for this inconsistency.

Westinghouse Response:

The AP1000 offsite consequences have now been calculated using release fractions from the AP1000-specific MAAP4.04 analyses incorporated into AP1000 Chapter 34 by the response to RAI 720.042. The CFI and CI Risk (REM/reactor year) are somewhat larger for AP1000 than for AP600, as expected.

Design Control Document (DCD) Revision:

None

PRA Revision:

AP1000 PRA Chapter 49 will be revised as shown in the attached markup.

NRC Additional Comments:

The RAI noted a number of inconsistencies between the offsite consequence estimates for AP1000 and AP600. AP1000-specific results have now been provided and the noted inconsistencies have been eliminated. However, two new inconsistencies are noted -- the dose for release category "CI" is identical to the AP600 value, and the dose for release category "CFE" is less than the AP600 value. The reasons need to be explained.

Westinghouse Additional Response:

We examined the AP1000 and AP600 source terms from MAAP analyses (see Tables 49-1 and 49-2 attached to this response for the convenience of the reader). The release fractions generated for AP600 and AP1000 for CI and CFE, and used in the dose analyses are not identical. Note that both the MAAP and the MACCS codes used in the level 2 and dose analyses have been upgraded to their later versions for AP1000 PRA. The fact that the CI doses for AP600 and AP1000 (see attached Tables 49-10 for AP600 and AP1000) are very close (2.05E+06 versus 2.01E+06 person-rem, 24 hours) is not because their release fractions are the same; if anything, it is coincidental, and is driven by the different in-vessel release correlations used, as discussed below for CFE dose.

CFE dose is mainly driven by CS and I elements, which have different release fractions predicted in AP600 and AP1000 (8.25% versus 5.5%; 33% difference). The effect of this difference on the population whole body dose (as calculated by two different versions of MACCS code, see Tables 49-10) is 9.25E+05 versus 8.51E+05 person-rem (8% difference). The percentage difference is relatively small but it is consistent with the input release fractions, and the fact that AP1000 inventories are higher than those of AP600 (which reduces difference between the AP1000 and AP600 doses despite the AP1000 release fractions being lower). So the question focuses on the AP1000 CS and I release fractions being lower than those of AP600.

The same reference sequence (3BE with hydrogen igniters failed) is used for CFE release fraction predictions for AP600 and AP1000. There are many competing factors in calculation of these release fractions, and the MAAP code versions, and MAAP input files are different. Two different in-vessel release correlations were used for the AP600 and the AP1000 calculations. Namely, AP600 PRA used the steam oxidation release model (EPRI/IDCOR), and the AP1000 PRA used the CORSOR-M model. We discuss this point below.

At the time of AP600 PRA, the EPRI/IDCOR model was recommended for the fission product release from the core. When the AP1000 model was created, the CORSOR model was the default. AP1000 uses the current default value based on the latest benchmarking. In the AP600 analysis, the values that were recommended at the time were used. For fission product releases, the latest data should be used because no separate benchmarking was done for the AP600 that would supercede the generic benchmarking done for the MAAP4.04 code. MAAP 4.0.4 actually uses a hybrid in-vessel release model that is a combination of the CORSOR-M and CORSOR-O models. The Cs and I releases are calculated with the CORSOR-M model and the balance of the fission product releases are calculated with the CORSOR-O model.

Thus, it is our conclusion that a more current and refined model to estimate release fractions is used for AP1000, in addition to the use of a later version of MAAP. Thus the AP1000 release fraction results are better estimates.

In any case, CFE is the major contributor to plant risk in both AP1000 and AP600. The plant risk results and insights are not altered if, for example, the AP1000 CFE dose is increased by 50% ; 1.2E+06 person-rem. In fact, a sensitivity analysis to support this conclusion has been performed. In Revision 0 of the AP1000 dose analysis, the AP1000 results with the AP600 release fractions were submitted to the NRC (Table 49-10, Revision 0). According to this table, with CFE dose of 1.46E+06 person-rem, the total risk is calculated to be 1.44E-02 person-rem/yr, 24 hours. This result is very similar to the AP1000 Revision 1 result of 1.24E-02 person-rem/yr, 24 hours.

AP1000 PRA Table 49-10 Revision 1

POPULATION WHOLE BODY EDE DOSE RISK – 24 HOURS

Release Category	Release Frequency (/Reactor Year)	Mean Dose (Person-Sieverts)	Dose (Person-REM)	Risk (Person-REM/ Reactor Year)	Percentage Contribution to Total Risk
CFI	1.89E-10	7.88E+03	7.88E+05	1.49E-04	1.2
CFE	**7.47E-09**	**8.51E+03**	**8.51E+05**	**6.36E-03**	**51.3**
IC	2.21E-07	7.19E+00	7.19E+02	1.59E-04	1.3
BP	1.05E-08	2.91E+03	2.91E+05	3.06E-03	24.7
CI	**1.33E-09**	**2.01E+04**	**2.01E+06**	**2.67E-03**	**21.6**
CFL	3.45E-13	5.32E+03	5.32E+05	1.84E-07	0.0
			Total Risk =	1.24E-02	100.0

AP600 PRA Table 49-10 Revision 11

POPULATION DOSE RISK - 24 HOURS

Release Category	Release Frequency (per reactor-year)	Mean Population Dose		Risk (person-rem per reactor-year)	Percent Contribution to Total Risk
		(sieverts)	(rem)		
IC	1.51E-07	3.12E+00	3.12E+02	4.71E-05	0.64%
CFE	**6.63E-09**	**9.25E+03**	**9.25E+05**	**6.13E-03**	**83.54%**
CFI	1.31E-11	3.35E+03	3.35E+05	4.39E-06	0.06%
CFL	1.51E-11	1.05E+01	1.05E+03	1.59E-08	0.00%
CI	**3.61E-10**	**2.05E+04**	**2.05E+06**	**7.40E-04**	**10.08%**
BP	1.12E-08	3.72E+02	3.72E+04	4.17E-04	5.68%
			Total Risk	7.34E-03	100.00%

AP1000 PRA Table 49-10 Revision 0 ("Sensitivity Analysis" With AP600 Source Terms)

POPULATION WHOLE BODY EDE DOSE RISK – 24 HOURS

Release Category	Release Frequency (/reactor year)	Mean Dose (person-sieverts)	Dose (person-REM)	Risk (person-REM/ reactor year)	Percent Contribution to Total Risk
CFI	1.89E-10	3.29E+03	3.29E+05	6.22E-05	0.4%
CFE	7.47E-09	1.46E+04	1.46E+06	1.09E-02	75.5%
IC	2.21E-07	2.73E+00	2.73E+02	6.03E-05	0.4%
BP	1.05E-08	5.83E+02	5.83E+04	6.12E-04	4.2%
CI	1.33E-09	2.11E+04	2.11E+06	2.81E-03	19.4%
CFL	3.45E-13	1.14E+01	1.14E+03	3.93E-10	0.0%
			Total Risk =	1.44E-02	100.0%

Table 49-1

AP1000 SOURCE TERMS FROM LEVEL 2 ANALYSIS (MAAP)

Case No.	Plume No.	Start Time (Seconds)	End Time (Seconds)	Duration (Seconds)	Release Fraction (MAAP Group) 1 Inert	2 CsI	3 TeO2	4 SrO	5 MoO2	6 CsOH	7 BaO	8 La2O3	9 CeO2	10 Sb	11 Te2	12 UO2	Plume Energy (Joules/sec) (Watts)	Plume Position
CFI	1	2930	10100	7170	2.88E-01	5.09E-03	7.92E-03	4.77E-03	1.03E-02	5.07E-03	8.12E-03	1.56E-04	1.82E-04	8.89E-03	0.00E+00	0.00E+00	0 00E+00	Leading
	2	10100	89850	79750	4.69E-01	3.50E-03	4.99E-03	9.23E-03	6.62E-03	3 49E-03	9.15E-03	1.08E-03	1.09E-03	5.96E-03	0.00E+00	0.00E+00	0.00E+00	Midpoint
	3	89850	176200	86350	6.98E-02	6.00E-06	1.00E-05	4.20E-04	1.00E-05	6.00E-06	1.70E-04	5.84E-04	5.84E-04	4.00E-05	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	176200	262600	86400	2.35E-02	0.00E+00	1.00E-05	1.50E-04	4.00E-05	0 00E+00	8.00E-05	3.23E-04	3.21E-04	4.00E-05	0.00E+00	0.00E+00	0.00E+00	Midpoint
CFE	1	3004	19810	16806	4.16E-01	5.53E-02	3.01E-02	3.14E-03	1.16E-02	5.35E-02	4.63E-03	5.57E-05	2.39E-04	2.03E-02	0.00E+00	0.00E+00	0.00E+00	Leading
	2	19810	89970	70160	4.05E-01	1.26E-03	1.48E-03	3.43E-04	2.58E-03	1 20E-03	6.45E-04	9.66E-06	1.14E-05	2.66E-03	0.00E+00	0.00E+00	0.00E+00	Leading
	3	89970	176300	86330	1 08E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	176300	262700	86400	3.43E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0 00E+00	0.00E+00	0 00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	0.00E+00	Midpoint
DIRECT	1	4378	84810	80432	2.95E-03	3.61E-05	2.86E-05	3.22E-05	3.94E-05	3.44E-05	3.61E-05	4.04E-06	4.39E-06	3.99E-05	0 00E+00	0.00E+00	0.00E+00	Midpoint
	2	84810	134400	49590	1.48E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-08	2.40E-08	2.40E-07	0.00E+00	0.00E+00	0.00E+00	Leading
	3	134400	177600	43200	1.18E-03	0.00E+00	0.00E+00	0.00E+00	0 00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-08	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	2.32E-03	0.00E+00	0 00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0 00E+00	0.00E+00	3.00E-08	0.00E+00	0.00E+00	0.00E+00	Midpoint
IC	1	4378	84810	80432	9.83E-04	1.20E-05	9.53E-06	1.07E-05	1.31E-05	1.15E-05	1.20E-05	1.35E-06	1.46E-06	1.33E-05	0.00E+00	0.00E+00	0.00E+00	Midpoint
	2	84810	134400	49590	4.93E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6 00E-09	8.00E-09	8.00E-08	0.00E+00	0.00E+00	0.00E+00	Leading
	3	134400	177600	43200	3.94E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-08	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	7.72E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-08	0.00E+00	0.00E+00	0.00E+00	Midpoint
BP	1	5984	22130	16146	6.32E-01	1.20E-02	1.85E-02	3.02E-04	4.97E-03	1.10E-02	7.91E-04	1.25E-05	3.52E-05	5.48E-02	0.00E+00	0.00E+00	0.00E+00	Midpoint
	2	22130	108500	86370	3.00E-04	5.00E-05	2.00E-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	0.00E+00	0.00E+00	Midpoint
	3	108500	194900	86400	4.00E-04	0.00E+00	0 00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint

Table 49-1

AP1000 SOURCE TERMS FROM LEVEL 2 ANALYSIS (MAAP)

					Release Fraction (MAAP Group)													Plume Energy	
	4	194900	267800	72900	3.00E-04	0 00E+00	0.00E+0 0	0.00E+00	0 00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
CI	1	101	50020	49919	5.73E-01	4.56E-02	2.12E- 02	2.03E-02	4.04E-02	1.78E-02	3.16E-02	2.39E-04	7.42E-04	2.71E-02	0.00E+00	0 00E+00	0.00E+00	0.00E+00	Midpoint
	2	50020	136400	86380	1.13E-01	0 00E+00	0.00E+0 0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-07	0.00E+00	1.90E-04	0.00E+00	0 00E+00	0.00E+00	0.00E+00	Midpoint
	3	136400	211700	75300	5.66E-02	0.00E+00	0.00E+0 0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	211700	259600	47900	2.74E-02	0.00E+00	0.00E+0 0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
CFL	1	4353	23610	19257	7.51E-01	3.57E-02	4.36E- 02	2.01E-03	9.90E-03	2.74E-02	3.02E-03	3.31E-05	1.60E-04	2.87E-02	1.14E-07	7.76E-10	0 00E+00	0.00E+00	Midpoint
	2	23610	91280	67670	1.22E-01	9.30E-04	3.00E- 05	0.00E+00	0.00E+00	2.70E-04	0.00E+00	0.00E+00	0.00E+00	2.90E-04	5.70E-09	2.00E-13	0 00E+00	0.00E+00	Midpoint
	3	91280	177600	86320	6.93E-02	2.40E-04	3.00E- 05	0.00E+00	0.00E+00	1.00E-04	0.00E+00	0.00E+00	0.00E+00	2.00E-04	1.00E-09	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	2.84E-02	1.00E-05	0.00E+0 0	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	0.00E+00	1.20E-04	3.00E-10	0.00E+00	0.00E+00	0.00E+00	Midpoint

Table 49-2

AP1000 SOURCE TERMS FOR DOSE EVALUATION (MACCS2)

Case No.	Plume No.	Start Time (Seconds)	End Time (Seconds)	Duration (Seconds)	Release Fraction (MACCS2 Group) 1 Inert	2 I	3 Cs	4 Te/Sb	5 Sr	6 Ru	7 La	8 Ce	9 Ba	Plume Energy Joules/sec (Watts)	Plume Position
CFI	1	2930	10100	7170	2.88E-01	5.09E-03	5.08E-03	5.14E-04	4.77E-03	1.03E-02	1.56E-04	6.04E-07	8.12E-03	0.00E+00	Leading
	2	10100	89850	79750	4.69E-01	3.50E-03	3.49E-03	3.45E-04	9.23E-03	6.62E-03	1.08E-03	3.61E-06	9.15E-03	0.00E+00	Midpoint
	3	89850	176200	86350	6.98E-02	6.00E-06	6.00E-06	2.31E-06	4.20E-04	1.00E-05	5.84E-04	1.94E-06	1.70E-04	0.00E+00	Midpoint
	4	176200	262600	86400	2.35E-02	0.00E+00	0.00E+00	2.31E-06	1.50E-04	4.00E-05	3.23E-04	1.06E-06	8.00E-05	0.00E+00	Midpoint
CFE	1	3004	19810	16806	4.16E-01	5.53E-02	5.37E-02	1.17E-03	3.14E-03	1.16E-02	5.57E-05	7.91E-07	4.63E-03	0.00E+00	Leading
	2	19810	89970	70160	4.05E-01	1.26E-03	1.21E-03	1.54E-04	3.43E-04	2.58E-03	9.66E-06	3.78E-08	6.45E-04	0.00E+00	Leading
	3	89970	176300	86330	1.08E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	176300	262700	86400	3.43E-02	0.00E+00	0.00E+00	5.78E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
DIRECT	1	4378	84810	80432	2.95E-03	3.61E-05	3.46E-05	2.31E-06	3.22E-05	3.94E-05	4.04E-06	1.45E-08	3.61E-05	0.00E+00	Midpoint
	2	84810	134400	49590	1.48E-03	0.00E+00	0.00E+00	1.39E-08	0.00E+00	0.00E+00	1.80E-08	7.95E-11	0.00E+00	0.00E+00	Leading
	3	134400	177600	43200	1.18E-03	0.00E+00	0.00E+00	3.47E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	2.32E-03	0.00E+00	0.00E+00	1.73E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
IC	1	4378	84810	80432	9.83E-04	1.20E-05	1.15E-05	7.69E-07	1.07E-05	1.31E-05	1.35E-06	4.85E-09	1.20E-05	0.00E+00	Midpoint
	2	84810	134400	49590	4.93E-04	0.00E+00	0.00E+00	4.62E-09	0.00E+00	0.00E+00	6.00E-09	2.65E-11	0.00E+00	0.00E+00	Leading
	3	134400	177600	43200	3.94E-04	0.00E+00	0.00E+00	1.16E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	7.72E-04	0.00E+00	0.00E+00	5.78E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
BP	1	5984	22130	16146	6.32E-01	1.20E-02	1.11E-02	3.17E-03	3.02E-04	4.97E-03	1.25E-05	1.17E-07	7.91E-04	0.00E+00	Midpoint
	2	22130	108500	86370	3.00E-04	5.00E-05	5.73E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	3	108500	194900	86400	4.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	194900	267800	72900	3.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
CI	1	101	50020	49919	5.73E-01	4.56E-02	2.10E-02	1.57E-03	2.03E-02	4.04E-02	2.39E-04	2.46E-06	3.16E-02	0.00E+00	Midpoint
	2	50020	136400	86380	1.13E-01	0.00E+00	0.00E+00	1.10E-05	0.00E+00	0.00E+00	1.00E-07	0.00E+00	0.00E+00	0.00E+00	Midpoint
	3	136400	211700	75300	5.66E-02	0.00E+00	0.00E+00	7.74E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	211700	259600	47900	2.74E-02	0.00E+00	0.00E+00	1.21E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
CFL	1	4353	23610	19257	7.51E-01	3.57E-02	2.84E-02	1.66E-03	2.01E-03	9.90E-03	3.31E-05	5.30E-07	3.02E-03	0.00E+00	Midpoint
	2	23610	91280	67670	1.22E-01	9.30E-04	3.46E-04	1.68E-05	0.00E+00	0.00E+00	0.00E+00	1.99E-13	0.00E+00	0.00E+00	Midpoint
	3	91280	177600	86320	6.93E-02	2.40E-04	1.16E-04	1.16E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	2.84E-02	1.00E-05	1.00E-05	6.93E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint

Table 49-1

AP600 SOURCE TERMS FROM LEVEL 2 ANALYSIS

Case No.	Plume No.	Start Time (Seconds)	End Time (Seconds)	Duration (Seconds)	Release Fraction (MAAP Group) 1 Inert	2 CsI	3 TeO2	4 SrO	5 MoO2	6 CsOH	7 BaO	8 La2O3	9 CeO2	10 Sb	11 Te2	12 UO2	Plume Energy (Joules/sec) (Watts)	Plume Position
CFI	1	18000	72000	54000	6 19E-01	3 38E-03	0 00E+00	5 75E-04	7 83E-03	2 92E-03	5 63E-03	1 12E-03	1 51E-03	1 01E-02	0 00E+00	0 00E+00	0 00E+00	Leading
	2	72000	158400	86400	8 30E-03	8 00E-06	0 00E+00	0 00E+00	0 00E+00	1 60E-05	0 00E+00	0 00E+00	0 00E+00	4 00E-05	0 00E+00	0 00E+00	0 00E+00	Midpoint
	3	158400	244800	86400	5 50E-03	5 90E-05	0 00E+00	0 00E+00	0 00E+00	1 21E-04	0 00E+00	0 00E+00	0 00E+00	1 00E-05	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	244800	300000	55200	2 54E-01	2 75E-04	0 00E+00	0 00E+00	0 00E+00	8 18E-04	0 00E+00	0 00E+00	0 00E+00	6 00E-05	0 00E+00	0 00E+00	0 00E+00	Midpoint
CFE	1	4060	17270	13210	5 45E-01	8 25E-02	0 00E+00	7 73E-04	2 55E-02	8 01E-02	8 13E-03	1 52E-04	2 88E-04	6 92E-02	0 00E+00	0 00E+00	0 00E+00	Leading
	2	17270	91140	73870	1 57E-01	4 90E-04	0 00E+00	1 83E-04	2 00E-03	5 80E-04	1 79E-03	4 53E-04	5 93E-04	3 31E-03	0 00E+00	0 00E+00	0 00E+00	Leading
	3	91140	177500	86360	5 80E-03	0 00E+00	0 00E+00	0 00E+00	1 00E-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	Midpoint
	4	177500	263900	86400	1 79E-02	1 00E-04	0 00E+00	0 00E+00	0 00E+00	2 20E-04	0 00E+00	0 00E+00	0 00E+00	1 00E-05	0 00E+00	0 00E+00	0 00E+00	Midpoint
DIRECT	1	3481	40760	37279	3 95E-04	1 36E-05	0 00E+00	8 26E-07	1 33E-05	1 30E-05	8 67E-06	2 56E-06	2 82E-06	2 03E-05	0 00E+00	0 00E+00	0 00E+00	Midpoint
	2	40760	90520	49760	5 29E-04	4 10E-07	0 00E+00	5 04E-08	6 20E-07	4 50E-07	4 90E-07	1 77E-07	1 85E-07	4 40E-06	0 00E+00	0 00E+00	0 00E+00	Leading
	3	90520	176900	86380	9 52E-04	1 00E-08	0 00E+00	7 00E-10	0 00E+00	1 00E-08	5 00E-09	6 00E-09	6 00E-09	2.20E-06	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	176900	263300	86400	9 46E-04	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	1 83E-06	0 00E+00	0 00E+00	0 00E+00	Midpoint
IC	1	3481	40760	37279	3 95E-04	4 53E-06	0 00E+00	2 75E-07	4 45E-06	4 34E-06	2 89E-06	8 53E-07	9 38E-07	6 77E-06	0 00E+00	0 00E+00	0 00E+00	Midpoint
	2	40760	90520	49760	5 29E-04	1 37E-07	0 00E+00	1 68E-08	2 07E-07	1 50E-07	1 63E-07	5 90E-08	6 17E-08	1 47E-06	0 00E+00	0 00E+00	0 00E+00	Leading
	3	90520	176900	86380	9 52E-04	3 33E-09	0 00E+00	2 33E-10	0 00E+00	3 33E-09	1 67E-09	2 00E-09	2 00E-09	7 33E-07	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	176900	263300	86400	9 46E-04	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	6 10E-07	0 00E+00	0 00E+00	0 00E+00	Midpoint
BP	1	8719	21300	12581	8 49E-01	3 73E-03	0 00E+00	5 79E-06	2 58E-04	3 10E-03	6 00E-05	3 71E-07	3 81E-07	1 29E-03	0 00E+00	0 00E+00	0 00E+00	Midpoint
	2	21300	104200	82900	1 01E-02	6 00E-05	0 00E+00	1 85E-05	4 30E-04	1 02E-04	1 76E-04	3 55E-06	9 41E-06	8 92E-04	0 00E+00	0 00E+00	0 00E+00	Midpoint
	3	104200	190600	86400	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	190600	277000	86400	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
CI	1	4777	23160	18383	6 24E-01	3 37E-02	0 00E+00	2 14E-03	4 06E-02	3 44E-02	2 15E-02	5 06E-03	6 38E-03	6 04E-02	0 00E+00	0 00E+00	0 00E+00	Midpoint
	2	23160	90340	67180	2 16E-01	4 00E-05	0 00E+00	2 10E-05	2 40E-04	4 00E-05	1 90E-04	8 00E-05	8 50E-05	1 03E-03	0 00E+00	0 00E+00	0 00E+00	Midpoint
	3	90340	176700	86360	8 54E-02	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	1 00E-05	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	176700	263100	86400	4 63E-02	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
CFL	1	3649	90030	86381	1 07E-03	1 18E-05	0 00E+00	5 87E-07	1 12E-05	1 09E-05	6 09E-06	1 58E-06	1 93E-06	1 71E-05	0 00E+00	0 00E+00	0 00E+00	Midpoint
	2	90030	144000	53970	9 97E-01	2 21E-04	0 00E+00	6 00E-06	1 11E-04	2 46E-04	5 74E-05	1 48E-05	1 70E-05	4 00E-03	0 00E+00	0 00E+00	0 00E+00	Midpoint
	3	144000	198000	54000	4 00E-04	1 53E-05	0 00E+00	2 65E-07	5 60E-06	8 88E-05	2 58E-06	5 60E-07	6 70E-07	9 08E-03	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	198000	263200	65200	0 00E+00	9 90E-05	0 00E+00	4 60E-08	1 00E-06	1 15E-03	3 10E-07	1 00E-07	9 00E-08	7 39E-02	0 00E+00	0 00E+00	0 00E+00	Midpoint

Table 49-2

AP600 SOURCE TERMS FOR DOSE EVALUATION (MACCS)

Case No.	Plume No.	Start Time (Seconds)	End Time (Seconds)	Duration (Seconds)	Release Fraction (MACCS Group) 1 Inert	2 I	3 Cs	4 Te/Sb	5 Sr	6 Ru	7 La	8 Ce	9 Ba	Plume Energy Joules/sec (Watts)	Plume Position
CFI	1	18000	72000	54000	6 19E-01	3 38E-03	2 97E-03	5 82E-04	5 75E-04	7 83E-03	1 12E-03	5 00E-06	5 63E-03	0 00E+00	Leading
	2	72000	158400	86400	8 30E-03	8 00E-06	1 51E-05	2 31E-06	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
	3	158400	244800	86400	5 50E-03	5 90E-05	1 14E-04	5 78E-07	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	244800	300000	55200	2 54E-01	2 75E-04	7 56E-04	3 47E-06	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
CFE	1	4060	17270	13210	5 45E-01	8 25E-02	8 03E-02	4 00E-03	7 73E-04	2 55E-02	1 52E-04	9 54E-07	8 13E-03	0 00E+00	Leading
	2	17270	91140	73870	1 57E-01	4 90E-04	5 70E-04	1 91E-04	1 83E-04	2 00E-03	4 53E-04	1 97E-06	1 79E-03	0 00E+00	Leading
	3	91140	177500	86360	5 80E-03	0 00E+00	8 85E-06	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	177500	263900	86400	1 79E-02	1 00E-04	2 06E-04	5 78E-07	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
DIRECT	1	3481	40760	37279	3 95E-04	1 36E-05	1 31E-05	7 54E-07	8 26E-07	1 33E-05	2 56E-06	7 35E-09	8 67E-06	0 00E+00	Midpoint
	2	40760	90520	49760	5 29E-04	4 10E-07	4 46E-07	1 63E-07	5 04E-08	6 20E-07	1 77E-07	4 83E-10	4 90E-07	0 00E+00	Leading
	3	90520	176900	86380	9 52E-04	1 00E-08	1 00E-08	8 17E-08	7 00E-10	0 00E+00	6 00E-09	1 57E-11	5 00E-09	0 00E+00	Midpoint
	4	176900	263300	86400	9 46E-04	0 00E+00	0 00E+00	6 79E-08	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
IC	1	3481	40760	37279	3 95E-04	4 53E-06	4 36E-06	2 51E-07	2 75E-07	4 45E-06	8 53E-07	2 45E-09	2 89E-06	0 00E+00	Midpoint
	2	40760	90520	49760	5 29E-04	1 37E-07	1 49E-07	5 45E-08	1 68E-08	2 07E-07	5 90E-08	1 61E-10	1 63E-07	0 00E+00	Leading
	3	90520	176900	86380	9 52E-04	3 33E-09	3 33E-09	2 72E-08	2 33E-10	0 00E+00	2 00E-09	5 22E-12	1 67E-09	0 00E+00	Midpoint
	4	176900	263300	86400	9 46E-04	0 00E+00	0 00E+00	2 26E-08	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
BP	1	8719	21300	12581	8 49E-01	3 73E-03	3 17E-03	4 78E-05	5 79E-06	2 58E-04	3 71E-07	9 95E-10	6 00E-05	0 00E+00	Midpoint
	2	21300	104200	82900	1 01E-02	6 00E-05	9 73E-05	3 31E-05	1 85E-05	4 30E-04	3 55E-06	2 46E-08	1 76E-04	0 00E+00	Midpoint
	3	104200	190600	86400	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	190600	277000	86400	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
CI	1	4777	23160	18383	6.24E-01	3 37E-02	3 44E-02	2.24E-03	2 14E-03	4 06E-02	5 06E-03	1 67E-05	2 15E-02	0 00E+00	Midpoint
	2	23160	90340	67180	2 16E-01	4 00E-05	4 00E-05	3 82E-05	2 10E-05	2 40E-04	8 00E-05	2 22E-07	1 90E-04	0 00E+00	Midpoint
	3	90340	176700	86360	8 54E-02	0 00E+00	0 00E+00	3 71E-07	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
	4	176700	263100	86400	4 63E-02	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	0 00E+00	Midpoint
CFL	1	3649	90030	86381	1 07E-03	1 18E-05	1 10E-05	6 33E-07	5 87E-07	1 12E-05	1 58E-06	5 03E-09	6 09E-06	0 00E+00	Midpoint
	2	90030	144000	53970	9 97E-01	2 21E-04	2 43E-04	1 49E-04	6 00E-06	1 11E-04	1 48E-05	4 44E-08	5 74E-05	0 00E+00	Midpoint
	3	144000	198000	54000	4 00E-04	1 53E-05	8 06E-05	3 37E-04	2 65E-07	5 60E-06	5 60E-07	1 75E-09	2 58E-06	0 00E+00	Midpoint
	4	198000	263200	65200	0 00E+00	9 90E-05	1 03E-03	2 74E-03	4 60E-08	1 00E-06	1 00E-07	2 35E-10	3 10E-07	0 00E+00	Midpoint

CHAPTER 49

OFFSITE DOSE RISK QUANTIFICATION

49.1 Introduction

The potential ground-level exposure, expressed as both effective dose equivalent (EDE) whole-body dose and acute red bone marrow dose, resulting from the possible accidental release of radioactive fission products is discussed in this chapter. Chapter 45 provides the estimated source term information; that is, the accidental release conditions. These conditions are:

- The amount of released material
- Release energy
- Duration
- Location

for the ~~seven~~ six identified release categories ~~(note, CFV is not analyzed in this calculation note)~~.

This information is used here, along with data provided in the Electric Power Research Institute (EPRI) Advanced Light Water Reactor Utility Requirements Document (Reference 49-1), to perform the atmospheric dispersion analyses. These analyses are conducted to estimate the EDE whole-body dose and acute red bone marrow dose, both at the site boundary (0.5 miles). The population whole-body dose out to 80.5 kilometers and the downwind, centerline, ground-level thyroid dose at the site boundary (0.5 miles) are also calculated for information. The estimated site boundary whole-body dose and the acute red bone marrow dose are compared to the Westinghouse goal of <25 rems (0.25 sieverts), at a frequency not to exceed $1x10^{-6}$ per year. This is consistent with the goal provided in Reference 49-1.

It should be noted that Reference 49-1 recommends evaluation of the whole-body dose. However, it does not clearly identify whether this dose analysis should be based on an acute or committed dose (EDE) basis. Consequence codes such as the MELCOR Accident Consequence Code System (MACCS and MACCS2) and their predecessor CRAC2 (codes are recommended by Reference 49-1) can only calculate the EDE whole-body dose, therefore the committed dose has been used in previous ALWR analyses. It is felt however, that the whole-body acute centerline dose is more appropriate for this 25 rem dose calculation since the purpose of this calculation is to establish a margin to the Nuclear Regulatory Commission (NRC) safety goals and the NRC staff safety goal implementation requirement. In this context, it is acute health effects versus long term effects from a committed dose that are of significance. For consequence codes such as MACCS2, the acute red bone marrow dose may be used to represent the acute whole-body dose. These doses are determined at the site boundary (0.5-mile radius).

The thyroid (site boundary) and whole-body (population) doses are also calculated during the first 24 and 72 hours following the onset of core damage, based on the probabilistic atmospheric dispersion analysis of the dose associated with each release category, coupled

with multiple meteorological conditions. The thyroid and population doses are provided for information.

49.2 Conformance with Regulatory Requirements

MACCS2 version 1.12 (Reference 49-2) is used for the analysis. The NRC sponsored the development of this code. The code performs probabilistic estimates of offsite consequences from potential accidental releases in conformance with Chapter 9 of the probabilistic risk assessment (PRA) guidelines described in NUREG/CR-2300 (Reference 49-3).

The analysis was based on the Westinghouse design goals, which are consistent with the guidelines provided in Reference 49-1, as discussed above. This reference document also identifies use of the MACCS2 code for offsite consequence analysis.

49.3 Assumptions

This section discusses the information, including assumptions, required to perform the dose evaluation. The primary information required for the dose evaluation includes the release source terms; the site meteorological data; population distribution data; site economic data; agricultural and land use data; and food uptake, ingestion, and retention factors. Additionally, available data on site emergency plans, such as sheltering and evacuation, and site decontamination and interdiction plans, may be included in the dose evaluation. Since the Westinghouse design goal specifies the site boundary dose as the only consequence of concern, the population, land use, sheltering, evacuation, decontamination, and interdiction data are not required for this calculation.

The advanced light water reactor reference site information described in Reference 49-1 provides the meteorological and population data for the analysis. Since the advanced light water reactor site data does not provide sufficient topographical data to define the MACCS2 site input file, the site land use and crop data are based on representative data from the Surry Plant Site. These data are provided in Reference 49-2. Due to the proximity of the Surry Site to the ocean, those site sectors that are ocean were arbitrarily changed to land. This was done to allow use of the advanced light water reactor reference site population data (without having people assigned to ocean sectors). These changes to the land and crop characteristics are made to provide an acceptable MACCS2 input file. They have no effect on the calculated dose at the plant site boundary.

49.4 Methodology

The dose evaluation uses the MACCS2 accident consequence code to estimate the potential offsite effects of the postulated accidental releases, developed by the Level 2 analysis. The MACCS2 code performs multiple air dispersion analyses, based on the yearly meteorological data, to estimate the air and ground-level concentrations of the released nuclides of concern. Multiple dispersion analyses allow the application of statistical analysis to the full range of results, based on the probability of the meteorological sequences that caused those results. This accounts for the possibility of an accident occurring at any time during the year. The air and ground-level concentrations are then converted to exposure dose, per nuclide, for the following pathways: cloudshine, groundshine, inhalation (direct and resuspended material),

and ingestion. For the potential exposure during the initial 24 and 72 hours, the calculated dose does not consider the ingestion pathway.

The MACCS2 code permits evaluation of the effects associated with direct exposure to the radioactive cloud (that is, cloudshine, groundshine, and inhalation), during the period initially following the accident (up to 1 week), and the long-term (over many years) effects due to exposure to contaminated land (ingestion of local farm products, ground shine, resuspension inhalation). It also examines accident costs, which might include permanent relocation and/or decontamination. The code also permits the modeling of the protective effects of sheltering and/or evacuation of the population during the acute exposure phase.

The Westinghouse goal only requires dose determination for exposure resulting from the first 24 hours following the initiation of core damage. Additionally, the Westinghouse goal requires only the total dose to a hypothetical individual located at the site boundary, which is assumed to be one-half mile, directly downwind, during the entire exposure period. Therefore, dose calculations related to the actual site population distribution are not required, nor are calculation of potential health effects, such as deaths and cancers. Finally, the calculation of the site boundary dose ignores any potential mitigating effects, including sheltering and evacuation.

Therefore, the consequence level evaluated in this analysis includes the whole-body effective dose equivalent dose and the acute red bone marrow dose resulting from the first 24-hour exposure versus distance from the reactor.

Statistical evaluation is applied to the multiple dispersion analysis results so that the consequences are presented in terms of a mean value, a peak value, and as complementary cumulative distribution functions. These functions present the value of the consequence level (whole-body effective dose equivalent dose) versus the probability of exceeding this level. The Westinghouse goal and the Reference 49-1 guidelines provide a value for the site boundary dose, not to exceed 25 rems whole-body dose at a frequency not to exceed $1x10^{-6}$ events per year.

A brief description of the code follows.

The MACCS2 code performs its processing in three steps, or modules: ATMOS, EARLY, and CHRONC. The description of the source term and the dispersion calculations occur in the first module, i.e., the ATMOS module. The EARLY module performs the calculations relating to the initial exposure dose and can also account for sheltering or evacuation schemes. The CHRONC module performs the calculations relating to the long-term exposure dose (for many years) and can account for decontamination or food uptake parameters. Only the ATMOS and EARLY modules are used for this analysis.

The MACCS2 code models the atmospheric transport of fission products that are released from containment, as defined by the source term characteristics, using a Gaussian plume model, and calculates the air and ground-level concentrations for the radionuclides of concern. Vertical plume rise depends on the release energy. Plume motion depends on the available meteorological conditions; that is, wind speed, wind direction, and atmospheric stability. The code includes models for radioactive decay and daughter product buildup, wet

and dry deposition of the nuclides due to gravity settling, and washout due to precipitation. Noble gases are not removed by deposition.

The MACCS2 code first reviews the hourly meteorological data for one year and sorts the data into predefined and user-defined meteorological categories. This allows MACCS2 to assess the frequency of occurrence of the different meteorological types, and to provide a realistic representation of a full year of site weather. It does this without overlooking those meteorological conditions that, although infrequent, may be instrumental in producing peak impacts. The probability of each meteorological category is also determined by this analysis.

In performing the dispersion analysis for a specific source term, the code samples each of the meteorological categories several times. The number of sampling per category is specified by the user. Each sample consists of starting the postulated release during one of the 8,760 hours during the year, which is identified with the meteorological type being sampled. This is done for each of the meteorological types. For example, if the user specifies four samples per meteorological category, and there are 30 defined meteorological categories, and if the database has at least four hours of meteorological samples per category, then 4 times 30, or 120, dispersion analyses are performed by MACCS2.

Once the release start time is selected, then the actual meteorological data is used to model the subsequent dispersion. That is, the meteorological data are allowed to change as the material moves downwind. The calculation continues until the material reaches the boundary of the spatial grid (receptor grid) defined by the user. Each dispersion simulation, therefore, results in calculated, integrated air and ground concentrations, (plume centerline, ground level) as a function of downwind distance. Each analysis is then weighted by the probability of occurrence of the meteorological condition. As each calculation is performed, the results are accumulated to provide an average estimate of the downwind integrated air and ground concentrations, including effects from all possible meteorological types. The MACCS2 code also notes the peak downwind concentration at each receptor distance and the associated meteorological condition that produced the peak.

The MACCS2 code then performs conversion calculations to estimate the radiation doses based on the air and ground concentrations. The radiation doses received by individuals are due to the passing radioactive cloud and the material deposited on the ground. Radiation doses received from the cloud result from direct radiation (cloudshine) and inhalation of material suspended in the air (inhalation). These processes occur only during the time that the cloud passes over the affected population. Radiation doses associated with the material deposited to the ground include direct radiation of the nuclides on the ground (groundshine) and inhalation of materials that are resuspended into the air (resuspension). The MACCS2 code simulates these dose paths. Therefore, the code estimates the dose levels for each nuclide and for each dispersion analysis performed.

~~Seven~~ Six release categories are identified for evaluation of potential offsite doses. These categories are discussed in detail in Chapter 45, and are summarized as the following:

- IC – Containment integrity is maintained throughout the accident, and the release of radiation to the environment is due to nominal leakage.

- BP – Fission products are released from the reactor coolant system to the environment via the secondary system or other interfacing system bypass. Containment failure occurs prior to onset of core damage.

- CI – Fission product release occurs through a failure of the system or valves that close the penetrations between containment and the environment. Containment failure occurs prior to onset of core damage.

- CFE – Fission product release occurs through a containment failure caused by some dynamic severe accident phenomena occurring after the onset of core damage but prior to core relocation. Such phenomena include: hydrogen detonation, hydrogen diffusion flame, steam explosions, and vessel failures.

- CFI – Fission product release occurs through a containment failure caused by some dynamic severe accident phenomena occurring after core relocation but before 24 hours. Such phenomena include: hydrogen detonation and hydrogen deflagration.

- CFL – Fission product release occurs through a containment failure caused by some dynamic severe accident phenomena occurring after 24 hours. Such phenomena include the failure of containment heat removal (failure of passive containment cooling).

- ~~CFV – Fission product release occurs through containment venting to prevent containment failure (note, CFV is not analyzed in this calculation because no credit for venting is considered).~~

Additionally, one sensitivity evaluation (called DIRECT) is performed. The DIRECT release case is a modification of the IC release category in which no credit is assumed for aerosol nuclide deposition in the middle annulus. This case is conservative.

Based on the analysis described in Chapter 45, source terms are generated for each of the release categories. The source terms provide the necessary parameters to describe the conditions of the release. Tables 49-1 and 49-2 contain listings of the source terms and their parameters considered in this analysis. Table 49-1 summarizes the output provided by the Modular Accident Analysis Program (MAAP) code, while Table 49-2 presents the conversion of this data into MACCS2 input categories.

There are nine source terms, ~~seven~~ **six** release categories, and ~~two~~ **one** sensitivity ~~studies~~ **study** defined for this analysis~~ (CFV and BP sensitivity are not analyzed in this calculation)~~. To conservatively estimate the ground-level dose exposure at the site boundary, it is assumed that all the release categories occur at ground level. Finally, it is conservatively assumed that 5 percent of the iodine released from containment is volatile and would not deposit. Reference 49-1 provides a guideline of 3 percent volatile iodine.

Reference 49-1 provides some of the MACCS2 input data, including the site, and meteorological data. The dose data conversion file provided with the MACCS2 PC Code, version 1.12 (Reference 49-2) is used for this analysis. This file is required to convert the predicted nuclide concentrations to dose values.

49.5 Dose Evaluation Results and Discussion

Doses are determined for the early exposure effects resulting from the initial 24 and 72 hours following the core damage initiation. The dose evaluation provides the conditional probability distributions for the consequence measures, which includes the whole-body dose and the acute red bone marrow dose for this analysis. These consequence probability distributions are based on the assumption that the accident that produced the source term has occurred. Therefore, the consequence probability distributions presented result from the variation in dose levels due to the various meteorological conditions. Hence, the actual probability of the identified dose levels would be the probability of the release category that produced the source term occurring multiplied by the probability of the dose level. The actual probability of the identified dose levels is presented in Section 49.7.

Tables 49-3 through 49-6 present the summary of the dose evaluations (the MACCS2 output) for the six source terms and the DIRECT sensitivity. The information is provided in the following columns: the mean dose; the 50, 90, 95, 99, and 99.5 percent confidence values that the dose will not exceed; and the peak dose produced by any dispersion analysis. The dose (one sievert equals 100 rem) is presented for the following source terms: IC, BP, CFI, CFE, CFL, CI and DIRECT release sensitivity. Table 49-7 summarizes the calculated mean and peak dose values for the source terms evaluated.

Figures 49-1 through 49-56 present plots of the complementary cumulative distribution functions for the population whole-body, the site boundary whole-body effective dose equivalent, the acute red bone marrow and thyroid doses resulting from the following source terms: CFI, CFE, CFL, IC, BP, CI, and the DIRECT release sensitivity study.

Results in Table 49-7 show that for release categories IC, ~~CFL,~~ and the DIRECT sensitivity study, the mean whole-body EDE dose at the site boundary in 24 hours is less than ~~4~~ **6** rem. For all other release categories: BP, CI, CFE, ~~and~~ CFI, **and CFL** the mean dose at the site boundary in 24 hours is greater than 25 rem. The sum of the probabilities of the release categories including an intact containment excess leakage category is approximately 2.4×10^{-7} events per year for at power conditions. Therefore, for the IC **and the DIRECT**~~and the CFL~~ release categories, there is a large margin in both the dose as well as the probability for meeting the Westinghouse design goal of limiting the frequency of exceeding the 25 rem whole-body effective dose equivalent for an individual at the site boundary 24 hours after core damage to 1×10^{-6} events per year, without any emergency protective action. For the other release categories: BP, CI, CFE ~~and~~ CFI, **and CFL** there is a large margin in the probability for meeting the Westinghouse design goal.

Results in Table 49-7 also show that for release categories IC, ~~CFL,~~ and the DIRECT sensitivity study, the acute red bone marrow dose at the site boundary in 24 hours is less than 1 rem. For all other release categories: BP, CI, CFE, ~~and~~ CFI, **and CFL** the mean dose at the site boundary in 24 hours is greater than 25 rem. Again, the sum of the probabilities of the release categories including an intact containment excess leakage category is approximately 2.4×10^{-7} events per year for at power conditions. Therefore, for the IC, ~~CFL,~~ and the DIRECT release categories, there is a large margin in both the dose as well as the probability for meeting the Westinghouse design goal of limiting the frequency of exceeding the 25 rem whole-body effective dose equivalent for an individual at the site boundary 24 hours after

core damage to $1x10^{-6}$ events per year, without any emergency protective action. For the other release categories: BP, CI, CFE ~~and~~ CFI, **and CFL** there is a large margin in the probability for meeting the Westinghouse design goal.

49.6 Quantification of Site Risk

This section documents the calculation of total radiation dose risk at the site boundary and to the surrounding population for internal, at power, initiating events. Results are quantified based on both a 24-hour and a 72-hour exposure.

The dose risks are quantified by multiplying the calculated fission product release category frequency vector by the release category mean dose vectors. The frequencies for each of the six release categories are quantified in Chapter 45, while the mean doses for each release category are identified in this section. The total dose risk for each case is calculated as:

$$D_n = \Sigma_i (R_i \times d_{i,n})$$

where:

D_n = Total dose risk for case n=1,2,3,4 (site-24-hr, site-72-hr, population-24-hr, population-72-hr),
R_i = Release frequency for category i,
$d_{i,n}$ = mean dose for release category i for case n.

As previously described, the six release categories analyzed in this calculation are designated: IC, BP, CI, CFI, CFE, and CFL.

Tables 49-8 through 49-11 present the results of the dose risk calculations. Each table presents the release category identifier, the release frequency (per reactor-year), the mean dose (in rem), and the resulting risk (in rem per reactor-year). In addition, each table presents the total dose risk and the percent that each release category contributes to the total risk.

It is shown that release category CFE presents the largest risk to the site safety in each of the four presented cases.

49.7 Risk Quantification Results

The complementary cumulative distribution function (CCDF) probabilities presented in Figures 49-1 through 49-56 are based on the assumption that the respective release category has occurred. The actual dose probability is equal to the probability of the release multiplied by the CCDF probability. Figure 49-57 summarizes this calculation for the 24 hour, whole-body, site boundary dose for all release categories, excluding the sensitivity study. Figure 49-58 summarizes this calculation for the 24 hour, acute red bone marrow, site boundary dose for all release categories, excluding the sensitivity study. In addition, a total probability-dose curve, which sums all the release categories, is provided. This figure demonstrates compliance with the large release goal (24 hour, whole-body, site boundary dose greater than 25 REM has a frequency of less than $1x10^{-6}$).

49.8 References

49-1 "Advanced Light Water Reactor Utility Requirements Document," Volume III, Appendix A to Chapter 1, PRA Key Assumptions and Groundrules," EPRI, Rev. 5 & 6, December 1993.

49-2 Chanin, D., Young, M. L., "Code Manual for MACCS2, User's Guide," NUREG/CR-6613, SAND97-0594, Vol. 1, Sandia National Laboratories, U.S. Nuclear Regulatory Commission.

49-3 "PRA Procedures Guide," NUREG/CR-2300, U.S. Nuclear Regulatory Commission, Vol. 2, Chapter 9, Washington, D.C.

Table 49-1

AP1000 SOURCE TERMS FROM LEVEL 2 ANALYSIS (MAAP)

Case No.	Plume No.	Start Time (Seconds)	End Time (Seconds)	Duration (Seconds)	Release Fraction (MAAP Group) 1 Inert	2 CsI	3 TeO2	4 SrO	5 MoO2	6 CsOH	7 BaO	8 La2O3	9 CeO2	10 Sb	11 Te2	12 UO2	Plume Energy (Joules/sec) (Watts)	Plume Position
CFI	1	2930	10100	7170	2.88E-01	5.09E-03	7.92E-03	4.77E-03	1.03E-02	5.07E-03	8.12E-03	1.56E-04	1.82E-04	8.89E-03	0.00E+00	0.00E+00	0.00E+00	Leading
	2	10100	89850	79750	4.69E-01	3.50E-03	4.99E-03	9.23E-03	6.62E-03	3.49E-03	9.15E-03	1.08E-03	1.09E-03	5.96E-03	0.00E+00	0.00E+00	0.00E+00	Midpoint
	3	89850	176200	86350	6.98E-02	6.00E-06	1.00E-05	4.20E-04	1.00E-05	6.00E-06	1.70E-04	5.84E-04	5.84E-04	4.00E-05	0.00E+00	0.00E+00	0 00E+00	Midpoint
	4	176200	262600	86400	2.35E-02	0.00E+00	1.00E-05	1.50E-04	4.00E-05	0.00E+00	8.00E-05	3.23E-04	3 21E-04	4.00E-05	0.00E+00	0.00E+00	0.00E+00	Midpoint
CFE	1	3004	19810	16806	4.16E-01	5.53E-02	3.01E-02	3.14E-03	1.16E-02	5.35E-02	4.63E-03	5.57E-05	2.39E-04	2.03E-02	0.00E+00	0.00E+00	0.00E+00	Leading
	2	19810	89970	70160	4.05E-01	1.26E-03	1.48E-03	3.43E-04	2.58E-03	1.20E-03	6.45E-04	9.66E-06	1.14E-05	2.66E-03	0.00E+00	0.00E+00	0.00E+00	Leading
	3	89970	176300	86330	1.08E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0 00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	176300	262700	86400	3.43E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	0.00E+00	Midpoint
DIRECT	1	4378	84810	80432	2.95E-03	3.61E-05	2.86E-05	3.22E-05	3.94E-05	3.44E-05	3.61E-05	4.04E-06	4.39E-06	3.99E-05	0.00E+00	0.00E+00	0.00E+00	Midpoint
	2	84810	134400	49590	1.48E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-08	2.40E-08	2.40E-07	0.00E+00	0.00E+00	0.00E+00	Leading
	3	134400	177600	43200	1.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-08	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	2.32E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-08	0.00E+00	0.00E+00	0.00E+00	Midpoint
IC	1	4378	84810	80432	9.83E-04	1.20E-05	9.53E-06	1.07E-05	1.31E-05	1.15E-05	1.20E-05	1.35E-06	1.46E-06	1.33E-05	0.00E+00	0.00E+00	0.00E+00	Midpoint
	2	84810	134400	49590	4.93E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E-09	8.00E-09	8.00E-08	0.00E+00	0.00E+00	0.00E+00	Leading
	3	134400	177600	43200	3.94E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-08	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	7.72E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-08	0.00E+00	0.00E+00	0.00E+00	Midpoint
BP	1	5984	22130	16146	6.32E-01	1.20E-02	1.85E-02	3.02E-04	4.97E-03	1.10E-02	7.91E-04	1.25E-05	3.52E-05	5.48E-02	0.00E+00	0.00E+00	0.00E+00	Midpoint
	2	22130	108500	86370	3.00E-04	5.00E-05	2.00E-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	0.00E+00	0.00E+00	Midpoint
	3	108500	194900	86400	4.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	194900	267800	72900	3.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
CI	1	101	50020	49919	5.73E-01	4.56E-02	2.12E-02	2.03E-02	4.04E-02	1.78E-02	3.16E-02	2.39E-04	7.42E-04	2.71E-02	0.00E+00	0.00E+00	0.00E+00	Midpoint
	2	50020	136400	86380	1.13E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-07	0.00E+00	1.90E-04	0.00E+00	0.00E+00	0.00E+00	Midpoint
	3	136400	211700	75300	5.66E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E-03	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	211700	259600	47900	2.74E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-04	0.00E+00	0.00E+00	0.00E+00	Midpoint
CFL	1	4353	23610	19257	7.51E-01	3.57E-02	4.36E-02	2.01E-03	9.90E-03	2.74E-02	3.02E-03	3.31E-05	1.60E-04	2.87E-02	1.14E-07	7.76E-10	0.00E+00	Midpoint
	2	23610	91280	67670	1.22E-01	9.30E-04	3.00E-05	0.00E+00	0.00E+00	2.70E-04	0.00E+00	0.00E+00	0 00E+00	2.90E-04	5.70E-09	2.00E-13	0.00E+00	Midpoint
	3	91280	177600	86320	6.93E-02	2.40E-04	3.00E-05	0 00E+00	0.00E+00	1.00E-04	0.00E+00	0.00E+00	0.00E+00	2.00E-04	1.00E-09	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	2.84E-02	1.00E-05	0.00E+00	0.00E+00	0.00E+00	1.00E-05	0.00E+00	0.00E+00	0.00E+00	1.20E-04	3.00E-10	0.00E+00	0.00E+00	Midpoint

Table 49-2

AP1000 SOURCE TERMS FOR DOSE EVALUATION (MACCS2)

Case No.	Plume No.	Start Time (Seconds)	End Time (Seconds)	Duration (Seconds)	Release Fraction (MACCS2 Group) 1 Inert	2 I	3 Cs	4 Te/Sb	5 Sr	6 Ru	7 La	8 Ce	9 Ba	Plume Energy Joules/sec (Watts)	Plume Position
CFI	1	2930	10100	7170	2.88E-01	5.09E-03	5.08E-03	5.14E-04	4.77E-03	1.03E-02	1.56E-04	6.04E-07	8.12E-03	0.00E+00	Leading
	2	10100	89850	79750	4.69E-01	3.50E-03	3.49E-03	3.45E-04	9.23E-03	6.62E-03	1.08E-03	3.61E-06	9.15E-03	0.00E+00	Midpoint
	3	89850	176200	86350	6.98E-02	6.00E-06	6.00E-06	2.31E-06	4.20E-04	1.00E-05	5.84E-04	1.94E-06	1.70E-04	0.00E+00	Midpoint
	4	176200	262600	86400	2.35E-02	0.00E+00	0.00E+00	2.31E-06	1.50E-04	4.00E-05	3.23E-04	1.06E-06	8.00E-05	0.00E+00	Midpoint
CFE	1	3004	19810	16806	4.16E-01	5.53E-02	5.37E-02	1.17E-03	3.14E-03	1.16E-02	5.57E-05	7.91E-07	4.63E-03	0.00E+00	Leading
	2	19810	89970	70160	4.05E-01	1.26E-03	1.21E-03	1.54E-04	3.43E-04	2.58E-03	9.66E-06	3.78E-08	6.45E-04	0.00E+00	Leading
	3	89970	176300	86330	1.08E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	176300	262700	86400	3.43E-02	0.00E+00	0.00E+00	5.78E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
DIRECT	1	4378	84810	80432	2.95E-03	3.61E-05	3.46E-05	2.31E-06	3.22E-05	3.94E-05	4.04E-06	1.45E-08	3.61E-05	0.00E+00	Midpoint
	2	84810	134400	49590	1.48E-03	0.00E+00	0.00E+00	1.39E-08	0.00E+00	0.00E+00	1.80E-08	7.95E-11	0.00E+00	0.00E+00	Leading
	3	134400	177600	43200	1.18E-03	0.00E+00	0.00E+00	3.47E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	2.32E-03	0.00E+00	0.00E+00	1.73E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
IC	1	4378	84810	80432	9.83E-04	1.20E-05	1.15E-05	7.69E-07	1.07E-05	1.31E-05	1.35E-06	4.85E-09	1.20E-05	0.00E+00	Midpoint
	2	84810	134400	49590	4.93E-04	0.00E+00	0.00E+00	4.62E-09	0.00E+00	0.00E+00	6.00E-09	2.65E-11	0.00E+00	0.00E+00	Leading
	3	134400	177600	43200	3.94E-04	0.00E+00	0.00E+00	1.16E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	7.72E-04	0.00E+00	0.00E+00	5.78E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
BP	1	5984	22130	16146	6.32E-01	1.20E-02	1.11E-02	3.17E-03	3.02E-04	4.97E-03	1.25E-05	1.17E-07	7.91E-04	0.00E+00	Midpoint
	2	22130	108500	86370	3.00E-04	5.00E-05	5.73E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	3	108500	194900	86400	4.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	194900	267800	72900	3.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
CI	1	101	50020	49919	5.73E-01	4.56E-02	2.10E-02	1.57E-03	2.03E-02	4.04E-02	2.39E-04	2.46E-06	3.16E-02	0.00E+00	Midpoint
	2	50020	136400	86380	1.13E-01	0.00E+00	0.00E+00	1.10E-05	0.00E+00	0.00E+00	1.00E-07	0.00E+00	0.00E+00	0.00E+00	Midpoint
	3	136400	211700	75300	5.66E-02	0.00E+00	0.00E+00	7.74E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	211700	259600	47900	2.74E-02	0.00E+00	0.00E+00	1.21E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
CFL	1	4353	23610	19257	7.51E-01	3.57E-02	2.84E-02	1.66E-03	2.01E-03	9.90E-03	3.31E-05	5.30E-07	3.02E-03	0.00E+00	Midpoint
	2	23610	91280	67670	1.22E-01	9.30E-04	3.46E-04	1.68E-05	0.00E+00	0.00E+00	0.00E+00	1.99E-13	0.00E+00	0.00E+00	Midpoint
	3	91280	177600	86320	6.93E-02	2.40E-04	1.16E-04	1.16E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint
	4	177600	264000	86400	2.84E-02	1.00E-05	1.00E-05	6.93E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	Midpoint

Table 49-3

SITE BOUNDARY WHOLE BODY DOSE (EFFECTIVE DOSE EQUIVALENT, EDE), SIEVERTS

24-hour Case Source Term	Quantiles						Peak Consequence
	Mean	50th	90th	95th	99th	99.5th	
CFI	3.25E+01	2.61E+01	7.11E+01	8.48E+01	NOT-FOUND	NOT-FOUND	9.29E+01
CFE	4.23E+01	2.22E+01	1.03E+02	1.35E+02	NOT-FOUND	NOT-FOUND	1.55E+02
DIRECT	5.48E-02	3.37E-02	1.36E-01	1.77E-01	NOT-FOUND	NOT-FOUND	2.37E-01
IC	1.82E-02	1.08E-02	4.84E-02	6.24E-02	NOT-FOUND	NOT-FOUND	7.88E-02
BP	1.15E+01	7.72E+00	3.15E+01	3.92E+01	NOT-FOUND	NOT-FOUND	4.39E+01
CI	5.10E+01	3.53E+01	1.24E+02	1.55E+02	NOT-FOUND	NOT-FOUND	2.27E+02
CFL	2.58E+01	2.10E+01	5.39E+01	6.47E+01	7.52E+01	7.81E+01	9.23E+01
72-hour Case Source Term	**Quantiles**						**Peak Consequence**
	Mean	**50th**	**90th**	**95th**	**99th**	**99.5th**	
CFI	3.49E+01	3.01E+01	7.12E+01	8.74E+01	NOT-FOUND	NOT-FOUND	9.71E+01
CFE	4.60E+01	2.31E+01	1.16E+02	1.47E+02	NOT-FOUND	NOT-FOUND	1.67E+02
DIRECT	6.09E-02	3.67E-02	1.66E-01	2.27E-01	NOT-FOUND	NOT-FOUND	2.56E-01
IC	2.21E-02	1.31E-02	5.73E-02	7.96E-02	NOT-FOUND	NOT-FOUND	8.97E-02
BP	1.23E+01	8.02E+00	3.18E+01	4.09E+01	NOT-FOUND	NOT-FOUND	4.66E+01
CI	5.40E+01	3.75E+01	1.39E+02	1.89E+02	NOT-FOUND	NOT-FOUND	2.38E+02
CFL	2.80E+01	2.13E+01	6.32E+01	7.12E+01	7.86E+01	8.20E+01	9.92E+01

Table 49-4

SITE BOUNDARY THYROID DOSE, SIEVERTS

24-hour Case Source Term	Quantiles						Peak Consequence
	Mean	50th	90th	95th	99th	99.5th	
CFI	5.67E+01	5 09E+01	1.14E+02	1.44E+02	NOT-FOUND	NOT-FOUND	1.62E+02
CFE	3.59E+02	2 02E+02	1.01E+03	1.18E+03	NOT-FOUND	NOT-FOUND	1.28E+03
DIRECT	1.34E-01	8.58E-02	3.55E-01	4.48E-01	NOT-FOUND	NOT-FOUND	5.23E-01
IC	4.47E-02	3.08E-02	1.20E-01	1.54E-01	NOT-FOUND	NOT-FOUND	1.74E-01
BP	7.71E+01	5.40E+01	2 04E+02	2.23E+02	2.73E+02	NOT-FOUND	2.73E+02
CI	1.82E+02	1.23E+02	4.58E+02	5.74E+02	NOT-FOUND	NOT-FOUND	7.30E+02
CFL	2.20E+02	1 68E+02	5 34E+02	6.39E+02	7.07E+02	7.11E+02	7.30E+02
72-hour Case Source Term	**Quantiles**						**Peak Consequence**
	Mean	**50th**	**90th**	**95th**	**99th**	**99.5th**	
CFI	6.14E+01	5.26E+01	1.23E+02	1.54E+02	NOT-FOUND	NOT-FOUND	1.73E+02
CFE	3.81E+02	2.11E+02	1.02E+03	1.23E+03	NOT-FOUND	NOT-FOUND	1.36E+03
DIRECT	1.56E-01	1.05E-01	4.20E-01	5.47E-01	NOT-FOUND	NOT-FOUND	5.94E-01
IC	5.65E-02	3.86E-02	1.33E-01	1.76E-01	NOT-FOUND	NOT-FOUND	2 09E-01
BP	8.19E+01	5 64E+01	2.10E+02	2.60E+02	NOT-FOUND	NOT-FOUND	2.89E+02
CI	1.98E+02	1.40E+02	4.70E+02	5.79E+02	NOT-FOUND	NOT-FOUND	7.90E+02
CFL	2.35E+02	2.08E+02	5.34E+02	6.39E+02	7.18E+02	7.29E+02	7.76E+02

Table 49-5

POPULATION WHOLE BODY DOSE (EFFECTIVE DOSE EQUIVALENT, EDE), 0-80.5 KM PERSON-SIEVERTS

24-hour Case Source Term	Quantiles						Peak Consequence
	Mean	50th	90th	95th	99th	99.5th	
CFI	7.88E+03	6.11E+03	1.47E+04	2.01E+04	3.21E+04	3.51E+04	5.34E+04
CFE	8.51E+03	6.25E+03	1.62E+04	2.31E+04	4.13E+04	5.06E+04	6.40E+04
DIRECT	2.16E+01	1.20E+01	4.78E+01	8.13E+01	1.14E+02	1.23E+02	1.68E+02
IC	7.19E+00	4.21E+00	1.71E+01	2.95E+01	3.56E+01	3.84E+01	5.60E+01
BP	2.91E+03	1.74E+03	5.90E+03	1.00E+04	1.52E+04	1.81E+04	2.58E+04
CI	2.01E+04	1.13E+04	4.71E+04	6.60E+04	1.23E+05	1.48E+05	1.61E+05
CFL	5.32E+03	3.87E+03	1.04E+04	1.35E+04	2.32E+04	2.77E+04	4.35E+04
72-hour Case Source Term	**Quantiles**						**Peak Consequence**
	Mean	**50th**	**90th**	**95th**	**99th**	**99.5th**	
CFI	8.89E+03	6.89E+03	1.63E+04	2.21E+04	3.42E+04	3.84E+04	5.73E+04
CFE	9.36E+03	6.89E+03	1.88E+04	2.54E+04	4.25E+04	5.12E+04	6.77E+04
DIRECT	2.45E+01	1.43E+01	5.50E+01	8.33E+01	1.16E+02	1.26E+02	1.78E+02
IC	8.80E+00	5.57E+00	1.98E+01	3.14E+01	4.41E+01	5.03E+01	6.33E+01
BP	3.11E+03	1.85E+03	6.31E+03	1.03E+04	1.54E+04	1.82E+04	2.69E+04
CI	2.14E+04	1.25E+04	4.90E+04	7.40E+04	1.27E+05	1.53E+05	1.67E+05
CFL	5.84E+03	4.32E+03	1.12E+04	1.48E+04	2.53E+04	3.04E+04	4.62E+04

Table 49-6

SITE BOUNDARY RED MARROW DOSE (TOTAL ACUTE), SIEVERTS

24-hour Case Source Term	Quantiles						Peak Consequence
	Mean	50th	90th	95th	99th	99.5th	
CFI	2.80E+00	1.89E+00	7.07E+00	7.93E+00	NOT-FOUND	NOT-FOUND	8.41E+00
CFE	7.81E+00	4.83E+00	2.01E+01	2.07E+01	2.22E+01	2.29E+01	2.70E+01
DIRECT	2.47E-03	1.49E-03	6.40E-03	8.69E-03	1.01E-02	1.01E-02	1.03E-02
IC	8.22E-04	5.34E-04	2.09E-03	2.67E-03	3.10E-03	3.15E-03	3.42E-03
BP	1.53E+00	1.09E+00	3.48E+00	4.77E+00	NOT-FOUND	NOT-FOUND	5.32E+00
CI	2.46E+00	1.67E+00	6.13E+00	7.72E+00	1.00E+01	NOT-FOUND	1.00E+01
CFL	3.01E+00	2.28E+00	6.38E+00	7.12E+00	7.86E+00	8.20E+00	9.90E+00
72-hour Case Source Term	**Quantiles**						**Peak Consequence**
	Mean	**50th**	**90th**	**95th**	**99th**	**99.5th**	
CFI	3.70E+00	3.14E+00	7.52E+00	9.09E+00	1.04E+01	1.07E+01	1.19E+01
CFE	1.02E+01	5.68E+00	3.01E+01	3.11E+01	3.36E+01	3.48E+01	4.17E+01
DIRECT	5.70E-03	4.48E-03	1.06E-02	1.13E-02	1.33E-02	1.43E-02	2.09E-02
IC	2.78E-03	2.44E-03	5.59E-03	7.00E-03	7.52E-03	7.76E-03	9.02E-03
BP	2.04E+00	1.28E+00	5.30E+00	6.75E+00	NOT-FOUND	NOT-FOUND	7.00E+00
CI	4.23E+00	3.13E+00	1.01E+01	1.08E+01	1.26E+01	1.34E+01	1.70E+01
CFL	4.34E+00	3.31E+00	9.35E+00	1.03E+01	1.13E+01	1.18E+01	1.42E+01

Table 49-7

DOSE SUMMARY

	Population Dose (Sieverts)				Site Boundary Whole Body Dose (Sieverts)				Site Boundary Thyroid Dose (Sieverts)				Site Boundary Red Marrow Dose Sieverts)			
	24-Hour		72-Hour		24-Hour		72-Hour		24-Hour		72-Hour		24-Hour		72-Hour	
	Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak
CFI	7.88E+03	5 34E+04	8 89E+03	5.73E+04	3 25E+01	9 29E+01	3 49E+01	9.71E+01	5.67E+01	1 62E+02	6.14E+01	1.73E+02	2 80E+00	8 41E+00	3 70E+00	1.19E+01
CFE	8 51E+03	6.40E+04	9 36E+03	6 77E+04	4.23E+01	1.55E+02	4 60E+01	1 67E+02	3 59E+02	1.28E+03	3 81E+02	1.36E+03	7.81E+00	2 70E+01	1.02E+01	4.17E+01
DIRECT	2.16E+01	1 68E+02	2.45E+01	1.78E+02	5 48E-02	2 37E-01	6 09E-02	2.56E-01	1.34E-01	5 23E-01	1.56E-01	5.94E-01	2 47E-03	1.03E-02	5 70E-03	2 09E-02
IC	7 19E+00	5.60E+01	8 80E+00	6 33E+01	1 82E-02	7 88E-02	2 21E-02	8 97E-02	4 47E-02	1.74E-01	5 65E-02	2.09E-01	8.22E-04	3 42E-03	2.78E-03	9 02E-03
BP	2.91E+03	2 58E+04	3.11E+03	2 69E+04	1.15E+01	4 39E+01	1 23E+01	4 66E+01	7.71E+01	2.73E+02	8.19E+01	2.89E+02	1 53E+00	5.32E+00	2 04E+00	7 00E+00
CI	2.01E+04	1.61E+05	2 14E+04	1.67E+05	5.10E+01	2.27E+02	5 40E+01	2.38E+02	1 82E+02	7.30E+02	1.98E+02	7 90E+02	2.46E+00	1 00E+01	4 23E+00	1.70E+01
CFL	5.32E+03	4.35E+04	5.84E+03	4 62E+04	2 58E+01	9 23E+01	2 80E+01	9 92E+01	2.20E+02	7.30E+02	2.35E+02	7.76E+02	3 01E+00	9.90E+00	4.34E+00	1 42E+01

Table 49-8

SITE BOUNDARY WHOLE BODY EDE DOSE RISK – 24 HOURS

Release Category	Release Frequency (/reactor year)	Mean Dose (sieverts)	Dose (REM)	Risk (REM/reactor year)	Percent Contribution to Total Risk
CFI	1.89E-10	3.25E+01	3.25E+03	6.14E-07	1.2%
CFE	7.47E-09	4.23E+01	4.23E+03	3.16E-05	61.4%
IC	2.21E-07	1.82E-02	1.82E+00	4.02E-07	0.8%
BP	1.05E-08	1.15E+01	1.15E+03	1.21E-05	23.5%
CI	1.33E-09	5.10E+01	5.10E+03	6.78E-06	13.2%
CFL	3.45E-13	2.58E+01	2.58E+03	8.90E-10	0.0%
			Total Risk =	5.150E-05	100.0%

Table 49-9

SITE BOUNDARY WHOLE BODY EDE DOSE RISK – 72 HOURS

Release Category	Release Frequency (/reactor year)	Mean Dose (sieverts)	Dose (REM)	Risk (REM/reactor year)	Percent Contribution to Total Risk
CFI	1.89E-10	3.49E+01	3.49E+03	6.60E-07	1.2%
CFE	7.47E-09	4.60E+01	4.60E+03	3.44E-05	61.8%
IC	2.21E-07	2.21E-02	2.21E+00	4.88E-07	0.9%
BP	1.05E-08	1.23E+01	1.23E+03	1.29E-05	23.2%
CI	1.33E-09	5.40E+01	5.40E+03	7.18E-06	12.9%
CFL	3.45E-13	2.80E+01	2.80E+03	9.66E-10	0.0%
			Total Risk =	5.56E-05	100.0%

Table 49-10

POPULATION WHOLE BODY EDE DOSE RISK – 24 HOURS

Release Category	Release Frequency (/reactor year)	Mean Dose (person-sieverts)	Dose (person-REM)	Risk (person-REM/ reactor year)	Percent Contribution to Total Risk
CFI	1.89E-10	7.88E+03	7.88E+05	1.49E-04	1.2%
CFE	7.47E-09	8.51E+03	8.51E+05	6.36E-03	51.3%
IC	2.21E-07	7.19E+00	7.19E+02	1.59E-04	1.3%
BP	1.05E-08	2.91E+03	2.91E+05	3.06E-03	24.7%
CI	1.33E-09	2.01E+04	2.01E+06	2.67E-03	21.6%
CFL	3.45E-13	5.32E+03	5.32E+05	1.84E-07	0.0%
			Total Risk =	1.24E-02	100.0%

Table 49-11

POPULATION WHOLE BODY EDE DOSE RISK – 72 HOURS

Release Category	Release Frequency (/reactor year)	Mean Dose (person-sieverts)	Dose (person-REM)	Risk (person-REM/ reactor year)	Percent Contribution to Total Risk
CFI	1.89E-10	8.89E+03	8.89E+05	1.68E-04	1.2%
CFE	7.47E-09	9.36E+03	9.36E+05	6.99E-03	51.9%
IC	2.21E-07	8.80E+00	8.80E+02	1.94E-04	1.4%
BP	1.05E-08	3.11E+03	3.11E+05	3.27E-03	24.2%
CI	1.33E-09	2.14E+04	2.14E+06	2.85E-03	21.1%
CFL	3.45E-13	5.84E+03	5.84E+05	2.01E-07	0.0%
			Total Risk =	1.35E-02	100.0%

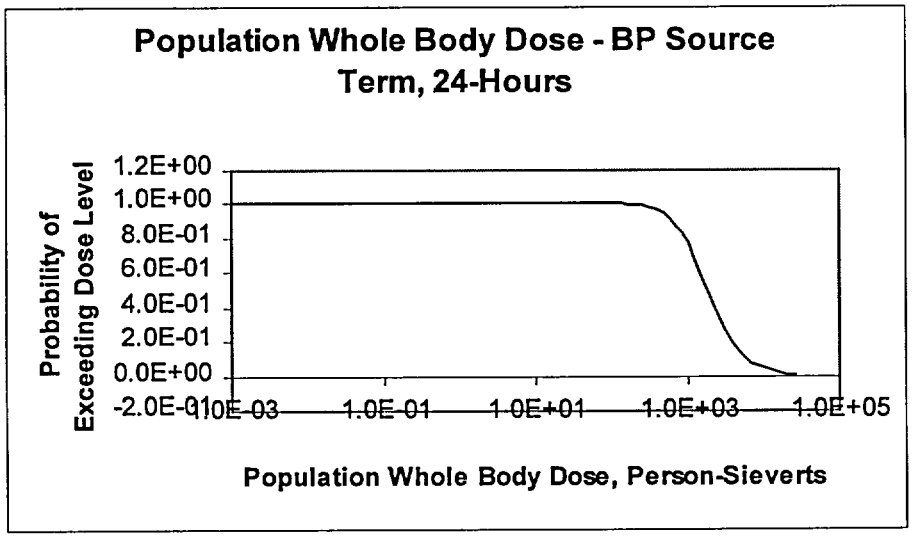


Figure 49-1

Population Whole Body Dose – BP Source Term, 24 Hours

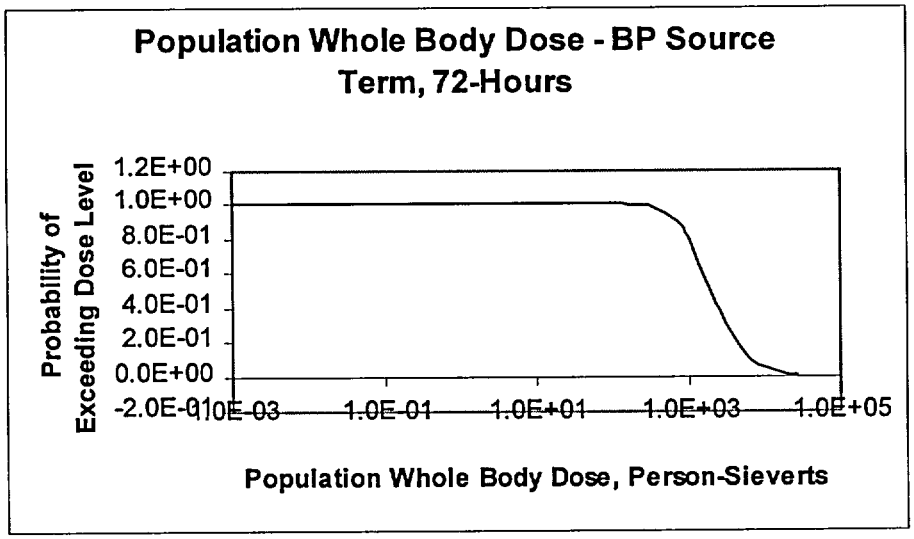


Figure 49-2

Population Whole Body Dose – BP Source Term 72 Hours

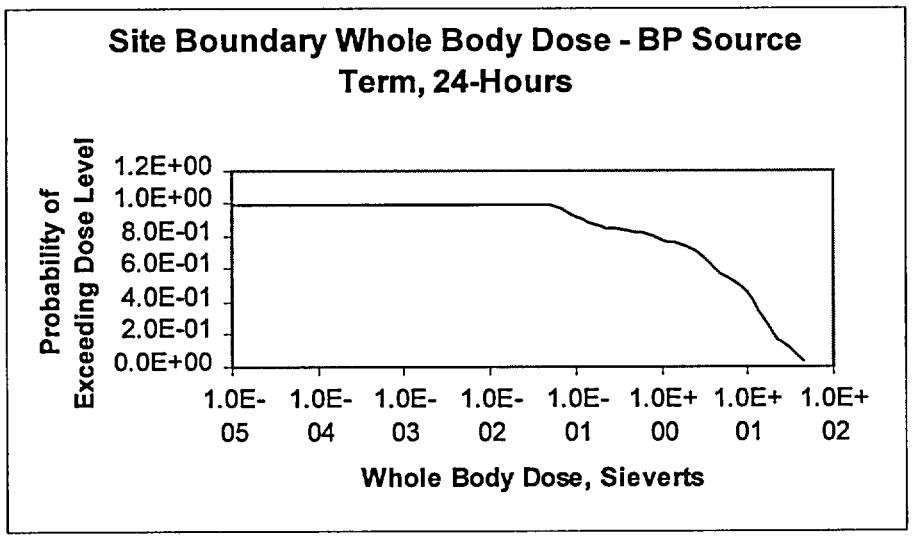


Figure 49-3

Site Boundary Whole Body Dose – BP Source Term, 24 Hours

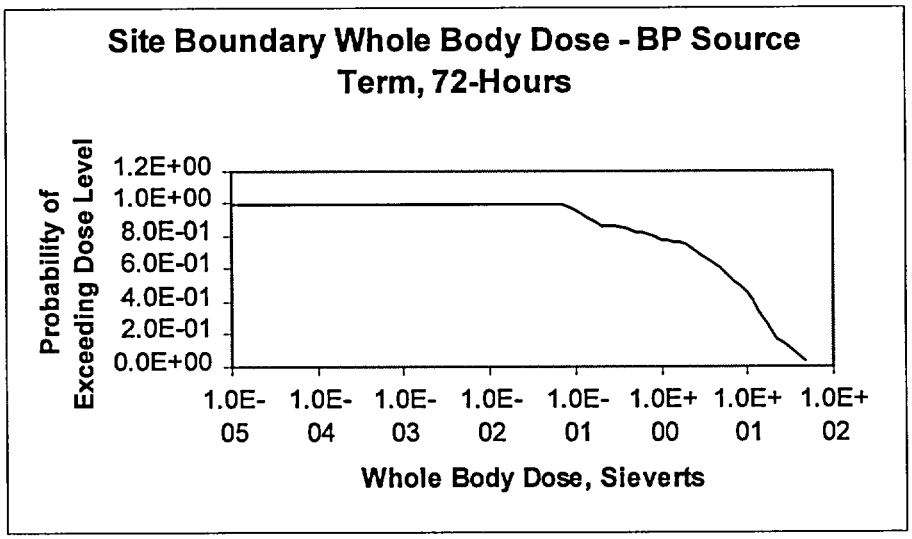


Figure 49-4

Site Boundary Whole Body Dose – BP Source Term, 72 Hours

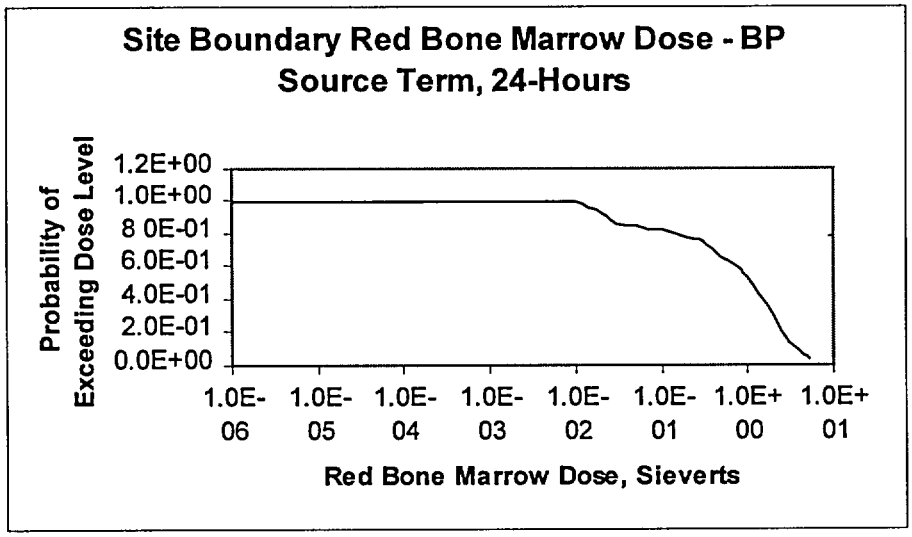


Figure 49-5

Site Boundary Red Bone Marrow Dose – BP Source Term, 24 Hours

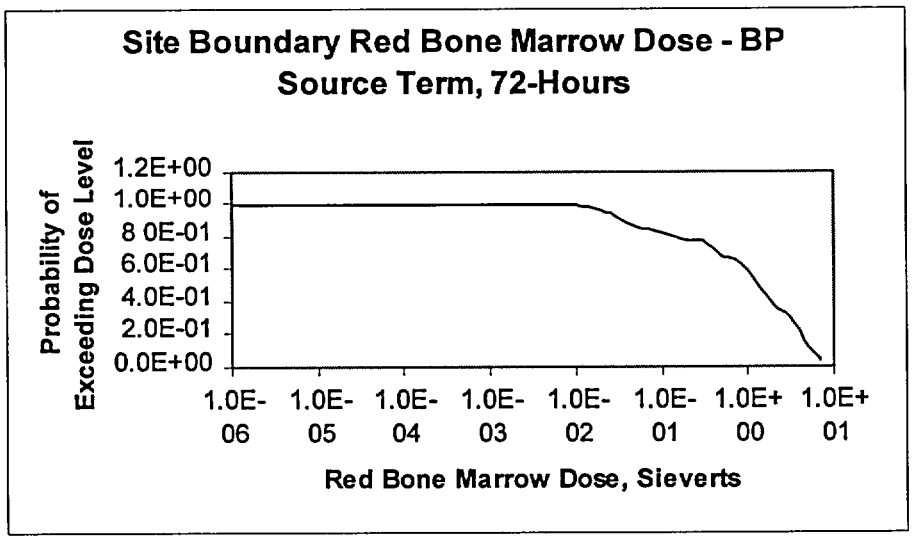


Figure 49-6

Site Boundary Red Bone Marrow Dose – BP Source Term, 72 Hours

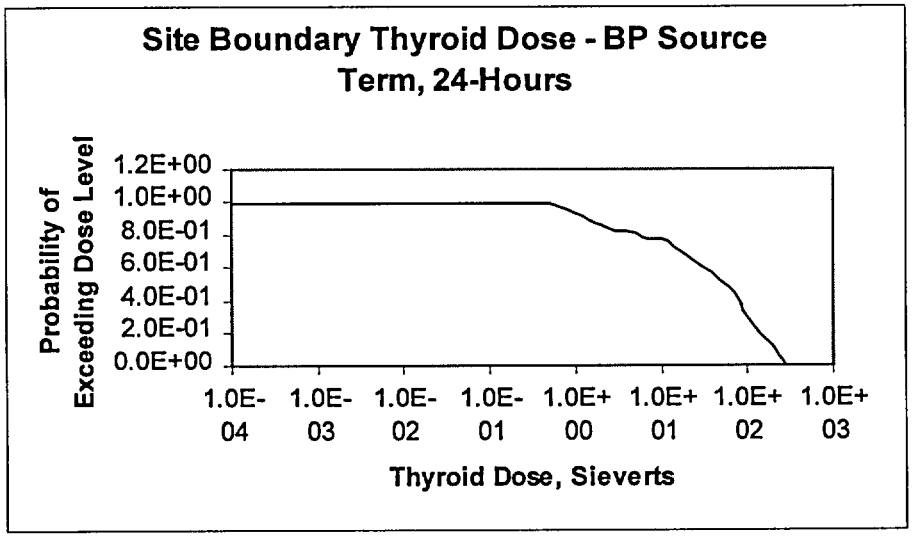


Figure 49-7

Site Boundary Thyroid Dose – BP Source Term, 24 Hours

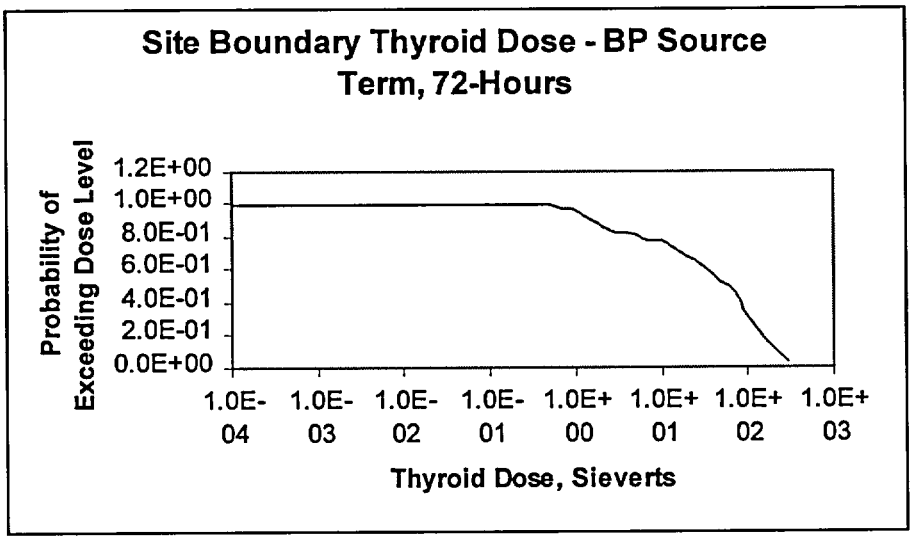


Figure 49-8

Site Boundary Thyroid Dose – BP Source Term, 72 Hours

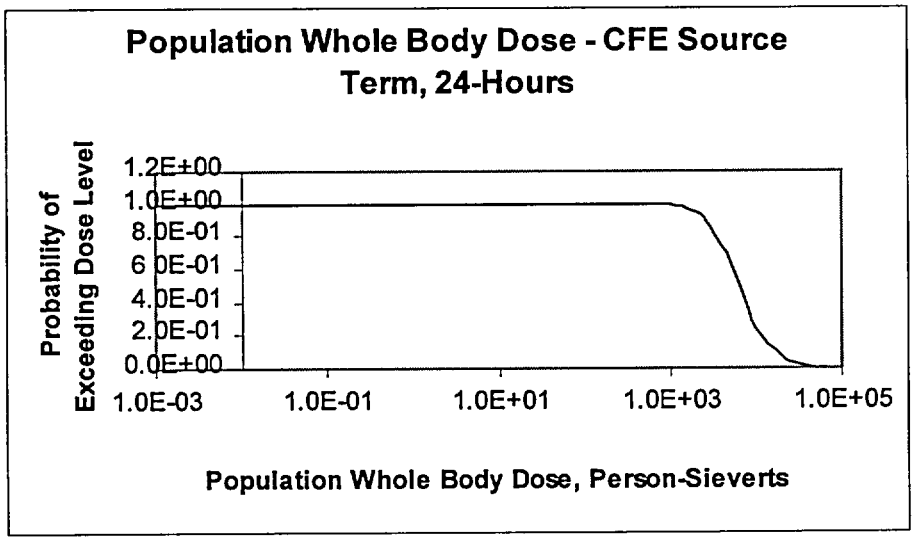


Figure 49-9

Population Whole Body Dose – CFE Source Term, 24 Hours

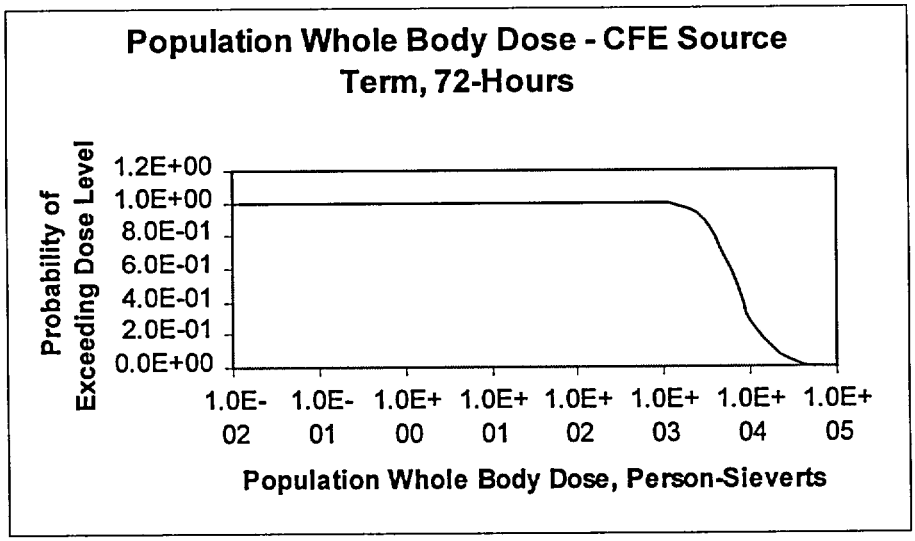


Figure 49-10

Population Whole Body Dose – CFE Source Term, 72 Hours

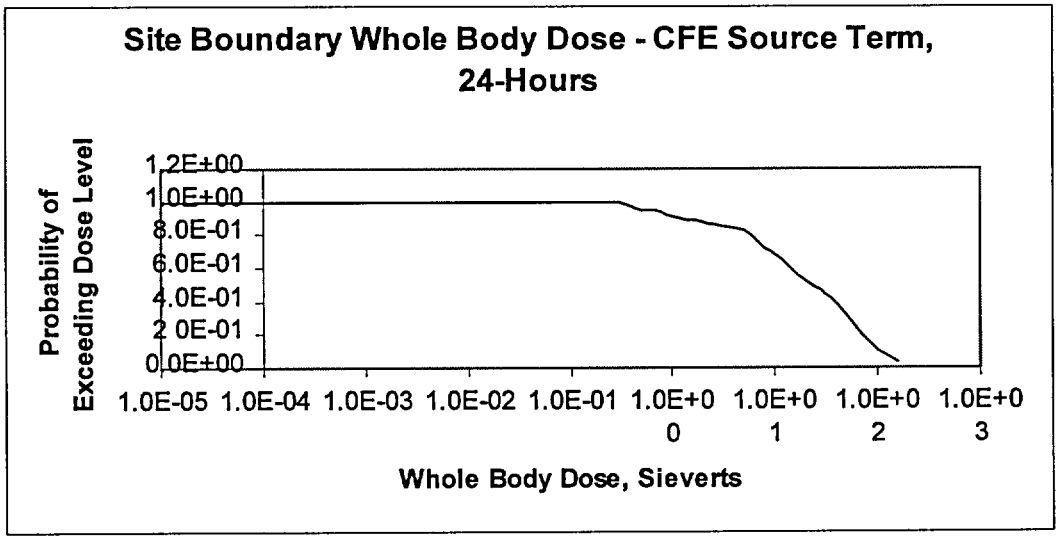


Figure 49-11

Site Boundary Whole Body Dose – CFE Source Term, 24 Hours

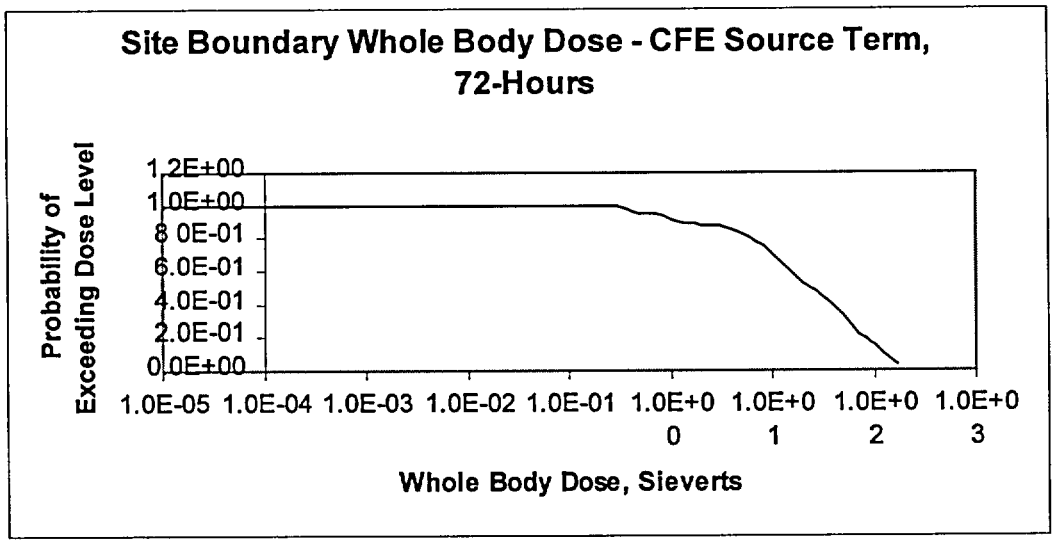


Figure 49-12

Site Boundary Whole Body Dose – CFE Source Term, 72 Hours

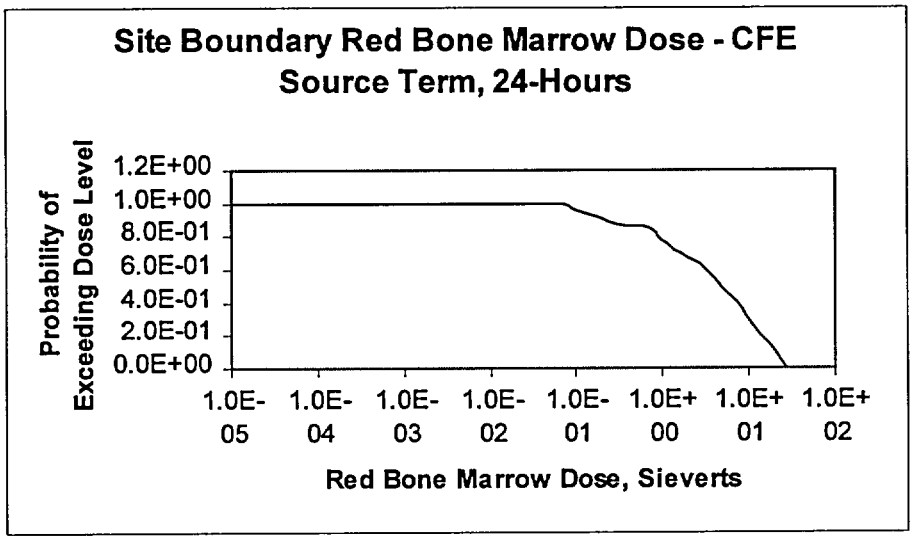


Figure 49-13

Site Boundary Red Bone Marrow Dose – CFE Source Term, 24 Hours

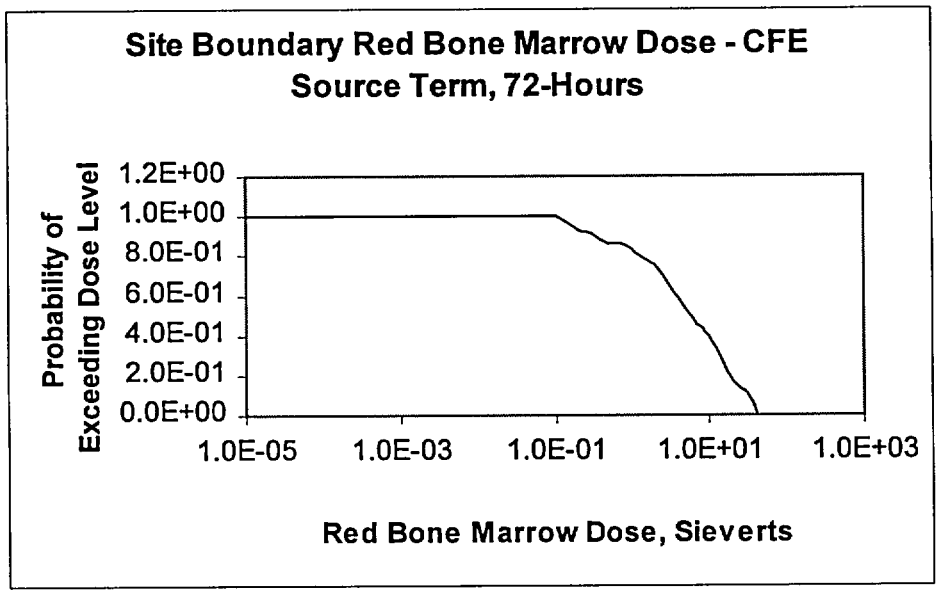


Figure 49-14

Site Boundary Red Bone Marrow Dose – CFE Source Term, 72 Hours

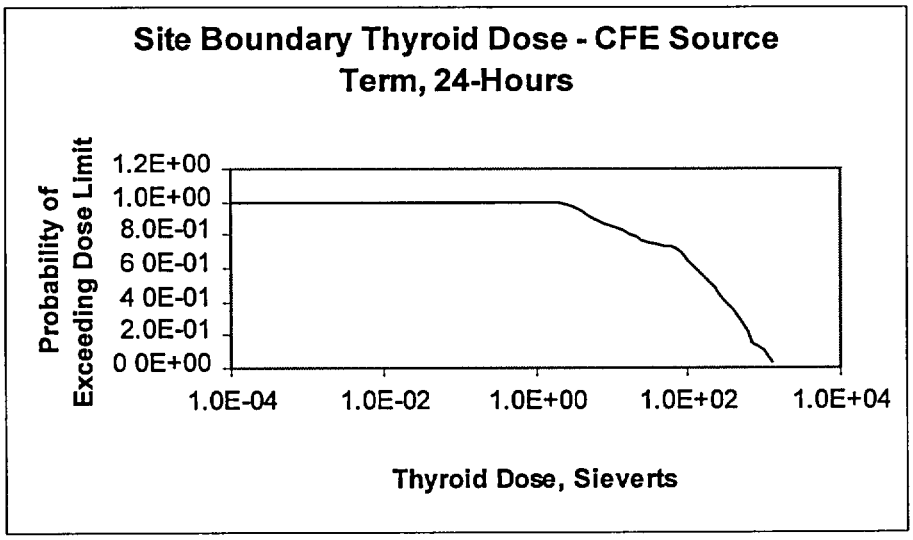


Figure 49-15

Site Boundary Thyroid Dose – CFE Source Term, 24 Hours

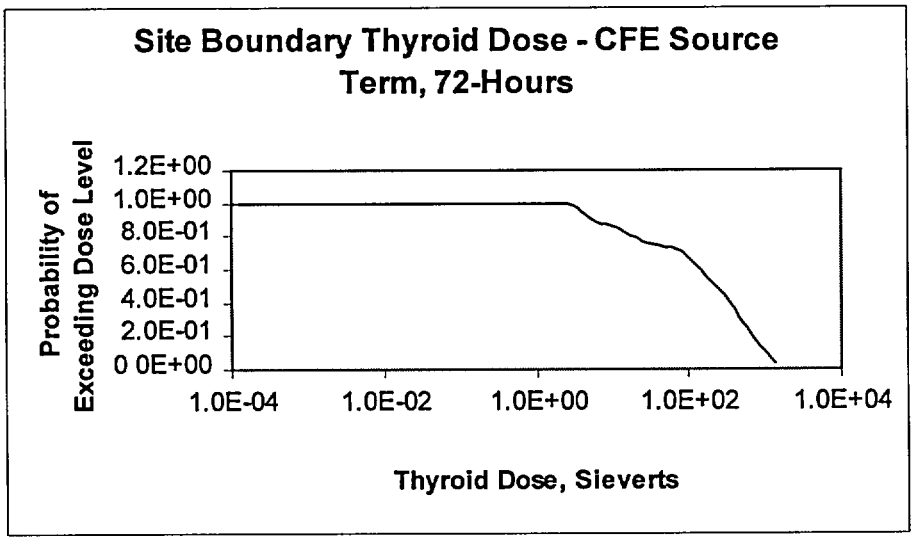


Figure 49-16

Site Boundary Thyroid Dose – CFE Source Term, 72 Hours

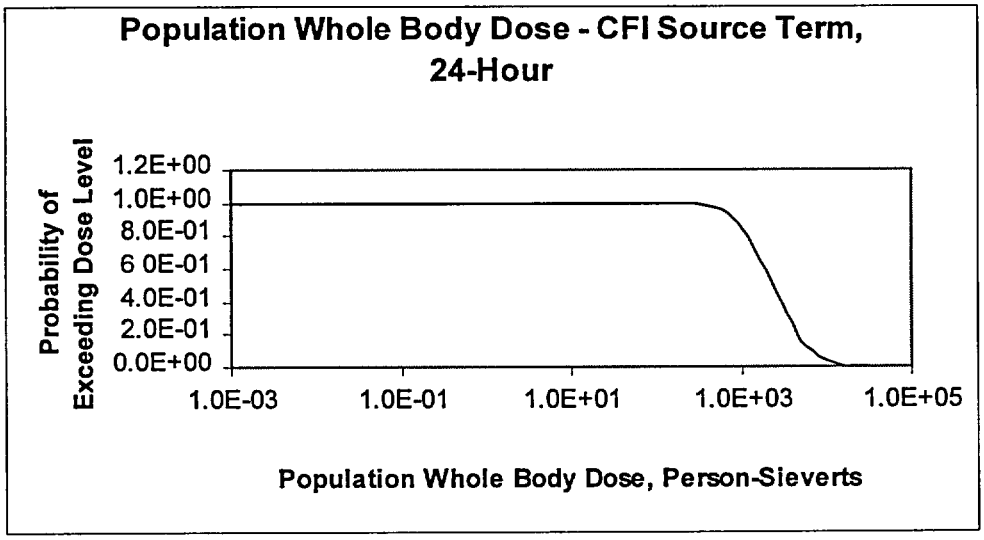


Figure 49-17

Population Whole Body Dose – CFI Source Term, 24 Hours

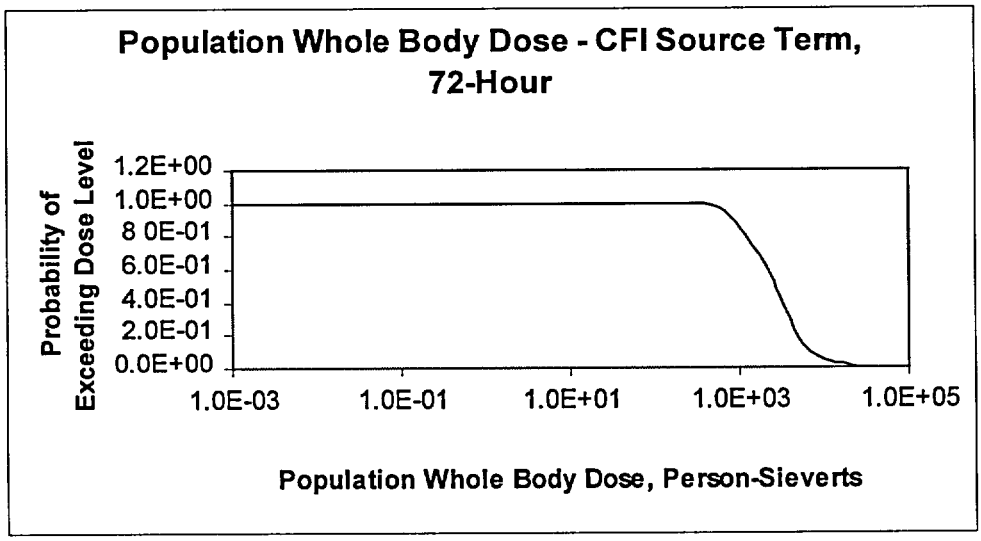


Figure 49-18

Population Whole Body Dose – CFI Source Term, 72 Hours

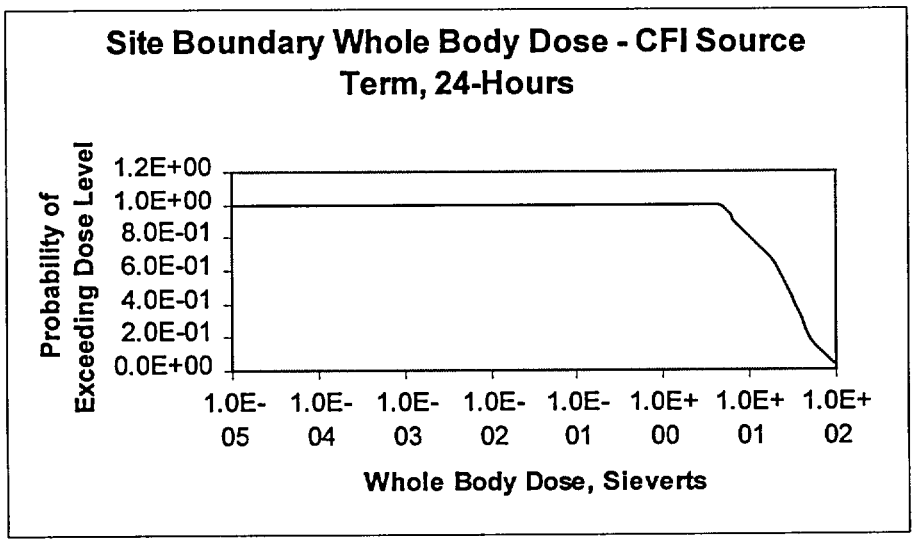


Figure 49-19

Site Boundary Whole Body Dose – CFI Source Term, 24 Hours

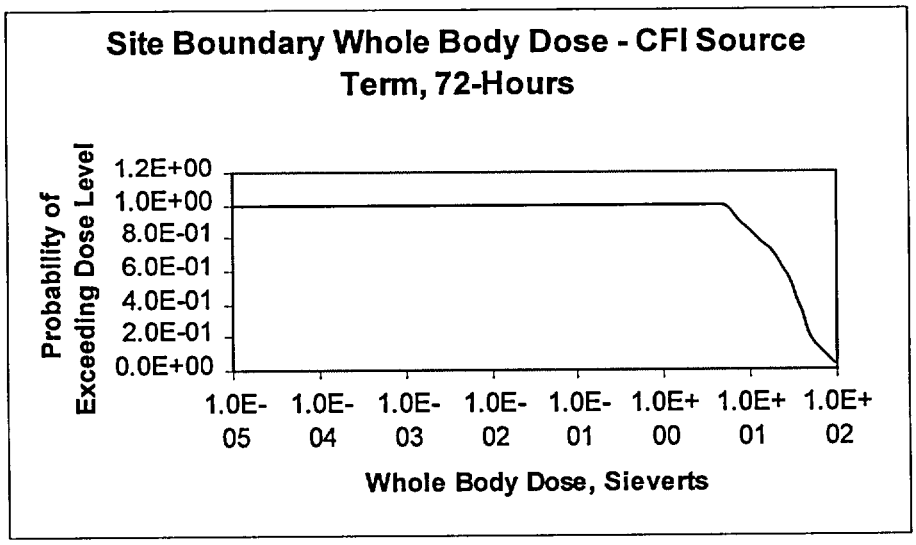


Figure 49-20

Site Boundary Whole Body Dose – CFI Source Term, 72 Hours

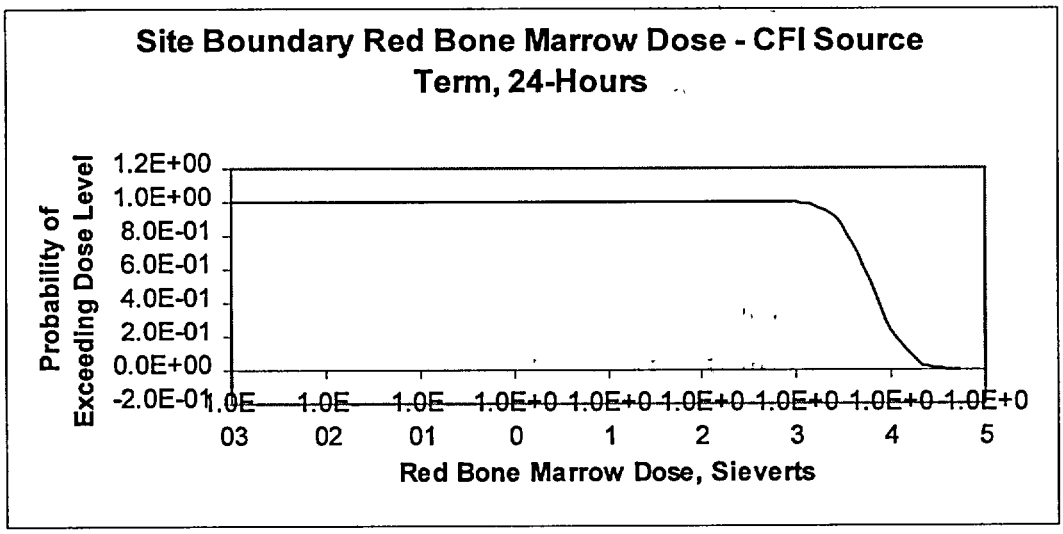


Figure 49-21

Site Boundary Red Bone Marrow Dose – CFI Source Term, 24 Hours

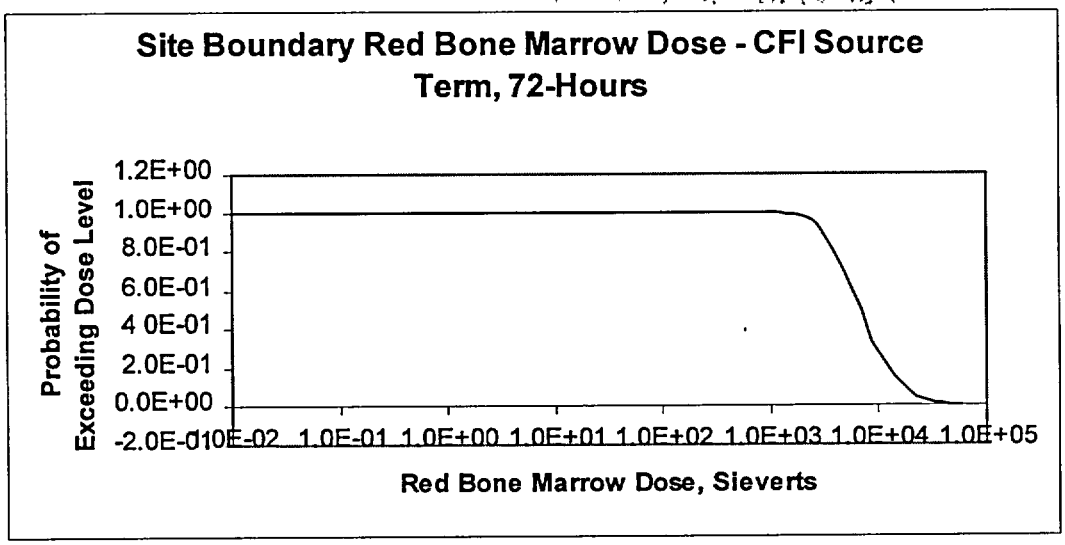


Figure 49-22

Site Boundary Red Bone Marrow Dose – CFI Source Term, 72 Hours

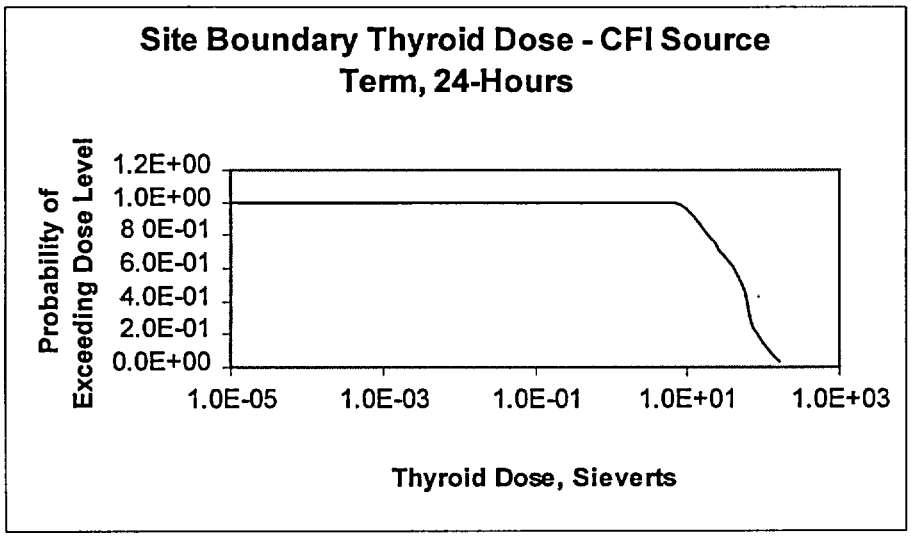


Figure 49-23

Site Boundary Thyroid Dose – CFI Source Term, 24 Hours

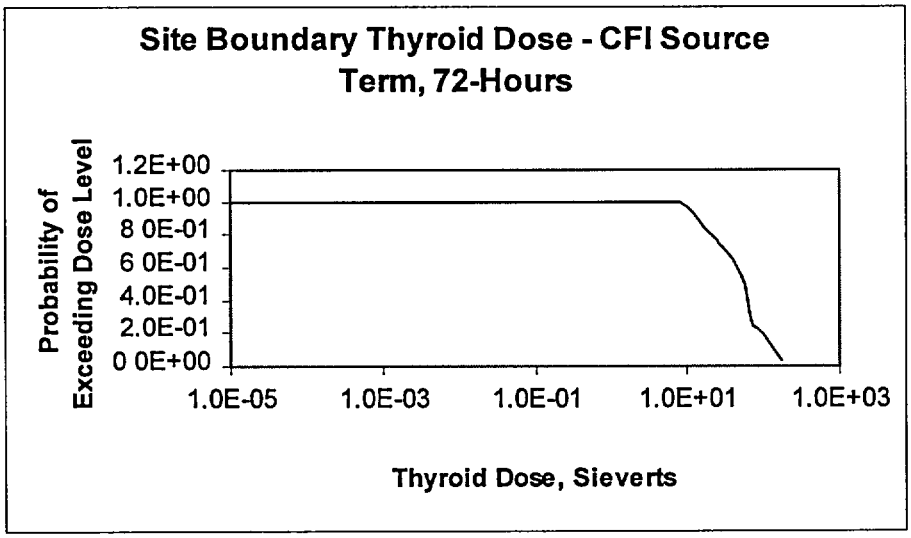


Figure 49-24

Site Boundary Thyroid Dose – CFI Source Term, 72 Hours

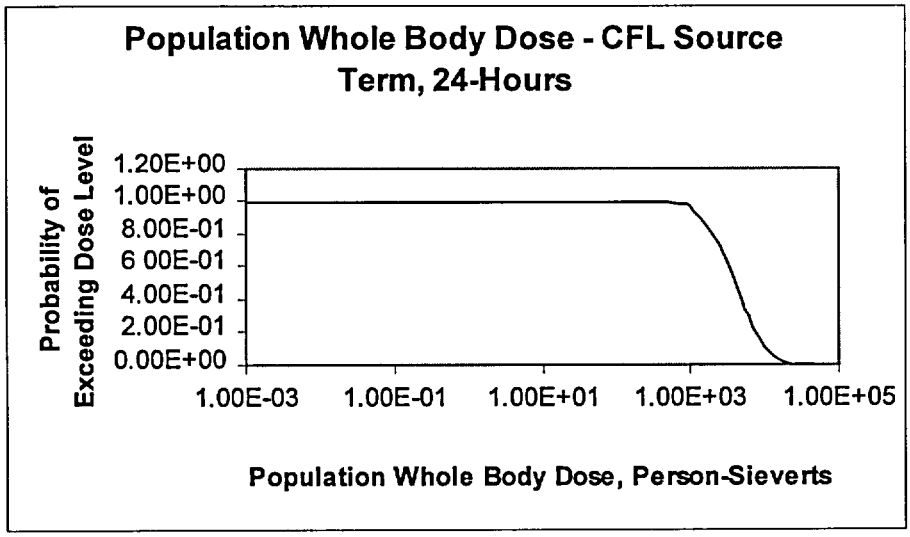


Figure 49-25

Population Whole Body Dose – CFL Source Term, 24 Hours

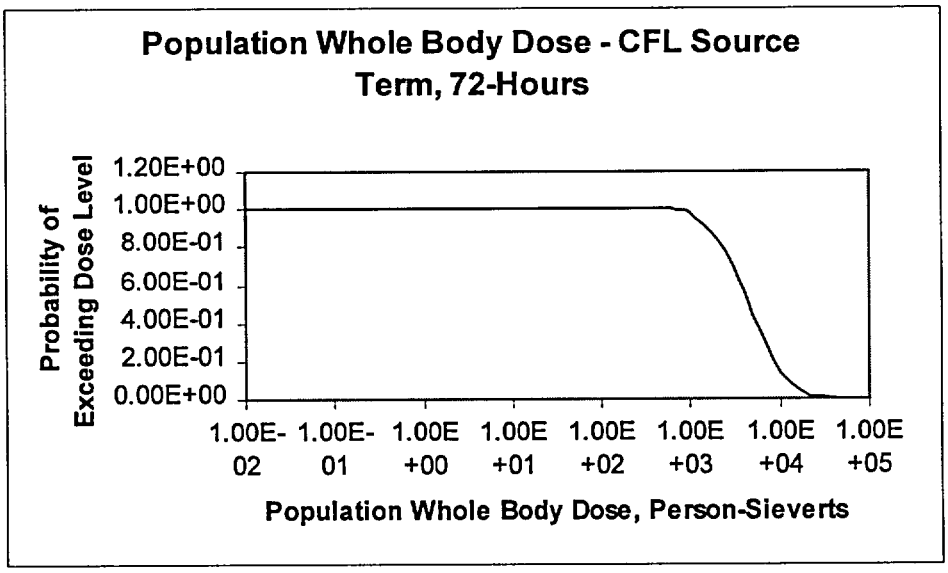


Figure 49-26

Population Whole Body Dose – CFL Source Term, 72 Hours

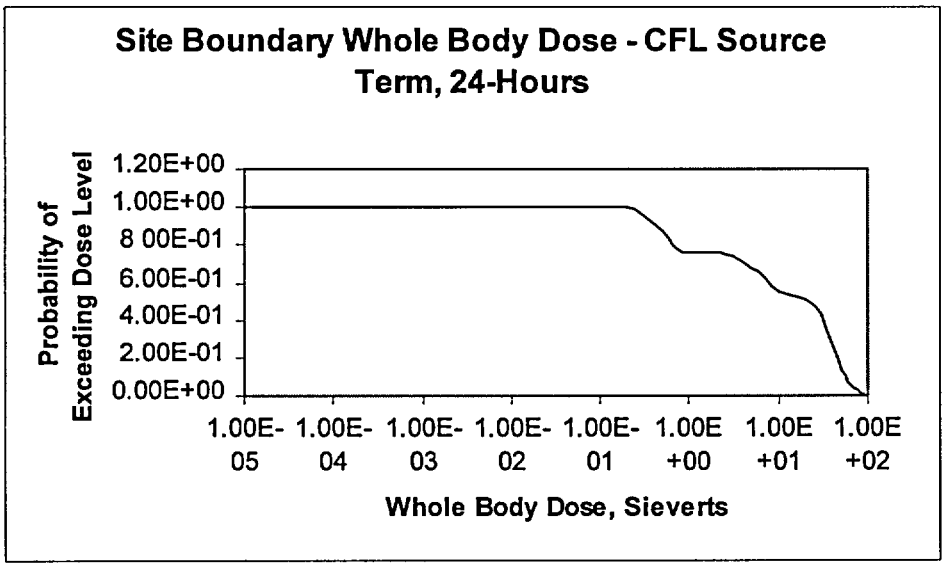


Figure 49-27

Site Boundary Whole Body Dose – CFL Source Term, 24 Hours

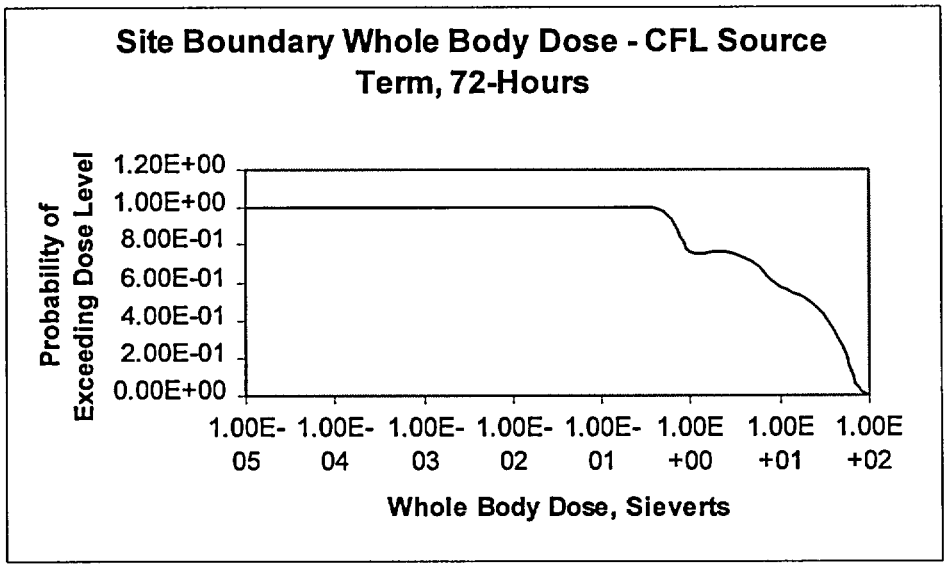


Figure 49-28

Site Boundary Whole Body Dose – CFL Source Term, 72 Hours

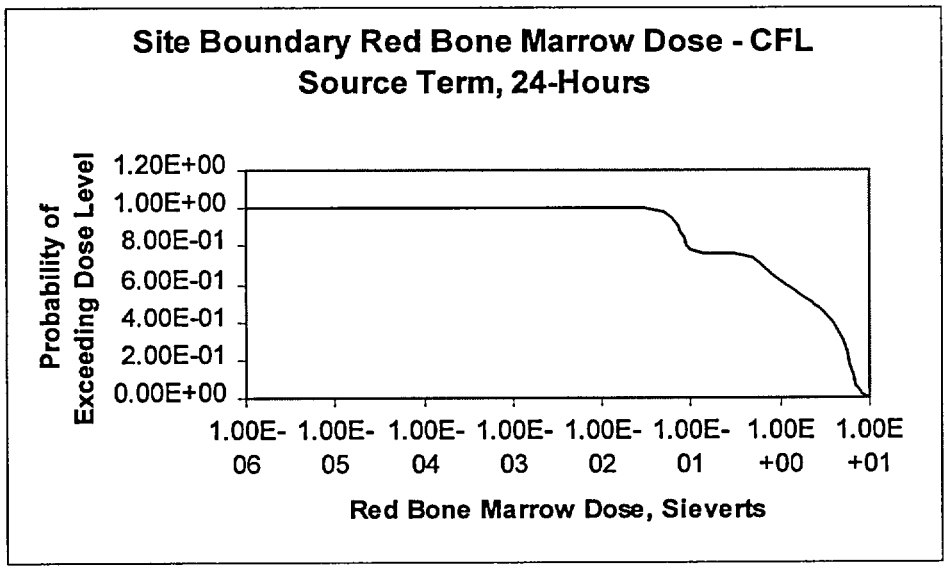


Figure 49-29

Site Boundary Red Bone Marrow Dose – CFL Source Term, 24 Hours

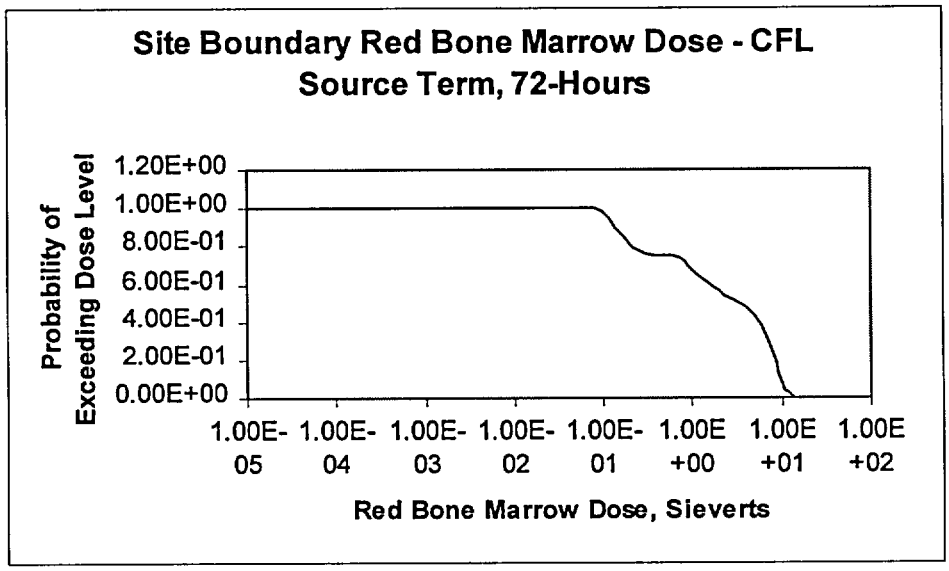


Figure 49-30

Site Boundary Red Bone Marrow Dose – CFL Source Term, 72 Hours

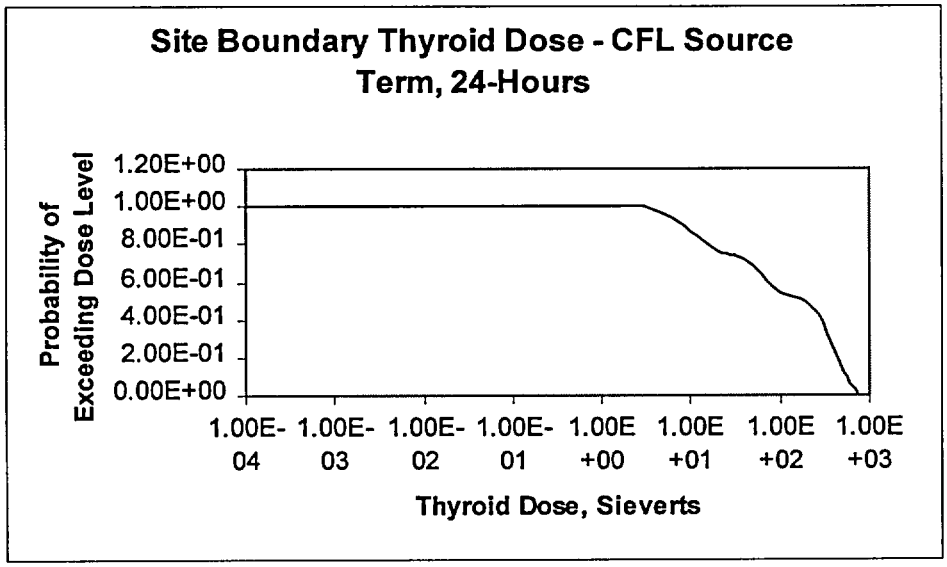


Figure 49-31

Site Boundary Thyroid Dose – CFL Source Term, 24 Hours

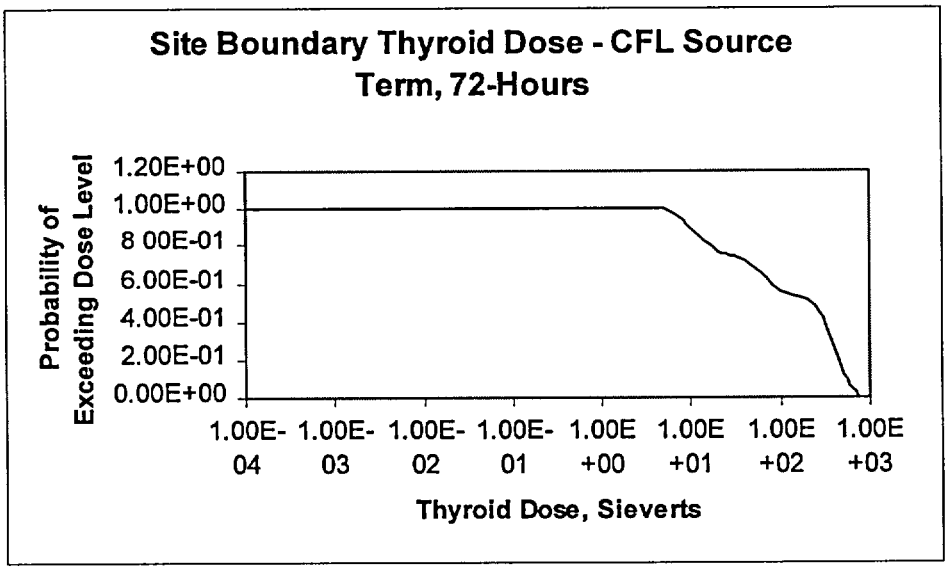


Figure 49-32

Site Boundary Thyroid Dose – CFL Source Term, 72 Hours

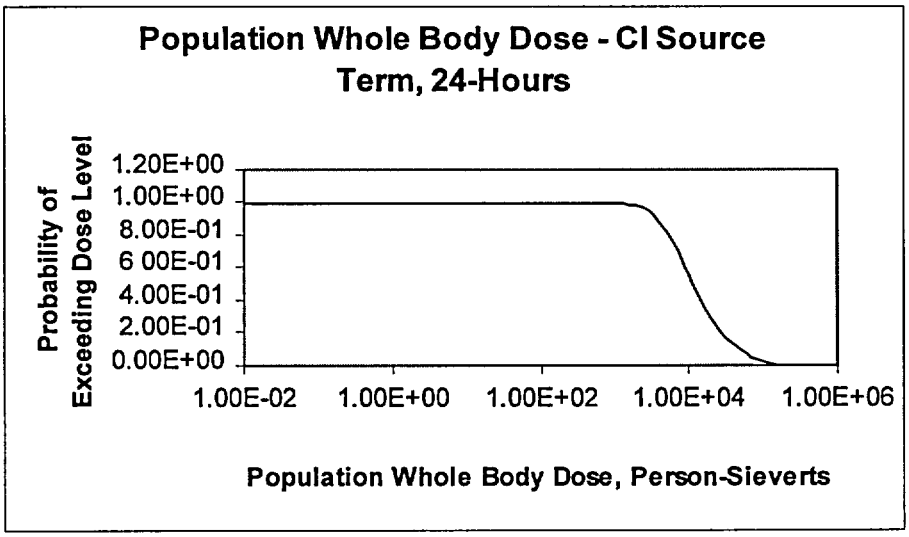


Figure 49-33

Population Whole Body Dose – CI Source Term, 24 Hours

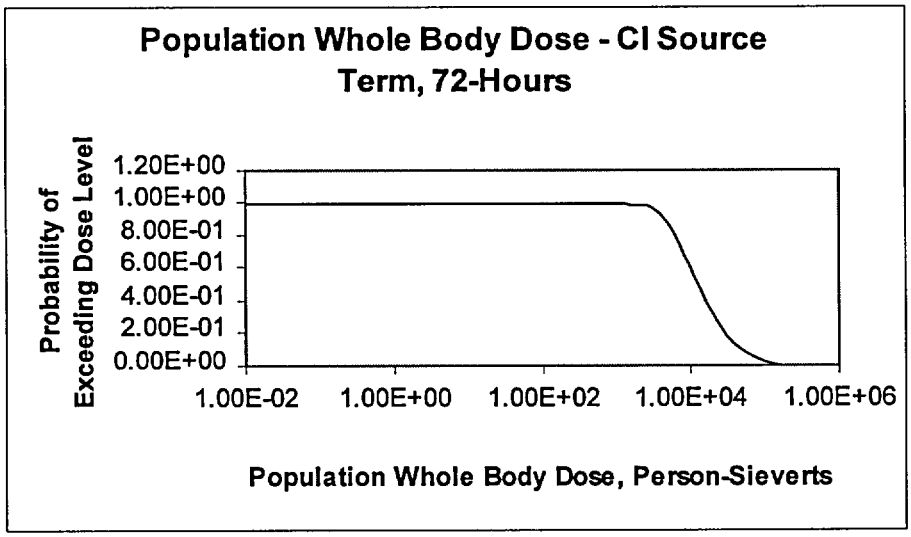


Figure 49-34

Population Whole Body Dose – CI Source Term, 72 Hours

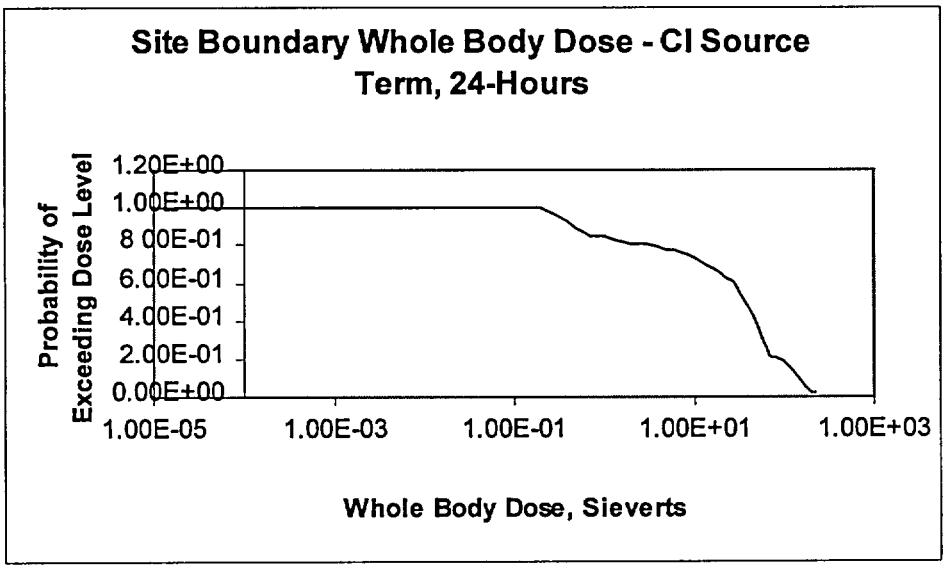


Figure 49-35

Site Boundary Whole Body Dose – CI Source Term, 24 Hours

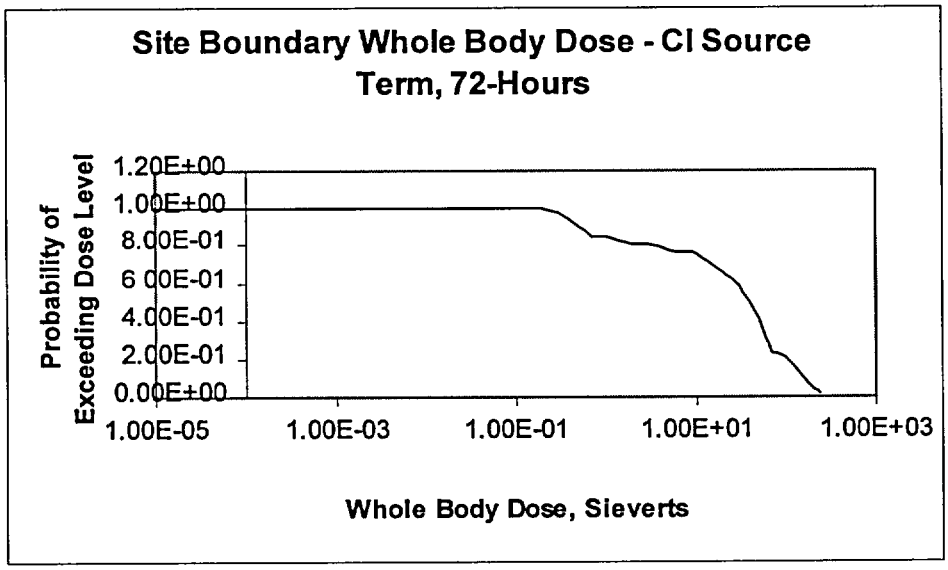


Figure 49-36

Site Boundary Whole Body Dose – CI Source Term, 72 Hours

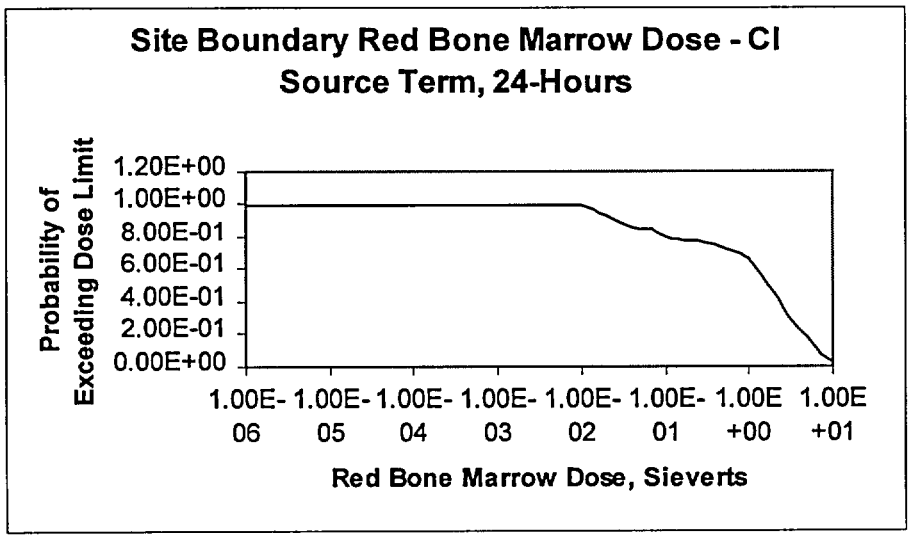


Figure 49-37

Site Boundary Red Bone Marrow Dose – CI Source Term, 24 Hours

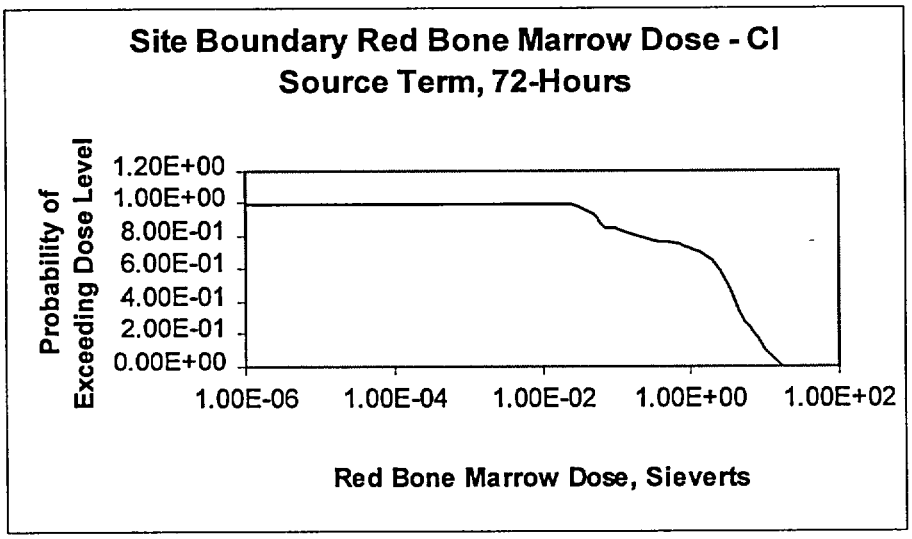


Figure 49-38

Site Boundary Red Bone Marrow Dose – CI Source Term, 72 Hours

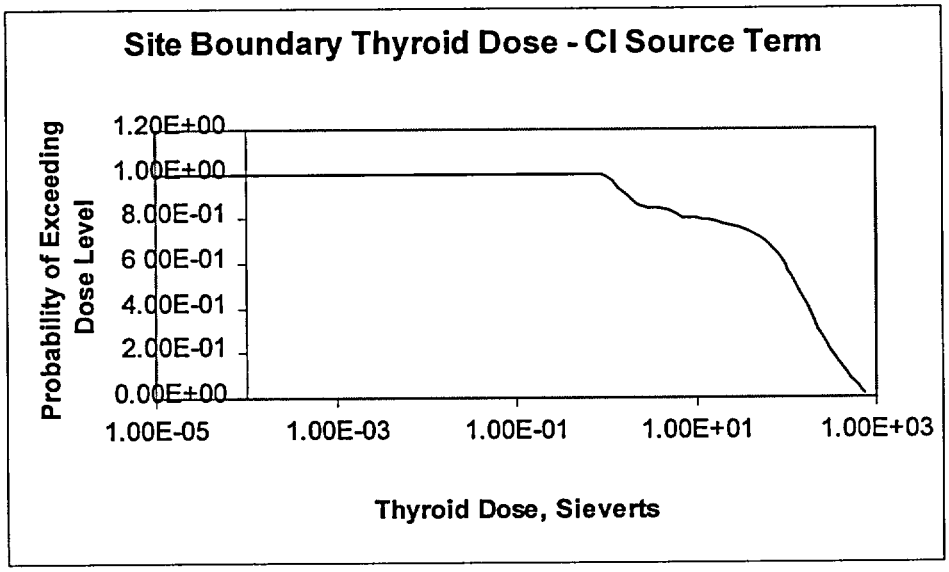


Figure 49-39

Site Boundary Thyroid Dose – CI Source Term, 24 Hours

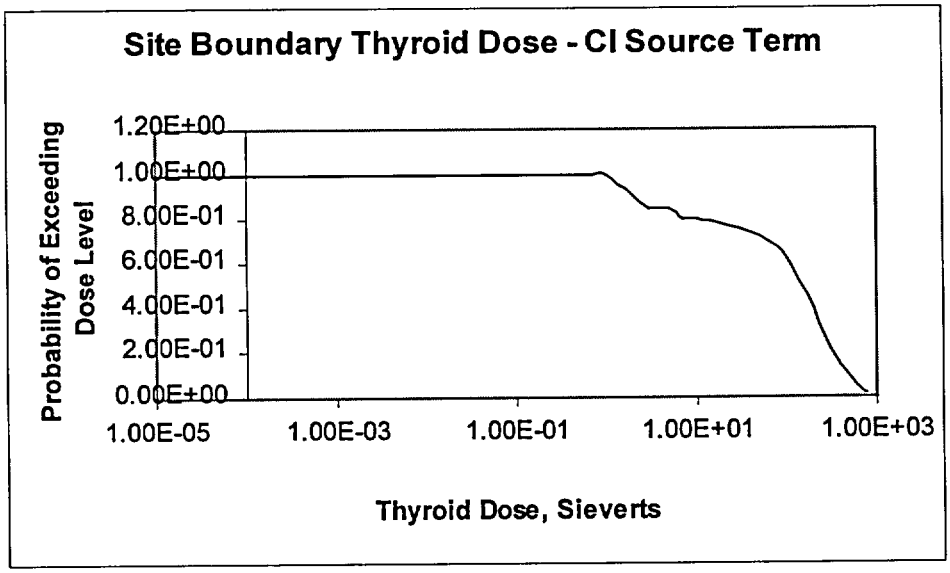


Figure 49-40

Site Boundary Thyroid Dose – CI Source Term, 72 Hours

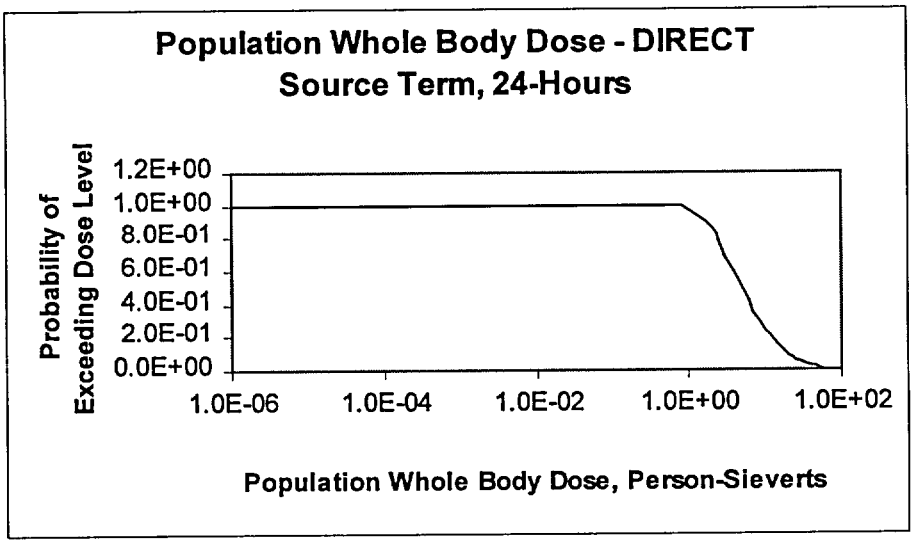


Figure 49-41

Population Whole Body Dose – DIRECT Source Term, 24 Hours

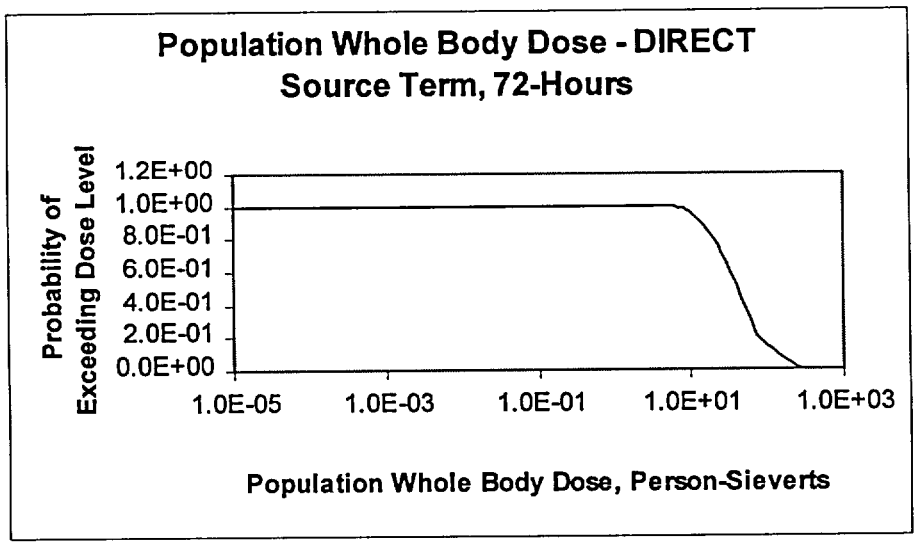


Figure 49-42

Population Whole Body Dose – DIRECT Source Term, 72 Hours

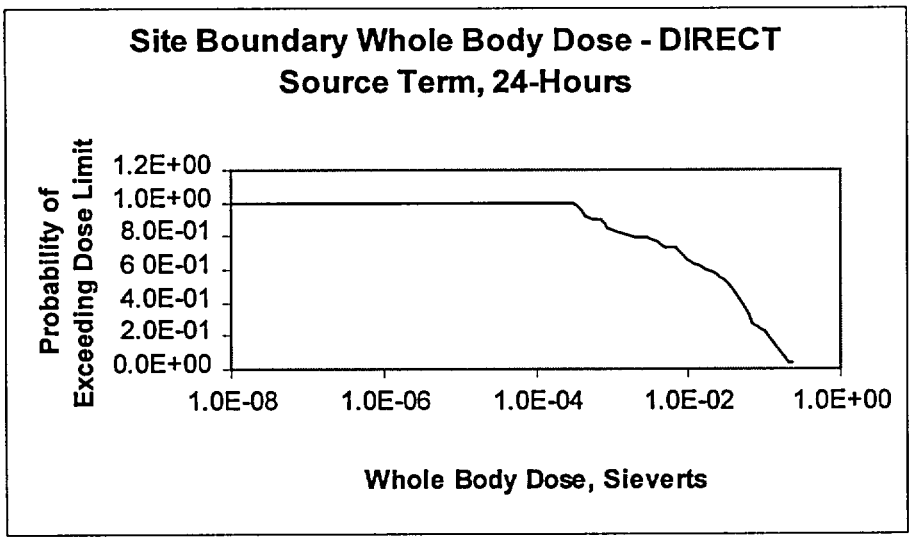


Figure 49-43

Site Boundary Whole Body Dose – DIRECT Source Term, 24 Hours

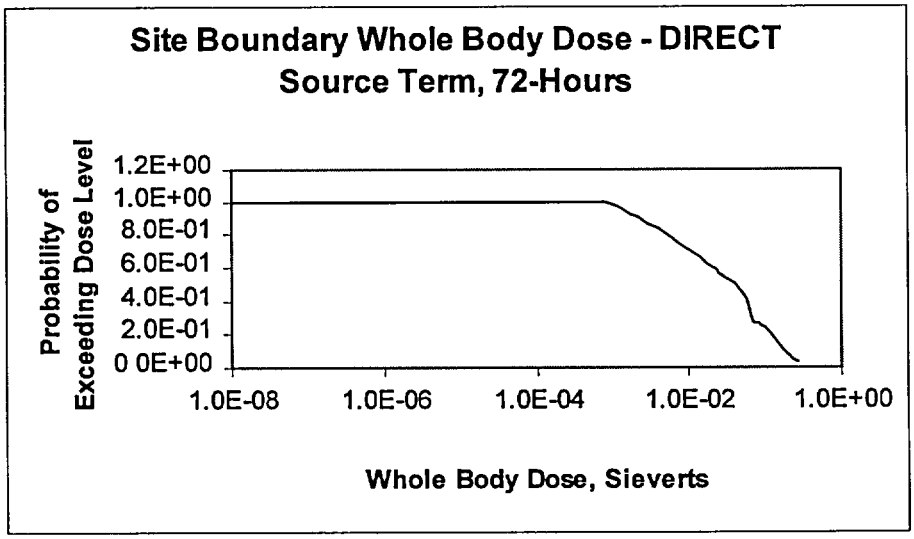


Figure 49-44

Site Boundary Whole Body Dose – DIRECT Source Term, 72 Hours

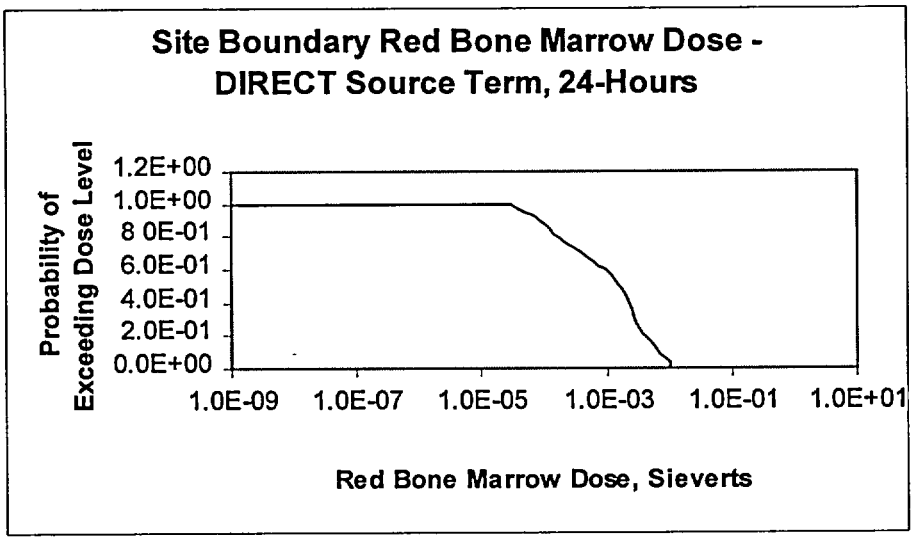


Figure 49-45

Site Boundary Red Bone Marrow Dose – DIRECT Source Term, 24 Hours

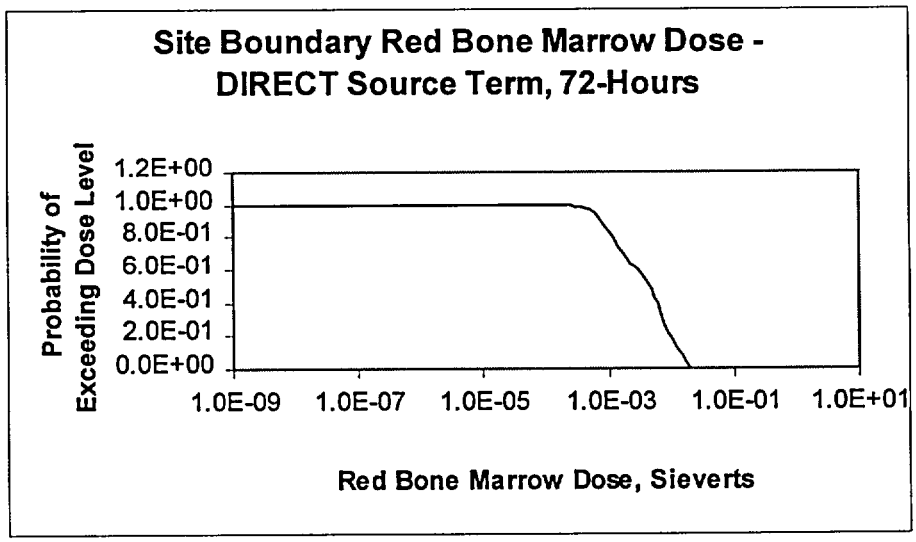


Figure 49-46

Site Boundary Red Bone Marrow Dose – DIRECT Source Term, 72 Hours

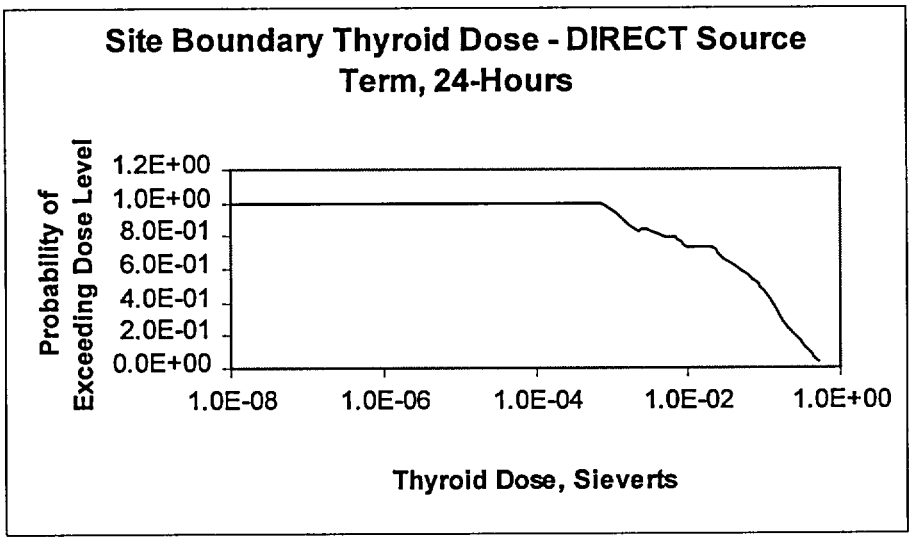


Figure 49-47

Site Boundary Thyroid Dose – DIRECT Source Term, 24 Hours

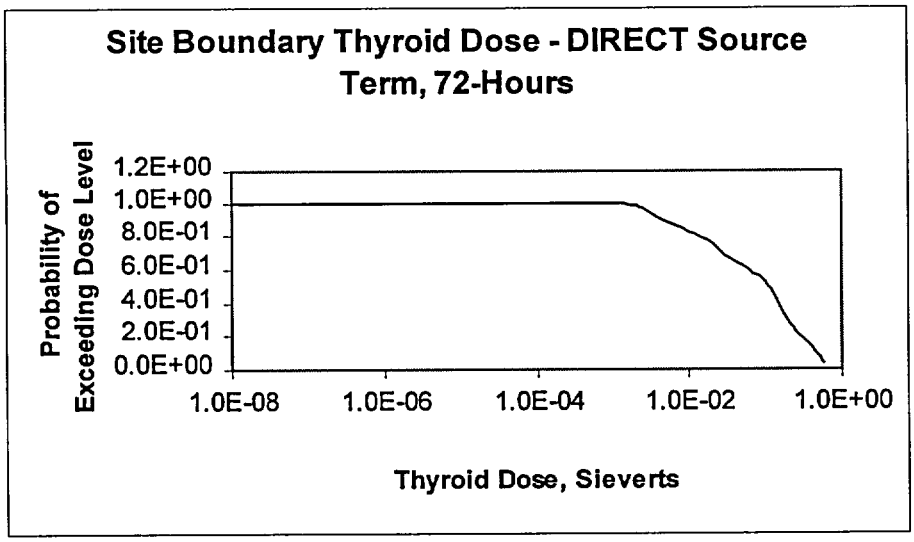


Figure 49-48

Site Boundary Thyroid Dose – DIRECT Source Term, 72 Hours

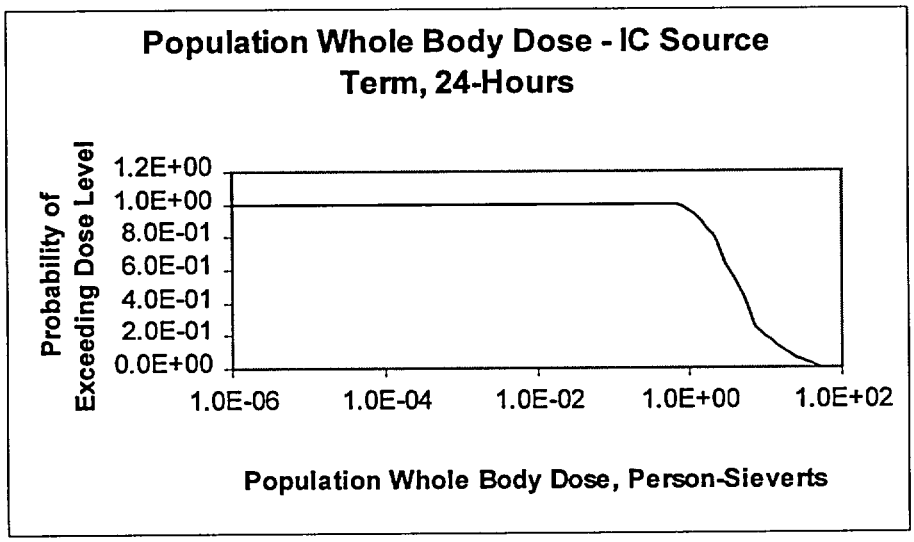


Figure 49-49

Population Whole Body Dose – IC Source Term, 24 Hours

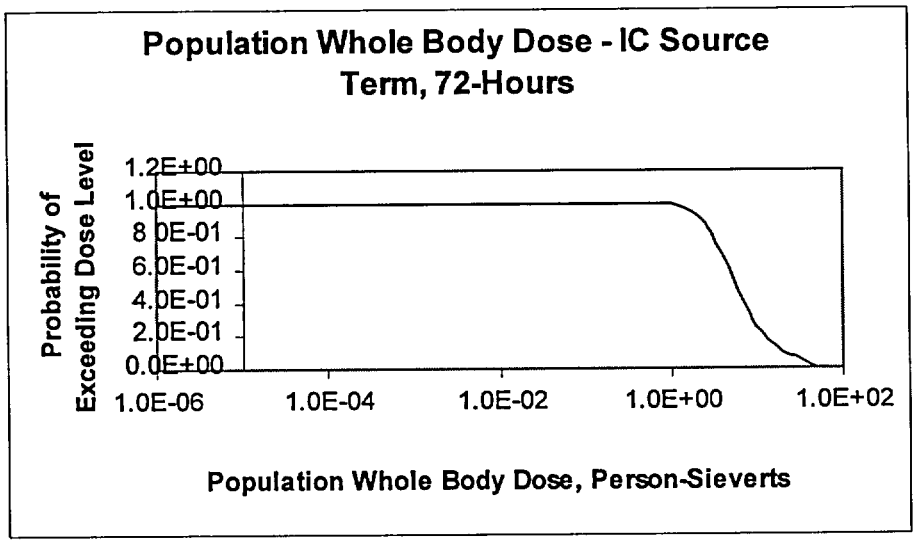


Figure 49-50

Population Whole Body Dose – IC Source Term, 72 Hours

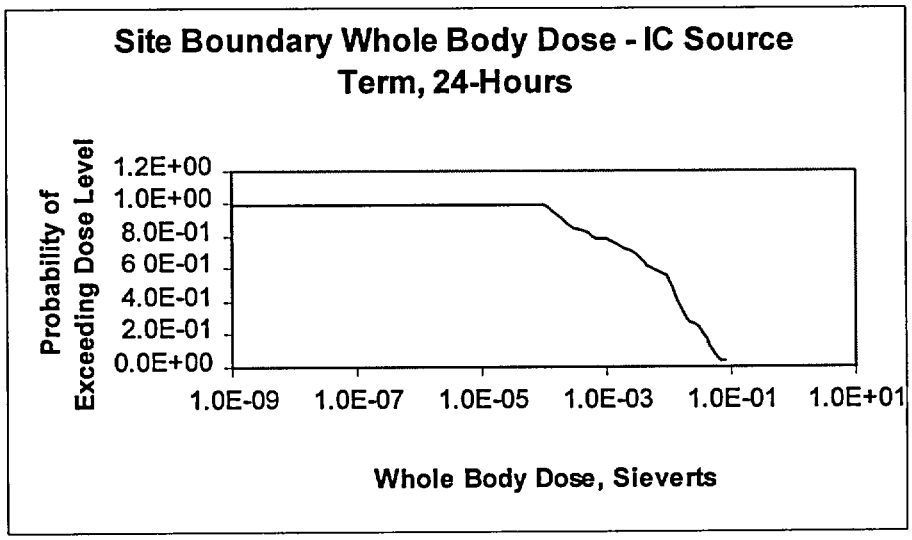


Figure 49-51

Site Boundary Whole Body Dose – IC Source Term, 24 Hours

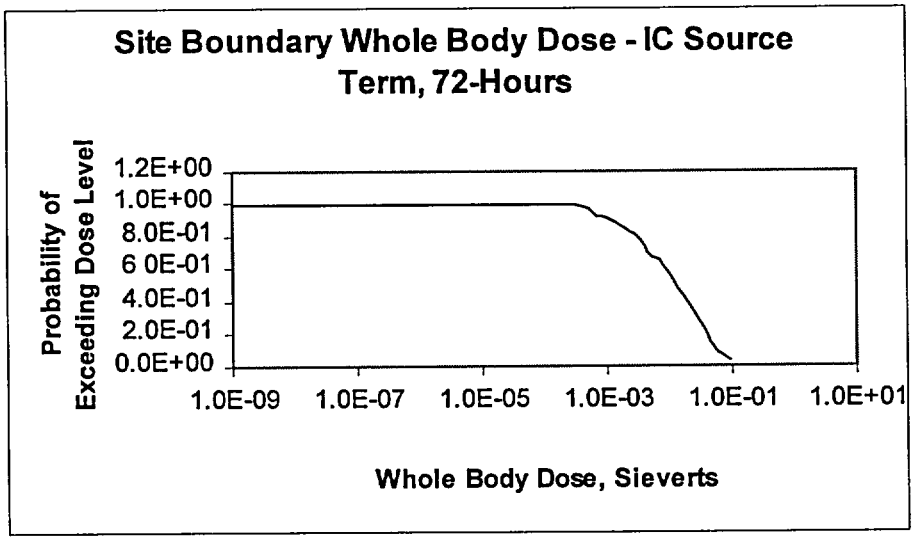


Figure 49-52

Site Boundary Whole Body Dose – IC Source Term, 72 Hours

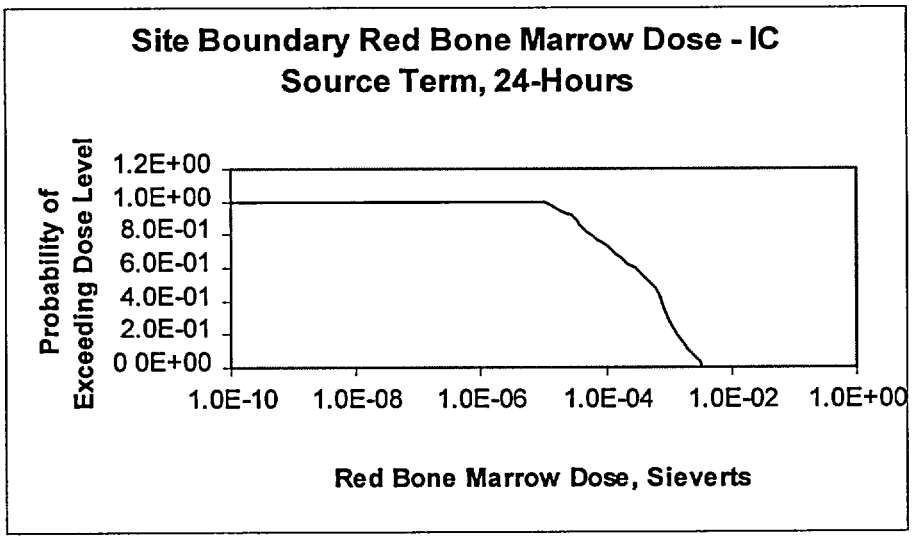


Figure 49-53

Site Boundary Red Bone Marrow Dose – IC Source Term, 24 Hours

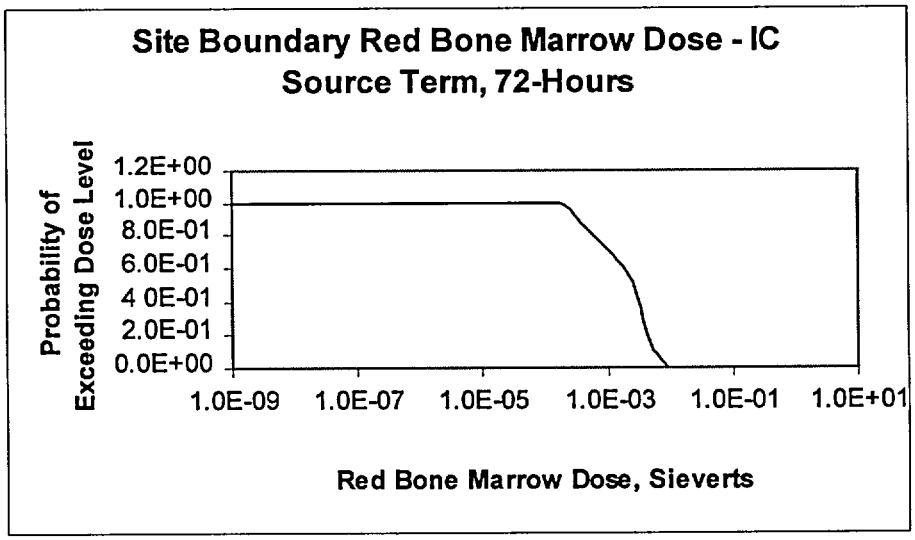


Figure 49-54

Site Boundary Red Bone Marrow Dose – IC Source Term, 72 Hours

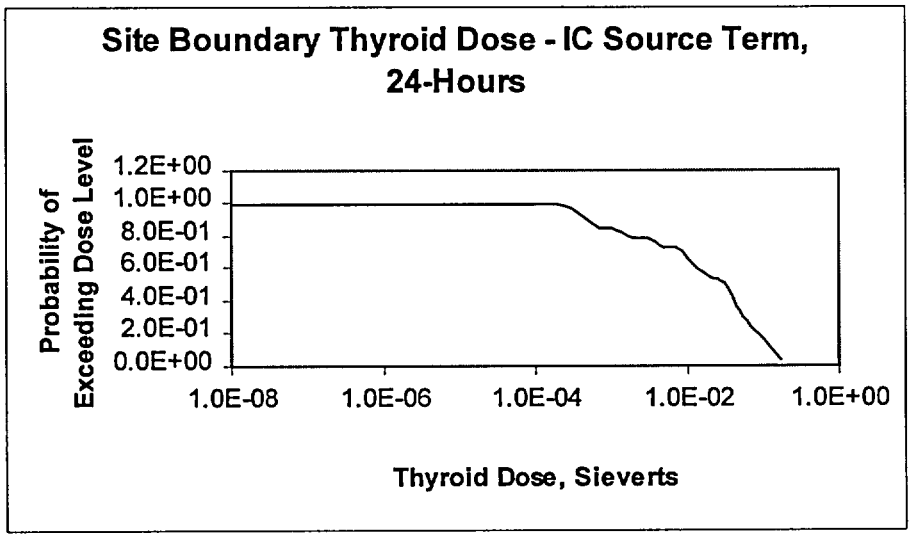


Figure 49-55

Site Boundary Thyroid Dose – IC Source Term, 24 Hours

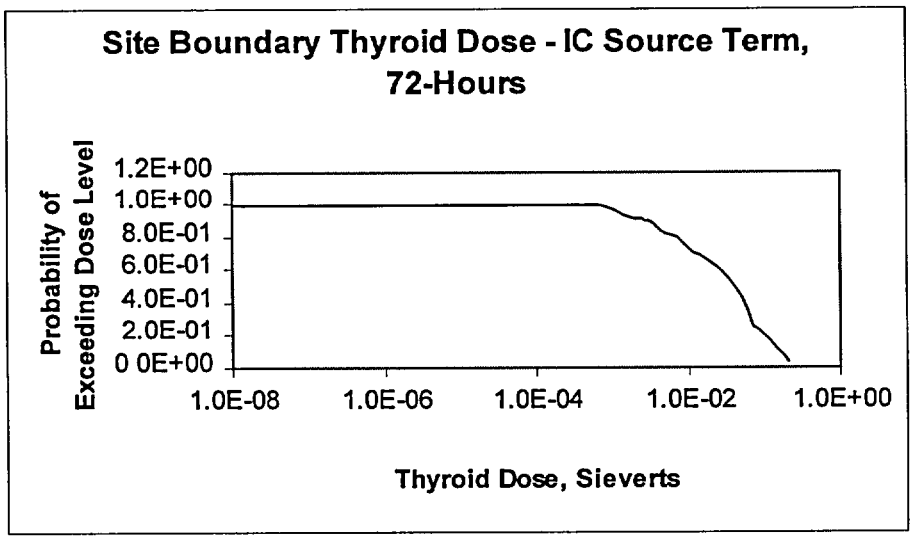


Figure 49-56

Site Boundary Thyroid Dose – IC Source Term, 72 Hours

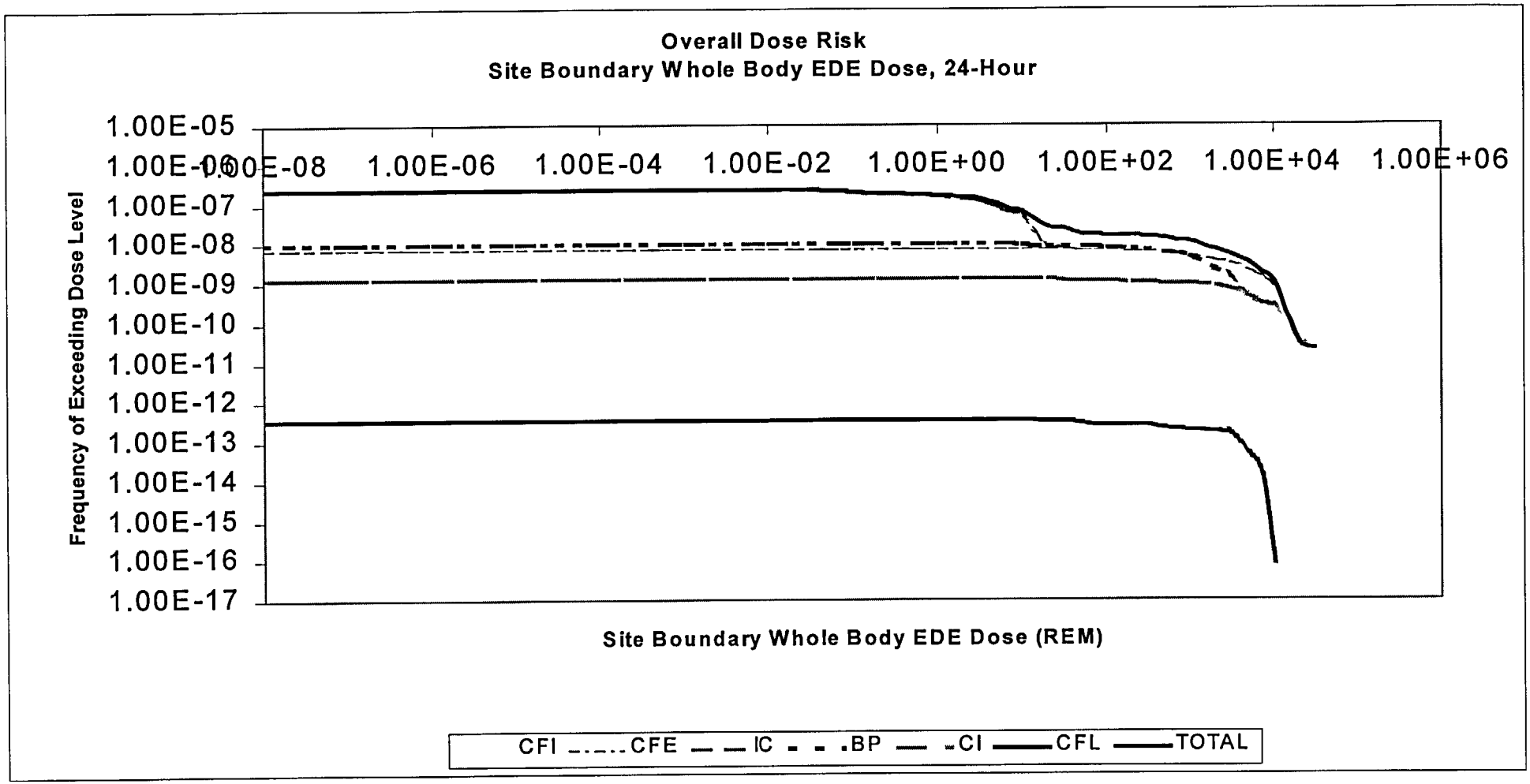


Figure 49-57

Overall Dose Risk Site Boundary Whole Body EDE Dose, 24 Hours

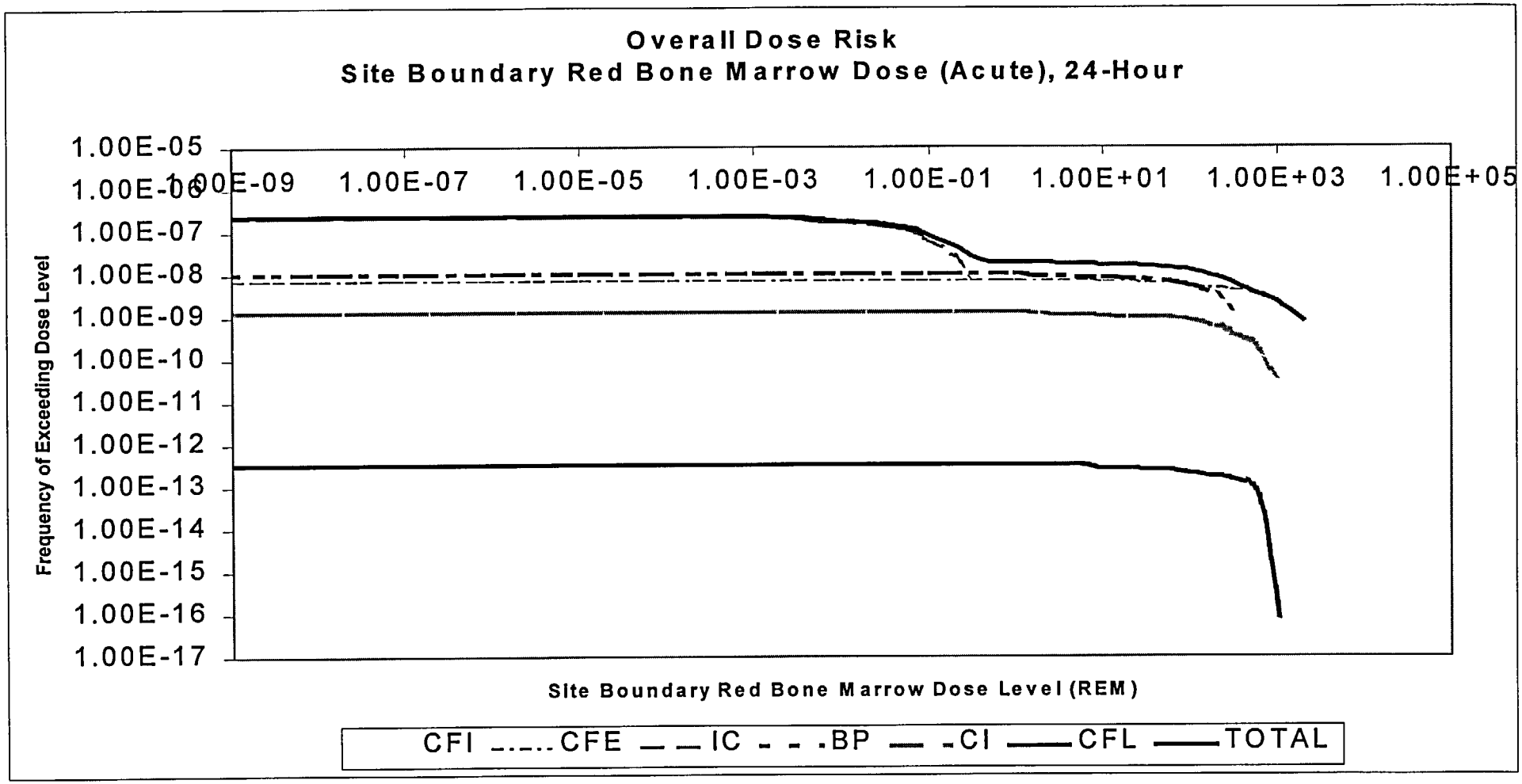


Figure 49-58

Overall Dose Risk Site Boundary Red Bone Marrow Dose (Acute), 24 Hours

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

RAI Number: 720.070 (Response Revision 1)

Question:

An assessment of shutdown risk, considering fires, internal floods, and seismic events has not been submitted. Please provide a shutdown assessment of these initiators considering (a) containment may be open, (b) fire/flood barriers may be breached for maintenance, and (c) transient combustibles for a given fire areas may be increased to support maintenance.

Westinghouse Response:

Shutdown fires, floods and seismic events have a negligible contribution to overall plant risk. Included within the AP1000 PRA is an overall shutdown evaluation that results in a core damage frequency (CDF) of 1.23E-08/year. This value is lower than the AP600 value of 9.0E-08/year.

The internal fire at power PRA for AP600 was a conservative analysis and yielded a CDF result of 6.5E-07/year. The AP600 fire PRA for shutdown CDF result was 3.5E-07/year. For AP1000, when a more realistic analysis was performed for internal events at power, the results were 5.61E-08/year. Based upon this improvement in the at power PRA result for fire based upon analysis technique only (the plant designs are the same for fire), shutdown fires will have a negligible contribution to plant risk.

The AP600 results for internal flooding events at power were 2.2E-10/year. For AP1000, they were 8.8E-10/year. Again, based upon this level of risk with the plants having the same design for shutdown flooding protection, shutdown floods will have a negligible contribution to plant risk

The AP600 and AP1000 at power PRA seismic margin results are similar. Shutdown seismic events will have a negligible contribution to plant risk.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

AP1000 DESIGN CERTIFICATION REVIEW

Response to Request For Additional Information

NRC Additional Comments:

Additional NRC comments related to this RAI were received at a meeting held at NRC on February 27, 2003. These additional comments are included in our Revision 1 response to RAI 720.038.

Westinghouse Additional Response:

See the response to Question 3 of RAI 720.038 Revision 1.