Schaperow, Jason

From: Schaperow, Jason
Sent: Tuesday, January 04, 2011 12:35 PM
To: Chang, Richard
Cc: 'Bixler, Nathan E'
Subject: FW:
Attachments: SOARCA_AppA_Rev3NEB01-04-2011.pdf

Hi Richard,

The email below is for your information.

Nate is hoping to get the calcs finished for the 2 dose truncation levels (background and HPS) by the end of tomorrow and get the results to us (in tables) by the end of tomorrow, as he is on leave the following 4 business days.

Jason

From: Bixler, Nathan E [mailto:nbixler@sandia.gov]
Sent: Tuesday, January 04, 2011 11:50 AM
To: Schaperow, Jason; Tinkler, Charles
Cc: McClellan, Yvonne; Gauntt, Randall O
Subject:

Jason and Charlie,

Here's an updated version of Chapter 7 of Appendix A for you to review. A number of the tables are out of whack because I am using an older version of Word. The formatting can be corrected later, so for now just focus on the values in the tables. I'll add the two tables that we discussed after I get the calculations finished.

Thanks,
Nate

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7.0 OFF-SITE CONSEQUENCES

7.1 Introduction

The MACCS2 consequence model (Version 2.5.0.0) was used to calculate offsite doses and their effect on members of the public. MACCS2 was developed at Sandia National Laboratories for the NRC for use in probabilistic risk assessments for commercial nuclear reactors to simulate the impact of accidental atmospheric releases of radiological materials on humans and on the surrounding environment. The principal phenomena considered in MACCS2 are atmospheric transport using a straight-line Gaussian plume model of, short-term and long-term dose accumulation through several pathways including cloudshine, groundshine, inhalation, deposition onto the skin, and food and water ingestion. The ingestion pathway was not treated in the analyses reported here because uncontaminated food and water supplies are abundant within the U.S. and it is unlikely that the public would eat radioactively contaminated food. The doses that are included in the reported risk metrics are as follows:

- Cloudshine during plume passage
- Groundshine during the emergency and long-term phases from deposited aerosols
- Inhalation during plume passage and following plume passage from resuspension of deposited aerosols. Resuspension is treated during both the emergency and long-term phases.

Additional enhancements were made to MACCS2 [24] as an element of the SOARCA project. In general, these enhancements reflect recommendations obtained during the SOARCA external review and also reflect needs identified by the broader consequence analysis community. The code enhancements done for SOARCA are primarily to improve fidelity, improve code performance, and enhance existing functionality. Nevertheless, these enhancements are anticipated to have a significant effect on the fidelity of the analyses performed under the SOARCA project.

MACCS2 previously allowed up to three emergency-phase cohorts. Each emergency-phase cohort represents a fraction of the population who behave in a similar manner, although response times can be a function of radius. For example, a cohort might represent a fraction of the population who rapidly evacuate after officials instruct them to do so. To create a high-fidelity model for SOARCA, the number of emergency-phase cohorts was increased as described in the previous chapter on emergency response. This allowed significantly more variations in emergency response (e.g., variations in preparation time prior to evacuation to more accurately reflect the movement of the public during an emergency). In a similar way, modeling evacuation routes using the network-evacuation model adds a greater degree of realism than in previous analyses that used the simpler, radial-evacuation model.

7.2 Peach Bottom Source Terms

Brief descriptions of the source terms for the Peach Bottom accident scenarios are provided in Table 20. For comparison, the largest source term from the Sandia Siting Study (SST1) [25] is also shown. Of the Peach Bottom source terms shown in the table, the unmitigated STSBO is the largest in terms of release fractions and the release begins at the earliest time; the mitigated STSBO with RCIC blackstart and the unmitigated LTSBO are the comparable in terms of release fractions; the release begins at the latest time for the LTSBO; and the mitigated STSBO with RCIC blackstart is intermediate in terms of timing but slightly lower in terms of release fractions, with the exception of barium, which is slightly greater than the release fraction for the unmitigated LTSBO.

The fission product inventory used in these analyses is presented in Appendix A.1. The inventory data were evaluated specifically for the SOARCA work and reflect realistic fuel cycle data from Peach Bottom. The inventory data are consistent with those used in MELCOR for decay heat values.

By comparison, the SST1 source term is significantly larger in magnitude, especially for the cesium group, than any of the Peach Bottom source terms. Moreover, it begins only 1.5 hours after accident initiation. Thus, the current understanding of accident progression has clearly led to a very different characterization of release signatures than was current at the time of the Sandia Siting Study.

Table 20 Brief Source-Term Description for Unmitigated Peach Bottom Accident Scenarios and the SST1 Source Term from the Sandia Siting Study

Scenario		Integral Release Fractions by Chemical Group									Release Timing	
	CDF (1/yr)	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La	Start (hr)	End (hr)
PB LTSBO	$3x10^{-6}$	0.978	0.005	0.006	0.020	0.022	0.000	0.001	0.000	0.000	20.0	48.0
PB STSBO w/ BS	$3x10^{-7}$	0.979	0.004	0.007	0.013	0.015	0.000	0.001	0.000	0.000	16.9	48.0
PB STSBO	$3x10^{-7}$	0.970	0.015	0.025	0.062	0.063	0.000	0.003	0.001	0.000	10.4	48.0
SST1	$1x10^{-5}$	1.000	0.670	0.070	0.450	0.640	0.050	0.050	0.009	0.009	1.5	3.5

For comparison, a set of consequence analyses using the old SST1 source term is presented in this chapter. This allows a direct comparison, using the same modeling options and result metrics, between the SST1 source term and the current, best-estimate source terms.

7.3 Consequence Analyses

The results of the consequence analyses are presented in terms of risk to the public for each of the three accident scenarios identified for Peach Bottom. Both unconditional and conditional risks are tabulated. The conditional risks assume that the accident occurs and show the risks to individuals as a result of the accident. The unconditional risks are the product of the core damage frequency and the conditional risks. The unconditional risks are the likelihood of receiving a fatal cancer or early fatality to an average individual living within a specified radius of the plant per year of plant operation.

The risk metrics are latent-cancer-fatality and early-fatality risks to residents in circular regions surrounding the plant. They are also averaged over the entire residential population within the circular region. The risk values represent the predicted number of fatalities divided by the population for four choices of dose-truncation level. These risk metrics account for the distribution of the population within the circular region and for the interplay between the population distribution and the wind rose probabilities.

In addition to the base case mitigated and unmitigated accident scenarios, three additional analyses are reported in this chapter. A sensitivity analysis for the unmitigated STSBO scenario shows the influence of the size of the evacuation zone on predicted risk. Another sensitivity analysis considers the effect of seismic activity on emergency response. A separate analysis of the SST1 source term [25] (summarized in Table 20) allows older source-term assumptions to be compared with the current state-of-the-art methods for source-term evaluation using otherwise equivalent assumptions and models. This analysis does not try to reproduce the Sandia Siting Study results; it merely overlays the older source term onto what are otherwise SOARCA assumptions for dose-response modeling, emergency response, etc.

7.3.1 Unmitigated Long-Term Station Blackout Scenario

Table 21 displays the conditional, mean, latent-cancer-fatality risks to residents within a set of concentric circular areas centered at the Peach Bottom site for the unmitigated, long-term station blackout (LTSBO) scenario. Four values of dose-truncation level are shown in the table: linear, no threshold (LNT); 10 mrem/yr; the average, annual, US-background radiation (including average medical radiation) of 620 mrem/yr; and the Health Physics Society (HPS) recommended dose truncation of 5 rem/yr, with a lifetime limit of 10 rem.

The HPS dose-truncation level is more complex that the others because it involves both annual and lifetime limits. According to the recommendation, annual doses below the 5-rem truncation level do not need to be counted toward health effects; however, if the lifetime dose exceeds 10 rem, all annual doses, no matter how small, count toward health effects.

Table 22 is analogous to Table 21, but displays the unconditional rather than the conditional risks. In the case of the Peach Bottom long-term station blackout, the mean core damage frequency of $3 \cdot 10^{-6}$/yr is used, a frequency that is based on the pessimistic assumption that B.5.b mitigation does not succeed (cf., Section 3.1.4). The unconditional risk is the product of the conditional risk and this core damage frequency.

Table 21 Conditional, i.e., assuming accident occurs, Mean, Latent-Cancer-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities are for the Unmitigated LTSBO Scenario, which has a Mean Core Damage Frequency of 3×10^{-6}/yr.

Radius of Circular Area (mi)	LNT	10 mrem/yr	620 mrem/yr	5 rem/yr, 10 rem lifetime
10	8.9E-05	6.7E-05	7.4E-07	3.7E-07
20	7.6E-05	6.1E-05	1.9E-05	2.2E-06
30	5.3E-05	4.1E-05	1.1E-05	8.9E-07
40	3.3E-05	2.5E-05	5.0E-06	3.7E-07
50	2.7E-05	2.0E-05	3.4E-06	2.4E-07

Table 22 Unconditional, Mean, Latent-Cancer-Fatality Risks (1/reactor year) for Residents within the Specified Radii of the Peach Bottom Site. Risks Are for the unmitigated LTSBO Scenario, which has a mean core damage frequency of $3\cdot10^{-6}$/yr.

Radius of Circular Area (mi)	LNT	10 mrem/yr	620 mrem/yr	5 rem/yr, 10 rem lifetime
10	2.7E-10	2.0E-10	2.2E-12	1.1E-12
20	2.3E-10	1.8E-10	5.8E-11	6.5E-12
30	1.6E-10	1.2E-10	3.3E-11	2.7E-12
40	1.0E-10	7.5E-11	1.5E-11	1.1E-12
50	8.0E-11	5.9E-11	1.0E-11	7.1E-13

The values in Table 21 are shown in Figure 77. The figure shows that for LNT and for a truncation dose of 10 mrem/year, the risk is greatest for those closest to the plant and diminishes monotonically as distance increases. On the other hand, for a large value of the truncation dose, the risk reaches a maximum outside the 10-mile evacuation zone. The explanation for this counterintuitive trend is provided in the following discussion of the risks incurred during the emergency versus the long-term phases.

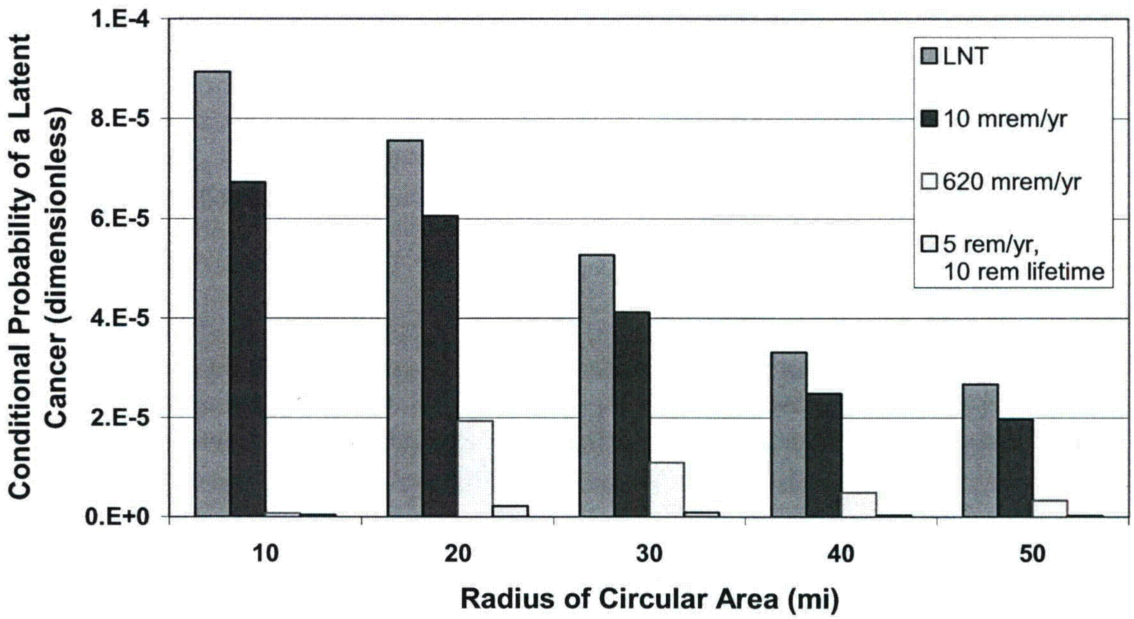

Figure 77 Conditional, i.e., assuming accident occurs, mean, latent-cancer-fatality probabilities from the Peach Bottom unmitigated LTSBO scenario for residents within a circular area of specified radius from the plant. The plot shows four values of dose-truncation level.

Figure 78 shows the conditional LNT risks for the Peach Bottom unmitigated LTSBO for the emergency (EARLY) and long-term (CHRONC) phases. The entire height of each column shows the combined (Total) risk for the two phases. The emergency response is very effective within the evacuation zone (10 mi) during the early phase, so those risks are very small and entirely represent the 0.5% of the population that does not evacuate. The peak in the EARLY risk curve is at 20 miles, which is the first location in the plot outside of the evacuation zone.

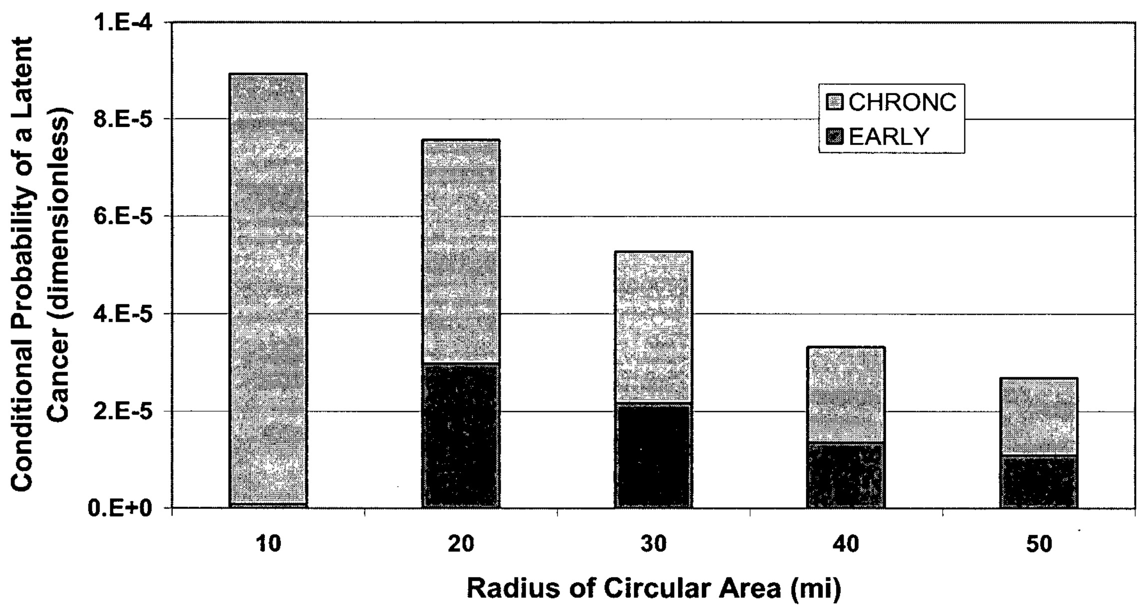

Figure 78 Conditional, i.e., assuming accident occurs, mean, LNT, latent-cancer-fatality probabilities from the Peach Bottom unmitigated LTSBO scenario for residents within a circular area of specified radius from the plant. The plot shows the probabilities from the emergency phase (EARLY), long-term phase (CHRONC), and the two phases combined.

The CHRONC risks dominate the total risks for the accident scenario when the LNT dose-response assumption is made. These long-term risks are controlled by the habitability (return) criterion, which is the dose level at which residents are allowed to return to their homes following the emergency phase. For Peach Bottom, the habitability criterion is an annual dose limit of 500 mrem. However, this dose rate is below the truncation levels for the background (620 mrem/yr) and HPS dose-truncation criteria; therefore, most of the doses received during the long-term phase are not counted toward health effects when using these criteria. Thus, most of the risks associated with the 620 mrem/yr and HPS dose truncation criteria are from doses received during the first year. Doses received during the first year include most of the EARLY doses plus a fraction of the CHRONC doses. Due to the habitability criterion, doses received after the first year generally fall below these truncation levels and so do not contribute to risk. This explains why the risk profiles for these dose-truncation criteria in Figure 77 are similar to the EARLY profile in Figure 78.

The prompt-fatality risks are identically zero for this accident scenario. This is because the release fractions (shown in Table 20) are too low to produce doses large enough to exceed the dose thresholds for early fatalities, even for the 0.5% of the population that does not evacuate.

The largest value of the mean, acute dose for the closest resident (0.5 to 1.2 km from the plant) for this scenario is about 0.1 Gy to the red bone marrow, which is usually the most sensitive organ for prompt fatalities; whereas, the minimum acute dose that can cause an early fatality is about 2.3 Gy to the red bone marrow. Calculated doses are all well below this threshold.

7.3.2 Short-Term Station Blackout with RCIC Blackstart

Table 23 displays the conditional, mean, latent-cancer-fatality risks to residents within a set of concentric circular areas centered at the Peach Bottom site for the short-term station blackout (STSBO) scenario with successful RCIC blackstart. These risks are shown graphically in Figure 79. The RCIC blackstart delays the beginning of release and provides more time for evacuation prior to release than in the subsequent scenario, in which RCIC blackstart is not attempted or fails.

Table 24 is analogous to Table 23, but shows unconditional rather than conditional risks. In the case of the Peach Bottom short-term station blackout with RCIC blackstart, the mean core damage frequency of $3 \cdot 10^{-7}$/yr is used, a frequency that is based on the pessimistic assumption that B.5.b mitigation does not succeed (cf., Section 3.2.4).

Table 23 Conditional, i.e., assuming accident occurs, Mean, Latent-Cancer-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities are for the STSBO Scenario with RCIC blackstart, which has a mean core damage frequency of $3 \cdot 10^{-7}$/yr.

Radius of Circular Area (mi)	LNT	10 mrem/yr	620 mrem/yr	5 rem/yr, 10 rem lifetime
10	7.1E-05	5.2E-05	6.5E-07	3.0E-07
20	6.5E-05	5.3E-05	1.6E-05	1.2E-06
30	4.6E-05	3.7E-05	9.2E-06	4.4E-07
40	2.9E-05	2.3E-05	4.4E-06	1.8E-07
50	2.4E-05	1.8E-05	3.0E-06	1.1E-07

Table 24 Unconditional, Mean, Latent-Cancer-Fatality Risks (1/reactor year) for Residents within the Specified Radii of the Peach Bottom Site. Risks are for the STSBO Scenario with RCIC blackstart, which has a mean core damage frequency of $3 \cdot 10^{-7}$/yr.

Radius of Circular Area (mi)	LNT	10 mrem/yr	620 mrem/yr	5 rem/yr, 10 rem lifetime
10	2.1E-11	1.6E-11	2.0E-13	9.0E-14
20	2.0E-11	1.6E-11	4.8E-12	3.6E-13
30	1.4E-11	1.1E-11	2.8E-12	1.3E-13
40	8.8E-12	6.8E-12	1.3E-12	5.3E-14
50	7.1E-12	5.4E-12	8.9E-13	3.4E-14

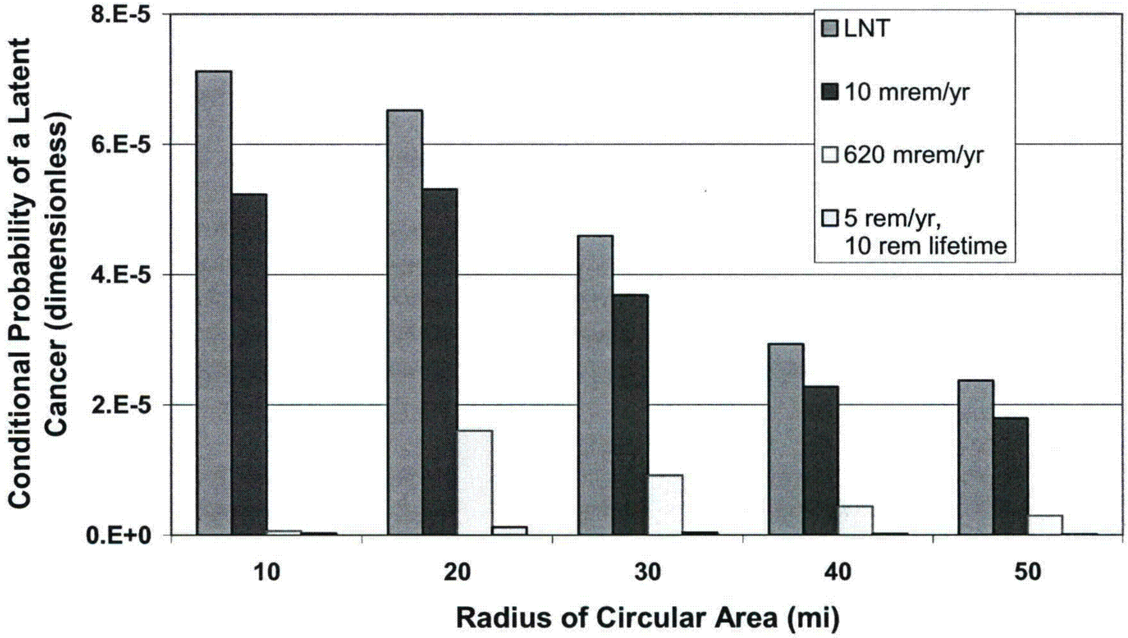

Figure 79 Conditional, i.e., assuming accident occurs, mean, latent-cancer-fatality probabilities from the Peach Bottom STSBO scenario with RCIC blackstart for residents within a circular area of specified radius from the plant. The plot shows four choices of dose-truncation level.

Figure 80 shows the LNT latent-cancer-fatality risks for the Peach Bottom short-term station blackout with RCIC blackstart for the emergency (EARLY) and long-term (CHRONC) phases. The height of each column indicates the combined (Total) risk for the two phases. The emergency response is very effective within the evacuation zone (10 mi) during the emergency phase, so those risks are very small and entirely represent the 0.5% of the population that does not evacuate. The peak in the EARLY risk curve is at 20 miles, which is the first location in the plot outside of the evacuation zone.

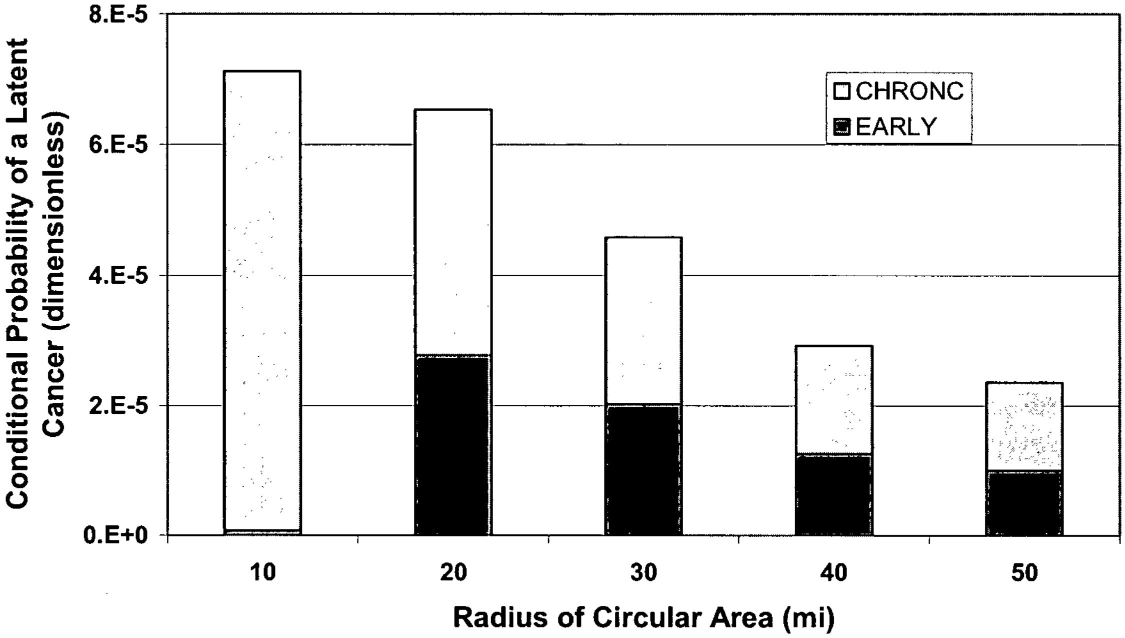

Figure 80 Conditional, i.e., assuming accident occurs, mean, LNT, latent-cancer-fatality probabilities from the Peach Bottom STSBO scenario with RCIC blackstart for residents within a circular area of specified radius from the plant. The plot shows the risks from the emergency phase (EARLY), long-term phase (CHRONC), and the two phases combined.

The trends for this accident scenario are very similar to those for the unmitigated LTSBO scenario. The long-term-phase risks for this scenario are greater than the emergency-phase risks, especially within the evacuation zone (10 mi) where the emergency-phase risks are very small. The long-term risks are controlled by the habitability or return criterion, which is an annual dose limit of 500 mrem.

Since the annual dose limit of the habitability criterion (500 mrem/yr) is lower than the dose truncation levels for the 620 mrem/yr and HPS criteria, those two risk profiles (shown in Figure 79) are similar to the emergency-phase profile shown in Figure 80. In other words, the long-term doses are largely excluded by the 620 mrem/yr and HPS criteria, so the health effects are dominated by doses received during the emergency phase. As a result, those risk profiles are similar to the emergency-phase profile in Figure 80.

The prompt-fatality risks are identically zero for this accident scenario. This is because the release fractions are too low to produce doses large enough to exceed the dose thresholds for early fatalities, even for the 0.5% of the population that does not evacuate.

7.3.3 Unmitigated Short-Term Station Blackout

Table 25 displays the conditional, mean, latent-cancer-fatality risks to residents within a set of concentric circular areas centered at the Peach Bottom site for the unmitigated short-term station blackout (STSBO) scenario (i.e., without RCIC blackstart). The releases for this scenario are larger and earlier than those for either of the previous ones.

Comparing Table 23 and Table 25, it can be seen that the risks are significantly larger for the STSBO when RCIC blackstart does not succeed. Table 26 is analogous to Table 25, but shows unconditional rather than conditional risks. In the case of the Peach Bottom short-term station blackout without RCIC blackstart, the mean core damage frequency of $3 \cdot 10^{-7}$/yr is used, a frequency that is based on the pessimistic assumption that B.5.b mitigation does not succeed (cf., Section 3.2.4).

The values in Table 25 are plotted in Figure 81. The plot shows that predicted risks reach a maximum beyond the EPZ (10 mi) for all choices of dose truncation level. Risks within the 10-mile evacuation zone are very small for the background and HPS truncation criteria because long-term doses are below these truncation levels.

Table 25 Conditional, i.e., assuming accident occurs, Mean, Latent-Cancer-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities are for the unmitigated STSBO Scenario, which has a mean core damage frequency of $3 \cdot 10^{-7}$/yr.

Radius of Circular Area (mi)	LNT	10 mrem/yr	620 mrem/yr	5 rem/yr, 10 rem lifetime
10	1.5E-04	1.2E-04	3.3E-06	2.9E-06
20	1.8E-04	1.6E-04	8.4E-05	4.2E-05
30	1.3E-04	1.1E-04	5.2E-05	2.0E-05
40	8.3E-05	7.1E-05	2.9E-05	8.6E-06
50	6.9E-05	5.7E-05	2.1E-05	5.6E-06

Table 26 Unconditional, Mean, Latent-Cancer-Fatality Risks (1/reactor year) for Residents within the Specified Radii of the Peach Bottom Site. Risks are for the unmitigated STSBO Scenario, which has a mean core damage frequency of $3 \cdot 10^{-7}$/yr.

Radius of Circular Area (mi)	LNT	10 mrem/yr	620 mrem/yr	5 rem/yr, 10 rem lifetime
10	4.4E-11	3.5E-11	9.8E-13	8.8E-13
20	5.5E-11	4.9E-11	2.5E-11	1.3E-11
30	3.9E-11	3.4E-11	1.6E-11	6.1E-12
40	2.5E-11	2.1E-11	8.6E-12	2.6E-12
50	2.1E-11	1.7E-11	6.3E-12	1.7E-12

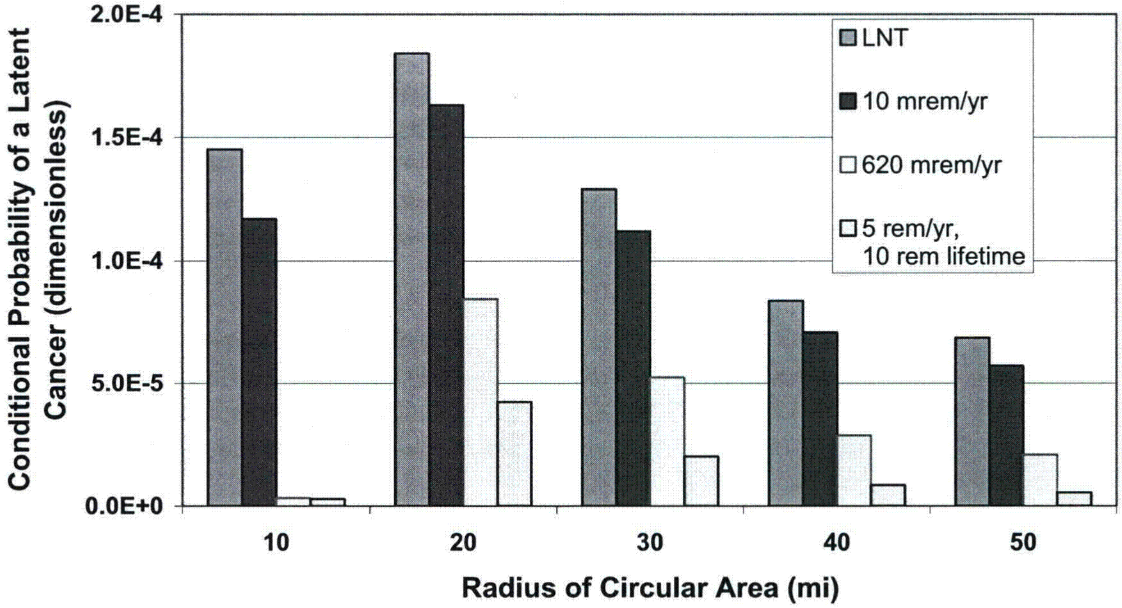

Figure 81 Conditional, i.e., assuming accident occurs, mean, latent-cancer-fatality probabilities from the Peach Bottom unmitigated STSBO scenario for residents within a circular area of specified radius from the plant. The plot shows four choices of dose-truncation level.

Figure 82 shows the LNT latent-cancer fatality risks for the Peach Bottom unmitigated STSBO scenario for the emergency and long-term phases. The height of each of the columns shows the combined (Total) risk for the two phases. The emergency response is very effective within the evacuation zone (10 mi) during the early phase, so those risks are very small and mostly represent the 0.5% of the population that does not evacuate. The peak in the EARLY risk profile is at 20 miles, which is the first location in the plot outside of the evacuation zone.

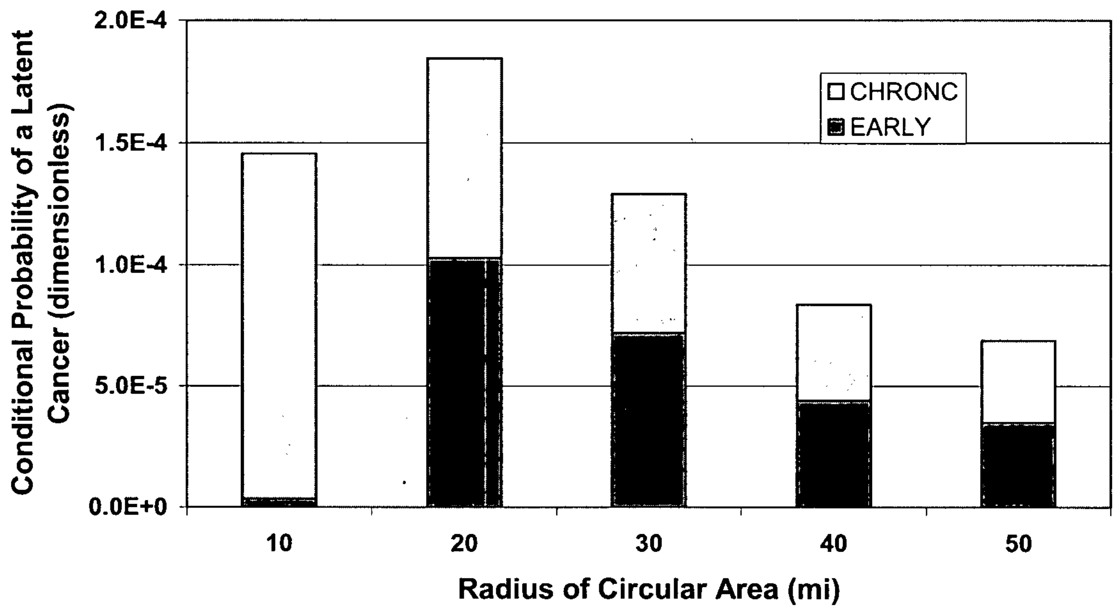

Figure 82 Conditional, i.e., assuming accident occurs, mean, LNT, latent-cancer-fatality probabilities from the Peach Bottom unmitigated STSBO scenario for residents within a circular area of specified radius from the plant. The plot shows the probabilities from the emergency phase (EARLY), long-term phase (CHRONC), and the two phases combined.

The long-term-phase risks for this scenario are slightly smaller than the emergency-phase risks except within the evacuation zone (10 mi), where emergency-phase risks are very small. The long-term risks are controlled by the habitability or return criterion, which is an annual dose limit of 500 mrem. Since the overall risks are somewhat dominated by the emergency-phase risks, the overall risk profile has a peak at 20 miles.

Because the annual dose limit of the habitability criterion is lower than the dose truncation levels of the 620 mrem/yr and HPS criteria, those two risk profiles (shown in Figure 81) are mainly influenced by risks during the emergency-phase, as shown in Figure 82.

The contribution of the emergency phase to the overall risk is less for the Peach Bottom unmitigated LTSBO and STSBO with RCIC blackstart scenarios discussed above and for all of the Surry scenarios presented in Chapter 7 of Appendix B of this report. The uniqueness of this scenario appears to be related to the relatively small release fraction for cesium compared with those for the other chemical groups (cf., Table 20). The cesium group, especially Cs-137, tends to dominate the long-term doses received following an accident. Most of the other chemical groups, e.g., the iodine, tellurium, and barium isotopes, tend to contribute more to short-term doses.

The prompt-fatality risks are identically zero for this accident scenario. This is because the release fractions are too low to produce doses large enough to exceed the dose thresholds for early fatalities, even for the 0.5% of the population that does not evacuate.

7.3.3.1 Sensitivity Analyses of the Size of the Evacuation Zone and the Evacuation Start Time

The base case analysis included evacuation of the 10-mile EPZ and a shadow evacuation cohort between 10 and 20 miles. For the unmitigated STSBO scenario, three additional calculations were performed to assess variations in the protective actions.

Sensitivity #1 - Evacuation of a 16-Mile Circular Area

In this calculation, the evacuation zone is expanded to 16 miles. Shadow evacuation occurs from within the 16- to 20-mile area.

Sensitivity #2 - Evacuation of a 20-Mile Circular Area

In this calculation, the evacuation zone is expanded to 20 miles. No shadow evacuation beyond the evacuation zone is considered.

Sensitivity #3 – Delayed Evacuation of a 10-Mile Circular Area

This calculation is identical to the base case case described above, with the exception that implementation of protective action is delayed by 30 minutes.

The results of all three sensitivity analyses are compared with the base case in Table 27. The results for the case with delayed evacuation are identical to those for the base case; the other two sensitivities are slightly different than the base case. These results are also shown in Figure 83. Since the delayed evacuation case is identical to the base case, it is omitted from the figure.

Table 27 Effect of Size of Evacuation Zone on Conditional, Mean, LNT, Latent-Cancer-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities are for the Unmitigated Short-Term Station Blackout Scenario.

Radius of Circular Area (mi)	Base Case 10-Mile Evacuation	Sensitivity #1 16-Mile Evacuation	Sensitivity #2 20-Mile Evacuation	Sensitivity #3 10-Mile Delayed Evacuation
10	1.5E-04	1.7E-04	2.2E-04	1.5E-04
20	1.8E-04	1.4E-04	1.0E-04	1.8E-04
30	1.3E-04	1.1E-04	1.0E-04	1.3E-04
40	8.3E-05	7.7E-05	7.2E-05	8.3E-05
50	6.9E-05	6.4E-05	6.1E-05	6.9E-05

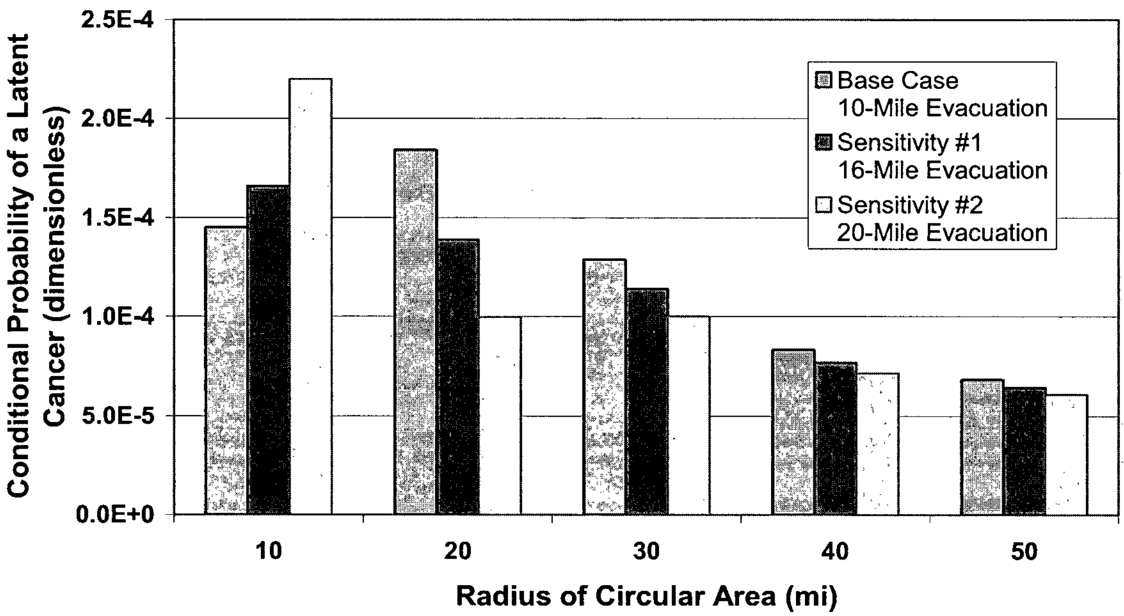

Figure 83 Conditional, i.e., assuming accident occurs, mean, LNT, latent-cancer-fatality probabilities from the Peach Bottom unmitigated STSBO scenario for residents within a circular area of specified radius from the plant. The plot shows the dependence of probabilities on the size of the evacuation zone.

Although expanding the size of the evacuation zone decreases the latent cancer fatality risk beyond the 10 mile radius for the unmitigated STSBO, there is an increase in the risk within 10 miles associated with this change. Beyond a 20 mile radius, the risk reduction associated with increasing the size of the evacuation zone is slight. Prompt-fatality risk remains zero for these sensitivity cases.

7.3.4 Evaluation of the Effect of the Seismic Activity on Emergency Response

Earlier sections in Chapter 7 provide offsite health consequence estimates for unmitigated sensitivity cases that reflect the effects of the seismic event on emergency response involving mitigation of the accident. However, these earlier sections do not reflect the effects of the seismic event on public evacuation. This subsection provides consequence estimates that also include the effects of the seismic event on public evacuation. The consequence estimates below were developed for the STSBO without RCIC blackstart. Although this is the lowest frequency and lowest unconditional risk scenario, this scenario was chosen for this analysis because it was believed to be the most likely to show an increase in risk. Seismic effects of ER are site-specific but have no substantial effect on health consequences at Peach Bottom. Although sirens fail, alternative notification is adequate and a larger shadow evacuation is expected. Although bridges fail, they are not significant for evacuation, an adequate road network remains, and evacuation speeds are unchanged. In addition, accident progression timing predicted by realistic analysis is relatively slow so that there is some margin for EP activation and execution.

Table 28 Conditional, i.e., assuming accident occurs, Mean, LNT, Latent-Cancer-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities Are for the Unmitigated STSBO Scenario and Compare the Unmodified Emergency Response (ER) and ER Adjusted to Account for the Effect of Seismic Activity on Evacuation Routes and Human Response.

Radius of Circular Area (mi)	Unmodified ER	ER Adjusted for Seismic Effects
10	1.5E-04	1.7E-04
20	1.8E-04	1.4E-04
30	1.3E-04	1.1E-04
40	8.3E-05	7.7E-05
50	6.9E-05	6.4E-05

7.3.5 Evaluation of SST1 Source Term

An objective of SOARCA is to update quantification of consequences in earlier studies, such as the 1982 Siting Study. However, because the 1982 Siting Study estimated latent cancer fatalities out to 500 miles whereas SOARCA estimates are limited to 50 miles, analyses are performed in this section to better understand the change in LCF risk associated with use of current state-of-the-art analysis. The approach used in this section was to substitute the SST1 source term into MACCS2 input files for two SOARCA scenarios. The MACCS2 input files chosen were the ones developed for the unmitigated LTSBO and STSBO scenarios. These sensitivity analyses show the impact of the improvements made in the source term methods and practices on the consequence results.

The SST1 source term is described in the Sandia Siting Study report as follows:

- Severe core damage
- Essentially involves loss of all installed safety features
- Severe direct breach of containment

An exact scenario and containment failure mechanism (e.g., hydrogen detonation, direct containment heating, or alpha-mode failure) are not specified.

Notification time (i.e., sounding a siren to notify the public that a general emergency has been declared) for the Peach Bottom unmitigated LTSBO occurs at 1.5 hr (see Figure 60). Declaration of a general emergency occurs at 45 min. and it takes an additional 45 min. to notify the public. Notification of the public is thus coincident with the beginning of release for the SST1 source term (cf., Table 20), which occurs 1.5 hr after accident initiation. The general public begins to evacuate 60 minutes later, which is 2.5 hrs after accident initiation. The start of evacuation for the general public for this scenario occurs 30 minutes later than the start of evacuation for the first cohort in the Sandia Siting Study. The largest segment of the population in the Sandia

Siting Study began to evacuate 1.5 hrs later, 4 hr after accident initiation. Thus, the evacuation used in this sensitivity study is earlier, on the whole, than that used at the time of the Sandia Siting Study.

As an additional comparison, the unmitigated STSBO scenario was modified to use the SST1 source term. Evacuation of the general public in this scenario begins 30 min. earlier in the than in the LTSBO scenario, as can be seen by comparing Figure 60 with Figure 66. Thus, this scenario has the general public beginning to evacuate at the same time as the first cohort in the Sandia Siting Study.

While the Sandia Siting Study treated emergency response very simplistically, a major emphasis of the SOARCA project is to treat all aspects of the consequence analysis as realistically as possible. Consequently, no attempt was made in this sensitivity analysis to reproduce the treatment of emergency response used in the Siting Study.

Table 29 shows the conditional latent-cancer-fatality risks for a release corresponding to the SST1 source term occurring at Peach Bottom based on the unmitigated LTSBO scenario and its timing for ER. Because the source term is very large, dose truncation level has a very minor influence on predicted risk. That is because the doses with the SST1 source term are large enough to exceed the dose truncation levels for most of the affected population. This concept is further elaborated in a subsequent paragraph.

Table 30 shows the conditional latent-cancer-fatality risks for a release corresponding to the SST1 source term occurring at Peach Bottom based on the unmitigated STSBO scenario. The same observation is made as for the calculation based on the LTSBO, i.e., that dose truncation level has a very minor influence on predicted risk. That is again because the doses with the SST1 source term are large enough to exceed the dose truncation levels for most of the affected population. The risks for this case are lower than for the case based on the LTSBO, showing the effect of evacuating 30 minutes earlier.

Table 29 Conditional, i.e., assuming accident occurs, Mean, Latent-Cancer-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities are based on the SST1 Source Term from the Sandia Siting Study. All Parameters Other than for Source Term Are Taken from the Unmitigated LTSBO Scenario.

Radius of Circular Area (mi)	LNT	620 mrem/yr	5 rem/yr, 10 rem lifetime
10	4.7E-03	4.6E-03	4.4E-03
20	2.0E-03	1.8E-03	1.7E-03
30	1.1E-03	9.5E-04	8.8E-04
40	6.3E-04	5.1E-04	4.5E-04
50	4.8E-04	3.7E-04	3.1E-04

Table 30 Conditional, i.e., Assuming Accident Occurs, Mean, Latent-Cancer-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities are based on the SST1 Source Term from the Sandia Siting Study. All Parameters Other than for Source Term are Taken from the Unmitigated STSBO Scenario.

Radius of Circular Area (mi)	LNT	620 mrem/yr	5 rem/yr, 10 rem lifetime
10	3.3E-03	3.2E-03	3.1E-03
20	1.8E-03	1.6E-03	1.5E-03
30	1.0E-03	9.0E-04	8.2E-04
40	6.1E-04	4.9E-04	4.2E-04
50	4.6E-04	3.5E-04	3.0E-04

Table 31 compares the LNT risks for the two cases using the SST1 source term with those for the largest source term calculated for Peach Bottom in this study, the unmitigated STSBO. The LNT risk within 10 miles for the SST1 source term using the STSBO ER timing is about a factor of 20 higher than the risk for the unmitigated STSBO; the factor is about 30 when comparing the SST1 source term risk using the LTSBO ER timing with the unmitigated STSBO risk. The 10-mile risk using a 620 mrem/yr dose-truncation criterion is a factor of 1000 higher when comparing the SST1 result using the STSBO ER timing with the unmitigated STSBO. At larger distances, the risks are less disparate. For example, the ratio is about a factor of 7 for a 50-mile area when comparing the LNT risks for the SST1 source term using the STSBO ER parameters with those for the unmitigated STSBO.

Table 31 Conditional, i.e., Assuming Accident Occurs, Mean, LNT, Latent-Cancer-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities Are for the SST1 Source Term from the Sandia Siting Study Using Emergency Response Parameters from the LTSBO and the STSBO Scenarios. The Final Column of the Table Shows the SOARCA Results for the Unmitigated STSBO.

Radius of Circular Area (mi)	SST1 ER for LTSBO	SST1 for ER for STSBO	Unmitigated STSBO
10	4.7E-03	3.3E-03	1.5E-04
20	2.0E-03	1.8E-03	1.8E-04
30	1.1E-03	1.0E-03	1.3E-04
40	6.3E-04	6.1E-04	8.3E-05
50	4.8E-04	4.6E-04	6.9E-05

The maximum risk is within 10 miles for the SST1 source term, which is largely because the release is very early and emergency response is not rapid enough to prevent exposures within the EPZ during the emergency phase. This is expected since release begins 30 and 60 minutes before evacuation of the public using the STSBO and LTSBO ER timings, respectively.

A notable feature of the risks presented in Table 29 and Table 30 is that the choice of dose truncation criterion has a minor influence on risk. This is very different than the SOARCA accident scenarios discussed in preceding subsections. Figure 84 provides some insights into this behavior. For the SST1 source term, nearly all of the risk, especially at short distances from the plant, is from exposures that occur during the emergency phase. Because a significant fraction of these doses are received over a short period of time, and the doses are large due to the large source term, the range of dose truncation values considered in this study have little influence on predicted risks. Again, this is a very different trend than is observed for the current, state-of-the-art source terms.

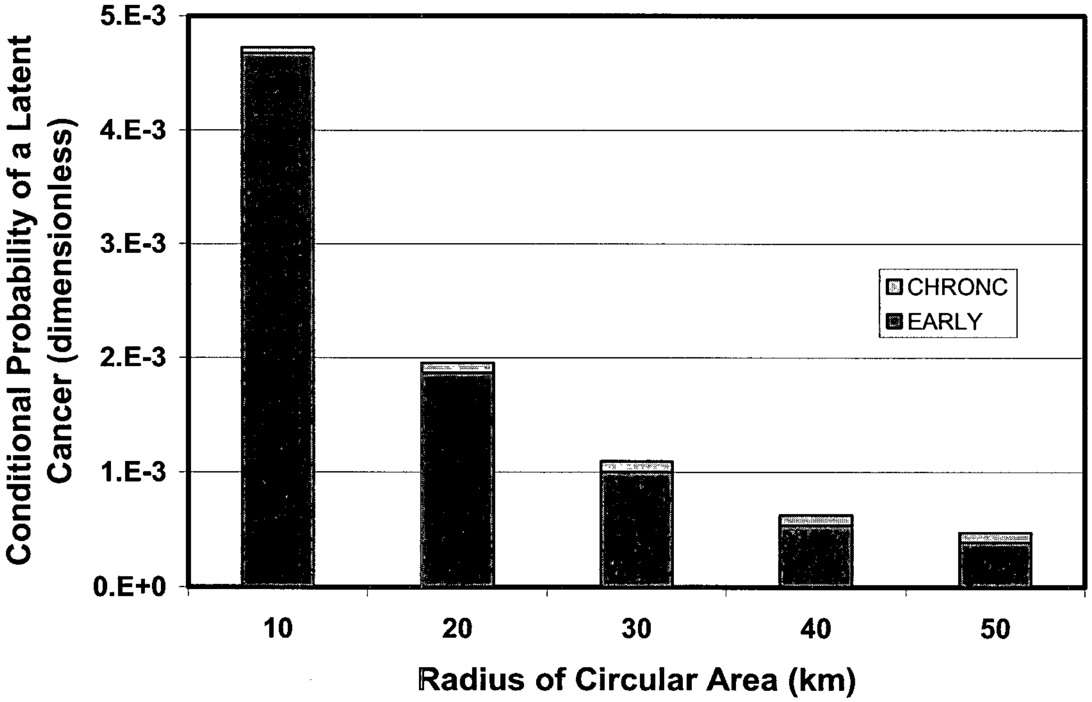

Figure 84 Conditional, i.e., assuming accident occurs, mean, LNT, latent-cancer-fatality probabilities (dimensionless) from the SST1 source term for residents within a circular area of specified radius from the Peach Bottom plant using the SOARCA LTSBO ER timing. The plot shows the probabilities from the emergency phase (EARLY), long-term phase (CHRONC), and the sum of the two is the total.

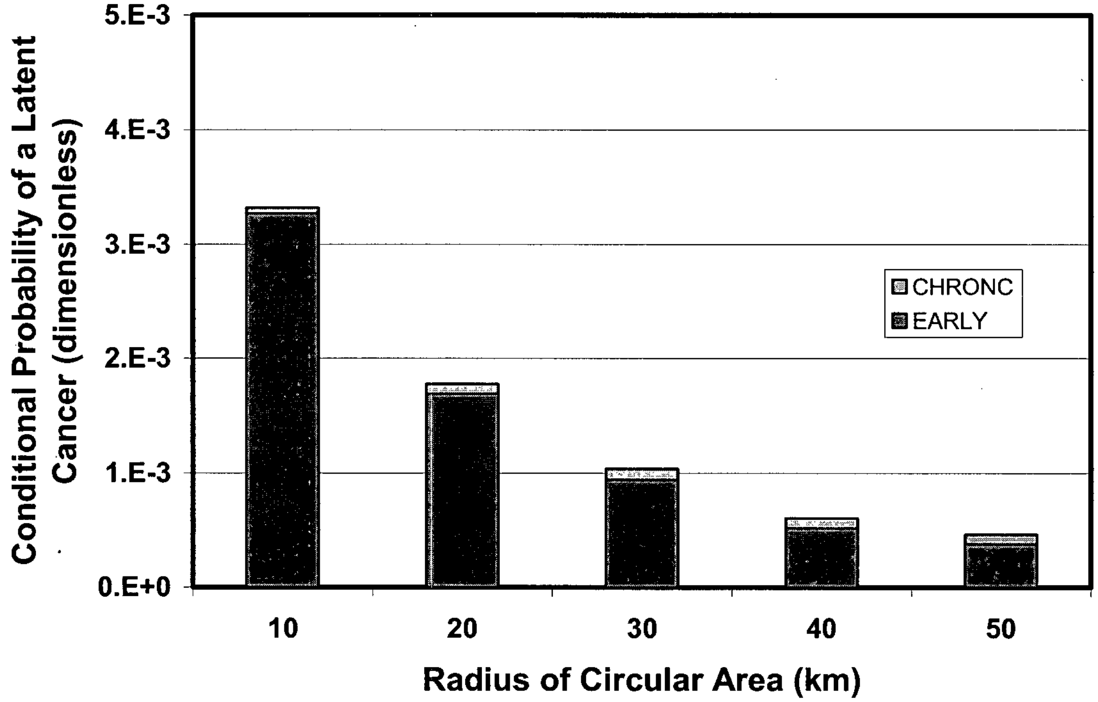

Figure 85 Conditional, i.e., assuming accident occurs, mean, LNT, latent-cancer-fatality probabilities (dimensionless) from the SST1 source term for residents within a circular area of specified radius from the Peach Bottom plant plant using the SOARCA STSBO ER timing. The plot shows the probabilities from the emergency phase (EARLY), long-term phase (CHRONC), and the sum of the two is the total.

Table 32 shows the risk of prompt fatalities for several circular areas of specified radii centered at the plant for the two SST1 cases. Unlike the source terms presented in the preceding sections, the predicted prompt-fatality risks are greater than zero. The SST1 release fractions are more than large enough and early enough to induce prompt fatalities for members of the public who live close to the plant.

The NRC quantitative health object (QHO) for prompt fatalities is generally interpreted as the unconditional risk within 1 mile of the exclusion area boundary. For Peach Bottom, the exclusion area boundary is 0.5 mile from the reactor building from which release occurs, so the outer boundary of this 1-mile zone is at 1.5 miles. The closest MACCS2 grid boundary to 1.5 miles used in this set of calculations is at 1.3 miles. Evaluating the risk within 1.3 miles should reasonably approximate the risk within 1 mile of the exclusion area boundary. The frequency stated for the SST1 source term in the Sandia Siting Study [25] is 10^{-5}/year, so the unconditional risk of a prompt fatality for this source term is approximately $1.4 \cdot 10^{-7}$/year using the LTSBO ER model and $9.8 \cdot 10^{-8}$/year using the STSBO ER model. Even for this very large source term, the prompt fatality risk is below the QHO value of $5 \cdot 10^{-7}$/year.

Table 32 Conditional, i.e., assuming accident occurs, Mean, Prompt-Fatality Probabilities (dimensionless) for Residents within the Specified Radii of the Peach Bottom Site. Probabilities are for the SST1 Source Term from the Sandia Siting Study Using Other Input Parameters from the Unmitigated LTSBO and STSBO Scenarios.

Radius of Circular Area (mi)	Probability of a Prompt Fatality Using LTSBO ER (dimensionless)	Probability of a Prompt Fatality Using STSBO ER (dimensionless)
1.0	1.4E-02	9.9E-03
1.3	1.4E-02	9.8E-03
2.0	7.1E-03	4.2E-03
2.5	4.9E-03	2.8E-03
3.0	3.3E-03	1.8E-03
3.5	1.8E-03	1.0E-03
5.0	5.0E-04	2.8E-04
7.0	2.2E-04	1.2E-04
10.0	9.7E-05	5.4E-05

7.3.6 Comparison with the Siting Study

This subsection discusses the results of a comparison of scenario-specific risk between SOARCA and the 1982 Siting Study analysis for the SST1 source term. Since the 1982 Siting Study does not provide latent cancer results at distance that are comparable to those in provided in the SOARCA study or to the NRC safety goal, an effort was made to reproduce the Sandia Siting Study results for Peach Bottom using the SST1 source term in order to produce results that are directly comparable to the SOARCA results. An exact reproduction of those results was not feasible because the CRAC2 code is no longer available and some of the models and modeling choices used in the Siting Study are cannot be readily reconstructed. The current successor to the CRAC2 code, MACCS2, shares a number of models with its ancestor, but other models have been improved and therefore produce different results. However, those model parameters that were known or presumed to have been used in the 1982 Siting Study were used to in an effort to reproduce the results of that study. The results presented in this appendix were all computed with MACCS2 version 2.5, but also discuss differences between current and original results from the Siting Study.

The motivation for this work is to establish another point of comparison between the Sandia Siting Study and SOARCA. The previous subsection (7.3.5) provides a comparison of scenario-specific risk focusing solely on source terms, using the oft-cited SST1 source term from the 1982 Siting Study. This additional comparison seeks to explore a scenario-specific risk using all aspects of the 1982 Siting Study, to the extent they can be understood and recreated. Key aspects of the modeling choices are discussed in the following subsection, 7.3.6.1.

Table 32 compares the release fractions from the Peach Bottom unmitigated STSBO sequence and the SST1 source term. The unmitigated STSBO sequence was chosen for this comparison because it is the largest of the source terms for Peach Bottom that were evaluated as part of the SOARCA investigation. Its frequency is only $3x10^{-7}$/yr compared with the frequency assigned to the SST1 source term of 10^{-5}/yr.

Table 32 Total Release Fractions by Chemical Group Comparison between the SST1 and the SOARCA Unmitigated STSBO Peach Bottom Sequences

	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
SOARCA	0.970	0.015	0.025	0.062	0.063	0.000	0.003	0.001	0.000
SST1	1.000	0.670	0.070	0.450	0.640	0.050	0.050	0.009	0.009

The last subsection, 7.3.6.2, compares the results and shows that predicted risk has diminished markedly between the time of the 1982 Siting Study and the current SOARCA study. Comparisons are based on the linear, no-threshold dose-response model, the only one used at the time of the 1982 Siting Study. Comparisons are also provided for the background dose level of 620 mrem/yr.

7.3.6.1 Comparison of Modeling Choices

Table 33 compares key modeling choices and parameters used in the Sandia Siting Study with those used in SOARCA for Peach Bottom. This table is not comprehensive. Some of the modeling choices listed in the table could be established with a reasonable degree of certainty from the Sandia Siting Study documentation; others represent best judgments as to how consequence analyses were performed at the time of the Siting Study. Generally, those judgments were based on NUREG-1150 or WASH-1400 modeling practices. Best judgments or approximations are denoted with an asterisk in the table. Each of the modeling choices shown in the table are discussed below.

Weather Sampling The exact strategy that was used in the Siting Study is unknown. The Siting Study does show a binned representation of each of the weather files used in the study, so it is highly likely that weather binning was used. Also, the exact weather data that were used in the study are unknown. Weather sampling used in this reconstruction uses the current Peach Bottom weather file and the NUREG-1150 choices for weather bin structure and samples per bin.

Habitability Criterion The habitability criterion used in the Siting Study was 25 rem over 30 years. This criterion leads to higher long-term doses than the one used in SOARCA, which is 500 mrem over 1 year.

Emergency Response Emergency response was treated simplistically and conservatively in the Sandia Siting Study; the SOARCA treatment of emergency response is more complex and realistic. For example, 30% of the population began to evacuate by 2 hours after accident initiation in the Siting Study; whereas, almost 93% of the population have begun to evacuate by 2 hours in the STSBO scenario. Also, SOARCA uses the more realistic network evacuation model to represent traffic on designated emergency routes. This model was not developed until after the Siting Study. The evacuation speed, 10 MPH, used in the Siting Study leads to faster evacuation than in the SOARCA representation of Peach Bottom once evacuation begins.

Table 33 Comparison of Modeling Choices and Parameters Used to Reconstruct Sandia Siting Study Results with the Peach Bottom Unmitigated STSBO from SOARCA

Modeling Choice or Parameter	Siting Study	SOARCA
Weather Sampling	142 Trials*	984 Trials
Habitability Criterion	25 rem in 30 yr	0.5 rem in 1 yr
Emergency Response	3 Cohorts	6 Cohorts
	30% Evacuate at 2 hr	37.2% Evacuate at 1.0 hr
	40% Evacuate at 4 hr	55.5% Evacuate at 2.0 hr
	30% Evacuate at 6 hr	6.8% Evacuate at 5.25 hr
		0.5% Do Not Evacuate
KI Ingestion	No One Takes KI	50% Take KI with 70% Efficacy
Number of Sectors	16	64
Fission Product Inventory	Low Burnup	Mid-Cycle High Burnup
Deposition Velocity	1 cm/s	0.05 to 1.7 cm/s
Mixing Height	Annual Ave.	Day & Night Seasonal Ave.
Risk Factors for Cancers	BEIR III*	BEIR V
Population Basis Year	1970	2005
Groundshine Weathering	WASH-1400*	MACCS2
Relocation Criteria		
Normal	25 rem / 24 hr*	1 rem / 24 hr
Hot Spot	50 rem / 12 hr*	5 rem / 12 hr
Plume Meander Model	MACCS2*	None
Dose Conversion Factors	ICRP-26, -30*	FGR-13
Food Ingestion Model	COMIDA2*	None

* Best judgment or approximation

KI Ingestion KI was not distributed at the time of the Siting Study. Because it was not distributed, no model for the effect of KI ingesting had been developed. Distribution of KI is relatively common now and is realistically accounted for in the SOARCA study.

Number of Sectors The only option available at the time of the Sandia Siting Study was to model wind directions using 16 compass sectors. That capability has been extended, and SOARCA takes advantage of the full 64-sector capability in the current version of MACCS2.

Fission Product Inventory The Siting Study report provides the fission product inventory used in that study. The inventory used for the SOARCA evaluation of Peach Bottom was based on current fuel cycle practices at Peach Bottom and assumes that the accident occurs at mid-cycle and is laid out in Appendix A.1.

Deposition Velocity Dry deposition of aerosol particles is represented through a set of aerosol size bins. Each size bin represents a range of aerosol sizes, usually characterized by a mass median diameter. Each aerosol bin is assigned a dry deposition velocity. The set of dry deposition velocities are used by MACCS2, along with airborne aerosol concentrations that are calculated using the Gaussian plume approximation, to determine the ground concentrations.

Common practice from the time of the Siting Study through NUREG-1150 was to treat a single aerosol bin using a representative deposition velocity of 1 cm/s. The current practice, used in SOARCA, uses all of the aerosol data from MELCOR. These data are for 10 aerosol bins, each representing a range of aerosol sizes. The representative deposition velocities for the 10 bins range from 0.05 for the smaller particles to 1.7 cm/s for the larger ones.

Mixing Height The Siting Study report shows mean annual daytime mixing heights for each location. Apparently, a single mixing height was used to represent the entire year. In SOARCA, seasonal average daytime and nighttime mixing heights are used.

Risk Factors for Cancer Cancer risk factors used in the Sandia Siting Study are presumed to have come from the BEIR III report, which would have been the latest available at the time. Cancer risk factors in the SOARCA study are based on BEIR V even though the BEIR VII study had been published before SOARCA started. BEIR V was chosen because the treatment of tissues is consistent with the FGR-13 dose conversion factors. The BEIR V risk factors are about a factor of 2.7 higher than those from BEIR III, so this single change in modeling parameters significantly affects the predicted cancer risks.

Population Basis Year To simplify recreation of the Siting Study results for Peach Bottom, the NUREG-1150 site file, which is for 1980, was used. Data provided in the Siting Study report give population densities at low resolution and would have been difficult to convert into a site file. This NUREG-1150 site file is based on the year 1980 rather than basis year for the Siting Study, which is believed to be 1970. Fortunately, individual risks only depend on the relative locations of the population, not on the total population. From that standpoint, the 1980 population data used to reconstruct the Siting Study should have a minor effect on the comparison presented below.

Groundshine Weathering The Siting Study report did not document the parameters used in the groundshine weathering model. It was judged that the model might have been the same as the one used in WASH-1400, which predated the Siting Study. The SOARCA model for groundshine weathering is the same as the one used in NUREG-1150. The specific model used turns out to play a small role for a large, early release like the SST1 source term because most of the doses are during the emergency phase. Weathering occurs during the long-term phase.

Relocation Criteria The values used for normal and hot-spot relocation were not described in the Siting Study report, so the values were assumed to be the same as those used in NUREG-1150. The SOACA dose values to trigger relocation were much smaller, but the relocation times were the same.

Plume Meander Model The plume meander model used in the Siting Study was assumed to be the same as the one used in NUREG-1150. Plume meander was not treated in SOARCA.

Dose Conversion Factors The original version of MACCS2 was distributed with a set of dose conversion factors (DCFs) using tissue weighting factors from ICRP-26 and organ-specific DCFs from ICRP-30. These publications predated the Siting Study, so it is reasonable to expect that they were also used in the Siting Study. These DCFs were used in the reconstruction of the Siting Study SST1 results.

Food Ingestion Model No details of the ingestion pathway are provided in the Siting Study report, but it does mention that ingestion of contaminated food and milk were treated. The food ingestion model that would have been used certainly predates the implementation of the COMIDA2 food model, which first became available in MACCS2. Since the food model used in the Siting Study would be difficult or impossible to reconstruct, the COMIDA2 model was used as a stand in. For comparison, the food pathway was not treated in the SOARCA analyses.

Making all of the changes listed above plus replacing the Peach Bottom unmitigated STSBO source term with the SST1 source term resulted in a best-effort attempt to reproduce the Siting Study results. However, this effort over-predicted the Siting Study latent cancer results using the SST1 source term for Peach Bottom by about a factor of 2. Thus, there are other changes in the models and parameter choices that could not be captured in the attempt to recreate this result. Nonetheless, even with this imprecision in recreating the 1982 study and a residual factor-of-2 bias in the results, the characterization of the 1982 study at shorter, more meaningful distances that can be compared directly with the SOARCA results provides a useful comparison.

7.3.6.2 Comparison of Results

Table 34 below compares the best-estimate Sandia Siting Study conditional probabilities of an excess, individual latent cancer using the SST1 source term with those for the unmitigated STSBO scenario evaluated in SOARCA. The comparison shows that the conditional probabilities within 10 miles of the plant are higher by a factor of 51. Accounting for a potential factor-of-2 bias, the ratio is about 25 within a 10-mile radius. Therefore, at the distance associated with the NRC Safety Goal for latent cancers, risk is substantially smaller than that predicted in the 1982 study. This ratio diminishes with increasing radius, becoming about a factor of 6 within a 50-mile radius. Again, accounting for a potential bias, the ratio may be more like a factor of 3. The decrease in the ratio from 25 to 3 occurs because relocation of the population beyond the 10-mile EPZ limits exposures during the emergency phase and the habitability criterion limits exposures during the long-term phase. However, implementing these measures results in significantly greater need for decontamination and condemnation of land in the case of the 1982 study than for SOARCA.

If these comparisons were made on the basis of unconditional risk, the factors would be much larger since the frequency of the Unmitigated STSBO is about a factor of 30 lower than the frequency estimated for the SST1 source term. The ratios on the basis of risk (1/reactor year) are therefore about 800 for residents living within 10 miles of the plant and about 100 for residents living within 50 miles of the plant.

Table 34 Conditional, i.e., Assuming the Accident Occurs, Mean, Latent-Cancer Fatality Probabilities (dimensionless) Using a LNT Dose-Response Model for Residents within the Specified Radii of the Peach Bottom Site. Probabilities Are for the Recreation of the Sandia Siting Study Using the SST1 Source Term at Peach Bottom and for the Unmitigated STSBO Calculated for SOARCA. Core Damage Frequencies Were Estimated to Be 10^{-5}/yr and $3 \cdot 10^{-7}$/yr for the SST1 and STSBO Source Terms, Respectively.

Radius of Circular Area (mi)	SST1	PB STSBO	Ratio SST1 to STSBO
10	7.6E-03	1.5E-04	51
20	2.1E-03	1.8E-04	12
30	9.2E-04	1.3E-04	7
40	5.3E-04	8.3E-05	6
50	4.2E-04	6.9E-05	6

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APPENDIX A.1 PEACH BOTTOM RADIONUCLIDE INVENTORY

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The following tables summarize the radionuclide core inventory for the Peach Bottom plant at the time of shutdown for each of the accident progression scenarios considered in this report.

Non-fuel activation products, such as Co-58 and Co-60, were not included in the inventory analysis. While these isotopes are important in terms of worker dose during routine maintenance, their activities are several orders of magnitude lower than most of the isotopes listed below and do not contribute much to offsite doses. Thus, the omission of these isotopes has a minor effect on the SOARCA results.

Table A.1-1 Peach Bottom radionuclide core inventory and class definition.

Radionuclide Class Name	Representative Element	Member Elements	Total Mass (kg)
Noble Gas	Xe	He, Ne, Ar, Kr, Xe, Rn, H, N	531.7
Alkali Metals	Cs	Li, Na, K, Rb, Cs, Fr, Cu	323.0
Alkaline Earths	Ba	Be, Mg, Ca, Sr, Ba, Ra, Es, Fm	235.6
Halogens	I	F, Cl, Br, I, At	19.9
Chalcogens	Te	O, S, Se, Te, Po	49.1
Platinoids	Ru	Ru, Rh, Pd, Re, Os, Ir, Pt, Au, Ni	342.8
Early Transition Elements	Mo	V, Cr, Fe, Co, Mn, Nb, Mo, Tc, Ta, W	400.2
Tetravalent	Ce	Ti, Zr, Hf, Ce, Th, Pa, Np, Pu, C	1555.5
Trivalents	La	Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Am, Cm, Bk, Cf	1793.7
Uranium	U	U	132794.0
More Volatile Main Group	Cd	Cd, Hg, Zn, As, Sb, Pb, Tl, Bi	6.6
Less Volatile Main Group	Sn	Ga, Ge, In, Sn, Ag	9.6

Table A.1-2 Peach Bottom noble gas radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)
Kr-85	3.79E+16
Kr-85m	1.03E+18
Kr-87	2.05E+18
Kr-88	2.77E+18

Xe-133	7.02E+18
Xe-135	2.58E+18
Xe-135m	1.43E+18

Table A.1-3 Peach Bottom alkali metals radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)
Cs-134	3.61E+17
Cs-136	1.43E+17
Cs-137	3.74E+17
Rb-86	4.38E+15
Rb-88	2.80E+18

Table A.1-4 Peach Bottom alkali earths radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)
Ba-139	6.48E+18
Ba-140	6.27E+18
Sr-89	3.79E+18
Sr-90	2.98E+17
Sr-91	4.77E+18
Sr-92	5.02E+18
Ba-137m	3.55E+17

Table A.1-5 Peach Bottom halogen radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)
I-131	3.38E+18
I-132	4.99E+18
I-133	7.15E+18
I-134	8.14E+18
I-135	6.80E+18

Table A.1-6 Peach Bottom chalcogen radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)

Te-127	2.71E+17
Te-127m	4.33E+16
Te-129	8.17E+17
Te-129m	1.55E+17
Te-131m	6.03E+17
Te-132	4.85E+18
Te-131	2.89E+18

Table A.1-7 Peach Bottom platinoid radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)
Rh-105	2.77E+18
Ru-103	4.83E+18
Ru-105	3.03E+18
Ru-106	1.31E+18
Rh-103m	4.82E+18
Rh-106	1.44E+18

Table A.1-8 Peach Bottom early transition element radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)
Nb-95	6.07E+18
Co-58	0.00E+00
Co-60	0.00E+00
Mo-99	6.52E+18
Tc-99m	5.83E+18
Nb-97	6.11E+18
Nb-97m	5.77E+18

Table A.1-9 Peach Bottom tetravalent radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)
Ce-141	5.89E+18
Ce-143	5.64E+18
Ce-144	4.19E+18
Np-239	5.61E+19
Pu-238	6.78E+15
Pu-239	1.37E+15
Pu-240	1.13E+15
Pu-241	3.87E+17
Zr-95	6.11E+18
Zr-97	6.08E+18

Table A.1-10 Peach Bottom trivalent radionuclide class specific isotopic activity at the time of reactor shutdown

Isotope	Activity (Bq)
Am-241	5.23E+14
Cm-242	9.57E+16
Cm-244	4.70E+15
La-140	6.48E+18
La-141	5.86E+18
La-142	5.70E+18
Nd-147	2.32E+18
Pr-143	5.55E+18
Y-90	3.03E+17
Y-91	4.82E+18
Y-92	5.05E+18
Y-93	5.58E+18
Y-91m	2.75E+18
Pr-144	4.20E+18
Pr-144m	5.85E+16