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SEQUOYAH SOARCA BEST-ESTIMATE AND UNCERTAINTY ANALYSIS OF A SHORT-TERM STATION BLACKOUT ACCIDENT

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ABSTRACT

The U.S. Nuclear Regulatory Commission initiated the state-of-the-art reactor consequence analyses (SOARCA) project to develop realistic estimates of the offsite radiological health consequences for potential severe reactor accidents. The SOARCA analysis of an ice condenser containment plant was performed because its relatively low design pressure and reliance on igniters makes it potentially susceptible to early containment failure from hydrogen combustion during a severe accident. The focus was on station blackout accident scenarios where all alternating current power is lost. Accident progression calculations used the MELCOR computer code. For scenarios leading to an offsite release of radioactive material, SOARCA analyzed atmospheric dispersion, emergency response, and potential health consequences using the MELCOR Accident Consequence Code System (MACCS). The analysis included hundreds of MELCOR and MACCS simulations to account for uncertainty in important accident progression and offsite consequence input parameters. As a result of the state-of-the-art approach, public health consequences from severe nuclear power plant accidents modeled in SOARCA are smaller than previously calculated. The delayed releases calculated provide more time for emergency response actions, such as evacuating or sheltering for affected populations. This analysis reinforces the results of past analyses of ice condenser containments showing that successful use of igniters is effective in averting early containment failure. Even for scenarios resulting in early containment failure, the calculated individual latent fatal cancer risks are very small.

1. INTRODUCTION

This paper describes an integrated analysis of accident progression, fission product behavior, source term, and offsite consequences of a seismically initiated, short-term station blackout accident (STSBO) at the Sequoyah Nuclear Power Plant (Sequoyah). This is the third pilot plant to be evaluated as part of the NRC's State of the Art Reactor Consequence Analysis (SOARCA) project. The paper reports both best estimate and uncertainty analyses using the MELCOR (for

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severe accidents) and MACCS (MELCOR Accident Consequence Code System for offsite consequences) codes that are being developed at Sandia National Laboratories for the U.S. Nuclear Regulatory Commission (NRC). The uncertainty analysis considers epistemic uncertainties of key input parameters for both the MELCOR and MACCS codes.

A primary focus of this work is on hydrogen combustion, which has long been considered a potential challenge to an ice condenser containment. The analysis indicates that containment failure is much more likely from gradual pressurization than from hydrogen combustion. The analysis reveals that only the first hydrogen burn has the potential to fail containment; subsequent hydrogen burns are too weak. Significant uncertainties influencing potential early containment failure are containment rupture pressure, time-in-cycle (what point in the refueling cycle) when the accident occurs, the melt temperature of ZrO_2/UO_2 eutectic, and the number of safety valve (SV) cycles before failure-to-close.

The dominance of late or no (i.e., not during the 72-hr calculation) containment failure strongly influences the offsite consequence results, which are presented as conditional, individual, early and latent cancer fatality risks. The consequence analysis accounts for significant seismic damage to bridges and uses the linear no-threshold assumption for cancer induction. Even for early release cases, there is essentially no early fatality risk. Conditional individual latent cancer fatality risk (assuming the accident occurs) is low, but is about an order of magnitude higher in the unlikely event of early containment failure. Generally, long-term risk (as opposed to the emergency phase risk) is the larger contributor to the overall risk. Regression analyses indicate that time-in-cycle when the accident occurs, which influences accident progression via decay heat and consequences via isotopic inventory, has the largest influence on individual latent cancer fatality risk. Other important uncertainties to risk within 50 miles are cancer risk factors for residual, lung, and colon cancers; containment rupture pressure; and the time of relocation of nonevacuees who exceed protective action limits.

2. APPROACH

The Sequoyah best estimate plus uncertainty analysis (UA) follows the approach developed for the previous Peach Bottom [1] and Surry [2] UAs. Lessons learned from the previous UAs and feedback from the NRC's Advisory Committee on Reactor Safeguards (ACRS) were considered, as well as additional knowledge gained since the Peach Bottom and Surry best estimate calculations [3,4]. Objectives for this work include: developing insights into the overall sensitivity of results to uncertainty in selected modeling inputs; evaluating the likelihood of early containment failure and resulting consequences; identifying the most influential input parameters contributing to accident progression and offsite consequences through application of a set of regression analyses; informing the NRC's Site Level 3 Probabilistic Risk Assessment (PRA) project and post-Fukushima-accident regulatory activities.

Figures of merit were selected to support the analysis and investigation of results. The source term (MELCOR) figures of merit were the environmental release fractions of cesium and iodine, in-vessel hydrogen production, and release timing. Cesium release fractions are discussed in this paper, since cesium is the dominant contributor to health consequences. The consequence (MACCS) figures of merit were individual latent-cancer fatality (LCF) risk and early fatality (EF) risk at specified distances using the linear, no-threshold (LNT) assumption for dose response.

The accident scenario selected for this analysis was an unmitigated STSBO at the Sequoyah plant, in part because of the importance of station blackout scenarios and in part because accident progression occurs relatively quickly under the postulated conditions. The relatively quick accident progression provides a basis to assess the effects of offsite response parameters for the cases with early containment failure.

To meet the objective of developing insights into the overall sensitivity of SOARCA results to uncertainty of selected modeling inputs, a reasonable number of modeling inputs important to the figures of merit being assessed were chosen. Many parameters are basic inputs, such as isotopic inventory, material properties, sizes and lengths of piping, weather files, etc. Selecting parameters was an iterative process to identify those expected to influence the results.

As developed, most of the parameters characterized epistemic uncertainties and a few characterized aleatory uncertainties. In practice, all uncertain parameters were treated as epistemic with the exception of weather variability, which was treated separately as described below. Often the mode (most likely value) or median (50^{th} percentile) of the distribution corresponded to the value used in the MACCS best-estimate (or “reference”) analyses.

MELCOR, MelMACCS, and MACCS are the three primary codes used in the integrated analysis. Uncertainties in the model inputs were propagated in a two-step Monte Carlo simulation (MCS). First, a set of source terms were generated using MELCOR by sampling uncertain MELCOR inputs. Each source term was then coupled with one set of sampled values for uncertain MACCS inputs in a second MCS to generate a set of consequence metrics. Simple random sampling was used in both MCS steps, to enable discarding incomplete MELCOR realizations and the use of bootstrapping methods to estimate confidence in results. The MACCS MCS further included an inner loop of ~1,000 weather trials to represent variability due to weather, for each epistemic vector of sampled MELCOR and MACCS inputs.

MELCOR input parameters were made uncertain across the following domains of modeling: accident sequence, in-vessel accident progression, ex-vessel accident progression, containment behavior, chemical forms of iodine and cesium, and aerosol physics. MACCS input parameters were made uncertain across the following domains of modeling: aerosol deposition, plume dispersion, radiation shielding, early health effects, latent health effects, and emergency response.

Evaluation of induced steam generator tube rupture (SGTR) had been considered as part of the Surry UA [2]. The Surry UA is currently being revised and an updated report is expected in the future. SGTR was not considered in this study for Sequoyah, but the potential for a SGTR is expected to be similar for Sequoyah to that for Surry. The only mechanism for early release in the current study is early containment failure from hydrogen combustion, which is a major focus of the work.

3. ACCIDENT PROGRESSION AND SOURCE TERM RESULTS

A high-performance computing cluster was used to execute a Monte Carlo simulation with 600 MELCOR runs, of which 567 successfully completed (MELCOR runs typically fail due to convergence failures, most commonly in the COR package) the 72-hour analysis time. No attempt was made to restart unsuccessful MELCOR runs because the restart process might have affected the predictions. However, the effect of ignoring the 33 unsuccessful runs was evaluated and was judged to have a small influence on the overall results.

An additional mini-UA was performed for Sequoyah to further refine the evaluation of early containment failure [5]. The results corroborate the overall conclusions of the full uncertainty analysis, but this topic is not discussed further in this paper.

3.1 Containment Response

For the successful realizations, the following observations are made relative to containment performance

- Containment failed at the first hydrogen deflagration on 4 of the realizations (0.7%),
- In 492 of the realizations (86.8%), containment failed between 36 and 72 hr due to gradual pressure increase in the containment, and
- In 71 of the realizations (12.5%), containment did not fail by the end of the 72-hour analysis time. Most of these sampled a beginning-of-cycle core inventory, i.e., about 6 days after re-starting from a refueling outage.

In most of the calculations the containment survived the first and any subsequent hydrogen deflagrations and failed much later due to simple static over pressurization from accumulating steam and non-condensable gases. Pressurizer safety valves functioned per design in most of these calculations. Hydrogen accumulation in containment was most often relatively small at the time of the first deflagration and subsequent deflagrations eventually were suppressed as oxygen concentration fell below lower flammability limits due to depletion from previous burns. Fission product decay heat caused a gradual monotonic pressurization as it generally heated containment, vaporized ice melt (water), and drove non-condensable gas generation through core-concrete interaction.

For the 4 cases with an early containment failure, the first hydrogen burn caused a sudden pressure increase that ruptured the steel containment vessel. In these cases, hydrogen accumulation in containment, notably in the containment dome, was relatively large at the time of the burn. The hydrogen accumulated as it was passively vented from the reactor coolant system (RCS) through a stuck-open pressurizer safety valve and ruptured the pressurizer relief tank burst disk during core degradation.

3.2 Environmental Cesium Release

The uncertainty analyses produced sets of time-dependent results (e.g., horsetail plots). Figure 1, shows the horsetails for Cs release over the 72-hr analysis period. The curves are color coded to indicate realizations with a beginning-of-cycle (BOC), a middle-of-cycle (MOC), and an end-of-cycle (EOC) inventory. A wide spread in cesium release fractions is observed. The set of four early-containment-failure cases are clearly delineated in the figure. For these cases, release into the environment begins between approximately 4 and 8 hours after accident initiation; for the other cases, significant environmental release is delayed until after 40 hours from the initiating event. The 5th percentile curve is not shown on the plot because it lies below a release fraction of 10^{-5}. Also, the BOC curves are not visible in the figure because the release fractions remain below the scale through the 72-hr transient.

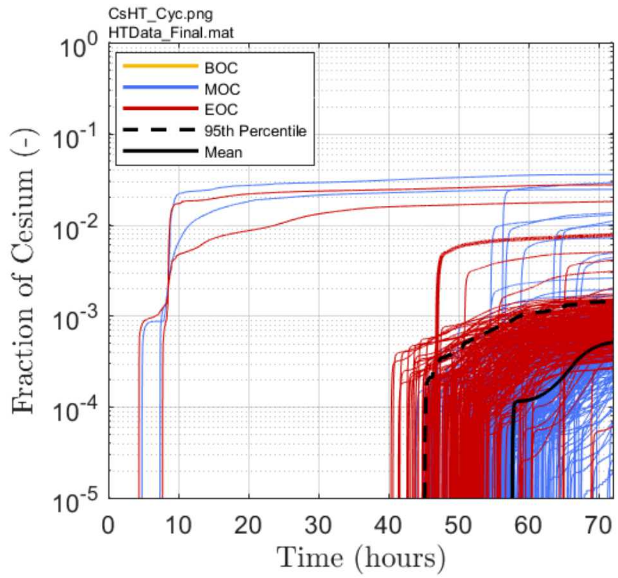

Figure 1 – Horsetail plot of environmental cesium release.

3.3 Influential Parameters for Environmental Cs Release

Table 1 shows results for the regression analysis of the cesium environmental release fraction. The parameters are listed in the first column, followed by the results from four regression techniques. The last two columns contain average values of the main (individual, independent) contribution of the parameter on the result metric and the conjoint influence of the parameter on the result metric. These are calculated as weighted averages of the overall contributions from the four regression techniques. Values of main contribution greater than 0.02 and conjoint contributions greater than 0.1 are considered potentially significant and are highlighted. The parameters in the first column of the tables are ordered by the values in the column labeled Main Contribution; thus, the parameters appear in rank order according to their independent contribution to uncertainty.

Table 1 shows that the number of primary SV cycles (priSVcycles) is the dominant parameter for all regression techniques. The number of primary SV cycles reflects the aggregate actual number of cycles performed by the three pressurizer SVs in the MELCOR calculations. The pressurizer SVs cycle one at a time due to different pressure setpoints. If the valve with lowest setpoint fails closed or with sufficiently small flow area, the next valve (with second-lowest setpoint) may start cycling. Cycling of the pressurizer SVs terminates once the primary RCS depressurizes, which may be the consequence of a valve sticking open with sufficient area, or creep rupture of an RCS component (e.g. hot leg piping). The parameter for aggregate cycles has relatively strong individual and joint contributions to the overall variation in the cesium environmental release fraction. The other top parameters are the time-in-cycle during burn-up/refueling cycle (Cycle), the rupture pressure of the containment (Rupture), and the effective liquefaction temperature of the UO_2–ZrO_2 system (Eu_Melt_T).

Table 1. Regression analysis summary of cesium environmental release fraction at 72 hours

Sequoyah_Final_RegResults_R2_Cs.png
Data: RegData_Final.xlsx

	Rank Regression		Quadratic		Recursive Partitioning		MARS		Main Contribution	Conjoint Contribution
Final R^2	0.40		0.77		0.51		0.77			
Input	R^2 contr.	SRRC	S_i	T_i	S_i	T_i	S_i	T_i		
priSVcyc	0.26	-0.53	0.32	0.86	0.58	0.96	0.41	0.76	0.280	0.294
Cycle	0.01	0.15	0.04	0.10	0.01	0.02	0.21	0.21	0.051	0.019
Rupture	0.05	-0.22	0.01	0.14	---	---	0.01	0.09	0.016	0.051
Eu_Melt_T	0.02	-0.15	0.02	0.27	0.02	0.40	0.01	0.30	0.013	0.205
Shape_Fact	0.04	0.21	---	---	0.00	0.00	0.00	0.00	0.010	0.000
Ox_Model	0.01	0.09	0.01	0.16	---	---	0.00	0.00	0.004	0.039
Fseal_Pressure	---	---	0.00	0.02	---	---	0.01	0.01	0.002	0.005
Seal_Open_A	0.01	-0.07	0.00	0.01	---	---	0.00	0.00	0.002	0.004
Burn_Dir	0.00	0.07	0.00	0.02	---	---	0.00	0.01	0.001	0.006

** highlighted if main contribution larger than 0.02 or conjoint contribution larger than 0.1*

3.4 Sensitivity Analyses Using Best-Estimate Parameters

Additional MELCOR analyses were performed using fixed inputs but varying one or a few parameters to explore sensitivities. These analyses explore the benefit of hydrogen igniters, sensitivity to reactor coolant pump (RCP) seal leakage, and the effect of availability of DC power at the beginning of the accident (long-term station blackout scenario). Some additional sensitivity analyses are presented in the original report [5] but are not included here.

Conclusions from these sensitivity analyses are that successful use of hydrogen igniters essentially eliminates the possibility of an early containment failure; RCP seal leakage does not have a significant impact on the source term metrics studied in this investigation; and hydrogen generation and source terms are expected to be lower for a LTSBO than for a STSBO.

4. CONSEQUENCE RESULTS

The results of the consequence analyses are presented in terms of individual LCF risk and individual EF risk for the population residing near the plant. The primary results are mean values over 1,031 weather trials. To examine the variation of risk with distances from the site, the reported risk measures are evaluated for residents within specified radial distance intervals (i.e., circular or annular areas with specified radii) centered on the reactor site. They are averaged over the entire residential population within each interval and over weather variability. These individual risk values are population weighted and are computed by dividing the predicted number of excess fatalities (early or latent), were the accident to occur, by the population living within the specified interval. These risk measures account for the distribution of the population within the distance interval and for the interplay between the population distribution and the wind-rose probabilities. The results are presented as conditional risks, which are the risks predicated on the accident occurring.

4.1 LCF Risks

Table 2 shows four statistics (mean, median, 5th percentile, and 95th percentile) for the mean (over weather variability), individual, LCF risk, conditional on an accident occurring (per event) from the 567 realizations of the MACCS uncertainty analysis. Risks are reported assuming linear, no-threshold (LNT) dose response. Results are provided at five spatial intervals representing annular areas centered on Sequoyah. The annular distance intervals shown are specified by the radii of the corresponding inner and outer circles defining each area. Each of the statistics in the table represents the overall epistemic (state of knowledge) uncertainty on the mean over weather variability for the groups of MELCOR and MACCS inputs that were treated as uncertain. The results show that mean conditional risks are on the order of 1.0 $x10^{-4}$ at all distances reported.

Risks within 10 miles are slightly lower than those within larger circular areas (except for the 5^{th} percentile results) because evacuation is effective and most of the emergency planning zone (EPZ) residents receive little or no dose during the emergency phase. The mean risk in the annular region from 10- to 20-miles is slightly lower than the risk in the area from 20-30 miles, which results in part because 20% of the residents between 10 and 15 miles are assumed to evacuate. Risks diminish slowly with distance for circular and annular areas beyond 30 miles, as expected.

Table 2. Mean individual LCF risk conditional on the STSBO accident occurring (per event) for five annular area intervals centered on Sequoyah

	0-10 miles	10-20 miles	20-30 miles	30-40 miles	40-50 miles
Mean	8.0E-05	9.7E-05	1.0E-04	8.2E-05	6.6E-05
Median	6.7E-05	7.5E-05	9.1E-05	7.8E-05	6.2E-05
5th percentile	1.2E-08	2.7E-09	1.1E-09	4.2E-10	2.6E-10
95th percentile	2.0E-04	2.5E-04	2.4E-04	1.8E-04	1.4E-04

Figure 2 shows the complementary cumulative distribution function (CCDF) for the same radial intervals summarized in Table 2. The points on the curves represent the mean LCF risk over variable weather for each of the 567 realizations. Each realization represents epistemic uncertainty (from both source term and consequence inputs) in this UA and the risks are conditional on the accident occurring. The curves show that the risks are bimodal and span the range of about 10^{-10} to 10^{-3} per event. The bimodal nature of the CCDF curves derives from the fact that the containment does not fail by 72 hours in 74 of the realizations (13% of the cases) and does fail before 72 hours in the remaining 495 realizations (87% of the cases). The cases with no containment failure account for the upper left (very low risk) portion of the CCDF curves; the cases with containment failure account for the right (relatively higher risk) portion of the CCDF curves.

One other notable feature of the CCDF curves is that the curves are close together for the portion representing containment failure but not for the portion representing no containment failure. This indicates that risk is nearly flat as a function of distance from the plant. The decrease in risk with distance is small for the cases with containment failure. On the other hand, there is more than an order of magnitude drop in risk over the set of annular intervals for the cases when containment does not fail. The difference between these two portions of the distribution is the extent to which remediation is required. More remediation (i.e., decontamination, interdiction, and condemnation of land and property) reduces consequences that would otherwise have been higher.

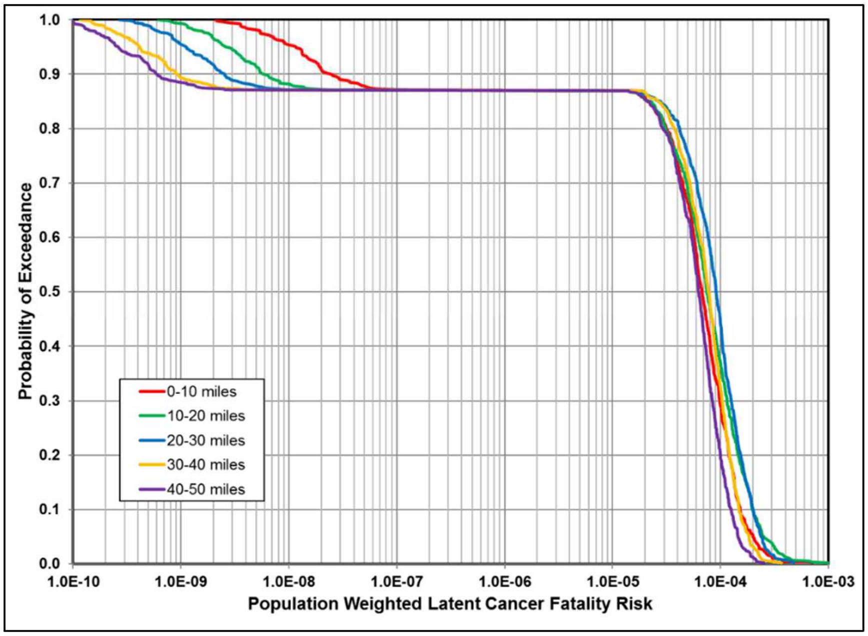

Figure 2 – CCDF of average, individual LCF risk using LNT dose response for five annual areas. Probabilities in the plot represents epistemic uncertainties in the inputs affecting both source term and consequences.

Table 3 shows that a relatively small percentage of the overall risk is from the emergency phase. The fraction is very small within the 10-mile EPZ because nearly all the population there evacuates, in most cases before environmental release begins. The peak percentage occurs beyond the distance where any evacuation is assumed to occur, in the 20- to 30-mile interval. Beyond this region, the contribution of the emergency phase diminishes because plume contents continually decrease with distance.

Table 3. Mean contribution of emergency phase to overall risk

0-10 miles	10-20 miles	20-30 miles	30-40 miles	40-50 miles
0.2%	20%	36%	27%	15%

4.2 EF Risks

The median, 5th percentile, and even the 95th percentile results are 0 for mean (over weather variability) individual EF risk, conditional on an accident occurring (per event) for the MACCS uncertainty analysis. Conditional mean EF risks are 3.0×10^{-9}, 1.8×10^{-9}, and 8.6×10^{-10} within circular intervals centered on Sequoyah of 1, 1.3, and 2 miles, respectively, based on three realizations that computed nonzero EF risks, as discussed below. These statistics represent the overall epistemic (state of knowledge) uncertainty for the groups of MELCOR and MACCS inputs that were treated as uncertain. Early fatality risk is calculated to be zero beyond 2 miles for all the realizations. Only three of the 567 realizations have a nonzero early fatality risk, and even those risks are so small that they can be considered negligible. All three are for cases of early containment failure. Even within these three realizations, EF risks are 0 for nearly all the weather trials. Thus, the early fatality risks, even assuming the unlikely occurrence of an STSBO accident sequence at Sequoyah compounded with the unlikely occurrence of an early containment failure, are essentially zero.

4.3 Influential Parameters for LCF Risks

The most influential parameter for LCF risk within 50 miles of the Sequoyah plant shown in Table 4 is Cycle, which represents the time during the fuel cycle that the accident occurs. Three values for Cycle were evaluated in this study, 6 days of operation after refueling (BOC), 200 days (MOC), and 525 days (EOC). This parameter affects both the decay heat in the MELCOR analysis and the fission product inventory in the MACCS analysis. It has the largest influence on consequences of all the uncertain inputs considered in the Sequoyah UA. Consequences are more severe as this parameter increases, but the differences are more profound between BOC and MOC/EOC and less profound between MOC and EOC.

Other influential parameters shown in Table 4 are CFRISK(8), Rupture, CFRISK(4), CFRISK(7), and TIMNRM. CFRISK(8) is the cancer risk factor for residual cancers, which are the set of cancers not specifically treated. Rupture represents the containment pressure at which containment ruptures (fails) and is correlated negatively with consequences, which means consequences decrease as containment failure pressure increases. Lower containment failure pressure biases failure to occur earlier and thus causes significant releases to start earlier. CFRISK(4) and CFRISK(7) are the cancer risk factors for lung and colon cancers, respectively. TIMNRM is the time at which nonevacuees are relocated, which affects the dose received during the emergency phase. All these parameters are positively correlated with LCF risk, with the exception of the containment failure pressure (Rupture). LCF risk increases with increasing values of positively correlated parameters and decreases with increasing values of negatively correlated parameters.

Table 4. Mean, individual, LCF risk regression results within a 0- to 50-mile interval based on LNT dose response

	Rank Regression		Quadratic		Recursive Partitioning		MARS		Main Contribution	Conjoint Contribution
Final R^2	0.59		0.86		0.65		0.75			
Input	R^2 contr.	SRRC	S_i	T_i	S_i	T_i	S_i	T_i		
Cycle	0.23	0.52	0.24	0.31	0.36	0.44	0.21	0.21	0.208	0.038
CFRISK(8)	0.06	0.24	0.09	0.13	0.05	0.14	0.09	0.08	0.059	0.029
Rupture	0.05	-0.21	0.06	0.10	0.05	0.22	0.10	0.25	0.052	0.086
CFRISK(4)	0.05	0.23	0.07	0.10	0.04	0.15	0.08	0.09	0.048	0.037
CFRISK(7)	0.04	0.22	0.05	0.07	0.02	0.10	0.08	0.11	0.040	0.028
TIMNRM	0.04	0.22	0.04	0.07	0.06	0.30	0.05	0.06	0.038	0.061
CYSIGA(1)	0.03	0.19	0.03	0.04	0.01	0.05	---	---	0.015	0.013
DDREFA(4)	0.02	-0.13	0.02	0.02	0.00	0.04	0.02	0.02	0.013	0.011
CFRISK(6)	0.01	0.08	0.03	0.12	---	---	0.02	0.08	0.012	0.042

** highlighted if main contribution larger than 0.02 or conjoint contribution larger than 0.1*

4.4 Sensitivity Analyses Using Best-Estimate Parameters

Additional sensitivity analyses were performed to examine the influence of key inputs on consequence results. These analyses used fixed parameters for all the inputs that were not part of the sensitivity analysis. The sensitivity analyses that were performed evaluate shelter-in-place as an alternative to rapid evacuation, degradation of shielding factors during the emergency phase because of seismic damage to houses and other buildings; influence of the weather year chosen for the analysis; and four alternative models of dose response for cancer induction, which were a 10 mrem annual threshold, a 3.1 mSv (310 mrem†) annual threshold (the value of US average natural background radiation), a 620 mrem annual threshold (the value of US average natural plus medical radiation), and a 5 rem annual threshold up to a lifetime limit of 10 rem based on a Health Physics Society position statement.

The conclusions of the sensitivity analyses are that rapid evacuation significantly reduces individual LCF risk as compared with shelter-in-place; shelter-in-place also increases EF risk, but it remains small nonetheless; degraded shielding increases LCF risk, and especially so in conjunction with shelter-in-place; degraded shielding increases EF risk, but it remains small nonetheless; generally, LCF risk for an individual weather year is within about ±5% of the 5-year average value; and examination of reasonable, non-LNT, doses-response models for LCF risk can result in one or more order-of-magnitude reduction in estimated individual risk.

5. CONCLUSIONS

A primary goal of the Sequoyah UA was to investigate input parameters contributing to the potential for an ice-condenser containment to fail early from a hydrogen deflagration in a severe accident situation. The containment end-state results are accordingly characterized into three general outcomes:

- Late containment failure due to a slow pressurization of the containment is the most likely outcome.
- No containment failure within 72 hours is the second most likely outcome. This outcome occurs mostly for the BOC realizations with lower decay heat.
- Early containment failure due to combustion of hydrogen generated in-vessel is very unlikely. All observed early containment failures occurred from the initial hydrogen burn when containment oxygen levels were relatively high.

The time in cycle is significant for cesium environmental release, varying from ‘nearly zero’ releases (at the end of the analysis) for BOC realizations, and increasing in magnitude and occurring earlier with increasing burnup (MOC and then EOC). The aggregate number of primary SV cycles experienced (priSVcycles) is also significant. The primary SV cycles parameter also has high interaction effects (identified from non-linear regression techniques) for cesium environmental release. No other parameters were identified as having significant main effects on cesium environmental release. In terms of significant effects only in interaction with other parameters, the U-Zr-O melt temperature was identified as significant. Generally, cesium environmental releases are minimal until about 42 hours into the simulation, and increase from 48 hours to 72 hours.

Regression analyses indicate that the time-in-cycle (Cycle) when the accident occurs has the largest influence on consequences of all the uncertain inputs considered in the Sequoyah STSBO UA; this parameter affects both isotopic inventory and the associated decay heat and so has a dual effect on consequence results. It should be noted, however, that even the BOC calculations appear to be headed toward containment failure, but after the 72-hr analysis time. If the accident could not be mitigated by 72 hr, as assumed, the impact of Cycle might have been diminished.

† 1 rem = 0.01 Sv

Other important MACCS parameters for LCF risks are the cancer risk factors for residual, lung, and colon cancers and the time needed to relocate nonevacuees. The cancer fatality risk factor for the residual organ represents all the cancer types not specifically treated in MACCS.

Containment rupture pressure (Rupture) is also significant for LCF risks. The pressure at which containment ruptures is correlated negatively with consequences, which means consequences decrease as containment failure pressure increases. Lower containment failure pressure generally corresponds to earlier containment failure. This could be due to reaching failure pressure earlier if failing by gradual overpressure, or greater chances of early containment failure from the initial hydrogen deflagration. Correspondingly, a higher failure pressure translates to a delay in containment failure timing, which benefits both evacuation timing as well as airborne fallout effectiveness within the containment.

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