RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

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Question No. 19-53

10 CFR 52.47(a)(23) and 10 CFR 52.47(a)(27), in part, require that the applicant perform a probabilistic risk assessment and an analysis of design features for the prevention and mitigation of severe accidents.

Chapter 19.0 of the NRC's Standard Review Plan (SRP), Revision 3 (draft), includes the following guidance to the NRC reviewer: "…the reviewer carries out an independent assessment of the plant response to selected severe accident scenarios using the latest version of the MELCOR computer code. The assessment should examine accident scenarios from the PRA, which are chosen based on a combination of frequency, consequence, and dominant risk. Some of these scenarios should be similar or identical to sequences analyzed by the applicant and reported in the PRA."

Per the above SRP guidance, the staff has performed MELCOR confirmatory calculations. The calculations' objectives are to enable the staff to confirm the plant response to severe accidents based on the applicant's MAAP calculations and to identify potential discrepancies. Because the objectives include confirming the expected plant response based on the applicant's MAAP calculations, the staff used realistic (see further discussion below) assumptions in its calculations. The staff evaluates initial and boundary conditions, the nodalization of the plant, and the assumptions involving the operation of severe accident mitigation systems. Performing confirmatory calculations enables the staff to better understand the design and ask questions regarding the expected response of the design to a severe accident.

Effect of issues identified on all of the applicant's MAAP calculations

For the APR1400 design, the staff performed MELCOR calculations for five selected scenarios modeled by the applicant with MAAP for its analysis of PRA and severe accident design features. Per the SRP, these scenarios were selected based on their importance to core damage frequency (CDF) and/or risk. These scenarios are similar or identical to sequences analyzed by the applicant and reported in the PRA. The staff compared the MELCOR and

MAAP results for these five scenarios and identified the potential issues described below. Some of the issues identified also may be applicable to the applicant's other MAAP calculations that use similar modeling or input assumptions. To minimize unnecessary regulatory burden, the staff has not reviewed the applicant's other MAAP calculations in detail. Nevertheless, the staff expects the applicant to revisit the other MAAP calculations to determine applicability of the issues identified by the staff to the other MAAP calculations.

Realism in the MAAP calculations

Severe accident models such as MAAP and MELCOR have been developed and validated to realistically simulate the progression of a range of severe accident scenarios for light-water nuclear power plants based on plant response. To ensure that the PRA and severe accident design feature analysis are accurately quantified, the staff expects the applicant's MAAP calculations to be based on realistic assumptions. By realistic, the staff means that the assumptions are based on the actual plant design and the operator actions that would be expected to occur during an accident. The staff uses the term realistic to be synonymous with most likely or best estimate. Since some uncertainty may still exist in these code predictions, there may also be a need for sensitivity calculations. For example, if the plant has four pilot operated safety relief valves (POSRVs) and the procedures direct the operator to open all four POSRVs during an accident, then assuming that the operator opens four POSRVs is expected or realistic. Assuming the operator opens two POSRVs may be helpful to understand the potential change in plant response if only two POSRVs were open (i.e., sensitivity calculation). Also, if the plant has four safety injection tanks (SITs) that automatically and passively inject water into the reactor coolant system (RCS) when it depressurizes, then assuming the SITs inject is realistic. Assuming SIT injection does not occur when the RCS depressurizes could similarly be a sensitivity calculation. Furthermore, assumptions that are believed by the applicant to be conservative or to not affect the results need to be technically justified. One way to justify such assumptions could be through the use of sensitivity calculations to demonstrate that the assumption is conservative or does not affect the results. Another way could be to cite uncertainty in the plant operation or response and perform sensitivity calculations to explore this uncertainty.

Request for additional information

For the staff to reach a reasonable assurance finding that the MAAP simulations reflect the expected plant response, please respond to the items below and update the DCD as needed. Also, please provide justification if the response information is excluded from the

DCD. The applicant's responses to the staff issues need to be sufficiently supported to enable the staff to reach the same safety conclusion as the applicant. For example, if the applicant response is that a particular modeling choice is conservative or does not affect the results, the applicant needs to provide data (e.g., sensitivity calculations) to support that statement. The items are grouped into four topical areas as shown below.

Area One: Assumptions Related to Operation of Systems

The MAAP calculations include assumptions regarding operation of systems. In some cases, the DCD and underlying documents do not identify these assumptions or provide justification for the use of these assumptions. Related requests for additional information are as follows:

1 The five MAAP calculations that the staff reviewed do not include SITs injection. Please provide justification.

2 One of the five MAAP calculations the staff reviewed does not include PARs operation. Please provide justification.

3 For four of the five MAAP calculations the staff reviewed, it was not clear to the staff how many valves (POSRVs, 3-way valves, and cavity flooding valves) were being opened. Please provide the justification for the assumed timing and number of valves opened.

4 The MAAP calculation for STC11 (emergency containment spray backup system (ECSBS) operation and no cavity flooding system operation) was performed using the normal containment spray with a reduced flow rate instead of ECSBS which draws water from outside containment. Please provide justification.

Area Two: Assumptions Related to Physical Phenomena

The MAAP calculations include assumptions that do not appear to consider certain physical phenomena. In some cases, the DCD and underlying documents do not identify or provide justification for not considering these phenomena. Related requests for additional information are as follows:

5 The five MAAP calculations that the staff reviewed do not include reactor coolant pump seal leakage flow paths and the resulting flow in the analysis. Please provide justification.

6 The five MAAP calculations that the staff reviewed do not include reactor coolant pump seal failure flow paths and the resulting flow in the analysis. Please provide justification.

7 For the high pressure MAAP calculation the staff examined (Q03), the MAAP output plots indicate that severe accident induced hot leg rupture was neglected. Please provide justification.

8 MAAP case STC16 includes a hole in the containment as a result of a hydrogen burn around 100,000 sec. While this MAAP calculation models containment failure as a result of a burn, it does not model other physical effects of the burn (e.g., decrease in mole fractions of combustibles, increase in containment pressure). Please provide justification.

9 For the high pressure MAAP calculation the staff examined (Q03), the MAAP output plots indicate that the reactor vessel lower head ruptures when the reactor vessel is still at high pressure. However, it appears that the effects of the resulting high pressure melt ejection were not modeled. Please provide justification.

Area Three: Clarifications

10 Please explain the basis for the decay power used in the MAAP calculations. For example, on what fuel burnup, operating power, and time in the operating cycle (e.g., end of cycle) was the decay power based?

11 Please describe the assumptions made in the MAAP calculations for feedwater injection coastdown and MSIV closure timing.

12 Please explain what is being assumed for hydrogen sinks in the simulation. For example, are passive autocatalytic recombiners (PARs) and igniters assumed to be operating? Under what conditions are hydrogen burns assumed to occur?

13 Please explain why the MAAP output plots appear to show core debris exiting the vessel more slowly for the high pressure MAAP calculation the staff reviewed (i.e., Q03) than for the low pressure MAAP calculations (e.g., STC16).

14 The MAAP output plots appear to show more CO2 being produced in the high pressure MAAP calculation the staff reviewed (i.e., Q03) than in the low pressure MAAP calculations (e.g., STC16). Please explain the basis for this.

15 For STC10, the MAAP RCS pressure plot indicates that the depressurization was stopped from 3640 sec to 4370 sec. Please explain why the depressurization was stopped.

16 For STC10, please explain the basis for the MAAP steam generator (SG) pressure to start trending down after 100,000 seconds.

17 For STC10, the MAAP SG water level plot seems to show that water level increases from a level of zero starting at 140,000 seconds. Please explain the basis for reintroduction of water into the SGs at this time.

18 For STC10, MAAP appears to be calculating no ablation, even though core debris is in contact with the cavity concrete floor. Please explain the basis for this modeling.

19 For STC11, from 12,400 to 55,000 sec, the MAAP cavity water level plot appears to show water in the cavity. However, the ablation depth and containment pressure plots during this time frame seem to indicate that the water is not taking away any heat from the core debris. Please explain the basis as to why overlying water is not taking away heat from the core debris.

20 For STC11, the MAAP cavity water level plot shows water level decreasing more slowly from 12,400 to 41,500 than from 41,500 to 55,000 sec. Please explain the basis as to why the water level decreases faster after 41,500 sec.

21 For STC11, starting at 55,000 sec, the MAAP cavity water level plot seems to show that water level drops below the bottom of the cavity (i.e., below 0 meters). Please explain the basis as to how the water can drop below the bottom of the cavity.

22 For STC11, after the ECSBS system starts (around 100,000 sec), the MAAP containment water level plot shows containment spray water going into the holdup volume tank but not into the cavity. Please provide the basis for containment spray water not reaching the cavity, which is the lowest point in the containment. If the basis is internal geometric obstacles, please describe these obstacles and how long the ESCBS would need to operate to overflow these obstacles.

23 For POS5, it is observed that the MAAP-predicted pressurizer pressure is higher than the MAAP-predicted containment pressure until RPV lower head failure. Please explain the basis for the predicted pressurizer pressure and why it is higher than containment pressure. Also, please explain how the flow path from the pressurizer to the containment representing the open 16-inch pressurizer manway was modeled and nodalized with MAAP, including justifying using a stuck-open POSRV to represent the manway.

24 For POS5, it is observed that MAAP-predicted cesium and tellurium release fractions (FREL(2) and FREL(3)). Please explain the basis for this.

25 LPSD Level 2 Modeling Notebook, APR1400-K-P-NR-013762-P, Table 4-2 has CsI and CsOH release fractions, respectively. The release fractions appear to be smaller than expected for source term categories (STCs) with early containment failure (hole sizes of 1 ft2 and 527 ft2 (49 m2)). Please explain the basis for the release fractions. In other words, where did the CsI and CsOH deposit and why?

Area Four: Key Risk Insights Gained from the MAAP analyses

As stated in Chapter 19.0 of the NRC's Standard Review Plan (SRP), Revision 3 (draft), "The staff will determine that the applicant has identified risk-informed safety insights based on systematic evaluations of the risk associated with the design such that the applicant can identify and describe the following:

A. The design's robustness, levels of defense-in-depth, and tolerance of severe accidents initiated by either internal or external events

B. The risk significance of potential human errors associated with the design."

The staff is requesting that the following key design features and operator actions be included in the applicant's risk insights table or the staff is requesting a justification why these additions are not necessary:

1 Operator actions to depressurize the RCS and redirect the resulting flow from the RCS bypassing the in-containment refueling water storage tank (IRWST) (e.g., opening POSRV and 3-way valves), due to its potential to affect containment pressurization, containment failure due to hydrogen combustion, and source term.

2 The design of the key flow paths for molten debris and hot gasses from the cavity below the reactor vessel to the containment reducing the potential for direct containment heating.

Response

Area One: Assumptions Related to Operation of Systems

The results of four (4) MAAP calculations for at power Level 2 PRA are provided as below. But the one MAAP calculation (POS5) for LPSD Level 2 PRA will be submitted by the end of June.

1. The five MAAP calculations that the staff reviewed do not include SITs injection. Please provide justification.

The four (4) MAAP calculations for at power Level 2 PRA are performed to simulate the following accident sequences. The purposes of cases of STC-10, STC-11 and STC-16 are to evaluate the source term releases to the environment, and the purpose of Q03 case is to review the containment pressurization for the sequence of SBO with a dry cavity without containment sprays.

Table 1-1 summarizes the accident condition for each case.

Table 1-1 Condition for MAAP cases

Case	Condition
STC-10	PLOCCW (partial loss of CCW) initiating event, the failure of secondary heat removal, the success of bleed operation, the failure of feed operation, the success of rapid depressurization, the success of cavity flooding system, the success of late containment spray (i.e., ECSBS) and the containment maintains its integrity
STC-11	PLOCCW initiating event, the failure of secondary heat removal, the success of bleed operation, the failure of feed operation, the success of rapid depressurization, the failure of cavity flooding system, the success of late containment spray (i.e., ECSBS) and the basemat melt-through.
STC-16	PLOCCW initiating event, the failure of secondary heat removal, the success of bleed operation, the failure of feed operation, the success of rapid depressurization, the failure of cavity flooding system, the failure of containment spray system and the containment fails due to a late hydrogen burn
Q03	SBO with dry cavity and without sprays

For the PLOCCW or SBO event, the SIT is not considered as a core damage preventing feature in the APR1400 Level 1 PRA. In addition, it's not considered as a severe accident mitigation feature in the APR1400 Level 2 PRA either. Therefore, when the MAAP simulations for those sequences above were modeled, the SITs injection is not modeled for each MAAP calculation following each accident scenario as defined in the Level 1 PRA Event Tree.

In Attachment 1, there are sensitivity studies for these MAAP calculations which include the SITs injection during the accidents. For the sensitivity studies for STC-10, STC-11 and STC-16, even if the SITs injection was modeled for those MAAP calculations, the release fractions of CsI, TeO2, CsOH and Te2 for both base case and sensitivity case have been smaller than 2.5% by the end of the MAAP run. As documented in APR1400 DCD 19.1.4.2.1.3 (Release Category Evaluations), the quantitative definition of a "large" release in the APR1400 Level 2 PRA is that the release fractions of the volatile/semi-volatile fission products (iodine, cesium, tellurium) are greater than 0.025 (2.5 percent). Therefore, it is concluded that the sensitivity studies do not significantly impact the release categorization for STC-10 (intact containment releases), STC-11 (small releases) and STC-16 (small releases). For the sensitivity study for Q03, it also shows that the containment pressurization is not significantly impacted by SITs injection.

2. One of the five MAAP calculations the staff reviewed does not include PARs operation. Please provide justification.

As per the accident scenarios shown in Table 1-1 of Response (1), the containment fails late due to a late hydrogen burn in the STC-16. Following the APR1400 Level 2 PRA Containment Event Tree, the containment is more likely to be challenged by a hydrogen burn if the HMS (Hydrogen Mitigation System) fails to operate. Therefore, to simulate the late containment failure due to a late hydrogen burn, all the PARs are conservatively assumed to be unavailable in the MAAP simulation of STC-16.

Other MAAP calculations are not directly related to a hydrogen burn. In these cases, it's reasonable and realistic that the PARs are assumed to be available because the PARs are passive and reliable features. Therefore, the PARs operation is included in other MAAP calculations such as STC-10 and STC11.

3. For four of the five MAAP calculations the staff reviewed, it was not clear to the staff how many valves (POSRVs, 3-way valves, and cavity flooding valves) were being opened. Please provide the justification for the assumed timing and number of valves opened.

But the one MAAP calculation (POS5) for LPSD Level 2 PRA will be submitted by the end of June.

1) Operation of POSRVs for Feed & Bleed operation prior to core damage

In the cases of STC10, STC11 and STC16, the partial loss of CCW event occurs with the failure of secondary heat removal, the success of BLEED operation, the failure of FEED operation. Following the success criteria notebook (Ref. ARP1400-K-P-NR-013103-P, Rev.0), the success criterion of BLEED operation is to open two out of four POSRVs for the bleed and feed cooling within 80 minutes after the accident initiations. The determination of success criterion of BLEED operation in the Level 1 PRA is based on the results of T/H analysis as follows;

- For a small LOCA (e.g., 2-inch piping break LOCA), the core damage was prevented when the bleed and feed cooling was started within 90 minutes of the initial loss of secondary cooling using one POSRV and one SI pump.
- For a general transient, the core damage was prevented when the bleed and feed cooling was started within 110 minutes of the initial loss of secondary cooling using one POSRV and one SI pump.
- For a loss of feedwater, the core damage was prevented when the bleed and feed cooling was started within 80 minutes of the initial loss of secondary cooling using two POSRV and one SI pump.

In the MAAP calculations of STC10, STC11 and STC16, the POSRVs are first open at 3,395 sec because the RCS pressure reached the POSRV set-point pressure (i.e., 2500 psia). And then, two out of four POSRVs are manually open for bleed and feed cooling operation at 3,600 sec after the accident initiation. The number of manually opened POSRV (i.e., two POSRVs) is in consistent with the success criterion of BLEED operation. For the MAAP calculations for these cases, the timing of manually POSRV open (i.e., one hour) is faster than the maximum coping time of BLEED operation (i.e., 80 minutes). However, it would not significantly impact the source term releases.

In the Q03 case, the POSRVs for BLEED operation are not modeled following the definition of accident scenario.

2) Operation of POSRVs and 3-way valves for rapid depressurization after severe accident initiation

In the cases of STC10, STC11 and STC16, two out of four POSRVs are already open for the BLEED operation prior to core damage. So, the operation of POSRVs for the rapid depressurization after the severe accident initiation is not modeled. However, two trains of 3-way valves are assumed to be open for the change of release point, 30 minutes after the severe accident initiation.

In the Q03 case, the POSRVs and 3-way valves for rapid depressurization are not modeled following the definition of accident scenario.

3) Operation of CFS valves for cavity flooding after severe accident initiation

In the case of STC10, two trains of CFS valves are assumed to be open for the cavity flooding, 30 minutes after the severe accident initiation.

In the case of STC-11, STC-16 and Q03 case, the CFS valves for cavity flooding are not modeled following the definitions of accident scenarios.

4) Sensitivity studies for the assumed timing and number of valves opened for POSRVs, 3-way valves, and CFS valves.

Even if the timing and the number of valves opened for POSRVs, 3-way valves, and CFS valves were changed, it has not significantly impacted the result for each MAAP calculation.

In Attachment 1, there are sensitivity studies for these MAAP calculations which include the SITs injection during the accidents. For the sensitivity studies for STC-10, STC-11 and STC-16, even if the timing and number of valves opened for POSRVs, 3-way valves, and CFS valves were changed for those MAAP calculations, the release fractions of CsI, TeO2, CsOH and Te2 for both base case and sensitivity case have been smaller than 2.5% by the end of the MAAP run. As documented in APR1400 DCD 19.1.4.2.1.3, the quantitative definition of a “large” release in the APR1400 Level 2 PRA is that the release fractions of the volatile/semi-volatile fission products (iodine, cesium, tellurium) are greater than 0.025 (2.5 percent). Therefore, it is concluded that the sensitivity studies do not significantly impact on the release categorization for STC-10 (intact containment releases), STC-11 (small releases) and STC-16 (small releases). For the sensitivity study for Q03, it also shows that the containment pressurization is not significantly impacted by changing the timing and number of valves opened for POSRVs, 3-way valves, and CFS valves.

4. The MAAP calculation for STC11 (emergency containment spray backup system (ECSBS) operation and no cavity flooding system operation) was performed using the normal containment spray with a reduced flow rate instead of ECSBS which draws water from outside containment. Please provide justification.

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Following the source term evaluation for base case using the CS pump with IRWST, the STC-11 is identified as the small release (i.e., less than 2.5 percent of release fractions for Cesium, Iodine and Tellurium). As shown in Attachment 1, the sensitivity case using ECSBS with an external water source also result in a small release. Therefore, it is concluded that STC-11 results in a small release with a significant damage on the cavity concrete.

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Figure 4-1. Cavity water level for base case (CSP) and sensitivity case (ECSBS)

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Figure 4-2. Cavity erosion depth for base case (CSP) and sensitivity case (ECSBS)

Area Two: Assumptions Related to Physical Phenomena

The results of four (4) MAAP calculations for at power Level 2 PRA are provided as below. But the one MAAP calculation (POS5) for LPSD Level 2 PRA will be submitted by the end of June.

5. The five MAAP calculations that the staff reviewed do not include reactor coolant pump seal leakage flow paths and the resulting flow in the analysis. Please provide justification.

   Normal RCP seal leakage is not considered in base model, because it is expected to have a small impact on the core uncover time because most of RCS inventory flow out through POSRV as safety function.

In Attachment 1, there are sensitivity studies for these MAAP calculations which include the normal RCP seal leakage. For the sensitivity studies for STC-10, STC-11 and STC-16, even if the normal RCP seal leakage was modeled for those MAAP calculations, the release fractions of CsI, TeO2, CsOH and Te2 for both base case and sensitivity case have been smaller than 2.5% by the end of the MAAP run. As documented in APR1400 DCD 19.1.4.2.1.3, the quantitative definition of a “large” release in the APR1400 Level 2 PRA is that the release fractions of the volatile/semi-volatile fission products (iodine, cesium, tellurium) are greater than 0.025 (2.5 percent). Therefore, it is concluded that the sensitivity studies do not significantly impact on the release categorization for STC-10 (intact containment releases), STC-11 (small releases) and STC-16 (small releases). For the sensitivity study for Q03, it also shows that the containment pressurization is not significantly impacted by normal RCP seal leakage.

6. <u>The five MAAP calculations that the staff reviewed do not include reactor coolant pump seal failure flow paths and the resulting flow in the analysis. Please provide justification.</u>

RCP seal failure is only modeled on the MAAP simulations for the accident scenarios which are defined including the RCP seal failure in the (extended) Level 1 event trees. However, in these accident scenarios, the RCP seal remains intact during the accident. Therefore, it’s not required to model the RCP seal failure on the MAAP simulations for these accident scenarios.

In Attachment 1, there are sensitivity studies for these MAAP calculations which include the RCP seal failure. For the sensitivity studies for STC-10, STC-11 and STC-16, even if the RCP seal failure was modeled for those MAAP calculations, the release fractions of CsI, TeO2, CsOH and Te2 for both base case and sensitivity case have been smaller than 2.5% by the end of the MAAP run. As documented in APR1400 DCD 19.1.4.2.1.3, the quantitative definition of a “large” release in the APR1400 Level 2 PRA is that the release fractions of the volatile/semi-volatile fission products (iodine, cesium, tellurium) are greater than 0.025 (2.5 percent). Therefore, it is concluded that the sensitivity studies do not significantly impact on the release categorization for STC-10 (intact containment releases), STC-11 (small releases) and STC-16 (small releases). For the sensitivity study for Q03, it also shows that the containment pressurization is not significantly impacted by RCP seal failure.

7. <u>For the high pressure MAAP calculation the staff examined (Q03), the MAAP output plots indicate that severe accident induced hot leg rupture was neglected. Please provide justification.</u>

The purpose of MAAP analysis for Q03 case is just to evaluate long-term containment pressurization in case of SBO with a dry cavity without containment spray. Other significant phenomena such as induced hotleg creep rupture and induced SGTR are not modeled in detail with the MAAP simulation for this case. The chance of induced hot leg rupture for a high pressure sequence is separately discussed in the section 6.2.1 of the CET analysis notebook (Doc no: APR1400-K-P-NR-013602-P, Rev.0).

In Attachment 1, there is a sensitivity MAAP calculation of Q03 in which it assumed to have the induced hotleg creep rupture occurs during the severe accident. The sensitivity study for Q03 shows that the containment pressurization is not significantly impacted even if hotleg creep rupture occurs during the severe accident.

And, other MAAP calculations such as STC-10, STC-11, and STC-16 are not related to the induced hotleg creep rupture because the RCS pressures for these sequences are low prior to core damage.

8. MAAP case STC16 includes a hole in the containment as a result of a hydrogen burn around 100,000 sec. While this MAAP calculation models containment failure as a result of a burn, it does not model other physical effects of the burn (e.g., decrease in mole fractions of combustibles, increase in containment pressure). Please provide justification.

Following the source term grouping logic, the release category 16 (i.e., STC-16) includes the late containment failure with a leak failure size, without containment sprays, with a dry cavity. In this release category, the containment fails due to either a late hydrogen burn or an over-temperature. To simulate the containment failure due to a late hydrogen burn in the MAAP calculation, it is assumed that containment is failed if the hydrogen burnable condition (e.g., > 10% hydrogen concentration) is satisfied. It means that, when the hydrogen mole fraction in the upper compartment is higher than 10%, the containment failure junction will be just open and the significant releases will be started in this MAAP calculation. Hence, in this MAAP calculation, the containment failure is not modeled as a result of the hydrogen ignition/burn and there is no decrease in the hydrogen mole fraction at the time of containment failure.

9. For the high pressure MAAP calculation the staff examined (Q03), the MAAP output plots indicate that the reactor vessel lower head ruptures when the reactor vessel is still at high pressure. However, it appears that the effects of the resulting high pressure melt ejection were not modeled. Please provide justification.

The purpose of MAAP analysis for Q03 case is just to evaluate long-term containment pressurization in case of SBO with a dry cavity w/o containment spray. Even though the HPME is not modeled in detail for this MAAP calculation, it is confirmed as shown in Figure 9-1 that the containment pressure increases at the time of reactor vessel failure. It's because the MAAP code basically includes a module to consider the high pressure melt ejection. As shown in Figure 9-1, it is founded that the peak containment pressure at the time of RPV failure is not high enough to cause the containment failure. The specific cavity design for APR1400 containment limited the containment pressurization at the time of RPV failure as shown in Figure 9-2 which shows the convoluted flow path to decrease the amount of ejected core debris from the cavity to the upper containment.

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Figure 9-1 Containment Pressure for Q03 Case

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Figure 9-2 Convoluted gas flow path from the cavity to the upper containment

Area Three: Clarifications

10. Please explain the basis for the decay power used in the MAAP calculations. For example, on what fuel burnup, operating power, and time in the operating cycle (e.g., end of cycle) was the decay power based?

    In the MAAP code, the power calculation is selected using the input parameter IANSI. This is set to a value of 1 in the parameter file which indicates that the ANSI/ANS5.1-1979 decay power standard will be used to calculate decay power without any adjustment for uncertainty/conservatism.

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11. Please describe the assumptions made in the MAAP calculations for feedwater injection coastdown and MSIV closure timing.

In these MAAP calculations, the coastdown of feedwater pump is not considered. The coastdown of feedwater pump can be modeled by manipulating the MAAP parameter of TDMFW (time delay for the feedwater isolation) to mimic the coastdown.

The time period for MSIV closure (i.e., MAAP parameter of TDMSIV) is set up to be 5.0 seconds based on the APR1400 DCD Table 6.2.4-1.

12. Please explain what is being assumed for hydrogen sinks in the simulation. For example, are passive autocatalytic recombiners (PARs) and igniters assumed to be operating? Under what conditions are hydrogen burns assumed to occur?

Table 12-1 shows the accident condition for operating status of PARs and igniters for each MAAP calculation.

Table 12-1 Accident conditions for PARs and Igniters for each MAAP calculation

Case	Status of PARs	Status of Igniters
STC-10	Available	Available
STC-11	Available	Available
STC-16	Unavailable	Unavailable
Q03	Available	Unavailable

STC16 case is defined as a late containment failure due to late hydrogen burn resulting from a loss of hydrogen mitigation system, so all the PARs and Igniters are conservatively assumed to be unavailable in the MAAP for simulation of STC16. If all the PARs and Igniters are assumed to be unavailable, it is expected to generate relatively rapid containment failure due to hydrogen burn resulting from high hydrogen concentrations inside the containment. Q03 case is a SBO sequence, so all the igniters are unavailable due to a loss of power. In the case of STC10 and STC11, the PARs and Igniters are modeled to be available in the MAAP simulation.

The operation conditions of PARs and igniters in the MAAP code are as below.

- PARs are passive components. So, PARs is working under capacity scale factor in the hydrogen depletion rate. PARs will operate any time the hydrogen concentration starts over 2% until below 0.5% in consideration of 25% efficiency reduction.

- If the operator has forced the igniters on or when the AC power is available, igniters are available to be operated. Igniters will initiate a burn when the hydrogen concentration exceeds the lean upward flammability limit (approximately 4-5%) and the atmosphere is not steam-inert.

13. Please explain why the MAAP output plots appear to show core debris exiting the vessel more slowly for the high pressure MAAP calculation the staff reviewed (i.e., Q03) than for the low pressure MAAP calculations (e.g., STC16).

The amount of remaining core debris in the vessel is related to RCS condition such as the RCS pressure. Both cases have different RCS conditions as below.

- Q03 has analysis conditions with an intact RCS boundary before RV failure, and RCS pressure is high at the time of RPV failure.
- STC-16 has analysis conditions without an intact RCS boundary, since the POSRVs are manually open for Bleed operation before RV failure. The RCS pressure is low at the time of RPV failure.

Table 13-1 shows the key event timings for Q03 case and STC-16.

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As shown in the Table 13-1, the accident progression of STC-16 such as timing of core uncover and core damage is much faster than that of Q03 after the POSRVs are manually open in the STC-16 case. It's because the RCS pressure and RCS inventory level of STC16 are reduced faster than Q03 case, as shown in Figure 13-1 and 13-2. In spite of the difference of accident progression, the timing of RPV failure for STC-16 is 12,908 sec, which is relatively close to the timing of RPV failure for Q03 (i.e., 12,949 sec).

Figure 13-3 and Figure 13-4 shows the mass of total core materials in the core and the mass of total corium pool in the cavity, respectively. In the STC-16 case, most of corium pool has been already relocated to the RPV lower head, and fall into the cavity after the RPV failure. However, in the Q03 case, the relocation of corium pool to the RPV lower head is just started at the time of RPV failure. Therefore, there is a difference in the amount of core debris out of the reactor vessel between STC-16 and Q03 case.

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Figure 13-1 RCS Pressure for Q03 and STC16

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Figure 13-2 RCS Inventory Level for Q03 and STC16

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Figure 13-3 Total Molten Core Material in Core for Q03 and STC16

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Figure 13-4 Mass of Total Corium Pool in the cavity for Q03 and STC16

14. The MAAP output plots appear to show more CO2 being produced in the high pressure MAAP calculation the staff reviewed (i.e., Q03) than in the low pressure MAAP calculations (e.g., STC16). Please explain the basis for this.

    The different burnable option for combustible gases (hydrogen and carbon monoxide (CO)) is the main reason for the difference of carbon dioxide (CO_2) between Q03 and STC-16 scenario.

In the MAAP calculations, initially carbon monoxide (CO) rather than carbon dioxide (CO_2) can be largely generated from the reactor cavity concrete floor by the MCCI phenomena (i.e., by the DECOMP and METOXA subroutine in the MAAP code), especially for these dry-cavity cases.

After then, CO gases distributed throughout sub-compartment atmospheres in the containment can be burnt if some burnable conditions are met, that is, CO can be converted into CO_2 after combustion by igniter or auto-ignitions ($CO + 1/2O_2 \rightarrow CO_2 + Q$ and $H_2 + 1/2O_2 \rightarrow H_2O + Q$) (i.e., by the FLAMM and BURN subroutine in the MAAP code).

Here, the Q03 case allowed the burnable option but STC-16 suppressed the combustion before 24 hours after initiation of MAAP run.

Figure 14-1 and 14-2 shows the mole fractions of CO and CO_2 in the containment (upper compartment node), respectively.

Even though the actual amount of CO generations might be similar, the major CO_2 conversion from CO by combustion started from relatively earlier time in case of Q03 scenario. However, STC16 scenario started after 57 hours (intentionally suppressed before 24 hours after that when burnable conditions (function of gas component and temperature) are met.). This difference of combustion startup time is the main reason for CO_2 mole fraction in the compartment between two scenarios.

TS

Figure 14-1. Mole Fraction of CO for Q03 and STC16

TS

Figure 14-2. Mole Fraction of CO_2 18 for Q03 and STC16

15. For STC10, the MAAP RCS pressure plot indicates that the depressurization was stopped from 3640 sec to 4370 sec. Please explain why the depressurization was stopped.

In the MAAP calculation for STC-10, two (2) POSRVs are manually open for BLEED operation at 3,600 seconds. It causes the RCS pressure to decrease after the POSRVs are manually open. This causes the pressurizer water level to swell and reach the POSRV. The pressure stabilizes because flashing occurs in the RCS while there is two-phase flow through the POSRVs.

Figure 15-1 shows the pressurizer pressure, liquid flow rate and gas flow rate through the POSRVs for STC-10. As shown in Figure 15-1, once enough water is discharged, the POSRV flow changes to gas only (around 4,400 seconds) and the RCS pressure begins to decrease again.

TS

Figure 15-1. Pressurizer Pressure, liquid and gas flow through POSRVs for STC-10

16. For STC10, please explain the basis for the MAAP steam generator (SG) pressure to start trending down after 100,000 seconds.

In the STC-10 case, the cavity flooding valves are open and the ECSBS operates during the severe accident. After the cavity flooding valves are open, the cavity is hydraulically connected with the HVT and the IRWST. Under this condition, if the ECSBS injects the sprays from the external water source, the water levels in the HVT and the IRWST will be increasing. And, the water level in the cavity will also be increasing because the cavity, HVT, and IRWST are connected by cavity flooding lines.

Figure 16-1 shows the SG secondary side pressure, RCS water level, and cavity water level for STC-10. As shown in Figure 16-1, the cavity is first flooded by CFS valve operation, and then the cavity water level and RCS water level starts to be increasing a few hours after the ECSBS operation.

Hence, the water in the cavity can flow into the failure location of reactor vessel breach. If the water in the cavity begins to flow into the ruptured lower head of the reactor vessel (around 100,000 seconds), SG secondary side pressure starts to trend down after 100,000 sec. The cool water decreases the gas temperature in the primary system which lowers the heat transfer rate from the primary system to the steam generators.

TS

Figure 16-1. SG Pressure, RCS water level, Cavity water level

17. For STC10, the MAAP SG water level plot seems to show that water level increases from a level of zero starting at 140,000 seconds. Please explain the basis for reintroduction of water into the SGs at this time.

Figure 17-1 shows the SG secondary side pressure, SG secondary side gas temperature and SG secondary side water level for STC-10 case. At the time of 140,000 sec, the SG secondary side is in a subcooled state because the SG 2nd side pressure is 6.23E6 Pa (903 psia) and SG 2nd side temperature is 551K (532°F). Therefore, SG water level is increased since SG 2nd side steam is condensed after time reached 140,000 sec.

TS

Figure 17-1. SG Pressure, SG gas temperature and SG water level

18. For STC10, MAAP appears to be calculating no ablation, even though core debris is in contact with the cavity concrete floor. Please explain the basis for this modeling.

Per definition of accident sequence of STC10, the ex-vessel core debris should be cooled by overlying water pool in the reactor cavity. So, the following MAAP parameter is established as the ex-vessel core debris is cooled with water.

- HTFB : the coefficient for film boiling heat transfer from corium to an overlying water pool (Default value: 300.0 W/M2-℃)

As shown in Figure 18-1, if the HTFB is extremely low such as 0.01, the MAAP code predicts that the wet cavity condition also results in a significant concrete ablation. However, it is almost impossible that such a significant concrete ablation occurs in case of wet cavity condition.

TS

Figure 18-1. Cavity Concrete Erosion Depth for STC-10

19. For STC11, from 12,400 to 55,000 sec, the MAAP cavity water level plot appears to show water in the cavity. However, the ablation depth and containment pressure plots during this time frame seem to indicate that the water is not taking away any heat from the core debris. Please explain the basis as to why overlying water is not taking away heat from the core debris.

In the MAAP code, the water level is assumed to sit on top of the corium. This means that when there is no water, the water level will be the same as the corium level. Figure 19-1 shows the water level and the corium pool level in the cavity for STC-11. As shown in Figure 19-1, the water level becomes the same as the corium pool level a few minutes after the RPV failure (i.e., after approximately 13,100 sec). Therefore, there is no longer overlying water pool in the cavity, which can remove heat from the ex-vessel core debris. This accident progression appears appropriate because of the definition of accident sequences for STC-11, which includes a dry cavity condition.

TS

Figure 19-1. Water level and corium pool level in the cavity for STC-11

20. For STC11, the MAAP cavity water level plot shows water level decreasing more slowly from 12,400 to 41,500 than from 41,500 to 55,000 sec. Please explain the basis as to why the water level decreases faster after 41,500 sec.

    A few minutes after the RPV failure, the water does not exist in the cavity as described in the response of (19), and the water level is just the corium pool level in the cavity.

    The slope of cavity corium pool level can be changed because the original geometry of the cavity floor is deformed by the concrete ablation. The change in slope can be caused by a discontinuity in the MAAP volume versus height table that occurs once the ablation depth sufficiently exceeds the original geometry of the compartment.

21. For STC11, starting at 55,000 sec, the MAAP cavity water level plot seems to show that water level drops below the bottom of the cavity (i.e., below 0 meters). Please explain the basis as to how the water can drop below the bottom of the cavity.

    A few minutes after the RPV failure, the water does not exist in the cavity as described in the response of (19), and the water level is just the corium pool level in the cavity. As a concrete ablation proceeding, it causes the corium level to decrease below the original elevation of the cavity floor.

22. For STC11, after the ECSBS system starts (around 100,000 sec), the MAAP containment water level plot shows containment spray water going into the holdup volume tank but not into the cavity. Please provide the basis for containment spray water not reaching the cavity, which is the lowest point in the containment. If the basis is internal geometric obstacles, please describe these obstacles and how long the ESCBS would need to operate to overflow these obstacles.

According to the definition of accident scenario of STC11, the cavity flooding system (CFS) is not operated (i.e., a dry cavity condition). In the APR1400 design, the reactor cavity can be flooded by a CFS operation, but not flooded by containment sprays. As shown in Figure 22-1 and 22-2, the flow of sprays is just directed into holdup volume tank (HVT) via a trash rack which is installed at 100-ft elevation in the containment, and is collected in the IRWST. Therefore, even though the reactor cavity is lowest elevation in the containment, the flow of spray cannot be directly injected into the reactor cavity.

TS

TS

Figure 22-1. Containment Building Section A-A

TS

Figure 22-2. Containment Building Elevation 100’-00”

23. For POS5, it is observed that the MAAP-predicted pressurizer pressure is higher than the MAAP-predicted containment pressure until RPV lower head failure. Please explain the basis for the predicted pressurizer pressure and why it is higher than containment pressure. Also, please explain how the flow path from the pressurizer to the containment representing the open 16-inch pressurizer manway was modeled and nodalized with MAAP, including justifying using a stuck-open POSRV to represent the manway.

    It will be submitted by the end of June.

24. For POS5, it is observed that MAAP-predicted cesium and tellurium release fractions (FREL(2) and FREL(3)). Please explain the basis for this.

    It will be submitted by the end of June.

25. LPSD Level 2 Modeling Notebook, APR1400-K-P-NR-013762-P, Table 4-2 has CsI and CsOH release fractions, respectively. The release fractions appear to be smaller than expected for source term categories (STCs) with early containment failure (hole sizes of 1 ft^2 and 527 ft^2 (49 m^2)). Please explain the basis for the release fractions. In other words, where did the CsI and CsOH deposit and why?

    It will be submitted by the end of June.

Area Four: Key Risk Insights Gained from the MAAP analyses

1. Operator actions to depressurize the RCS and redirect the resulting flow from the RCS bypassing the in-containment refueling water storage tank (IRWST) (e.g., opening POSRV and 3-way valves), due to its potential to affect containment pressurization, containment failure due to hydrogen combustion, and source term.

   The operator action for rapid depressurization with 3-way valve alignment and the design characteristics of reactor cavity will be included in No. 11 of risk insight table (Table 19.1-4 in DCD 19.1) as shown in Attachment 2.

2. The design of the key flow paths for molten debris and hot gasses from the cavity below the reactor vessel to the containment reducing the potential for direct containment heating.

   The operator action for rapid depressurization with 3-way valve alignment and the design characteristics of reactor cavity will be included in No. 41 of risk insight table (Table 19.1-4 in DCD 19.1) as shown in Attachment 2.

Impact on DCD

The DCD will be revised to reflect the response of this RAI as shown in Attachment 2.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on the Technical/Topical/Environmental Report

Sensitivity Studies for MAAP Calculations in APR1400 Level 2 PRA

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1.0 INTRODUCTION

A number of MAAP calculations were performed to support the APR1400 Level 2 PRA analysis such as PDS binning, CET phenomenological evaluations, and source term evaluations. However, it is impossible that all the sequences with all combinations of accident condition are evaluated by using a MAAP code. The number of MAAP calculations is limited, and there could be some conservatism in those MAAP calculations. This document provides the sensitivity studies for following four MAAP calculations of At-Power Level 2 PRA which are selected in the RAI 426-8492, Question 19-53. By performing the sensitivity studies, the impacts on those MAAP calculations will be reviewed.

- STC-10 – estimate source term for scenarios without containment failure (DBA leakage only)
- STC-11 – estimate source term for basemat melt-through scenario
- STC-16 – estimate source term for scenario with late containment failure for 0.1ft^2 hole
- Q03 – estimate containment pressure for scenario with dry cavity

2.0 Sensitivity studies for STC-10 Case

2.1 Base case for STC-10 Case

The purpose of the MAAP calculation for STC-10 case is to evaluate the source term releases for release category 10. The representative sequence for STC-10 includes the PLOCCW initiating event, the failure of secondary heat removal, the success of bleed operation, the failure of feed operation, the success of rapid depressurization, the success of cavity flooding system, the success of late containment spray (i.e., ECSBS) and the containment maintains its integrity. Table 1 shows the accident conditions for STC-10 case and other sensitivity cases. And, Table 2 shows the key event timings for STC-10 case and other sensitivity cases.

2.2 Sensitivity Case for STC-10a (Crediting the SITs injection)

As shown in Table 1, the SIT injection is not modeled in the MAAP calculations for base case. The sensitivity case STC-10a used four SITs injection during the accident. As shown in Table 2, the SITs injection is started at 5,772 sec, which occurs after the CET exceeds 1,200 ℉. Compared with base case without SITs injection, the timings of core damage (i.e., Maximum core temperature exceeds 1,800 ℉) and RPV failure are relatively delayed due to the SITs injection.

2.3 Sensitivity Case for STC-10b (Changing the number of opening POSRVs)

As shown in Table 1, the number of opening POSRVs for bleed operation is two (2) in the MAAP calculations for base case. The sensitivity case STC-10b assumed that all the four POSRVs are manually open for bleed operation. In the STC-10b case, the flow rate out of RCS through the POSRVs is greater than bases case. Therefore, the key event timings for STC-10b such as core uncover, core damage and RPV failure are slightly faster than those of base case.

2.4 Sensitivity Case for STC-10c (Changing the delay time of 3-way valves and CFS valves)

As shown in Table 1, the 3-way valves and the CFS valves are assumed to be manually open 30 minutes after the severe accident initiation (i.e., CET > 1,200℉). The sensitivity case STC-10c assumed that the 3-way valves and the CFS valves are open right after the severe accident initiation. As shown in Table 2, the key event timings such as core damage and RPV failure are hardly impacted by the changing the delay time of 3-way valves and CFS valves.

2.5 Sensitivity Case for STC-10d (Assuming the normal RCP seal leakage and the RCP seal failure during the accidents)

As shown in Table 1, the normal RCP seal leakage and the RCP seal failure are not considered in the MAAP calculations for base case. The sensitivity case STC-10d assumed that there are normal RCP seal leakages (21 gpm/pump) and the RCP seal failure (182 gpm/pump) during the accident initiation. In this case, the normal RCP seal leakage is assumed to occur after the accident initiation, and the RCP seal failure is assumed to occur 10 minutes after the severe accident initiation (i.e., CET > 1,200 ℉). Due to the normal RCP seal leakage, the first POSRVs opening is delayed compared with base case. And then, the POSRV manual opening (i.e., Bleed operation) is assumed to be operated after the first POSRV opening. Hence, the key event timings such as core damage and RPV failure are slightly delayed compared with base case.

2.6 Sensitivity Case for STC-10all (Incorporating all the condition of STC-10a to STC10d)

STC-10all case includes all the accident conditions as described in the STC-10a to STC10d.

2.7 Impacts on the STC-10 case from the sensitivity studies

Figure 1 to Figure 4 show the source term releases of CsI, TeO2, CsOH and Te2 for each case, respectively. Even though some sensitivity cases result in more releases than the base case, all the cases do not result in neither a containment failure nor a large release. In other words, the release fractions of CsI, TeO2, CsOH and Te2 for all the cases have been smaller than 2.5% by the end of the MAAP run. Therefore, it is concluded that the sensitivity studies do not significantly impact on the release categorization for STC-10, and STC-10 case and its sensitivity cases result in an intact containment release.

3.0 Sensitivity studies for STC-11 Case

3.1 Base case for STC-11 Case

The purpose of the MAAP calculation for STC-11 case is to evaluate the source term releases for release category 11. The representative sequence for STC-11 includes the PLOCCW initiating event, the failure of secondary heat removal, the success of bleed operation, the failure of feed operation, the success of rapid depressurization, the failure of cavity flooding system, the success of late containment spray (i.e., ECSBS) and the basemat melt-through. Table 3 shows the accident conditions for STC-11 case and other sensitivity cases. And, Table 4 shows the key event timings for STC-11 case and other sensitivity cases.

3.2 Sensitivity Case for STC-11a (Crediting the SITs injection)

As shown in Table 3, the SIT injection is not modeled in the MAAP calculations for base case. The sensitivity case STC-11a used four SITs injection during the accident. As shown in Table 4, the SITs injection is started at 5,778 sec, which occurs after the CET exceeds 1,200 ℉. Compared with base case without SITs injection, the timings of core damage and RPV failure are relatively delayed due to the SITs injection.

3.3 Sensitivity Case for STC-11b (Changing the number of opening POSRVs)

As shown in Table 3, the number of opening POSRVs for bleed operation is two (2) in the MAAP calculations for base case. The sensitivity case STC-11b assumed that all the four POSRVs are manually open for bleed operation. In the STC-11b case, the flow rate out of RCS through the POSRVs is greater than bases case. Therefore, the key event timings for STC-11b such as core uncover, core damage and RPV failure are slightly faster than those of base case.

3.4 Sensitivity Case for STC-11c (Changing the delay time of 3-way valves)

As shown in Table 3, the 3-way valves are assumed to be manually open 30 minutes after the severe accident initiation (i.e., CET > 1200℉) (It should be noted that the CFS valves are defined to be inoperable per the accident scenario for STC-11). The sensitivity case STC-11c assumed that the 3-way valves are open right after the severe accident initiation. As shown in Table 4, the key event timings such as core damage and RPV failure are hardly impacted by the changing the delay time of 3-way valves.

3.5 Sensitivity Case for STC-11d (Assuming the normal RCP seal leakage and the RCP seal failure during the accidents)

As shown in Table 3, the normal RCP seal leakage and the RCP seal failure are not considered in the

MAAP calculations for base case. The sensitivity case STC-11d assumed that there are normal RCP seal leakages (21 gpm/pump) and the RCP seal failure (182 gpm/pump) during the accident initiation. In this case, the normal RCP seal leakage is assumed to occur after the accident initiation, and the RCP seal failure is assumed to occur 10 minutes after the severe accident initiation (i.e., CET > 1,200 ℉). Due to the normal RCP seal leakage, the first POSRVs opening is delayed compared with base case. And then, the POSRV manual opening (i.e., Bleed operation) is assumed to be operated after the first POSRV opening. Hence, the key event timings such as core damage and RPV failure are slightly delayed compared with base case.

3.6 Sensitivity Case for STC-11ecsbs (Using ECSBS with external water sources instead of CS pump with IRWST)

Even though the ECSBS should be used following the definition of the accident scenario for STC-11, the MAAP calculation for STC-11 base case was performed using the normal CS pump with IRWST water instead of ECSBS. It's because the MAAP execution was crashed unintentionally when it was performed to simulate the STC-11 using the ECSBS with an external water source. In the sensitivity case of STC-11ecsbs, some containment nodes were adjusted to prevent a MAAP run crash. And then, the ECSBS and the external water source are used in the MAAP calculation for case of STC-11ecsbs.

Compared with base case using CS pump operation, the timings of core damage and RPV failure are not significantly impacted. However, in this case, the external water is continuously injected into the containment since the ECSBS operates at 91,952 sec, and continuously accumulated inside the containment. The overflowed water has been flowing out into the cavity after approximately 195,500 sec. The ex-vessel molten corium has been ablating the cavity concrete until the cavity is flooded by overflowed water, however, the cavity erosion is no longer proceeding after the cavity is flooded. Consequently, the maximum cavity erosion depth is 3.0 m (9.8 ft), which means that the containment basemat (i.e., 14 ft below the cavity floor) has not been totally melting through. In the APR1400 Level 2 PRA, the containment basemat is assumed to be failed when the concrete erosion depth reaches 14 ft. Therefore, it is not shown that the fission products releases to the environment through the containment failure location.

3.7 Sensitivity Case for STC-11all (Incorporating all the condition of STC-11a to STC11ecsbs)

STC-11all case includes all the accident conditions as described in the STC-11a to STC11ecsbs. This case does not neither result in the basemat melt-through because the overflowed water from the ECSBS has been flowing out into the cavity after approximately 195,000 sec. In this case, the maximum cavity erosion depth is 2.8 m (9.4 ft) at the end of MAAP run. Therefore, it is not shown that the fission products releases to the environment through the containment failure location.

3.8 Impacts on the STC-11 case from the sensitivity studies

Figure 5 to Figure 8 show the source term releases of CsI, TeO2, CsOH and Te2 for each case, respectively. Even though some sensitivity cases result in more releases than the base case, all the cases result in a basemat melt-through failure and a small release. For all the cases, the release fractions of CsI, TeO2, CsOH and Te2 have been smaller than 2.5% by the end of the MAAP run. Therefore, it is concluded that the sensitivity studies does not significantly impact on the release categorization for STC-11, and STC-11 case and its sensitivity cases result in a small release with a basemat melt-through.

4.0 Sensitivity studies for STC-16 Case

4.1 Base case for STC-16 Case

The purpose of the MAAP calculation for STC-16 case is to evaluate the source term releases for release category 16. The representative sequence for STC-16 includes the PLOCCW initiating event, the failure of secondary heat removal, the success of bleed operation, the failure of feed operation, the success of rapid depressurization, the failure of cavity flooding system, the failure of containment spray system and the containment fails in late phase. Table 5 shows the accident conditions for STC-16 case and other sensitivity cases. And, Table 6 shows the key event timings for STC-16 case and other sensitivity cases.

4.2 Sensitivity Case for STC-16a (Crediting the SITs injection)

As shown in Table 5, the SIT injection is not modeled in the MAAP calculations for base case. The sensitivity case STC-16a used four SITs injection during the accident. As shown in Table 6, the SITs injection is started at 5,774 sec, which occurs after the CET exceeds 1,200 ℉. Compared with base case without SITs injection, the timings of core damage (i.e., Maximum core temperature exceeds 1,800 ℉) and RPV failure are relatively delayed due to the SITs injection.

4.3 Sensitivity Case for STC-16b (Changing the number of opening POSRVs)

As shown in Table 5, the number of opening POSRVs for bleed operation is two (2) in the MAAP calculations for base case. The sensitivity case STC-16b assumed that all the four POSRVs are manually open for bleed operation. In the STC-16b case, the flow rate out of RCS through the POSRVs is greater than bases case. Therefore, the key event timings for STC-10b such as core uncover, core damage and RPV failure are slightly faster than those of base case.

4.4 Sensitivity Case for STC-16c (Changing the delay time of 3-way valves)

As shown in Table 5, the 3-way valves are assumed to be manually open 30 minutes after the severe accident initiation (i.e., CET > 1,200℉) (It should be noted that the CFS valves are defined to be inoperable per the accident scenario for STC-11). The sensitivity case STC-11c assumed that the 3-way valves can be open right after the severe accident initiation. As shown in Table 6, the key event timings such as core damage and RPV failure are hardly impacted by the changing the delay time of 3-way valves.

4.5 Sensitivity Case for STC-16d (Assuming the normal RCP seal leakage and the RCP seal failure during the accidents)

As shown in Table 4-1, the normal RCP seal leakage and the RCP seal failure are not considered in the MAAP calculations for base case. The sensitivity case STC-16d assumed that there are normal RCP seal leakages (21 gpm/pump) and the RCP seal failure (182 gpm/pump) during the accident initiation. In this case, the normal RCP seal leakage is assumed to occur after the accident initiation, and the RCP seal failure is assumed to occur 10 minutes after the severe accident initiation (i.e., CET > 1,200℉). Due to the normal RCP seal leakage, the first POSRVs opening is delayed compared with base case. And then, the POSRV manual opening (i.e., Bleed operation) is assumed to be operated after the first POSRV opening. Hence, the key event timings such as core damage and RPV failure are slightly delayed compared with base case.

4.6 Sensitivity Case for STC-16all (Incorporating all the condition of STC-16a to STC16d)

STC-16all case includes all the accident conditions as described in the STC-16a to STC16d.

4.7 Impacts on the STC-16 case from the sensitivity studies

Figure 9 to Figure 12 show the source term releases of CsI, TeO2, CsOH and Te2 for each case, respectively. Even though some sensitivity cases result in more releases than the base case, all the cases result in a late containment failure and a small release. For all the cases, the release fractions of CsI, TeO2, CsOH and Te2 have been smaller than 2.5% by the end of the MAAP run. Therefore, it is concluded that the sensitivity studies does not significantly impact on the release categorization for STC-16, and STC16 case and its sensitivity cases result in a small release with a late containment failure.

5.0 Sensitivity studies for Q03 Case

5.1 Base case for Q03 Case

The purpose of the MAAP calculation for Q03 case is to review the containment pressurization for a sequence with a dry cavity without containment spray. The accident sequence for Q03 case includes the SBO initiating event without EDG and AAC DG, the failure of secondary heat removal, the failure of bleed & feed operation, the failure of rapid depressurization, the failure of cavity flooding system, the failure of containment spray system. Table 7 shows the accident conditions for Q03 case and other sensitivity cases. And, Table 8 shows the key event timings for Q03 case and other sensitivity cases.

5.2 Sensitivity Case for Q03a (Crediting the SITs injection)

As shown in Table 7, the SIT injection is not modeled in the MAAP calculations for base case. The sensitivity case Q03a used four SITs injection during the accident. As shown in Table 8, the SITs injection is started at 12,983 sec, which occurs after the RPV failure. The RCS pressure has been too high to be injected from the SITs until the RPV fails. Hence, the timings of key event such as core damage and RPV failure are not impacted by the SITs injection.

5.3 Sensitivity Case for Q03b (Assuming the normal RCP seal leakage and the RCP seal failure during the accidents)

As shown in Table 7, the normal RCP seal leakage and the RCP seal failure are not considered in the MAAP calculations for base case. The sensitivity case Q03b assumed that there are normal RCP seal leakages (21 gpm/pump) and the RCP seal failure (182 gpm/pump) during the accident initiation. In this case, the normal RCP seal leakage is assumed to occur after the accident initiation, and the RCP seal failure is assumed to occur 10 minutes after the severe accident initiation (i.e., CET > 1,200 ℉). Due to the normal RCP seal leakage, the first POSRVs opening is delayed compared with base case. However, the key event timings such as core damage and RPV failure are similar with base case.

5.4 Sensitivity Case for Q03c (Assuming the hotleg creep rupture during the severe accident)

As shown in Table 7, it is assumed that there is no hotleg creep rupture in the MAAP calculation for base case. The sensitivity case Q03c assumed that the hotleg creep rupture occurs after the severe accident initiation. In this case, the failure size of hot leg creep rupture is assumed to be 0.1 m2 (i.e., 1.08 ft2). After hotleg creep rupture, the RCS pressure is significantly depressurized.

5.6 Sensitivity Case for Q03all (Incorporating all the condition of Q03a to Q03c)

Q03all case includes all the accident conditions as described in the Q03a to Q03c.

5.7 Impacts on the Q03 case from the sensitivity studies

Figure 13 shows the containment pressurization for each case, respectively. Even though some sensitivity cases show more severe containment pressurizations than the base case, the maximum containment pressure for each case is not greater than 70 psia (55.3 psig) by the end of MAAP run (i.e., 72 hours after accident initiation). According to the containment fragility curve for APR1400 containment, the total containment failure probability at 55.3 psig is very negligible. Therefore, it is concluded that the sensitivity studies does not significantly impact on the containment pressurization for Q03, and Q3 case and its sensitivity cases do not result in a containment failure due to over-pressurization.

Table 1 Accident Conditions for STC-10 and sensitivity cases

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Table 2 Key Event Timing for STC-10 and Sensitivity Cases

TS

Table 3 Accident Conditions for STC-11 and sensitivity cases

TS

Table 4 Key Event Timing for STC-11 and Sensitivity Cases

TS

Note 1) In the case of STC11-ecsbs, the water has been flowing out into the cavity after 195,500 sec. The cavity basemat ablation is no longer proceeding since the cavity is flooded by overflowed water from the ECSBS. At the end of MAAP run, the cavity erosion depth is 3.0 m (9.8 ft). Similarly, in the case of STC11-all, the water has been flowing out into the cavity after 195,500 sec, and the cavity basemat ablation is no longer proceeding. At the end of MAAP run, the cavity erosion depth is 2.8 m (9.4 ft).

Table 5 Accident Conditions for STC-16 and sensitivity cases

TS

Table 6 Key Event Timing for STC-16 and Sensitivity Cases

TS

Table 7 Accident Conditions for Q03 and sensitivity cases

TS

Table 8 Key Event Timing for Q03 and Sensitivity Cases

TS

TS

Figure 1 Release Fraction of CsI for STC-10 and Sensitivity Cases

TS

Figure 2 Release Fraction of TeO2 for STC-10 and Sensitivity Cases

TS

Figure 3 Release Fraction of CsOH for STC-10 and Sensitivity Cases

TS

Figure 4 Release Fraction of Te2 for STC-10 and Sensitivity Cases

TS

Figure 5 Release Fraction of CsI for STC-11 and Sensitivity Cases

TS

Figure 6 Release Fraction of TeO2 for STC-11 and Sensitivity Cases

TS

Figure 7 Release Fraction of CsOH for STC-11 and Sensitivity Cases

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Figure 8 Release Fraction of Te2 for STC-11 and Sensitivity Cases

TS

Figure 9 Release Fraction of CsI for STC-16 and Sensitivity Cases

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Figure 10 Release Fraction of TeO2 for STC-16 and Sensitivity Cases

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Figure 11 Release Fraction of CsOH for STC-16 and Sensitivity Cases

[ ]TS

Figure 12 Release Fraction of Te2 for STC-16 and Sensitivity Cases

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Figure 13 Containment Pressure for Q03 and sensitivity cases

Table 19.1-4 (4 of 25)

No.	Insight	Disposition
Risk Insights from Key Design Features		
11	The following are important aspects of pilot-operated safety relief valves (POSRVs) as represented in the PRA:	
	The POSRVs, located on the top of the pressurizer, have two functions: overpressure protection and rapid depressurization (RD). When long-term decay heat removal is not available through the steam generators, the rapid depressurization (or bleed) function provides a means of rapidly depressurizing the RCS manually from the control room so that the SIS can inject to the RCS, enabling a "feed and bleed" cooling capability.	Subsection 5.2.2.1 Subsection 5.4.14.2
	Another function of the RD is to provide the capability to depressurize the RCS during a severe accident to minimize the potential for high pressure melt ejection (HPME).	Subsection 19.2.3 Subsection 6.8.4.4
	The POSRV discharge line is immersed into the IRWST water through the sparger, the discharging load dissipation device. When POSRVs actuate, the discharged RCS fluid is scrubbed in the IRWST, reducing the fission product releases.	Subsection 5.2.2.10 Subsection 5.2.5.1.2.1
	The 3-way valves located in the POSRV discharge path are manually operated to redirect the steam release to the containment atmosphere via the SG compartment to rapidly depressurize the RCS.	Subsection 19.1.3.2 Subsection 19.2.3.3.2.2 Subsection 19.2.3.3.2.3
	The COL applicant is to provide a program for developing and implementing emergency operating procedures, including the procedures for use of the RD for "feed and bleed" cooling.	COL 13.5(5)

Table 19.1-4 (19 of 25)

No.	Insight	Disposition
Risk Insights from Severe Accident Design Features		
40	The emergency containment spray backup subsystem (ECSBS) for severe accident management is provided. The ECSBS is used as an alternate means of providing containment spray in the event of a beyond design basis accident in which all CSPs/SCPs or the IRWST are unavailable. The ECSBS is to be placed in service 24 hours after a severe accident to prevent a catastrophic failure of the containment. The fire engine truck as ECSBS pumping device is used to deliver water from external water sources to the ECSBS containment spray header after the initiation of a severe accident.	Subsection 6.2.2.2
	The operating procedure(s) for use of the ECSBS is to be developed by the COL applicant.	COL 19.2(2)
41	The reactor cavity is configured to promote retention of and heat removal from the postulated core debris during a severe accident, thus serving roles in accident mitigation.	Subsection 19.2.3.3
	The cavity flooding system consists of two independent divisions and is supplied, via gravity, from the IRWST via the HVT.	Subsection 6.8.3.1
	Procedures for use of the cavity flood system during a severe accident are to be developed by the COL applicant as part of its plant-specific severe accident management guidelines (SAMG).	COL 19.2(2)

The reactor cavity is designed to prevent and mitigate the severe accident phenomena such as HPME/DCH, EVSE and MCCI. The reactor cavity design characteristics include a core debris chamber inside a reactor cavity, a convoluted gas vent path, large floor area, and the CFS.