REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

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

Docket No. 52-046

RAI No.:	**404-8488**
SRP Section:	**15.06.05 – Loss of Coolant Accidents Resulting From Spectrum of Postulated Piping Breaks Within the Reactor Coolant Pressure Boundary**
Application Section:	**15.6.5.2.2**
Date of RAI Issue:	**02/10/2016**

Question No. 15.06.05-11

REGULATORY BASIS

Title10 of the Code of Federal Regulations, Part 50.46(b)(5) requires that after any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core. Additionally, 10CFR50, Appendix A, General Design Criterion (GDC) 35, Emergency core cooling, requires that a system to provide abundant emergency core cooling shall be provided. GDC 4 requires structures, systems, and components (including pumps, valves, and strainers) important to safety to accommodate the effects of and to be compatible with the dynamic and environmental conditions associated with postulated accidents.

Regulatory Guide 1.82, Revision 4, “Water Sources for Long-term Recirculation Cooling Following a Loss-of-Coolant Accident," provides detailed guidance for evaluating the adequacy and the availability of the containment sump for long-term recirculation cooling following a loss-of-coolant accident.

ISSUE

The following requests for additional information pertain to technical report APR1400-E-N-NR-14001-P, Revision 0, “Design Features to Address GSI-191”:

REQUESTS

1. In Section 3.8.1, a logarithmic temperature decrease is assumed for the containment air and IRWST temperatures from 1,000,000 seconds to 2,592,000 seconds post-LOCA. Please justify this assumption by comparing to the GOTHIC code results from Technical Report APR1400-Z-A-NR-14007-P, Rev. 0, “LOCA Mass and Energy Release Methodology.”

2. In Section 4.3.3.1, “Available Driving Head under the Hot-leg Break Condition”, it is stated that “the downcomer liquid density is based on the IRWST liquid conditions.” Please justify this assumption considering that the downcomer liquid temperature will be higher than the IRWST temperature, and the density would be reduced.
3. In Section 4.3.4.4, states that “The RV coolant temperature is assumed to be 10 °F higher than the containment temperature. The containment temperature profile is shown in Table 4.3-6.” Please provide the basis for this assumption and explain whether the value used in the LOCADM analysis is conservative.
4. In Section 4.3.2.2, it is assumed that in the case of a cold leg LOCA, all debris is generated during the first 700 seconds after the cold-leg break. However, in Section 4.3.4.3, it is stated that “It is assumed that Mode 3 for recirculation injection from the IRWST begins at 900 seconds (15 minutes).” Please, explain the basis for this assumption, the reason for discrepancy, and describe the extent of conservatism (or lack thereof) by using 900 vs. 700 seconds for the recirculation time.
5. In Section 4.3.4.3 is stated that “There is no fiber insulation inside the ZOI. Only latent fiber amount is assumed to be 6.80 kg (15 lb_m) inside the entire containment. However, 13.6 kg (30 lb_m) of latent fiber is assumed to bypass the ECCS sump strainers for conservatism.” The values shown in Table 4.2-3, ‘Total Quantity of Debris Generated during a LOCA’ and Table 4.3-2, ‘Bypass Debris Types and Amounts per FA’ do not show 30 lb_m of latent fiber. These tables show total latent fiber debris of 15 lb_m where about 25% of the total latent fiber, or 3.68 lb_m, would bypass the sump strainer and be entrained into the ECCS and CSS streams. Please, clarify the reason for this difference.
6. In Table 4.2-3, ‘Total Quantity of Debris Generated During a LBLOCA,’ it is shown that total latent debris of particulate type is 185 lbm and total latent debris of fibers type is 15 lbm. This would add up to total latent debris of 200 lbm. Therefore, the faction of debris of fibers type would be calculated as 15/200 = 7.5% by weight. The guidelines of NEI 04-07 assume the amount of fiber should be 15% by weight. Please clarify the reason for the difference between the weight fraction of fibrous debris in the analysis versus that of NEI 04-07. Note that any increase in the fiber weight percent would increase the calculated fiber load per fuel assembly and reduce the available driving head.
7. Please explain how the LOCADM code input of 9344 ft^2 for concrete was determined. The staff notes that typical large dry containments’ concrete area is on the order of 60,000 to 70,000 ft^2.
8. Please provide the Sump Pool Volume (ft^3) specified on the Material Input worksheet of the LOCADM program.
9. LOCADM, the analysis tool used to assess the impact of debris and chemical effects on fuel heat transfer, accounts for fiber by using “bump-up” factors for the impact of chemical effects on fuel heat transfer, resulting in a decrease in heat transfer. With the fiber levels in APR1400 being much less than in current operating plants, justify that these “bump-up” factors are still valid.

Response – (Rev. 1)

1. The temperature profile used for the chemical effects analysis in the technical report, APR1400-E-N-NR-14001-P, Revision 0 (hereafter, technical report), Section 3.8 is no

longer valid, since the temperature profile will be updated for 30 days post-LOCA without an assumption of logarithmic temperature from 1,000,000 seconds to 2,592,000 seconds post-LOCA. The updated temperature profiles are generated by GOTHIC code and extended to 30 days from the results shown in Technical Report, Figure B-4D of APR1400-Z-A-NR-14007-P, Rev.0.

The technical report, Section 3.8.2 will be revised to delete the assumption of logarithmic temperature from 1,000,000 seconds to 2,592,000 seconds post-LOCA, as shown in the Attachment 1. The chemical effects analysis results caused by the change of temperature profile will be provided in the response to RAI 391-8462, Question 06.02.02-35 (Ref. KHNP submittal MKD/NW-16-0772L).

2. The sentence, “The downcomer liquid density is based on the IRWST liquid conditions,” will be revised to “The downcomer liquid density is based on the reactor coolant system (RCS) pressure.” as shown in the Attachment 2. The downcomer liquid density is assumed to be the saturated water density at the highest RCS pressure under each LOCA scenario. The revised available driving heads for each LOCA scenario are described in the Attachment 2 and Attachment 3.

3. The sentence, “The RV coolant temperature is assumed to be 10 °F higher than the containment temperature,” will be revised to “The RV coolant temperature is assumed to calculate the RV pressure which is shown in DCD Tier 2, Table 6.2.1-7 Part B.” as indicated in the Attachment 4. The evaluation of deposition on the fuel (LOCADM) was revised to reflect the revised IRWST temperature, containment temperature, and RV pressure for 30 days post-LOCA, as indicated in the Attachment 4.

4. The assumption for the recirculation start time will be changed to 700 seconds. The revised evaluation of LOCADM also reflects the modified recirculation start time of 700 seconds.

5. Total bypass debris for the APR1400 with 6.80 kg (15 lb_m) of latent fiber is 1.67 kg (3.68 lb_m). However, all the latent fiber of 6.80 kg (15 lb_m) is assumed to bypass the ECCS strainers, and 13.6 kg (30 lb_m) of latent fiber is used for the LOCADM input applying a “bump-up” factor of 2, for conservatism in the calculation.

6. The guideline of NEI 04-07 assuming 15% of latent fibrous debris in the total 200 lb_m of latent debris is based on the containment surveys of fiber plants which use the fibrous material for the insulation of major primary systems.

   Since the APR1400 uses the reflective metal insulation (RMI) for the insulation of major primary systems, the sources of latent fibrous debris are reduced significantly. From the data provided in Table 2 of NUREG/CR-6877, it is seen that 3 of the 4 plants evaluated in the manner described in the NEI 04-07 SER have less than 7.5% fiber in their latent debris totals. Thus the assumption of 7.5% of latent fibrous debris is a reasonably achievable value.

   To meet this design value, the APR1400 ensures successful operation of the ECCS by administrative controls that the COL applicant implements containment cleanliness, housekeeping, and the foreign materials exclusion program as described in DCD Section 6.8.4.5.10.

7. The surface area of concrete structures is estimated from the civil structural drawings and three-dimensional computer-aided design (CAD) as described in the technical report, Section 3.8.3. The amount of concrete in the containment is provided in Table 3.8-2 (Submerged: 2,087 ft^2, Unsubmerged: 7,257 ft^2). In the LOCADM input, 1,736 m^2 (18,688 ft^2) for concrete was used by applying the “bump-up” factor of 2, as shown in the Attachment 4.
8. The minimum IRWST water volume of 35,076 ft^3 (262,388 gallons), as shown in Figure 3.9-3, was conservatively used for the LOCADM input. The typo in the initial IRWST water volume of Table 4.3-8 will be changed from 933.2 m^3 to 993.2 m^3.
9. The “bump-up” factor for materials input of the LOCADM calculation have been considered. The fibrous debris that may be transported into the core is also considered in the LOCADM calculation. This consideration is done through a bump-up factor which adds scale buildup on the fuel related to the amount of fiber transported into the core. The bump-up factor in LOCADM is independent of the type, diameter, or length of the fiber. The application of the bump-up factor to the APR1400 LOCADM is consistent with other operating PWRs.

   The use of the bump-up factor in the APR1400 LOCADM calculation is appropriate because even though the amount of fibrous debris is small, all the latent fiber of 13.6 kg (30 lb_m) is assumed to bypass the ECCS strainers. The fibrous debris per fuel assembly is about 56.5 grams, and it is not that much smaller value compared to current operating plants.

Impact on DCD

There is no impact on the DCD.

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

Technical Report, APR1400-E-N-NR-14001-P, Rev. 0, “Design Features to Address GSI-191” will be revised as indicated in the Attachment 1, Attachment 2, and Attachment 4.

Technical Report, APR1400-K-A-NR-14001-P, Rev. 0, “In-vessel Downstream Effect Tests for the APR1400” will be revised as indicated in the Attachment 3.

3.8 Chemical Effects

In order to assess potential chemical effects in the APR1400 sump, the materials that are in the containment building that may react with coolant in the post-accident containment environment have been identified. Reactive plant materials in the containment building are categorized as metallic and non-metallic items and generally include insulation and concrete, as well as other potential sources of aluminum. The materials inventory includes the overall mass, location in containment and potential for being sprayed with or immersed in coolant following a LOCA.

The WCAP-16530-NP methodology (Reference [3-11]) referenced in NRC RG 1.82 (Reference [1-1]) provides a conservative model to predict the corrosion and dissolution of containment materials in a post-LOCA environment and the formation of chemical precipitates for participating PWRs. The primary corrosion products contributing to these chemical precipitates are calcium, silicon, aluminum, and the precipitates that can form aluminum oxy-hydroxide, calcium phosphate, and sodium aluminum silicate. Surrogate suspensions of chemical precipitates representing this chemical debris can be included as an additional debris source to the strainer testing program to qualify the strainer for “chemical effects.” The quantities of chemical precipitates are based on reactive material surface areas and quantities, temperature, water level, pH, and other parameters related to the plant specific environment and post-accident evolution.

3.8.1 Containment Spray pH Control

The pH of IRWST water is evaluated to provide reasonable assurance that the calculated minimum and maximum pH values under any possible water chemistry conditions caused by a LOCA are between 7.0 and 8.5. The calculated minimum and maximum IRWST pH during operation of the CSS is 7 and 10, respectively. The minimum time to reach a minimum pH of 7.0 is 157 minutes, as shown in Figure 3.8-1. The IRWST pH ranges are included in Table 3.8-1.

3.8.2 Assumptions

1) The maximum IRWST water volume is used for the chemical effects analysis. Using the maximum water volume ensures that the maximum material dissolution and quantity of precipitates are analyzed.

~~2) Temperature data is only available from zero to 1,000,000 seconds post LOCA. Since the mission time is 30 days (2,592,000 seconds), the containment air temperature and IRWST temperatures are extrapolated using a logarithmic fit of the last 9 days of available temperature data to predict the containment air and IRWST temperatures from 1,000,000 seconds to 2,592,000 seconds. This time period is chosen due to the consistently logarithmic temperature decrease for the entire time period~~.

3) The maximum IRWST and spray pH profile is used to conservatively maximize dissolution and precipitate generation.

4) The minimum ECCS flow case is used because it results in the highest sump temperatures, and therefore the highest corrosion rate of reactive materials in the sump. Both the minimum and maximum ECCS flow cases result in the comparable containment air temperature profiles.

4.3.3 Available Driving Head

It must be demonstrated that the available head to drive the ECC flow into the core is greater than the head loss across the core due to possible debris buildup. The following relationship must be true to ensure that a sufficient flow is available to maintain the LTCC:

$dP_{avail} > dP_{debris}$

The core flow is only possible if the manometric balance between the downcomer (DC) and the core is sufficient to overcome the flow losses in the reactor vessel (RV) downcomer, RV lower plenum, core, and loops, at the appropriate flow rate.

$dP_{avail} = dP_{dz} - dP_{flow}$

Where,

dP_{avail} = total available driving head
dP_{dz} = pressure head due to liquid level between core inlet and outlet
dP_{flow} = pressure head due to flow losses in the RCS

The flow losses (dP_{flow}) for each LOCA scenario are based on the values provided in LOCA analyses (Reference [4-11]).

4.3.3.1 Available Driving Head under the Hot-leg Break Condition

In the event of a hot-leg break, the driving force is the manometric balance between the liquid in the downcomer and the core, as shown in Figure 4.3-2. If a debris bed begins to build up in the core, the liquid level will begin to build in the cold legs and steam generators (SGs). As the level begins to rise in the SG tubes, the elevation head driving the flow through the core increases as well. The driving head reaches its peak when the shortest SG tube has been filled.

RCS

<u>Assumptions</u>

1) The core liquid level is assumed to be at the bottom of the hot leg.

RCS pressure

2) The downcomer liquid density is based on the ~~IRWST liquid conditions~~. Since density is inversely proportional to liquid temperature, and a lower density will reduce the driving head from the downcomer, a conservatively high ~~IRWST liquid~~ temperature is selected. So, the saturated water density at ~~atmospheric pressure is assumed (958.12 kg/m^3 (59.81 lbm/ft^3))~~.

3) The reactor vessel downcomer and lower plenum k/A^2 is small (typically << 0.1). Further, the liquid density is large (> ~~958.12 kg/m^3 (59.81 lbm/ft^3)~~) and bulk velocity is low. Therefore, the losses in these regions can be neglected.

~~926.16~~ kg/m^3 (58.0 lbm/ft^3)

929.15

4) To account for the potential for voiding in the SG tubes, it is assumed that the siphon break occurs at the bottom of the SG tubesheet.

5) The flow losses in reactor core and loops are based on the values in the data from LOCA analyses.

the highest RCS pressure of 3.312 kg/cm^{2}A (47.113 psia) is assumed (~~926.16~~ kg/m^3 (58.0 lbm/ft^3))

929.15

Calculations

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The inputs are found in APR1400 drawings and evaluations. The values in Table 4.3-3 are used to calculate the hot-leg break available head loss. As stated in the assumptions, the flow losses in the downcomer and lower are negligible. Therefore, the hot-leg $dP_{available}$ is as follows:

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4.3.3.2 Available Driving Head under the Cold-leg Break Condition

In the event of a cold-leg break, the driving force is the manometric balance between the liquid in the downcomer and core, as shown in Figure 4.3-3. The ECC water from each DVI line runs to the break, ensuring that the downcomer is full to at least the bottom of the cold-leg nozzles. The $dP_{available}$ is established by the manometric balance between the downcomer liquid level and the core liquid level considering the pressure drop through the RCS loops due to the steam flow.

Assumptions

1) The assumptions used in the case of a hot-leg break (assumptions # 2, 3, 5) are also applied to the cold-leg break case~~.~~ excluding the water density.

2) The saturated water density at the highest RCS pressure of 4.469 kg/cm^{2}A (63.57 psia) is assumed (919.59 kg/m^3 (57.41 lbm/ft^3)).

Calculations

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The values in Table 4.3-4 are used to calculate the cold-leg break available head loss. The dP_{avail} for a cold-leg break is dependent upon the time at which the value is calculated. Therefore, the inputs described here can be used to calculate the expected dP_{avail} as a function of time. Since, the boil-off rate decreases with time, the minimum dP_{avail} for a cold-leg break is calculated at the recirculation start time (700 seconds.)

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4.3.3.3 Available Driving Head under the Condition of Cold-leg Break after HLSO

In the event of a cold-leg break after HLSO operation, the driving force is the manometric balance between the liquid in the downcomer and the core, as shown in Figure 4.3-4. If a debris bed begins to build up in the core, the liquid level will begin to build in the HLs and SGs. As the level begins to rise in the SG tubes, the elevation head driving the flow through the core increases as well. The driving head reaches its peak when the shortest SG tube has been filled.

excluding the water density.

Assumptions

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1) The assumptions used in the case of a hot-leg break (# 2, 5) are also applied to the case of a cold-leg break after HLSO~~.~~
2) The HLSO operation is assumed to start at 1.5 hours after a cold-leg break for the earliest time.
3) The saturated water density at the highest RCS pressure of 3.71 kg/cm^{2}A (~~57.2~~ psia) is assumed (925.65 kg/~~c~~m^3 (57.78 lbm/ft^3)).

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The inputs are found in APR1400 drawings and evaluations. The values in Table 4.3-4 are used to calculate the available head loss for a cold-leg break after HLSO. The dP$_{available}$ is as follows:

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4.3.4 LOCADM Calculations

This section provides evaluation results of two parameters (cladding temperature and cladding deposit thickness) during the 30 day period following a LOCA.

WCAP-16793-NP Revision 2, developed by the PWR Owners Group (PWROG), defines an NRC approved methodology for evaluating the impact of debris on long-term fuel cladding performance subsequent to a LOCA. The methodology and the implementing software, an Excel spreadsheet based tool identified as the LOCA Deposition Model (LOCADM), is used to evaluate the effect from deposition of chemical species carried into the core by safety injection coolant, on the fuel and the resultant cladding temperatures. The chemical-effects-modeling methods developed in (Reference [3-11]) are used in the LOCADM methods to determine the types and concentrations of the chemical species present in the safety injection coolant.

LOCADM uses a conservative model for decay heat generation and heat removal to evaluate local core boiling and the subsequent deposition of dissolved solids on the surfaces of fuel rods. The combination of deposit thickness and conductivity, coolant temperature and localized decay heat generation are then used to determine cladding temperature throughout the duration of a LOCA event.

LOCADM is used with the methodology provided in Reference [4-7] and the guidance provided in (Reference [4-8]) to evaluate cladding-deposit thickness and temperature.

4.3.4.5 Results

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In conclusion, the maximum total deposit thickness and the peak cladding temperature are maintained within acceptance bases provided in Reference [4-7] with sufficient margin.

4.3.5 Boric Acid Precipitation

The APR1400 design uses boron to control core reactivity, and is subject to concerns regarding potential post-LOCA boric acid precipitation (BAP) in the core. To prevent the core region boric acid concentration from reaching the precipitation point, there is a procedure that instructs the operators to initiate a hot-leg switchover operation within 3 hours after a cold-leg break (Reference [4-9]).

There are additional concerns about the potential for debris in the core to change flow patterns or otherwise inhibit the mixing of boric acid that could result in earlier BAP. Debris beds within the core could block the coolant channels and inhibit core cooling when higher amounts of fiber are involved.

To address these concerns on higher fibrous-debris loads, the APR1400 is designed as a “low fiber plant” by exclusion of fibrous material within the zone of influence of a high-energy line break. The maximum anticipated fibrous-debris load for a cold-leg break is about [3.83^{TS}] grams per fuel assembly (Section 4.3.2.2). This is less than the 7.5 grams (0.017 lbm) limit accepted by the NRC (Reference [4-8]).

Therefore, it is concluded that the debris ingested by the reactor vessel would not significantly affect the mixing capability of boric acid in the APR1400.

4.3.6 Fuel Assembly Testing

APR1400 fuel-assembly tests have been performed to confirm that the head losses caused by debris deposited on a fuel assembly, meet the available driving head following a LOCA.

In this test, various ranges of debris amounts (15 g (0.033 lbm) of fiber, 900 g (1.984 lbm) of particulates, and 768 g (1.693 lbm) of chemical debris) are applied. The testing represents that the particle-to-fiber ratio of ‘1’ produces the highest pressure drop for constant fiber loading under the hot-leg break condition, and ‘50’ under cold-leg break condition. The presence of chemical debris causes an additional increase in the overall pressure drop. However, after some amount of chemical debris is added, subsequent chemical debris does not increase the pressure drop. A summary of test results is presented in Table 4.3-12.

The pressure drop criterion of the hot leg-break condition is [^{TS}] kPa. All the test results show lower pressure drop than the acceptance criterion, and the highest pressure-drop is [^{TS}] kPa. The pressure drop acceptance criterion for the cold-leg break condition is [^{TS}] kPa, and the highest pressure drop is [^{TS}] kPa. Figures 4.3-8 and 4.3-9 present the pressure-drops for hot-leg break and cold-leg break tests, which give the limiting results. Detailed descriptions of the test results are found in (Reference [4-10]).

Therefore, a sufficient driving force is available to maintain an adequate flow rate, and the long-term core cooling capability is adequately maintained in the APR1400.

4.3.7 Evaluation Summary

The intent of this section is to assess the in-vessel downstream effects of the APR1400, by applying the evaluation methods and acceptance bases provided in Reference [4-7] and [4-8].

To remain within the 15 gram (0.033 lbm)/FA fiber limit, there is no fibrous insulation within the ZOI. The evaluation results of the APR1400 in-vessel downstream effects are:

1) Following a LOCA, the ECC flow rate per FA is 78 L/min (20.5 gpm) for the hot-leg break condition, and 14 L/min (3.64 gpm) for the cold-leg break condition.

2) The amount of bypass fiber per FA is less than the 15 gram (0.033 lbm) limit.

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5) The debris ingested by the reactor vessel would not significantly affect the mixing capability of boric acid in the APR1400.

6) A sufficient driving force is available to maintain an adequate flow rate, and the long-term core cooling capability is adequately maintained in the APR1400

In conclusion, sufficient long-term core cooling following a LOCA in the APR1400 is achieved, given the presence of the range of debris and chemical products postulated to be transported to the reactor vessel.

Table 4.3-3 Inputs for Calculation of Hot-leg dP_{avail}

Variable	Description	Unit	Value	Comments
Z_{SG}	Bottom of the SG tubesheet	m		DC liquid density is selected at the saturation pressure ~~(1.03 kg/cm^2, 100 °C (14.7 psia, 212 °F)).~~ (3.312 kg/cm^3 (47.113 psia), DCD Table 6.2.1-8 Part B, 599.9 sec)
$Z_{core\text{-}in}$	Bottom of active fuel	m		
ρ_{DC}	Downcomer (DC) liquid density	kg/m^3		
Z_{RVCL}	RV nozzle centerline	m		

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Table 4.3-4 Inputs for Calculation of Cold-leg dP_{avail}

Variable	Description	Unit	Value	Source
$Z_{core-in}$	Bottom of active fuel	m		DC liquid density is selected at the saturation pressure ~~(1.03 kg/cm2, 100 °C (14.7 psia, 212°F))~~
ρ_{DC}	DC liquid density	kg/m^3		
Z_{brk}	Z_{RVCl}-Z_{IDCL}/2	m		
Z_{RVCL}	RV nozzle centerline	m		
Z_{IDCL}	Inner diameter of cold-leg pipe	m		

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(4.469 kg/cm^3 (63.57 psia), DCD Table 6.2.1-7 Part B, 600.0 sec)

Table 4.3-5 Inputs for Calculation of Cold-leg after HLSO dP_{avail}

Variable	Description	Unit	Value	Comments
Z_{so}	SG spillover elevation	m		DC liquid density is selected at the saturation pressure ~~(1.03 kg/cm2, 100 °C (14.7 psia, 212°F))~~
$Z_{core\text{-}out}$	Top of active fuel	m		
ρ_{DC}	DC liquid density	kg/m^3		
Z_{RVCL}	RV nozzle centerline	m		

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(3.71 kg/cm^3 (52.769 psia), DCD Table 6.2.1-8 Part B, 3,996.9 sec)

Table 4.3-8 Coolant Material Inputs

Parameter	Unit	Value	Note
IRWST water density	g/cm^3 (lbm/ft^3)		Minimum liquid density
Initial IRWST water volume	m^3 (ft^3)		Minimum IRWST level for SIS NPSH during LOCA recirculation
Initial IRWST water mass	kg (lbm)		Minimum IRWST level for SIS NPSH during LOCA recirculation
Core region water Density	g/cm^3 (lbm/ft^3)		Minimum liquid density
Initial core region water volume	m^3 (ft^3)		OG-07-419
Initial core region water mass	kg (lbm)		From minimum liquid density and initial core region water volume

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Table 4.3-12 Summary of Fuel Assembly Test Results

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Table 3-4 Available Driving Heads in each LOCA Scenario

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LOCA scenario				
Hot-leg break				
Cold-leg break				
CL break after HLSO				

Table 3-5 Test Matrix

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5 TEST RESULTS

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Table 5-1 Summary of the Test Results

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5.1 Hot-leg Break Tests

5.1.1 Summary of Hot-leg Break Tests

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Figure 5-1 Pressure Drops vs. Particle to Fiber Ratio under a Hot-leg Break Condition

5.2 Cold-leg Break Tests

5.2.1 Summary of Cold-leg Break Tests

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Figure 5-13 Pressure Drops vs. Particle to Fiber Ratio under a Cold-leg Break Condition

5.3 Cold-leg Break after a HLSO Test

5.3.1 Summary of Cold-leg Break after a HLSO Test

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7 CONCLUSION

In-vessel downstream effect tests with a mock-up PLUS7 fuel assembly were performed to confirm that the head losses caused by debris meet the available driving head following a LOCA.

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Therefore, sufficient driving force is available to maintain an adequate flow rate to remove decay heat, and thus the LTCC capability is adequately maintained in the APR1400.

APPENDIX B EFFECT OF DEBRIS SETTLING

Violation No. 99901453/2014-201-01(b)

The NRC requests that KHNP provide the evaluation for the impact of debris settling on the validity of testing in response to the NOV, under the inspection report number and project number, when that portion of the evaluation has been completed.

Response

This Appendix describes the impact of debris settling on the validity of testing that has already been conducted to address in-vessel downstream effects of the APR1400.

B.1 Purpose

The phenomenon of debris settling was observed at the in-vessel effect tests of simulating cold-leg beak. In this report, the applicability of the test results was evaluated by providing pressure drops through debris bed in which condition debris settling did not occur under the same particle to fiber (P/F) mass ratio.

B.2 Evaluation Method and Results

B.2.1 Conservatism in the Test Design

Two conservative parameters were selected to cope with debris settling in the cold-leg (CL) break tests, as shown in Table B.2-1. The flow rate during the CL break tests was set to an increased value of 144% compared to the boil-off rate at 700 seconds after a loss-of-coolant accident (LOCA). The increased flow rate induces increased pressure drops, as shown in Figure B.2-1, and gives conservative test results.

The quantity of fibrous debris used in the tests was set to an increased value of 391% compared to the plant data. This implies that 74.4% of debris settling is allowed to simulate cold-leg break conditions.

In addition, debris settling at the structures and debris filtering at the sump strainers expected in the plant were not credited in the tests for conservatism.

B.2.2 Bounding Value of the Pressure Drop under the Cold-leg Break Tests

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3) RVLqFlow – coolant that drains from the reactor vessel through the RCS break

4) RVSteamFlow – steam that vents from the RCS to containment through the RCS break

5) TSPFlow – tri-sodium phosphate flow into the IRWST

6) SprayFlow – containment spray drawn from the IRWST

7) SIFlow - safety injection flow that is drawn from the IRWST and injected into the intact loop (i.e., ‘CleanSIFlow’) and into the broken loop (i.e., ‘CleanBypass’)

8) The recirculation flow drawn from the IRWST includes recirculation water injected into the intact loop (i.e., ‘RecircLqFlow’) and the broken loop (i.e., ‘RecircBypass’)

4.3.4.3 Assumptions

The following assumptions have been made regarding inputs to provide a conservative evaluation.

1) It is assumed that all aluminum exposed to containment spray, and submerged in the IRWST sumps, is pure unalloyed aluminum (i.e., Alloy 1100).

2) It is assumed that 0.36 m^3 (12.5 ft^3) of fiber debris (a density of 0.038 g/cm^3 (2.4 lbm/ft^3)) bypasses the ECCS sump strainers, and is entrained in the safety injection and recirculation flows.

   Basis: There is no fiber insulation inside the ZOI. Only latent fiber amount is assumed to be 6.80 kg (15 lbm) inside the entire containment. However, 13.6 kg (30 lbm) of latent fiber is assumed to bypass the ECCS sump strainers for conservatism.

3) It is assumed that Mode 3 for recirculation injection from the IRWST begins at ~~900~~ 700 seconds ~~(15 minutes)~~.

4) It is assumed that Mode 4 for hot-leg switch over injection from the IRWST begins at 5,225 seconds (1.45 hours).

4.3.4.4 Inputs

APR1400 specific inputs used in the LOCADM evaluations are discussed below.

4.3.4.4.1 ‘Time-Input’

Guidance for input to populate the ‘Time-Input’ worksheet comes primarily from the ‘Instructions’ worksheet in the LOCADM spreadsheet. The input consists primarily of times during, and subsequent to, the LOCA, the corresponding fluid temperatures and flows, and the plant-operating mode.

<u>Time, seconds</u>

In order to model the start of recirculation at ~~15 minutes~~ 700 seconds post-LOCA and ~~1.5~~ 1.45 hours post-LOCA, time steps are added to the base worksheet at a) ~~900 and 901~~ 700 and 701 seconds, and b) 5,224 and 5,225 seconds. The calculations have been executed with a mission time of 30 days consistent with WCAP-16793-NP methodology.

IRWST pH

The IRWST pH profile is assumed to be pH 10 for the first ~~15 minutes~~ 4 hours post-LOCA, and pH 8.5 thereafter. The use of the higher values is conservative as a higher pH enhances dissolution of debris in the IRWST, thereby generating larger scale thickness and slightly higher cladding temperatures.

IRWST Temperature, °C (°F)

The IRWST temperature profile used for this calculation is shown in Table 4.3-6.

Spray Flow, kg/sec (lbm/sec)

The containment spray flow, in accordance with the guidance provided (Reference [4-13]) for LOCADM Option 2 operation, is set to zero for all input times.

Spray pH

The containment-spray pH profile is set to pH 10.0 for the first ~~15 minutes~~ 4 hours post-LOCA, and pH 8.5 thereafter. As discussed above, the use of the higher values is conservative as a higher pH enhances dissolution of debris in the IRWST and components wetted by the IRWST fluid, thereby generating larger scale thickness and slightly higher cladding temperatures.

Reactor Vessel Coolant Temperature, °C (°F)

The RV coolant temperature is assumed to ~~be 5.6 °C (10 °F) higher than the containment temperature~~. The ~~containment~~ temperature profile is shown in Table 4.3-6.

calculate the RV pressure which is shown in DCD Tier 2, Table 6.2.1-7 Part B

Clean Safety Injection Flow into Reactor Vessel, kg/sec (lbm/sec)

The clean safety injection flow is set to zero for Modes 1, 3, and 4. The clean safety injection flow for Mode 2 is obtained from the maximum steaming rate.

Recirculation Flow into Reactor Vessel, kg/sec (lbm/sec)

The recirculation flow into the reactor vessel, in accordance with the guidance provided (Reference [4-13]) for LOCADM Option 2 operation is set to:

1) ‘0’ for Modes 1 and 2
2) the ‘Reactor Vessel Steam Flow’ (i.e., Column V) for Mode 3
3) the calculated recirculation flow for Mode 4

TSP Dissolution Rate, kg/sec (lbm/sec)

While the APR1400 implements TSP for IRWST coolant pH control, its impact on IRWST pH is accounted for in the IRWST coolant pH profile. Therefore, the TSP dissolution rate is unused and the value is set to ‘0’.

Reactor Vessel Pressure in Upper Plenum, kg/cm^3 (psia)

Reference [4-13], indicates that the saturation pressure at the reactor coolant temperature should be entered until the saturation pressure falls below the containment pressure, at which point the containment pressure should be entered. Values provided for ‘Reactor Vessel Pressure in Upper Plenum’ are evaluated internally by LOCADM. For conservatism, calculated sub-atmospheric pressures are reset to 1 atm (14.7 psia).

<u>Maximum Steaming Rate, lbm/sec</u>

The ‘Maximum Steaming Rate’ is evaluated internally in LOCADM. The calculated values are not overwritten and remain as calculated.

4.3.4.4.2 ‘Materials Input’

Guidance for input to populate the ‘Materials Input’ worksheet comes primarily from the ‘Instructions’ worksheet in the LOCADM spreadsheet itself. The input consists primarily of material types, their surface areas or volumes, and/or masses.

<u>Metallic Aluminum Alloy 1100 or Unknown Alloy Type</u>

As the specific aluminum alloy has not been specified, information regarding submerged and unsubmerged aluminum is entered as ‘Metallic Aluminum Alloy 1100 or Unknown Alloy Type’.

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1) aluminum submerged (m^2 / ft^2) :

2) aluminum submerged (kg / lbm) :

3) aluminum not submerged (m^2 / ft^2) :

4) aluminum not submerged (kg / lbm) :

<u>Calcium Silicate</u>

This material type includes low density calcium silicate mat insulation, asbestos and asbestos-containing insulation, and high density refractory materials (e.g., transite). However, no calcium silicate materials are used in the APR1400.

<u>E-Glass</u>

This material type includes fiberglass insulation.

- Fiberglass insulation : 0.36 m^3 (12.5 ft^3)

Using a density of 0.038 g/cm^3 (2.4 lbm/ft^3), a value of 0.36 m^3 (12.5 ft^3) is entered for ‘Fiberglass Insulation’.

<u>Concrete</u>

Exposed concrete surfaces in containment are input to allow consideration of chemical leaching and dissolution. 868.1 m^2 (9,344 ft^2) of concrete is exposed in containment.

In the LOCADM input, 1,736 m^2 (18,688 ft^2) was used by applying the “bump-up” factor of 2.

<u>Coolant</u>

Coolant material inputs are provided to specify coolant specific characteristics for input to LOCADM. Table 4.3-7 and Table 4.3-8 summarize the containment material inputs and coolant material inputs, respectively.

Table 4.3-6 Time Dependent Temperature Data

Time (sec)	IRWST Temp (ºF)	CTMT Temp (ºF)	RV Coolant Temp (ºF)
3	120.0	220.0	230.0
17	120.6	264.2	274.2
40	122.4	261.7	271.7
114	125.1	265.4	275.4
121	125.3	265.8	275.8
301	130.0	273.1	283.1
600	140.2	269.1	279.1
900	140.2	269.1	279.1
901	148.3	264.5	274.5
1202	153.6	261.2	271.2
2409	166.3	250.7	260.7
3002	171.4	246.6	256.6
3606	175.9	243.0	253.0
5224	175.9	243.0	253.0
5225	185.6	235.4	245.4
9429	200.2	223.8	233.8
12002	204.8	219.8	229.8
28002	210.1	208.1	218.1
80002	190.9	187.7	197.7
100002	185.1	182.6	192.6
1000182	146.5	146.5	156.5
2600000	134.3	134.3	144.3

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Table 4.3-6 Time Dependent Temperature Data

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Time (sec)	IRWST Temp (ºF)	CTMT Temp (ºF)	RV Coolant Temp (ºF)
3	120.0	213.5	586.1
17	121.4	265.8	374.4
40	126.7	262.8	307.4
114	137.8	266.0	302.4
121	138.3	266.3	302.1
301	151.1	274.0	296.0
600	169.1	271.2	296.9
700	173.0	269.9	295.9
701	173.0	269.9	295.9
900	178.7	267.5	294.1
1202	184.9	264.7	292.2
2409	203.4	258.5	287.8
3002	210.2	256.9	286.7
3606	215.9	255.5	285.5
5224	227.3	252.6	283.4
5225	227.3	252.6	283.1
9429	241.0	248.2	280.0
12002	244.0	246.5	278.9
14400	245.1	245.2	278.0
14401	245.1	245.2	278.0
28002	241.9	238.6	273.6
80002	221.4	218.6	261.3
100002	212.4	208.4	255.6
1000182	153.8	152.2	231.8
2600000	140.9	139.3	231.8

Table 4.3-7 Containment Material Input

Class	Material	Value
Metallic aluminum	Aluminum submerged (ft²)	0.0
	Aluminum submerged (lbm)	0.0
	Aluminum not-submerged (ft²)	~~5,602~~ 4,652
	Aluminum not-submerged (lbm)	~~9,148~~ 7,598
Calcium silicate	Calcium silicate insulation(ft³)	0
	Asbestos insulation (ft³)	0
	Kaylo insulation (ft³)	0
	Unibestos insulation (ft³)	0
E-glass	Fiberglass insulation (ft³)	12.5
	NUKON (ft³)	0
	Temp-Mat (ft³)	0
	Thermal wrap (ft³)	0
Silica powder	Microtherm (ft³)	0
	Min-K (ft³)	0
Mineral wool	Min-wool (ft³)	0
	Rock wool (ft³)	0
Aluminum silicate	Cerablanket (ft³)	0
	FiberFrax durablanket (ft³)	0
	Kaowool (ft³)	0
	Mat-ceramic (ft³)	0
	Mineral fiber (ft³)	0
	PAROC mineral wool (ft³)	0
Concrete	Concrete (ft²)	~~9,344~~ 18,688

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Figure 4.3-6 Maximum LOCA Scale Thickness

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Figure 4.3-6 Maximum LOCA Scale Thickness

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Figure 4.3-7 Fuel Cladding Temperature

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Figure 4.3-7 Fuel Cladding Temperature