Sensitivity Study of Long-Term Core Cooling Associated with Debris Effects Using a LOCADM

Jeong-kwan Suh*, Sun-guk Kwon
KHNP Central Research Institute, 1312-70 Yuseong-daero, Yuseong-gu, Daejeon 305-343, Korea
**Corresponding author: jksuh@khnp.co.kr*

1. Introduction

KEPCO and KHNP are pursuing the USNRC design certification (DC) of the APR1400 since 2009. After the acceptance of the application for standard DC of the APR1400 on March 4, 2015, KHNP has performed the response to request for additional information (RAI) raised by the USNRC.

The USNRC issued RAIs pertain to technical report APR1400-E-N-NR-14001-P, Revision 0, "Design Features to Address GSI-191" [1] as follows (RAI 404-8488 Question 15.06.05-11):

- In Section 3.8.1, a logarithmic temperature decrease is assumed for the containment air and in-containment refueling water storage tank (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.
- In Section 4.3.4.4, states that "The reactor vessel (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.

To address these issues, KHNP updated the temperature profiles using GOTHIC code and extended them to 30 days. The RV coolant temperature was also updated to calculate the RV pressure which is shown in design control document (DCD) Tier 2, Table 6.2.1-7 Part B.

In this paper, the evaluation results of LOCADM for the APR1400 are described. In addition, the sensitivities of RV coolant temperature, pH, IRWST liquid volume, aluminum area, aluminum mass, fiber mass and concrete area are evaluated.

2. LOCADM Modeling and Results

2.1 LTCC Acceptance Criteria

The long-term core cooling (LTCC) acceptance criteria have been defined based on the requirements of 10 CFR 50.46 as clarified by the USNRC. They are summarized as follows [2, 3]:

- The cladding temperature during recirculation from the containment sump will not exceed 426.67 °C (800 °F).
- The deposition of debris and/or chemical precipitates will not exceed 1,270 microns (50 mils) on any fuel rod.

These criteria will facilitate the demonstration of acceptable core cooling following a postulated large break LOCA.

2.2 LOCADM Modeling

The LOCADM inputs are classified as 'Time input,' 'Materials input,' and 'Core data input.' The detailed description on input modeling and assumptions are provided in Reference 4.

2.2.1 Base Case

The base case was modeled assuming the most limiting condition of a cold-leg break which gave the most conservative results. The RV coolant temperature was generated to calculate the RV pressure which is shown in DCD Tier 2, Table 6.2.1-7 Part B (full line of Fig. 1). The IRWST and spray pH were assumed to be the maximum values – a constant 10 pH for the first 4 hours post-LOCA and 8.5 thereafter. The initial IRWST liquid volume was assumed to be the minimum value. The bump-up factor of 2 was applied to all the types of debris input (aluminum area, aluminum mass, fiber mass and concrete area).

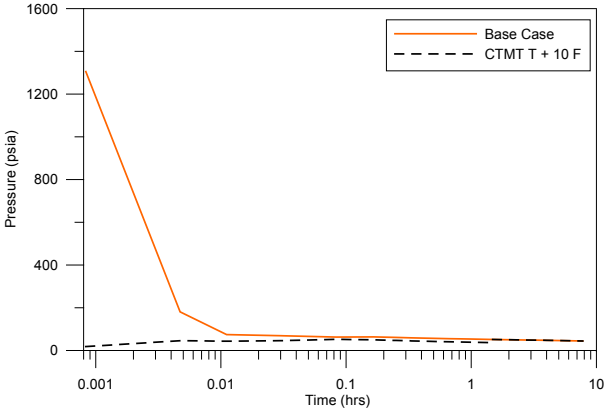

Fig. 1. RV pressure at base case and case 2

2.2.2 Sensitivity Cases

A total of 7 sensitivity cases were generated and executed for the APR1400, as shown in Table 1.

- Case 2: The RV coolant temperature was assumed to be 10 °F higher than the containment temperature. The pressure profiles calculated by LOCADM are shown in Fig. 1 (dotted line).

- Case 3: The IRWST and spray pH were assumed to be the minimum values – a constant 4 pH for the first 4 hours post-LOCA and 7 thereafter.
- Case 4: The initial IRWST liquid volume was assumed to be the maximum value.
- Cases 5~8: The nominal value was applied to specific sensitivity parameters of aluminum area, aluminum mass, fiber mass and concrete area.

Table I: LOCADM Cases Executed

Case ID	Parameter	Description
1	Base case	Max. RV coolant temp., Max. pH, Min. IRWST liq. vol., Bump-up factor 2
2	RV coolant temp.	Containment temp. + 10 ºF
3	pH	Minimum
4	IRWST liquid vol.	Maximum
5	Aluminum area	Nominal value
6	Aluminum mass	Nominal value
7	Fiber mass	Nominal value
8	Concrete area	Nominal value

2.3 Calculation Results

The calculation results are summarized in Table 2.

- Base case: The maximum LOCA scale thickness is predicted to be 154.5 μm (6.08 mil), as shown in Fig. 2 (full line). The peak cladding temperature at any time during the 30 day mission time is 439.96 °F (226.64 °C), as shown in Fig. 3 (full line).
- Case 2: The maximum LOCA scale thickness is predicted to be 106.9 μm (4.21 mil), as shown in Fig. 2 (dotted line). The peak cladding temperature at any time during the 30 day mission time is 423.33 °F (217.41 °C), as shown in Fig. 3 (dotted line).
- Cases 3~8: The maximum LOCA scale thicknesses for Cases 3~5, 7 and 8 are predicted to be less than that of base case. The maximum LOCA scale thickness for Case 6 is predicted to be the same to the value of base case. The peak cladding temperature at any time during the 30 day mission time is the same to the value of base case.

Table II: Summary of Calculation Results

Case ID	Parameter	Max. scale thickness (micron)	Max. cladding temperature (ºF)
1	Base case	154.5	439.96
2	RV coolant temp.	106.9	423.33
3	pH	58.5	439.96
4	IRWST liquid vol.	151.7	439.96
5	Aluminum area	79.0	439.96
6	Aluminum mass	154.5	439.96
7	Fiber mass	153.7	439.96
8	Concrete area	154.3	439.96

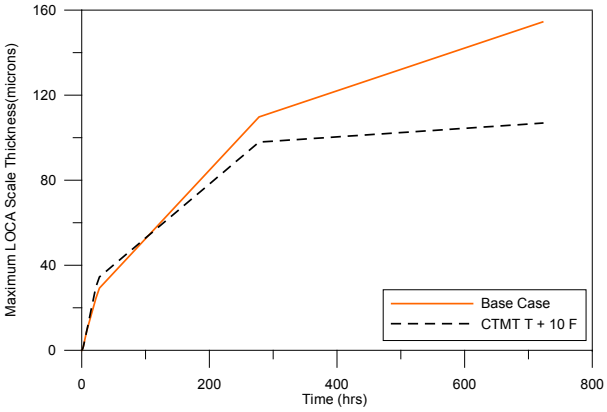

Fig. 2. Maximum scale thickness at base case and case 2

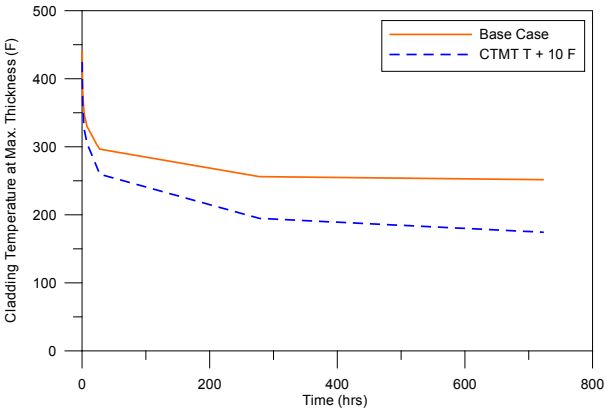

Fig. 3. Maximum cladding temperature at base case and case 2

3. Conclusions

A sensitivity study was performed to assess the effect of specific parameters such as RV coolant temperature, IRWST/spray pH, IRWST liquid volume, aluminum area, aluminum mass, fiber mass and concrete area using a LOCADM. Of the calculation results, base case has generated the limiting cladding deposit thickness and temperature. Therefore, the assumptions used in the LOCADM analyses for the APR1400 are conservative, and the LTCC is maintained since the calculation results meet the acceptance criteria with sufficient margins.

REFERENCES

[1] APR1400-E-N-NR-14001-P, Rev. 0, "Design Features to Address GSI-191," December 2014.
[2] WCAP-16793-NP, Rev. 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," 2011.
[3] USNRC, "Final Safety Evaluation by the Office of Nuclear Reactor Regulation: Topical Report WCAP-16793-NP, Revision 2," April 2013.
[4] J.K. Suh, et al., "Effects of Chemical Precipitates and Debris Deposited on Fuel Rods after a LOCA," Trans. of the KNS Spring Meeting, Gwangju, Korea, May 30-31, 2013.
[5] OG-07-419, "Transmittal of LOCADM Software in Support of WCAP-16793-P," September 2007.