Development of Pressure and Temperature Analysis Methodology for APR1400 Containment in CONTEMPT-LT/028

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***Keywords : CONTEMPT-LT/028, Pressure and Temperature Analysis, Design Based Accident, APR1400.**

1.Introduction

After exporting the APR1400 (Advanced Power Reactor 1400), a Korean Nuclear Power Plant (NPP), to the UAE Barakah NPP, South Korea has heightened expectations for new overseas NPP projects. Consequently, efforts are underway to localize the Pressure and Temperature analysis methodology in APR1400 NPP's Containment. South Korea uses various computer codes for this analysis, including COPATTA, PAREO6, COCO, CONTRANS, CONTEMPT-LT/028, CAP, and GOTHIC. Currently, CONTEMPT-LT is utilized during construction for this purpose. This study develops a methodology for analyzing Pressure and Temperature in South Korea's APR1400 units using CONTEMPT-LT/028 code focusing on LBLOCA during DBA accidents. The methodology developed applies to Shin-Kori Units 3 and 4 based on Shin-Kori Units 5 and 6's FSAR methodology.

2. Methods and Node Schematic

2.1 Criteria

As per General Design Criteria 50 of Appendix A of 10CFR50, a reactor containment structure should withstand calculated pressure-temperature conditions from any loss-of-coolant accident without exceeding design leakage rate while providing sufficient margin. The analysis should assume off-site power loss with the most severe single failure in emergency power system or containment heat removal systems or core cooling systems as outlined in 10CFR50 GDC 38/50 and SRP 6.2.1.1.

The containment structure also needs to endure peak pressure-temperature conditions calculated from Design Basis Accidents without surpassing its design leakage rate while providing enough margin. Containment pressure must decrease below half of peak calculated pressure within a day following DBAs based on severe single active failure assumption among emergency power system or containment active heat removal system or emergency core cooling system or related secondary components like MSIV or MFIV concurrent with LOOP. If there isn't a specific model calculating maximum IRWST water temperature available separately prepared analyses at start recirculation from peak pressure analysis then maximum IRWST water temperature should equal saturation temperature at total containment pressure criteria [1].

2.2 Current Node Schematic

Pressure-Temperature analysis relies on CONTEMPT-LT/028 code considering passive structures like concrete walls/domes comprising eighteen Heat Structures activating by set points considering spray startup time assuming entire Floor area instead only water area because higher IRWST Temperatures result in lower atmospheric heat removal rates due to maximizing IRWST water temperatures having minimal impact lowering atmosphere's Temperature or Pressure due to low evaporation rate [2].

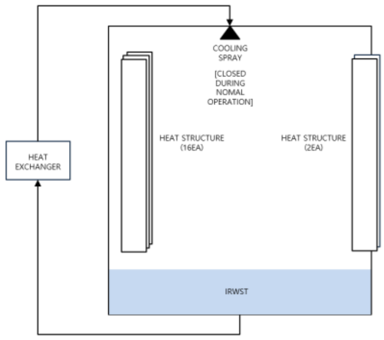

Fig. 1. Node schematic for Current CONTEMPT-LT/028 maximum pressure and temperature analysis

The Pressure result of CONTEMPT-LT/028 is calculated using the energy equation and is computed based on an initial input of Specific Volume in Equation (5).

$$v_w = (1-x)v_f(T_v) + xv_g(T_v) \quad (1)$$

$$U_v = M_{vw}u_w(T_v, v_w) + M_a c_v T_v \quad (2)$$

$$V_v = M_{wv}v_w \quad (3)$$

$$U_v = M_{vw}u_w(T_v, v_w) + M_a c_v T_v. \quad (4)$$

$$P = P_{vw}(T_v, v_w) + \frac{M_a R_a T}{xM_{wv}v_g(T_v)} \quad (5)$$

c_v = constant volume heat capacity of air
M_a = mass of air
M_{wv} = mass of water
P = total pressure
p_{wv} = pressure of water
R_a = temperature(absolute units)

T_v = total internal energy
u_v = specific internal energy of water
u_w = specific internal energy of water
v_f = specific volume of saturated liuquid
v_g = specific volume of saturated vapor
v_w = specific volume of saturated liuquid

Due to these reasons, the change in water level caused by condensed steam turning into water through heat equilibrium cannot impact the pressure [3].

2.3 New Node Schematic

Due to the characteristics of the CONTEMPT-LT/028 code, changes in water level do not affect pressure. However, to reach the maximum temperature in the IRWST, the SI injection flow is removed from the IRWST. Additionally, when the spray is activated, water accumulates in the reactor building's structures. This water is also removed from the IRWST to achieve the maximum containment pressure and temperature.

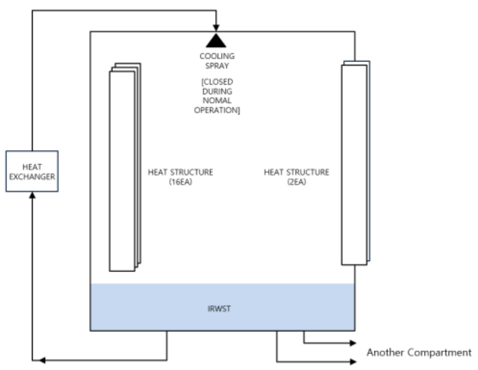

Fig. 2. Developed CONTEMPT-LT/028 Node schematic for Maximum Pressure and Temperature analysis.

3.Analysis Results

The new node configuration for peak pressure and temperature is chosen based on these conservative conditions and assumptions:

(1) Assumption of SI injection flow for maximum Pressure and Temperature.
(2) Water trapping in reactor building structures for maximum pressure and temperature during spray operation.
(3) Conservative assumption of interfacial area between atmosphere and water pool in the IRWST for maximum Pressure and Temperature.

Figures 3 to 8 present the Sensitivity Analysis results for assumptions (1) and (2), summarizing peak Pressure, Temperature in the atmosphere, and Temperature in the IRWST. The peak atmospheric Pressure and Temperature do not significantly change because it's assumed that SI flow removal from the IRWST occurs after 2,000 seconds, following their peak values. However, conservative data emerged regarding half of atmospheric Pressure and Temperature within 24 hours (86,400 seconds). Due to significantly low evaporation and condensation rates in CONTEMPT-LT/028 [2], it's expected that results for maximum Pressure and Temperature will be higher compared to other codes. Moreover, equal pressure from both methodologies after 106 seconds stems from CONTEMPT-LT/028 disregarding pressure changes caused by water level fluctuations. Therefore, it's necessary to input an optimal Liquid-Vapor Region Interactions Area.

Table. 1. Summary Table Comparing the Two Methodologies

Description	DESLGB Max Si		DESLGB Min SI		DEDLGB Max SI		DEDLGB Min. SI		DEHLGB Max. SI		DEHLGB Min. SI	
	1*	2**	1*	2**	1*	2**	1*	2**	1*	2*	1*	2**
Time of Peak Containment Pressure [sec]	575.0	575.0	520.0	515.0	10800	1085.0	24.0	24.0	16.6	16.6	16.6	16.6
Peak Containment Pressure [psia]	58.9	58.9	59.2	59.2	59.0	59.0	58.3	58.3	62.2	62.2	62.2	62.2
Time of Peak Containment Temperature [sec]	575.0	575.0	116.0	116.0	1080.0	1085.0	24.0	24.0	20.5	20.5	20.5	20.5
Peak Containment Temperature [F]	264.5	264.5	273.6	273.6	264.6	264.6	263.6	263.6	269.8	269.8	269.8	269.8
Time of Max. IRWST Water Temperature [sec]	32500.0	20100.0	29000.0	19000.0	32500.0	20000.0	31500.0	20400.0	39500.0	24950.0	33000.0	21600.0
Max. IRWST Water Temperature [F]	219.8	228.2	219.5	228.8	220.2	228.7	216.4	225.3	209.1	217.2	213.5	222.1

Notes :
DESLGB : Double-Ended Suction Leg Guillotine Break
DEDLGB : Double-Ended Discharge Leg Guillotine Break
DEHLGB : Double-Ended Hot Leg Guillotine Break
1* : Without Water Trap & SI Flow from Containment (Fig.1. Case)
2** : Considering Water Trap & SI flow from Containment (Fig.2. Case)

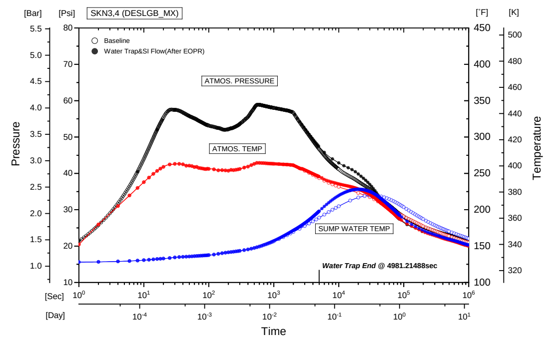

Fig. 3. Double-Ended Suction Leg Guillotine Break, Max. SI

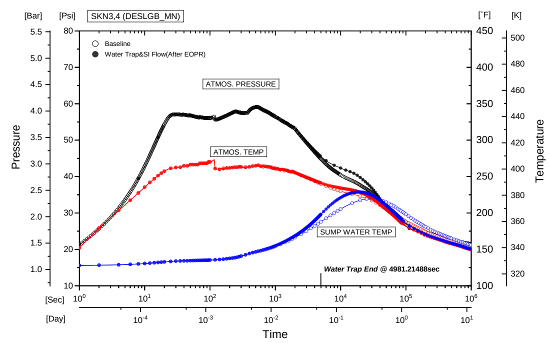

Fig. 4. Double-Ended Suction Leg Guillotine Break, Min. SI

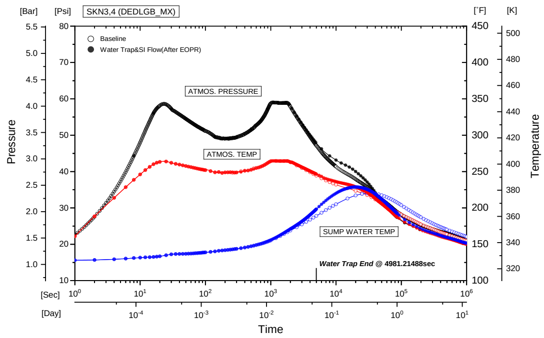

Fig. 5. Double-Ended Discharge Leg Guillotine Break, Max. SI

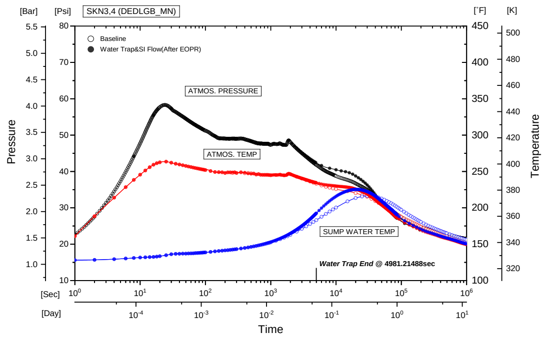

Fig. 6. Double-Ended Discharge Leg Guillotine Break, Min. SI

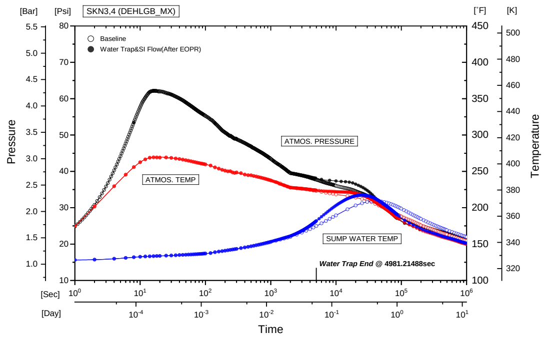

Fig. 7. Double-Ended Hot Leg Guillotine Break, Max. SI

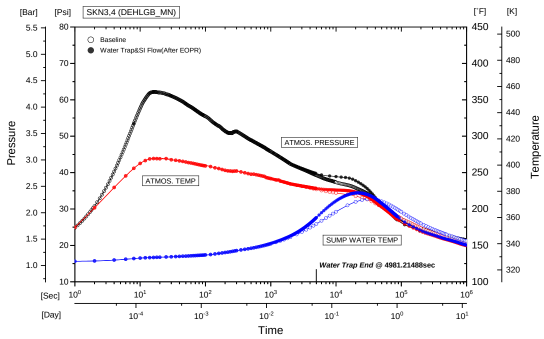

Fig. 8. Double-Ended Hot Leg Guillotine Break, Min. SI

4. Summary

For the NPP's export, the domestic code (e.g. CAP) has been customized using the CONTEMPT-LT/028 methodology. In the revised methodology, the phenomenon of water accumulation in the Spray and the removal of SI injection flow in the IRWST have been addressed. Although no significant differences are observed in the Peak Pressure and Temperature of the Containment between the two methodologies, a considerable discrepancy is noted in the decrease rate of Pressure and Temperature within the first 24 hours. In the previous approach, the areas of the atmosphere and the IRWST are calculated based on Floor Area (i.e. Liquid-Vapor Region Interactions Area) due to the code characteristics of CONTEMPT-LT/028, necessitating changes for other codes.

REFERENCES

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[2] Yongju Cho et al. "Comparison of CAP3.0 and CONTEMPT-LT/028 evaporation models in an indoor pool", Korean Nuclear Society Autumn Meeting Changwon, Korea, October 20-21, 2022.
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ACKNOWLEDGEMENT

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20217810100020).