CAP Code Version-up to 3.0 and Its Application to Pressure and Temperature Analysis

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1. Introduction

Korea nuclear industry is now pursuing the development of an SMR (Small Modular Reactor). For the design of a containment of the SMR, the PT (pressure and temperature) analysis is analyzed. The PT of conventional PWR (Pressurized Water Reactor) containment, which is a type of large dry containment using containment spray system, has been analyzed by a single volume model which is adopted in CONTEMPT-LT code[1]. Even when more advanced codes such as GOTHIC[2] are used, still the single volume model is applied. It may be because the containment atmosphere can be treated equilibrium by the containment spray effect.

However, the containment design of the SMR is far different from that of PWRs. The SMR does not use the containment spray system for the containment heat removal. Instead, CPRSS (Containment Pressure and Radioactivity Suppression System) is used.

CAP code was developed and received a code license in March, 2017 in the version of 2.21. CAP code can be applied to backpressure calculation of LOCA (Loss of Coolant Accident), PT analysis, sub-compartment PT calculation, environmental qualification analysis, and hydrogen concentration calculation. However, each part should be licensed for the actual plant application for its methodology. Even more, the plant type is limited into domestic PWR containment type. For the PT analysis of the SMR, the CAP code should be upgraded and the methodology should be developed.

This paper introduces the CAP version-up to 3.0 and the PT analysis method in order to apply to SMR containment.

2. Description of the SMR and Important Phenomena

The outline of the SMR containment which includes CPRSS is shown in Fig.1. The pressurization of the containment is usually caused by SBLOCA (Small Break LOCA) or MSLB (Main Steam Line Break) accident. The ME (mass and energy) from a break is released into LCA (Lower Containment Area). The steam or water of high energy is condensed in IRWST (Incontainment Refueling Water Storage Tank) or passes the CHRS (CPRSS Heat Removal System) to remove the heat into ECT (Emergency Cooldown Tank) by condensing the steam. The noncodensable gas in LCA moves to UCA (Upper Containment Area) via IRWST and RRT (Radioactive material Removal Tank). After 72hours, natural circulation mode is initiated and the heat is only removed into ECT.

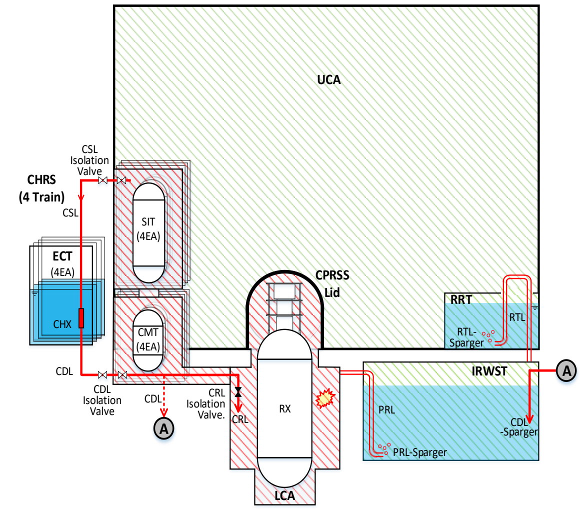

Fig. 1. Layout of the SMR containment

For the upgrade of CAP code and for the development of PT analysis method, PIRT (Phenomena Identification and Ranking Table) was developed and described in reference 3. New essential phenomena for CAP3.0 is shown in Table I. The other phenomena were already verified and validated (V&Ved) in CAP2.21.

Table I: Phenomena for V&V in CAP3.0

	Phenomenon in PIPE	Experiment or Method
1	Pressure drop in pipe	GE Experiment (Janssen, 1964)
2	Condensive heat transfer (CHX)	MIT Experiment (Siddique, 1993) KAIST Experiment (Park et al., 1999)
3	Boiling heat transfer	Code Cross Check (MARS code)

3. Development of CAP3.0

2.1 Original CAP of version 2.21

Licensed CAP is version 2.21 and featured by

- Lumped model: 1-dimensional flow model
- Three-field: Gas, Continuous liquid, Dispersed droplet
- Three components: Water, air, and hydrogen
- Mathematical basis: Governing equation (Continuous Eq., Momentum Eq., Energy Eq., Gas species Eq.), Constitutive models, Special flow models, Heat conductor model, Engineered safety feature and component models, Input/output model
- Numerics: FVM (Finite Volume Method), ICE (Implicit Continuous Eulerian) method

2.2 CAP3.0 development

Newly developed features of CAP3.0 are as follows

- PIPE component model: Momentum equation suitable for pipe flow is applied
- Corresponding input/output
- Flow regime and relevant interfacial models for PIPE
- Wall boiling mode: Chen model
- Wall condensation model: Diffusion Layer Model (DLM)

For PIPE model, the scalar equations are same to the CAP2.21. The flow and numerical cell for pipe is sketched in Fig. 2. Flow regime map in CAP3.0 for the general pipe flow is shown Fig. 3.

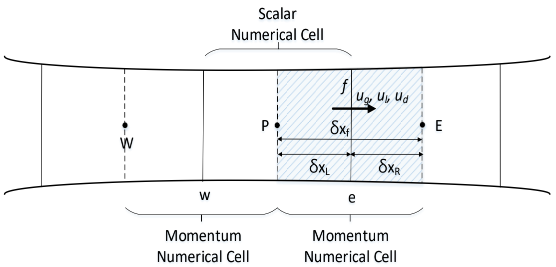

Fig. 2. Pipe flow and numerical cell

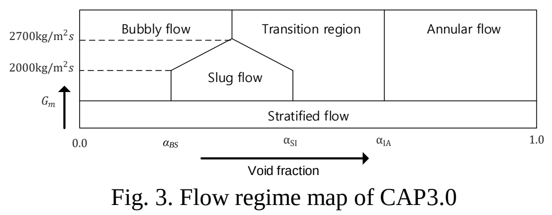

Fig. 3. Flow regime map of CAP3.0

4. V&V of CAP3.0

The importance phenomena discussed in section 2 were validated. The other phenomena in PIRT were already validated in CAP2.21

4.1 Wall condensation

MIT experiment [4] and KAIST experiment [5] were assessed and the results are shown in Fig. 4 and Fig. 5. They show reasonable agreement within 20% error.

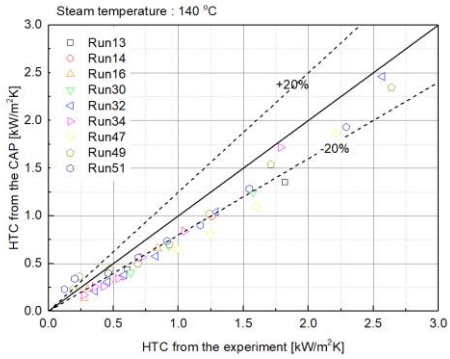

Fig. 4. CAP3.0 assessment of MIT experiment

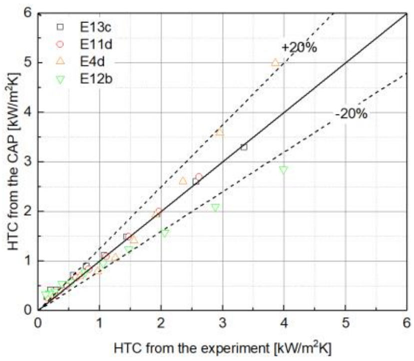

Fig. 5. CAP3.0 assessment of KAIST experiment

4.2 Two-phase pressure drop in pipe

GE experiment [6] was assessed and was predicted within 30% error as shown in Fig. 6.

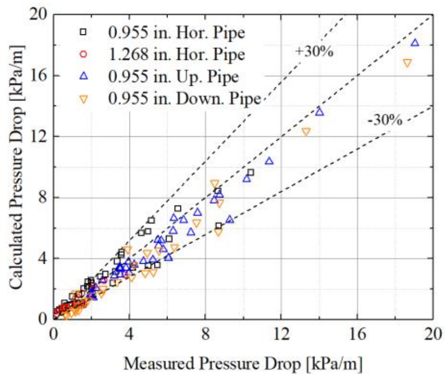

Fig. 6. CAP3.0 assessment of GE experiment

4.3 Assessment of integral test: SISTA

SISTA is a thermal-hydraulic conceptual verification test apparatus that reduces CPRSS to 1/5,000 by volume ratio (1/10 by height, 1/500 by width). The test apparatus includes importance component of CPRSS, as shown in Fig. 7, together with CAP nodalization.

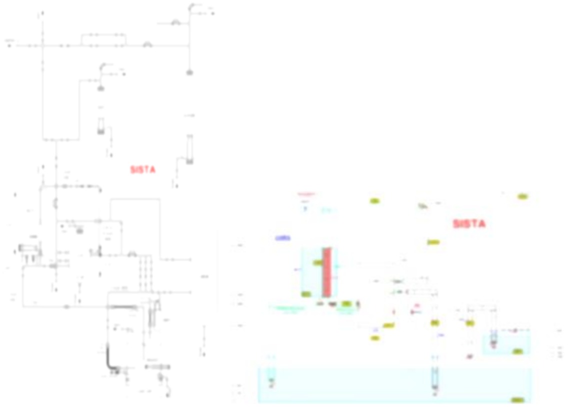

Fig. 7. SISTA schematics and CAP nodalization

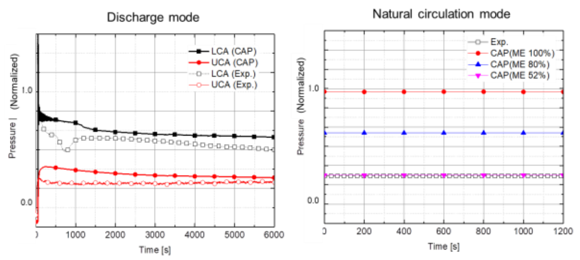

Fig. 7. SISTA assessment results

CAP results show higher pressure than test. It is believed to be caused by heat loss in SISTA.

5. Evaluation Methodology

Conservative approach was taken. Initial conditions were conservatively taken on the base of operational limits in technical specification. ME also has 10~30% margin. Geometry input was made conservatively in volume, flow area, and so on. Single failure was assumed in CHRS. The passive heat sinks were model as a minimum. The heat transfer coefficient was adjusted by multiplier of less than 1.0.

6. Sample Calculation

For SBLOCA of safety injection line break and MSLB of 8inch break were analyzed. All satisfied the design values as shown in Fig. 8 and Fig. 9.

Sensitivity studies were also conducted. Nodalization and time step sensitivities showed little affect. And the heat transfer coefficient in CHX affected only the natural circulation mode.

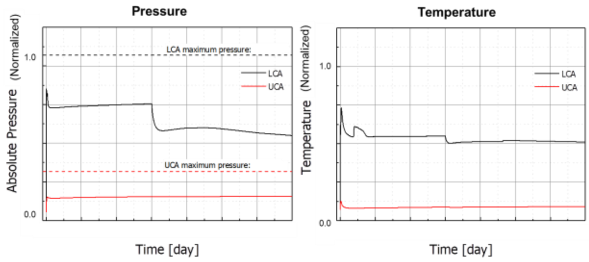

Fig. 8. SBLOCA sample calculation

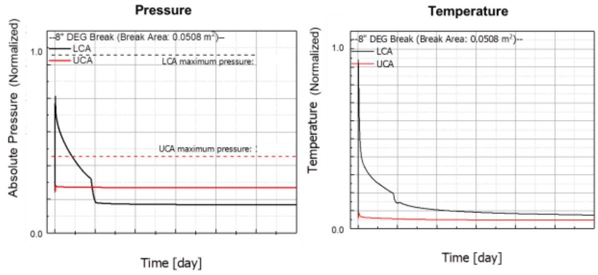

Fig. 9. MSLB sample calculation

7. Conclusions

CAP3.0 was developed for pipe flow (PIPE model) and relevant constitutive models were also developed. Using this CAP 3.0 PT analysis method for SMR was successfully developed using conservative approach. This shows the successful calculation for the passive safety system and all showed that the design values were satisfied.

REFERENCES

[1] Hargroves, D. W., et. al., 1979, CONTEMPT LT/028 A Computer Program for Predicting Containment Pressure-Temperature Response to a Loss-of-Coolant-Accident, United State Nuclear Regulatory Commission, NUREG/CR 0255.

[2] GOTHIC Containment Analysis Program Version 7.2. Electric Power Research Institute, Palo Alto, CA, NAI 8907-06 Rev. 15, 2004.

[3] Topical Report on the SMART100 Containment Pressure/Temperature Analysis Methodology, 2020

[4] Siddique, The Effect of Noncondensable Gases on Steam Condensation under Forced Convection Condition, Ph.D. dissertation, Massachusetts Institute of Technology, 1992.

[5] Park, H. S., Steam Condensation Heat Transfer in the Presence of Noncondensables in a Vertical Tube of Passive Containment Cooling System, Ph.D. dissertation, Korea Advanced Institute of Science and Technology, 1999.

[6] Janssen et al., Two-Phase Pressure Drop in Straight Pipes and Channels; Water - Steam Mixtures at 600 to 1400 psia, GEAP 4616, General Electric Co. Atomic Power Equipment Dept., San Jose, Calif. May 1964