Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Evaluation of High-Pressure RCS Natural Circulations Under Severe Accident Conditions

Byung Chul Lee[a], Young Suk Bang[a] and Nam Duk Suh[b]
[a]*FNC Technology Co., Ltd., SNU RPIC #516, San 4-2 Bongchun7-dong, Gwanak-gu, Seoul 151-818, Republic of Korea*
bclee@fnctech.com
[b]*Korea Institute of Nuclear Safety, 19 Gusung-dong, Yusong-gu, Daejeon, 305-338, Republic of Korea*

1. Introduction

Since TMI-2 accident, the occurrence of severe accident natural circulations inside RCS during entire in-vessel core melt progressions before the reactor vessel breach had been emphasized and tried to clarify its thermal-hydraulic characteristics [1,2]. As one of consolidated outcomes of these efforts, sophisticated models have been presented to explain the effects of a variety of engineering and phenomenological factors involved during severe accident mitigation on the integrity of RCS pressure boundaries, i.e. reactor pressure vessel(RPV), RCS coolant pipe and steam generator tubes [3].

In general, natural circulation occurs due to density differences, which for single phase flow, is typically generated by temperature differences. Three natural circulation flows can be formed during severe accidents: in-vessel, hot leg countercurrent flow and flow through the coolant loops. Each of these flows may be present during high-pressure transients such as station blackout (SBO) and total loss of feedwater (TLOFW).

As a part of research works in order to contribute on the completeness of severe accident management guidance (SAMG) in domestic plants by quantitatively assessing the RCS natural circulations on its integrity, this study presents basic approach for this work and some preliminary results of these efforts with development of appropriately detailed RCS model using MELCOR[4] computer code,

2. Basic Approach and Modeling of RCS Natural Circulation

2.1 Basic Approach

The primary effect of the natural circulation flows is to redistribute the energy being generated in the core. This energy redistribution will slow the heatup of the core, which in turn may affect the damage progression or the extent of the core damage. Slowing the core damage would allow more time for systems to be recovered to mitigate or terminate the accident. However, the energy removed from the core will affect the structures in which it is deposited. The difference between without natural circulation and with natural circulation models results in quite a different subsequent accident progression, as shown Table 1.

Table 1. Influence of RCS natural circulation on accident consequences

Physical Factors	Without NC	With NC
Core melt progression	Fast	Slow
Composition of melted core including metal oxidation	Metal	Oxide or Ceramic
Effect on early containment failure at VB	Large	Small
Release of radionuclides into environment	Direct CF	Bypass containment or SG tube rupture)
Available time for system recovery and operator action	Less	More

Phenomena identification and ranking tables (PIRTs) for in-vessel and hot leg countercurrent flows were developed in Reference 2, of which the purpose was to provide an indication of the relative importance of various parameters under severe accident conditions of interest. Given a high-pressure accident sequence, this table can be utilized to guide sensitivity analysis to confirm the intrinsically phenomenological uncertainties in implementing the SAMG strategies.

Table 2 shows an outline of the sequence-specific uncertainty analysis developed for Ulchin 1&2 Nuclear Power Plant, of which accident sequence was found to be most likely among core damage accidents. With this table, the confirmation of the effect of severe accident mitigation actions is expected to achieve reasonably and objectively under possible severe accident conditions, if other severe parameters are not engaged in accident progression.

2.2 Detailed RCS Natural Circulation Model for MELCOR Code

Based on normal MELCOR simulation model for Ulchin 1&2 RCS and related safety systems[5], detailed RCS natural circulation model was developed, as shown in Figure 1. The detailed model has 18 control volumes per each loop and 59 control volumes for RPV including reactor core, lower plenum and upper plenum, which includes the modification of the basic model in order to explain general thermo-hydraulic transients appearing in RCS loop as well as the natural circulations.

3. Preliminary MELCOR Analyses

In this study, a preliminary MELCOR analysis was performed using detailed RCS natural circulation model, focused on the effect of RCS loop natural circulation. The simulated accident sequence is station blackout with all loss of safety systems in which the operations of turbine-driven auxiliary feedwater pump and emergency batteries were not considered conservatively.

Table 2. The analysis cases considering the importance of RCS natural circulation

Parameter	Base [No NC/sys]	CASE A [No sys]	CASE B [No NC, 1st SAMG]	CASE C [No NC, All SAMG]	CASE D [NC, 1st SAMG]	CASE E [NC, All SAMG]	CASE F [NC, All SAMG]
PORV Operation	×	×	○	○	○	○	○ (L)
Pressurizer draining	×	×	○	○	○	○	○ (L)
SG secondary conditions	×	×	×	○	×	○	○ (L)
RCS pressure	POSRV setpoint	POSRV setpoint	Press. Dec.	Press. Dec.	Press. Dec.	Press. Dec.	Press. Dec.
Vapor-to-structure heat transfer	○	○	○	○	○	○	○
Hot leg countercurrent flow	×	○	×	×	○	○	○
Noncondensible gas effects	○	○	○	○	○	○	○
Fission product behavior	○	○	○	○	○	○	○
Material properties	○	○	○	○	○	○	○
SG inlet plenum mixing	×	○	×	×	○	○	○
Hot leg circumferential temperature	×	○	×	×	○	○	○
Vapor-to-vapor heat transfer	×	○	×	×	○	○	○

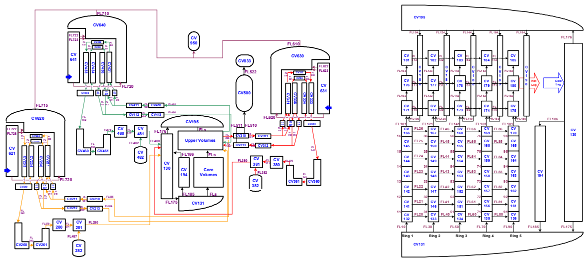

Figure 1. MELCOR RCS nodalization for Ulchin 1&2

The calculation results are summarized in Table 3, compared with that of normal RCS model. As seen in this table, the accident progression is much slower due to heat transfer to SG secondary side through the SG tubes, but the RPV failure time is somewhat similar. However, it was found from core melt progression that extensive core damage and subsequent RPV failure has occurred in detailed RCS natural circulation model.

Figure 2 shows thermodynamic conditions at typical locations of RCS with detailed RCS natural circulation model. They deviate from normal simulation results due to difference to thermal states of inside and outside RPV.

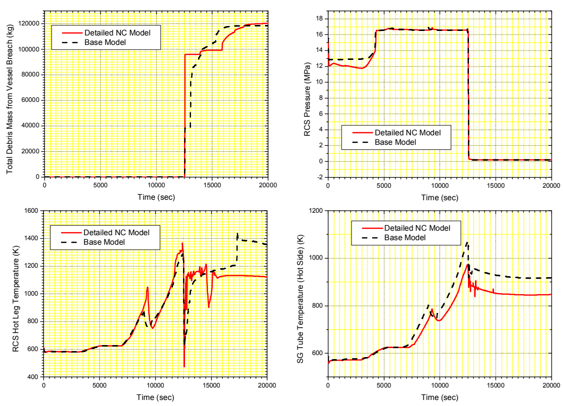

Figure. 2. RCS transients during SBO sequence

Table 3. Accident progression for SBO sequence

Physical Factors	Without NC	With NC
Core uncovery	6,500	6,820
Release of radionuclides in core	8,110	8,374
Core support plate failure	8,676	8,957
Core uncovery (fully)	8,806	9,171
Relocation of core matrial into LH	12,193	12,097
Reactor vessel failure	12,550	12,536

4. Conclusion

In this study, the detailed MELCOR RCS modeling for RCS natural circulation phenomena under severe accident conditions was developed and applied for operating domestic nuclear power plant. Although it was partially applied for RCS loop only, its effectiveness is confirmed with a comparison with normal simulation model. Using fully developed PIRT-like accident sensitivities supported by this study, plant-specific SAMG feasibility on diagnostic and mitigative actions could be more clear than outcomes of previous works

REFERENCES

[1] M. Silberberg, et al., "Reassessment of the Technical Bases for Estimating Source Terms," NUREG-0956, July, 1986.
[2] U.S. Nuclear Regulatory Commission, "Reactor Risk Reference Document," NUREG-1150, December, 1990.
[3] P.D. Bayless, et al., "Severe Accident Natural Circulation Studies at the INEL," NUREG/CR-6285, INEL-94/0016, February, 1995.
[4] R.O. Gauntt, et al., "MELCOR Computer Code Manuals," NUREG/CR-6119, SAND2000-2417, vol. 1, Rev. 2, May, 2000.
[5] S.W. Cho, et al., "Development of MELCOR Code Input Deck for Ulchin 1&2," KINS/HR-723, February, 2006.