한국에너지공학회지(2003), 제12권 제2호
Energy Engg. J(2003), Vol. 12, No. 2, pp. 93~100

Development of Main Steam Line Break Mass and Energy Release Analysis with RETRAN-3D Code

Young-Chan Park and Yoo Kim

Department of Mechanical Engineering, Chungnam National University, 220 Gung-dong, Yuseong-gu, Daejeon 305-764, Republic of Korea
E-mail : k2pyc@kepri.re.kr, yookim@cnu.ac.kr

Abstract — An estimation methodology of the mass and energy (M/E) release due to the main steam line break (MSLB) has been developed with the RETRAN-3D code. In the case of equipment qualification (EQ), the over-estimated temperature would exceed the design limits of some cables or valves. In order to have a more flexible EQ profiles from the MSLB M/E release, the methodology with the best-estimated code was used. The major conditions affecting the MSLB M/E were found to be the initial SG level, heat transfer between primary and secondary sides, power level, operable protection system, main or auxiliary feedwater availability, and break conditions. The RETRAN-3D models were developed for the Kori unit 1 (KRN-1) which is typical two loop Westinghouse (WH) designed plant. Particularly, a detailed model of the steam generators was developed to estimate a more realistic two-phase heat transfer effect of the steam flow. After the modeling, the methodology has been developed through the sensitivity analyses. The M/E release data generated from the analyses have been used as the input to the inside containment pressure and temperature (P/T) analysis. According to the results at the point of view containment P/T, the Kori unit 1 can have more margin of 5~15 kPa in pressure and 8~15°C in temperature.

1. Introduction

The purpose of this study is to develop a methodology for the analysis of main steam line break (MSLB) event with mass and energy (M/E) releases inside containment using the RETRAN-3D code. The current methods for the MSLB M/E releases of westinghouse (WH) plants are documented using the LOFTRAN code as the analysis tool. So, in order to solve these matters, an in-house methodology has been developed.

Generally, the steam flow due to the steam generator (SG) rupture increases rapidly after the MSLB, and the increased steam flow causes a higher heat extraction rate from the primary system, which results in reduced primary coolant temperature and pressure conditions[1][2][3][4].

Steam line ruptures occurring inside reactor containment induce a significant release of high-energy flow to the containment environment, which could result in high containment temperature and pressure. The high temperature and pressure would result in failures of an equipment not qualified to perform their function in the harsh environment. Thus, the containment response analysis should be required to demonstrate that the existing environmental qualification envelopes are not violated by any conditions caused by MSLB.

2. Methodology Development

To develop the analysis methodology of MSLB M/E release, some vendor's methodologies have been reviewed. Especially, the safety analysis standard (SAS) of WH has been used as the main reference, and the methodologies of some utilities have been referred[5].

2-1. Selection of Code

The RETRAN-3D code has been selected to analyze the MSLB M/E release. This code has been developed by electric power research institute (EPRI) for use in transient thermal-hydraulic analysis of light water reactor systems. So, it has all the capabilities required to analyze the accident and release[6].

2-2. Cases Analyzed

Selected power levels are 102, 70, 30, and 0%. Break sizes are from 0.13 m^2 to the area of the steamline. If the flow restrictor exists, the steamline area equals the area of the flow restrictor. Four different single failures are assumed. i.e, CSS (One containment spray safeguards train), MSIV (Main steam isolation valve), FWIV (Feedwater isolation valve), SI (One safety injection train), and LOOP (Loss of offsite power). Break types are double-ended rupture (DER) and split break (Break area doesn't generate a safety injection signal). Generally, transient analysis time is 30 minutes during which the operator can turn off auxiliary feedwater valves.

2-3. Initial Conditions

Reactor coolant system (RCS) the average temperature is the programmed value corresponding to the appropriate initial power level plus uncertainties. RCS pressure is used as nominal pressure at nominal power level. Pressurizer (PZR) water level is the programmed value corresponding to the initial average temperature. Thermal design flow is used as the RCS flow. SG fluid mass is estimated under the condition of nominal conditions water level plus the appropriate steam generator level uncertainty (at least 5% narrow range span) for the faulted loop. For the intact loop, the value corresponding to the nominal level minus the uncertainty is used. Pressurizer level, SGs pressure, main feedwater flow, enthalpy and recirculation ratio of SGs are changed according to the power level[7][8][9].

2-4. Major Parameters

The initial thermal power is represented as the sum of the core nuclear power and the pump power induced by the irrecoverable losses. In this methodology, the pump power is generated by the code. So, the core power is only considered as an input power. The power levels used are 102, 70, 30, and 0%. And the stored energy of the thick metal is considered also to maximize the available energy in the system. The thick metal has been modeled using the heat conductor geometry cards and some control cards required for RETRAN-3D. The break has been modeled as two types, i.e., double-ended rupture and split break. The size range of the breaks has been modeled to account the SG nozzles, main steam lines, and some restrictors.

2-4-1. Reactor trip

Reactor trips are generated from overpower differential temperature, safety inject (SI), low pressurizer pressure, and high containment pressure.

2-4-2. Safety injection signal

SI signals are generated from PZR low pressure, steamline low pressure, and PZR high pressure.

2-4-3. Auxiliary feedwater flow

Mass and energy release rates are highly sensitive to the auxiliary feedwater (AFW) flowrates. Conservatively, the flowrate delivered to the faulted loop should be more than those delivered to the intact loop. This maximizes the mass inventory available to be released. And the lower flow to the intact loop removes less heat from the primary system, so more heat can be transferred to the secondary system via the faulted loop. And the temperature of the AFW is selected as the maximum value available at the power of analysis, such as 102, 70%, etc. The volume of upstream line from the feedwater isolation valve (FWIV) is considered also for a more conservative mass flow in the case of the credit of FWIVs. And in the case of faulted FWIV, the volume of upstream line from feedwater control valves are considered. Auxiliary feedwater data are fed to the SG of the faulted loop as a function of SG pressure. This data have been calculated as the pressure of the pump at the feedwater line.

2-4-4. Main feedwater flow

As mentioned in the case of auxiliary feedwater flow, the main feed water flow to the faulted loop is assumed to be more than those to the intact loop. The feedwater flows are estimated based on the design data of the pump and the feedwater lines. The values are varied according to the power level and the secondary steam pressure and are represented as the fill data cards of the code.

2-4-5. Steam line volume

A steam line volume is considered sensitively to determine the appropriate steam flow of reverse blow down. The volume of the reverse blowndown should include the faulted loop steam lines, common head, and upstream line to turbine stop valves in the case of the failure of main steamline isolation valves (MSIVs). In this methodology, the case of operable MSIVs does not considered due to the less conservative assumption.

2-4-6. LOOP, SI, Boron model

Typically, in the case of M/E release estimation, the loss of offsite power is not assumed. That is, all reactor coolant pumps (RCPs) are assumed to be operable during MSLB. The operable primary flow keeps the forced circulation and more heat transfer from the primary to the secondary system. And the safety injection flow is considered as the minimum value, i.e., one train of SI systems is assumed in the accident. This assumption has two effects on releasing higher energy. The power gets higher by the reduction in the amount of boron that lessens neutron flux. Another effect would be that it is possible to prevent the RCS from cooling down with a lesser amount of SI flow.

2-4-7. Single failure

To develop the methodology, many cases of single failures have been considered to keep the conservatism. There are several single failures which could adversely affect the containment pressure and temperature. First, to protect the intact loop inventory and maintain the heat sink, the main steamline is isolated by the MSIVs in the case of MSLB. Closure of the faulted loop MSIV does not terminate the break flowrate from the faulted steam generator, since the postulated break is located between the steam generator and the MSIV. However, the faulted loop MSIV isolate the break from the remainder of the steamline and the other steam generators. If the faulted loop MSIV fails to close, blowdown from multiple steam generators is prevented by the closure of the corresponding MSIV for each of the intact steam generators. But the MSIV failure increases the unisolable steamline volume containing steam which will be released to the containment. Secondly, failure of the auxiliary feedwater pump runout protection system results in an increased auxiliary feedwater flow rate to the faulted steam generator. And failure of a feedwater control, regulator, or isolation valve would be also considered as single failures.

3. Transient Analyses

To confirm the feasibility of the methodology developed, the MSLB M/E release and the containment pressure and temperature (P/T) have been calculated for Kori Unit 1.

In the WH methodologies, there are no special assumptions, applicable to the MSLB M/E estimation for equipment qualification. So, in this methodology, the assumptions used in the analysis of the containment P/T are selected. And the initial conditions are

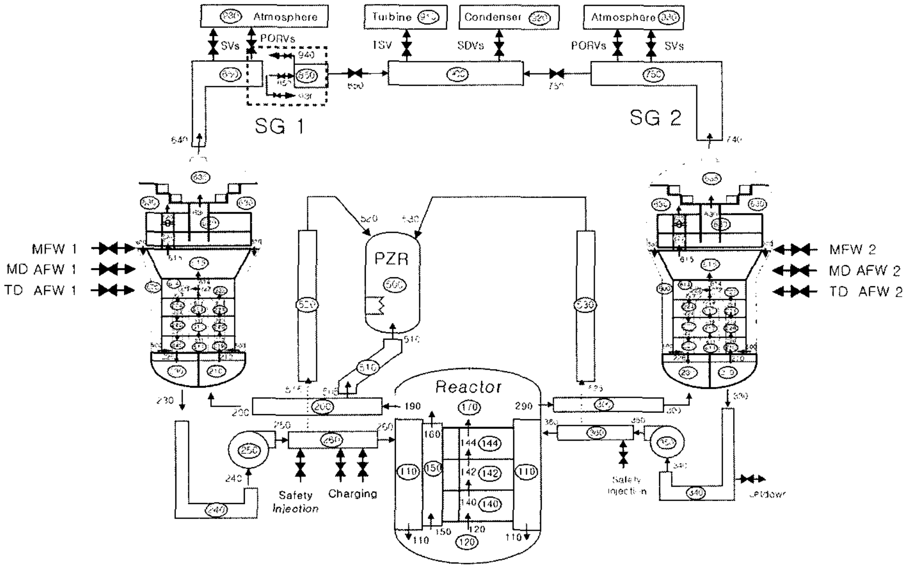

Fig. 1. Kori-1 Nodal diagram for RETRAN.

chosen according to the power level of the MSLB cases.

3-1. RETRAN Modeling for Kori Unit 1

Kori Unit 1 (Kori1) is a 2-loop pressurizer water reactor (PWR) designed by WH. To model the plant, the operation and design data were used. Reactor coolant system (RCS) and reactor vessel of primary side were modeled. The break is located at which the pressurizer is. This is conservative for the steam line break analysis. The steamline of secondary side was modeled up to the turbine stop valve. The model consists of 68 volumes, 103 junctions, and 3 reactor core heat conductors. And to model the reactor control and protection systems, 163 trip cards and 363 control block description cards were used. The SGs (Model-Delta60) are modeled as 9 nodes, respectively. And the steamline was modeled to the turbine stop valve. To consider the effect of the stored energy in RCS, the thick metals were modeled with 35 heat conductors. The models required to represent the reactivity feedback and boron concentration of SI flow were implemented by the general data tables and control block cards in RETRAN 3D code. The nodal diagram is shown in Fig. 1.

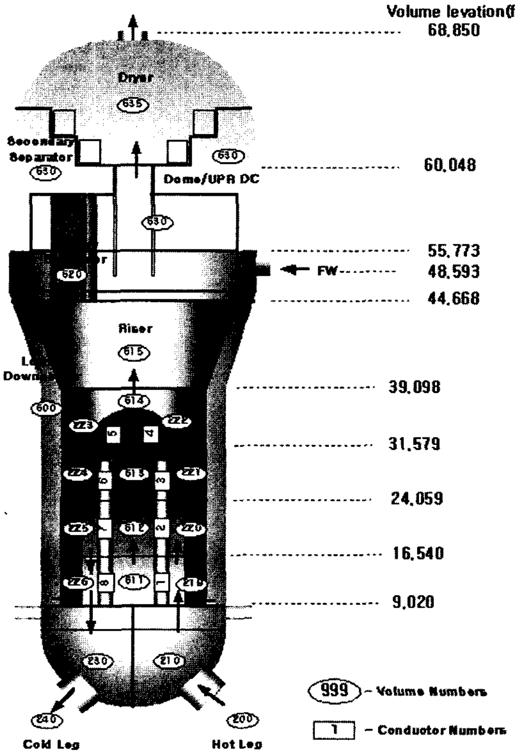

Fig. 2. Delta60 SG nodal diagram for RETRAN.

Prior to the analyses, to confirm the deviations of the RETRAN and LOFTRAN models, some cases of

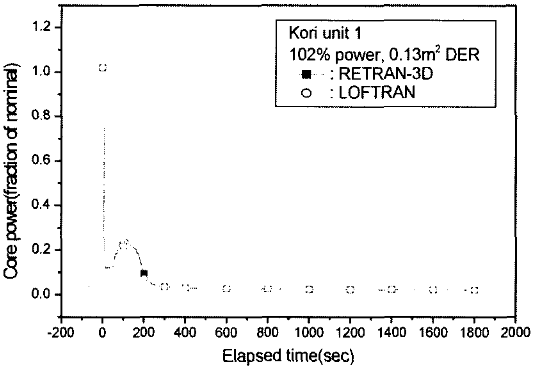

Fig. 3. Core power benchmark.

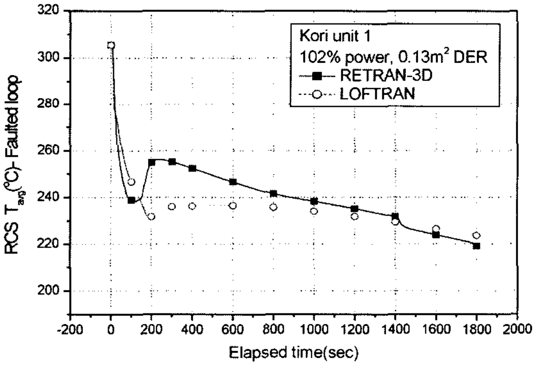

Fig. 4. RCS average temperature benchmark.

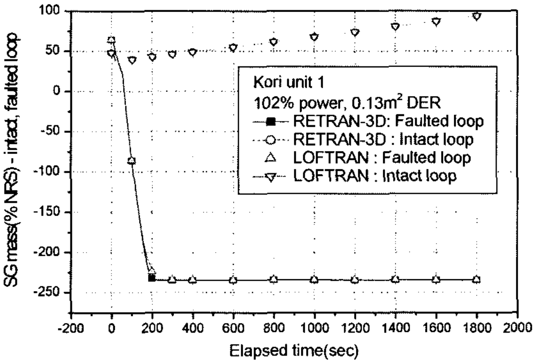

Fig. 5. SG1/2 Total fluid mass benchmark.

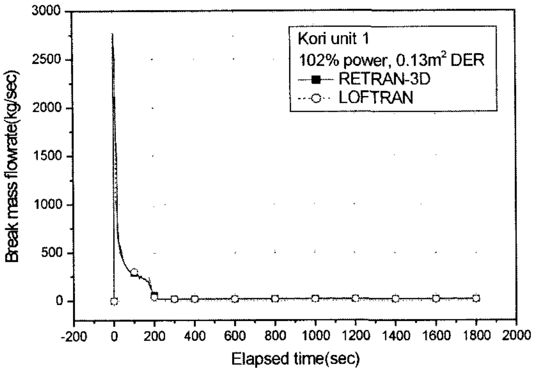

Fig. 6. Break mass flow benchmark.

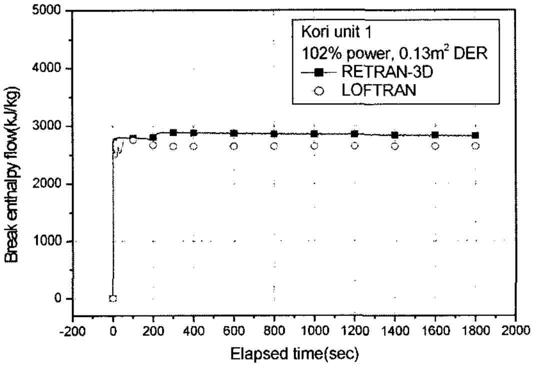

Fig. 7. Break enthalpy flow benchmark.

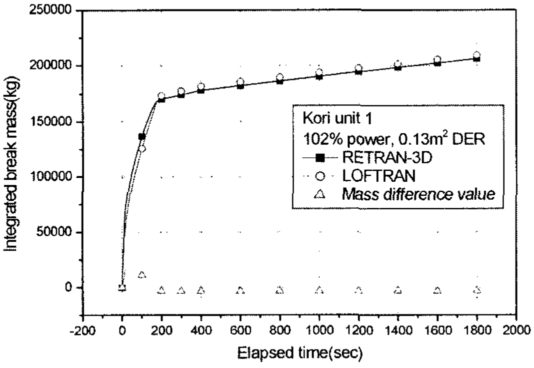

Fig. 8. Break integrated mass benchmark.

MSLB were analyzed for the case of 102% power level, 200% double-ended rupture break size, and 2,400 ppm boron concentration of SI flow. The results of some important parameters are depicted in following figures.

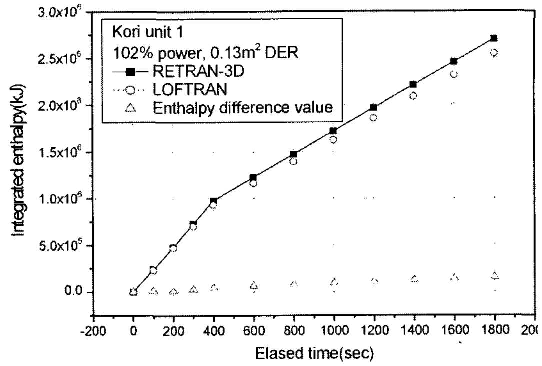

Fig. 9. Break integrated enthalpy benchmark.

The following figures (Figs. 3 to 9) show comparison with the output data of LOFTRAN code for the DER at 102%. Feedwater is modeled to vary according to the pressure of SGs. The moderator temperature coefficient (MTC), doppler coefficient (DC) and some other parameter required to estimate the core conditions are selected by the end-of-fuel (EOF) conditions to maximize the reactivity feedback. The maximum feedback would raise the possibility of return-to power conditions.

The rupture of the MSLB is located between the SG nozzle and the steamline of the faulted loop. To simulate the rupture, three types of valves are modeled in junction cards. During the steady-state operation, the nominal valve is used to model the forward and reverse blowdown, respectively.

As shown in the figures (Figs. 3 to 9), there are good agreement between the RETRAN and the LOFTRAN model. However, the RCS averaged temperature show somewhat different trends. The difference would be explained by two reasons. The first is the difference of the heat transfer mechanism between primary and secondary system. In this model the heat transfer areas and rates are corrected by the codes through the steady-state initialization function. In the LOFTRAN code, however, the parameters are given by the users and fixed. And the next possible reason is the capability to simulate the recirculation flow occurred in the steam generator. The recirculation model in this study would change the heat transfer mechanisms and the amount of the heat removed from the primary system. The following figures (Figs. 10 to

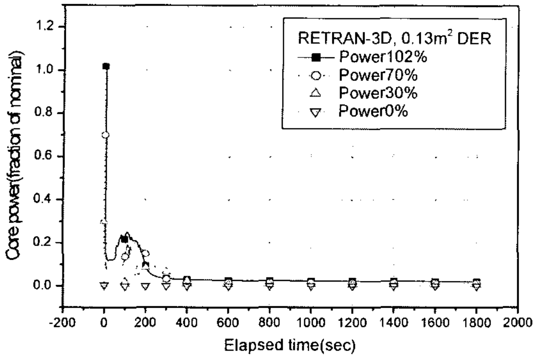

Fig. 10. Core power at the various power levels.

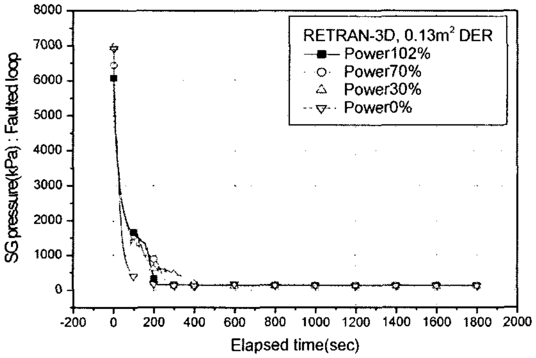

Fig. 11. SG pressure of faulted loop at the various power levels.

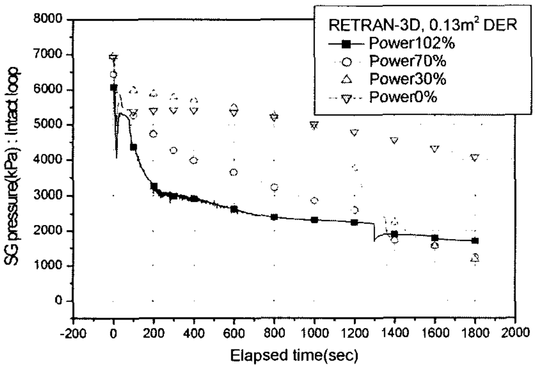

Fig. 12. SG pressure of intact loop at the various power levels.

14) indicate trends of the various power level for break area with 200% DER. To confirm the effect the power level on the MSLB M/E, the analyses of the various power level, such as 102, 70, 30, and 0%,

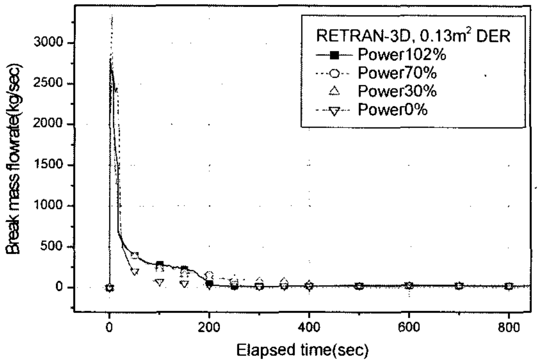

Fig. 13. Break mass flow at the various power levels.

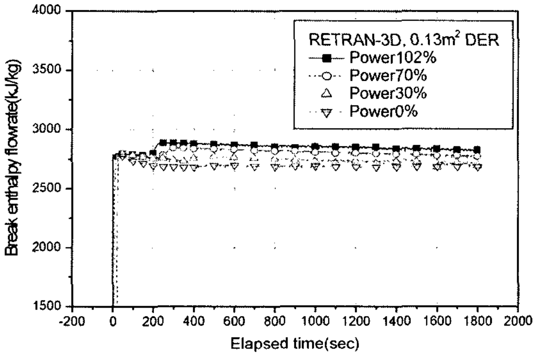

Fig. 14. Break enthalpy flow at the various power levels.

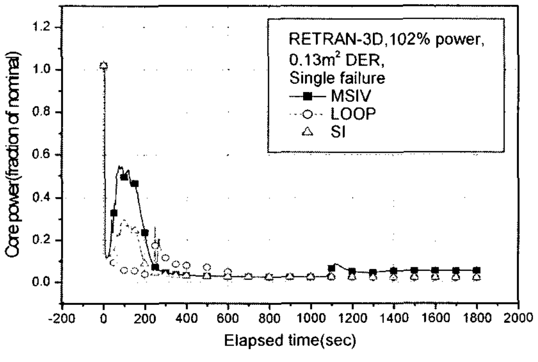

Fig. 15. Core power curves for each single failure.

were performed for the same conditions of 200% DER MSLB. The results of the analyses are represented as following figures.

3-2. Single Failure Assumptions

As a sensitivity study, three single failure assump-

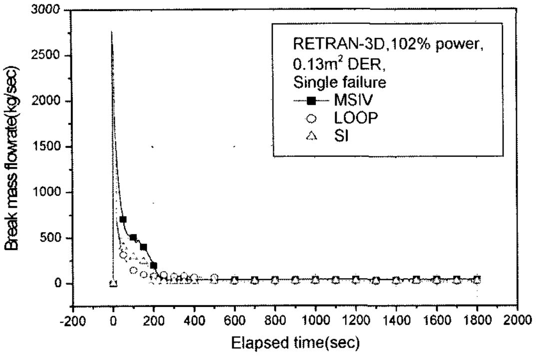

Fig. 16. Break mass flow for each single failure.

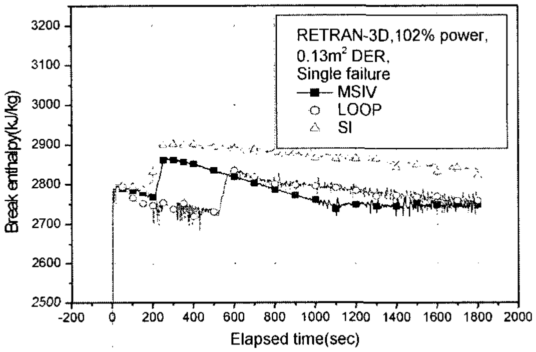

Fig. 17. Break enthalpy flow for each single failure.

tions (LOOP, MSIV, and SI train failures) have been considered in the analysis of MSLB M/E release (Figs. 15 to 17). As mentioned above, the LOOP is not acted as an advantage to more conservative assumptions due to the loss of forced circulation.

In the case of P/T calculation of the containment, the most severe single failure is the fail of a single train of containment spray system. However, this assumption is not required to estimate the MSLB M/E release but assumed in P/T calculation.

3-3. Inside Containment Pressure and Temperature Analysis

The M/E release data generated from the analyses have been used as the input to the containment pressure and temperature analysis code, CONTEMP/LT-28. To overcome the M/E data limit, CONTEMPT/LT-28 has been modified to accommodate more data sets. It is confirmed that the modified code calculated the P/T values as the same ones as the old code

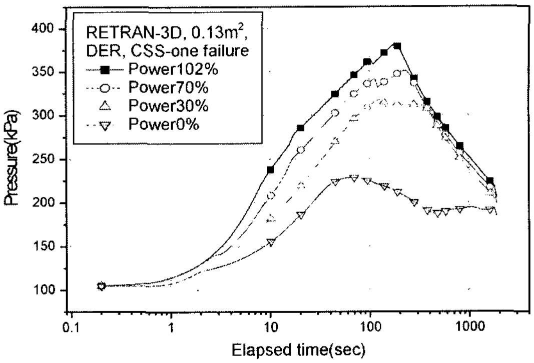

Fig. 18. Containment pressure at various power levels.

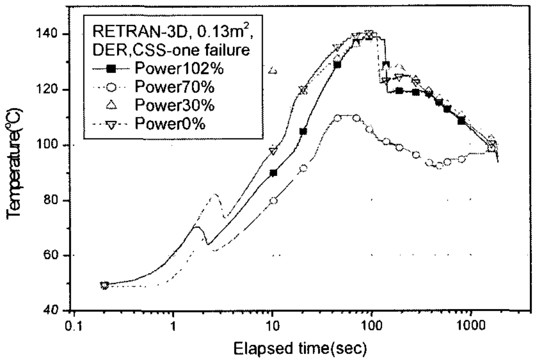

Fig. 19. Containment temperature at various power levels.

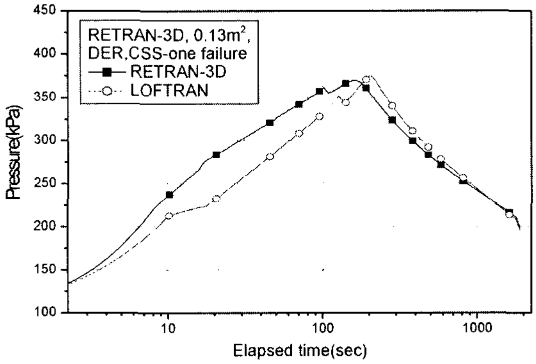

Fig. 20. Atmosphere pressure at the inside containment.

under the same M/E data sets.

The design pressure of Kori-1 containment is 392.5 kPa. So the calculated results should be below the value with some uncertainties. In terms of pressure, the most limiting value of the analyses on the condi-

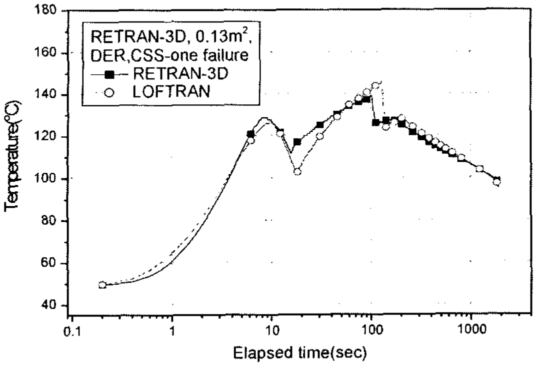

Fig. 21. Atmosphere temperature at the inside containment (RETRAN vs. LOFTRAN benchmark).

tion of 200% DER, was 365.0 kPa (159.0 sec) at 102% power level.

In terms of temperature, the limiting value was 139.2°C (94.0 sec) at 102% power level and 200% DER.

4. Conclusions

The analysis methodology for MSLB M/E release to apply in the RETRAN code has been developed and applied to some cases to check the feasibility of methodology. Some MSLB cases were analyzed to confirm the effects of some parameters and assumptions, such as power level, single failure, etc., also the MSLB M/E release and the containment P/T have been calculated as well. According to the results at the point of view containment P/T, the Kori unit 1 can have a more margin of 5~15 kPa in pressure and 8~15°C in temperature for 102% power and 0.13 m^2 DER. So, it has been found that the developed methodology using RETRAN-3D code can contribute to generate improved P/T profiles for EQ envelope.

References

1. SAS 12.2: "Mass and Energy Release to containment Following a Steamline Rupture," Westinghouse Co., June (2000).
2. SAS 19.0: LOFTRAN Base Deck, Revision 4, January (1997).
3. Park, Y.-C. and Song, D.-S.: "Development methodology MSLB M/E release," TM. 00NE20.P2001.208, Korea Electric Power Research Institute, May. (2001).
4. Heberle, G.H.: "LOFTRAN-Code Description and Users Manual," WCAP-7878, Rev.5, Westinghouse Co., Nov. (1989).
5. WCAP-8860: "Mass and Energy Releases Following a Steam line Rupture," September (1976).
6. Agee, L.J.: "RETRAN-3D A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems," NP-7450, Research Project 889-10 Computer Code Manuals, December 1997 Prepared by Computer Simulation & Analysis, Inc. Prepared for Electric Power Research Institute.
7. "Kori Unit 1 Functional Diagram," KEPCO.
8. "Kori Unit 1 Block Diagram," KEPCO.
9. "Final Safety Analysis Report for Kori Unit 1," KEPCO (1997).