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

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Abstract

The purpose of this study is to develop the methodology for the analysis of the steamline break event with mass and energy releases inside containment using the RETRAN-3D code. The current methods for the SLB M/E releases are documented using the LOFTRAN code as the analysis tool. A steamline rupture in an increased steam flow from one or more steam generator. The increased steam flow causes an increase in the heat extraction rate from the reactor coolant system, resulting in reduced primary coolant temperature and pressure and pressure transient conditions.

Three types of the MSLB M/E calculations have been carried out to confirm the effects of the methodology developed. That is, the calculations have been done using LOFTRAN with/without the entrainment effect and RETRAN-3D. The results of them have been compared each other. At the viewpoint of P/T values calculated, the developed methodology has ensured additional margin which about 2 4 psia in pressure and about 10 20°F in temperature. So, it's been found out that the developed methodology using RETRAN-3D code have some contributes to EQ analyses.

1. Introduction

The estimation methodology of the mass and energy (M/E) release in main steam line break (MSLB) has been developed with RETRAN-3D code. In the methodology being used in Korea, there are some limitations to model the two-phase flow in the secondary side of steam generators (SGs) with the vendor code, LOFTRAN. So the M/E release in MSLB have been estimated more conservatively. Especially, in the case of equipment qualification (EQ), the over-estimated temperature would exceed the design limits of some cables or valves. So we’ve launched the project to develop the MSLB M/E release estimation methodology with best-estimated code since Sep. 2000 by the fund of MOST(Ministry of Science & Technology).

Prior to the development, the methodologies of foreign utilities and vendor, such as Wisconsin Public Service Corp., and Westinghouse Electric Co.(WH), were investigated to develop the in-house methodology of MSLB M/E release. After the review the major conditions affecting the MSLB M/E were found as initial SG level, heat transfer between primary and secondary sides, power level, operable protection system, main or auxiliary feedwater availability, and break conditions. And it was concluded that the entrainment in steam flow played remarkable role to reduce the steam temperature at MSLB.

Next to the review step, the RETRAN-3D models were developed for the target plants, Kori units 1 & 2 (KRN-1/2) which are typical two loop WH-designed plants. Particularly the detail model of steam generators was developed to estimate more realistic two-phase heat transfer effect of the steam flow. The main or auxiliary feedwater flows were modeled according to the current plant conditions, and the thick metal effects on the energy store have been considered also.

After the modeling, the methodology has been developed through the sensitivity analyses using the conditions mentioned before. The power ranges of 0 102%, the break types of double-ended or split, and the break sizes of 0 200% have been used as the accident conditions in the analyses. The M/E release data generated from the analyses have been used as the input to the containment pressure and temperature (P/T) analysis code, CONTEMP/LT. To overcome the M/E data limit CONTEMPT/LT has been modified to accommodate more data sets. It has been confirmed that the modified code calculated the P/T values as the same ones from the old code under the same M/E data sets. The more data sets, the more reasonable results have been estimated using the modified code.

2. Methodology Development

Selection of Code

The best estimated codes, RETRAN-3D, has been selected to analyze mainsteam line break mass and energy releases. This code has been proven as a versatile and reliable computer program for use in best estimate transient thermal-hydraulic analysis of light water reactors. And this code has get the SER(Safety Evaluation Report) from US NRC on 25th, Jan. 2001.

Development of Methodology for MSLB Mass and Energy

To develop MSLB M/E releases analysis methodology, the related documents of Westinghouse methodology were reviewed. Especially, Documents of Safety Aanalysis Standard(SAS) and lecture notes or consulting reports of US utilities were referred.

Plant Initial Conditions

The power levels of 102, 70, 30, 0% were selected to cover the range of 0 102% power. Reactor coolant system (RCS) average temperature and feedwater temerature was selected as the programmed value corresponding to the appropriate initial power level plus uncertainties. The nominal pressure corresponding to 100% power level was used as the RCS. Pressurizer water level was selected as the programmed value corresponding to the initial average temperature. The thermal design flow was selected as RCS flow. Steam generator fluid mass was value corresponding to the nominal steam generator water level at the initial power level plus the appropriate steam generator level uncertainty (at leat 5% NRS) for the faulted loop. For the intact loop, use the value corresponding to the nominal level at the initial power level minus the steam generator level uncertainty.

Major Parameter

As used in design basis analysis, the power is presented as the sum of nuclear power, pumping power and so on. In this analysis, for more conservative assumption, the reactor coolant pump heat has been used. And the input for the NSSS power is defined as the fraction of the nominal value. Appropriate inputs for the SLB M/E release analyses are 1.02, 0.7, 0.3 and about 0.01 for hot zero power. The SLB M/E releases need to include such inputs to maximize the account of energy available for release out through the postulated pipe rupture. The energy stored in RCS thick metal also considered. The RETRAN model for the thick-metal is presented as the heat conductor cards and the heat conductor geometry cards. The simulations of the breaks would be carried out through two viewpoints. The one is break area, and the other is break type. Break area should simulate from 1.4ft^2(if SG outlet nozzle have flow restrictor) to split break size(not generate safety signal), also Break type is double-ended rupture and split break.

- Auxiliary Feedwater flowrate to all steam generators

Mass and Energy release rates are highly sensitive to the auxiliary feedwater flowrate assumptions. Typically, the flowrates assumed to be delivered to the faulted loop should be conservatively high. This maximizes the amount of mass available to be released via the break into containment end subsequently maximizes the peak containment pressure and temperature achieved. Typically, the flowrates assumed to be delivered to the intact loops should be conservatively low. The intact steam generator removes energy from the primary coolant and may add energy to the RCS as the primary coolant cools down.

- Maximum auxiliary feedwater temperature at the power levels that have been selected for the analysis (typically 1.02, 0.7, 0.3, 0.01 fraction of power) need to be provided.

- Maximum feedwater line unisolable volume in each intact loop, the faulted loop without a feedwater control or isolation valve closure failure, and the faulted loop with a feedwater control or isolation valve closure failure are required. the maximum unisolable volume is the section of the feedline from the feedwater control or isolation valve to the feedline connection.

- Maximum main feedwater flow delivered to the faulted and minimum main feedwater flow delivered to the intact steam generator

This information is necessary to determine the feedwater flow transient which is used as the input for large DERs. Method for determinning the analysis input values is to obtain main feedwater flowrates as a function of steam generator pressure and power level.

- Volume of the steam system between the flow restrictors including the header

This information is necessary to determine the appropriate steam piping reverse blowdown. This also defines the volume of the steam system which should be included in the analysis considering both no failure and a failure of the faulted loop main steamline isolation valve (MSIV). With a failure of the faulted loop MSIV, this is the total volume of the faulted loop steamline from the faulted steam generator to the header, plus the volume of the header, plus the volumes from each intact steam generator steamline isolation valve to the header.

- Minimum safety injection (SI) flow vs. reactor coolant pressure all lines injections

(no spilling)

Typically, steamline break mass and energy release calculations are performed assuming there is no loss of offsite power, however, to be conservative, the SI flowrates are based on the failure of one SI train. In addition, it may be advantageous to obtain the minimum SI flow curve assuming all trains of SI injecting with no spilling.

- Consistent offsite power power available assumptions

The benefit of analyzing with consistent offsite power available assumptions is associated with an increase in SI flows which can be justified since a failure of one train of SI does not have to be assumed. In addition, the containment analysis may be assumed smaller delay times for equipment needed to mitigate the containment pressure and temperature transient. However, the RCPs are assumed to continue to operate, which not only provides full RCS flow but also maximizes the heat from the primary available to be released to containment

- Consistent offsite power lost available assumptions

The benefit of analyzing with consistent offsite power lost assumptions is that the RCPs trip with a loss of offsite power. One of the effects of tripping the RCPs is that the amount of heat generated in the primary is reduced, which ultimately would get transferred to the secondary side and be released as mass and energy to containment. However, the greatest effect of tripping the RCPs is due to the reduction in forced reactor coolant flow as a result of going to natural circulation.

- Single failure

The most limiting single failure must be considered in all containment analyses. There are several failures which would adversely affect the containment pressure and temperature. The main stealine isolation function is accomplished via the closure of the MSIV in each of the loop steamlines. Closure of the faulted loop MSIV does not terminate the break flow from the faulted steam generator, since the postulated break is located between the steam generator and the MSIV. However, the faulted loop MSIV does 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 dose increase the unisolable steamline volume containing steam which will be released to the containment. Failure of the auxiliary feedwater run-out protection system results in an increased auxiliary feedwater flow to the faulted steam generator.

3. Transient Analyses

Power Level

For the Main stemline break M/E releases, the initial conditions are represented power level according to WH methodology. Usually the analyses should be assumed power level, single failure, break size, etc.

Kori Unit 2 & RETRAN Modeling

Kori 2 is 2-loop PWRs designed by WH. To model the plant, the operation and design data of the plant were used. Steam generator (F-Model) is presented as one node. And steamline of secondary side is modeled up to turbine stop valve. The model consists of 39 volumes, 72 junction, 3 reactor core heat conduct, 17 heat conduct considering RCS thick-metal stored energy, 118 trip cards, and 285 control block description cards. The nodal diagram is as show in Figure 1.

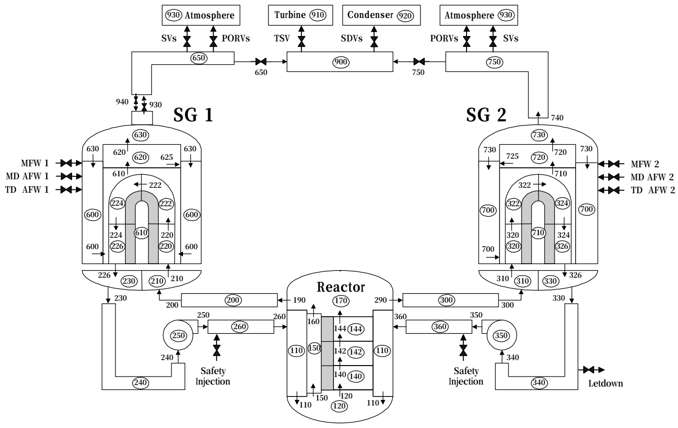

Figure 1. Kori-2 Nodal Diagram for RETRAN

The following figures show the results of comparison the output data with those of LOFTRAN code for the DER at 102%. Feedwater modeling is followed pressure change of the steam generators. It is reflected as the form of SG pressure vs. feedwater flowrates using the general data table in RETRAN. MTC, DTC of EOF and maximum values are used. During the transient, boron injections through SI flows are considered also with the general data cards and control blocks. The location of the DER inside containment is the steamline at the nozzle of the faulted steam generator. Three valves are designed for the break in the forward flow direction, the break in the reverse flow direction, and the normal flow through the nozzle junction.

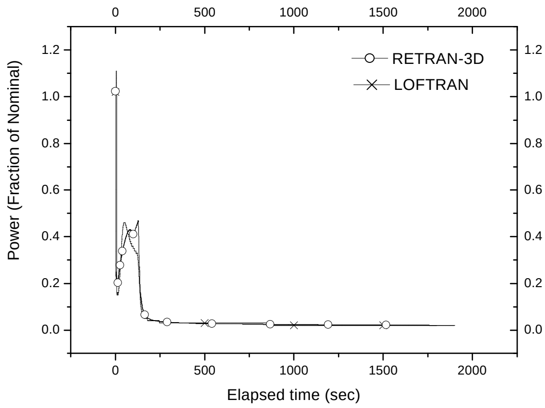

Figure 2. Core Power(Fraction of nominal)

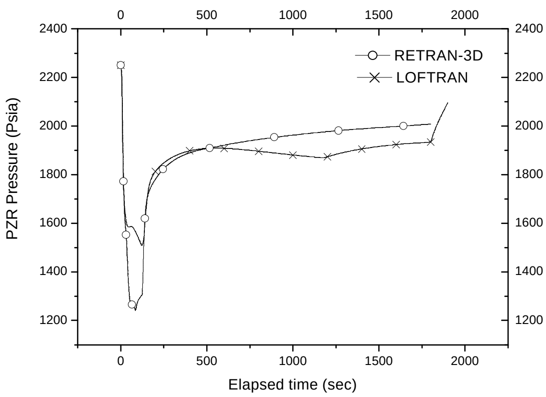

Figure 3. Pressurizer Pressure

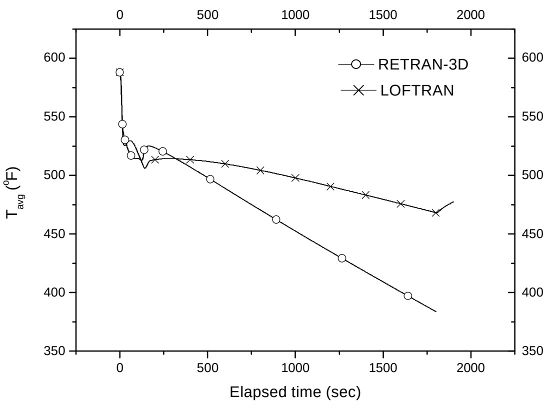

Figure 4. Average Temperature

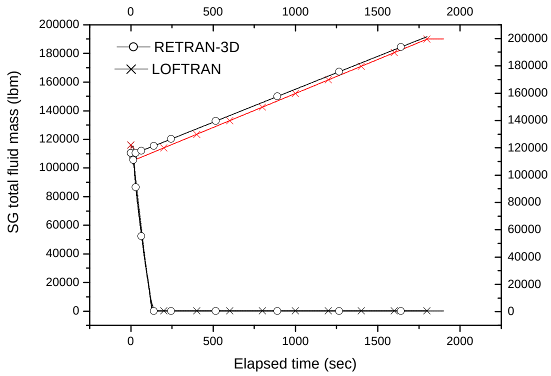

Figure 5. Steam Generator Total Fluid Mass

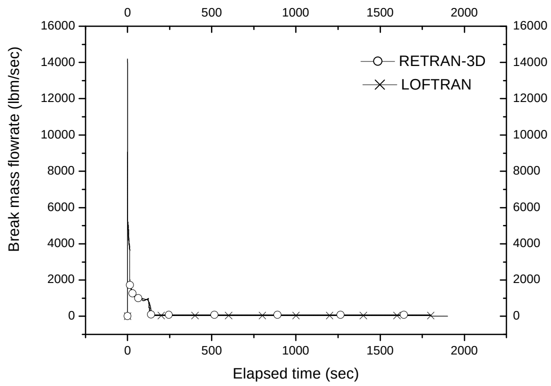

Figure 6. Break Mass Flowrate

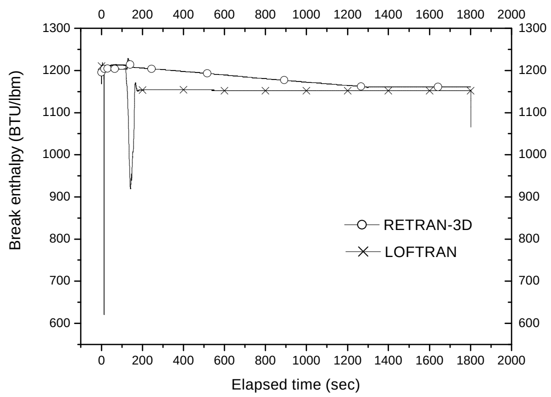

Figure 7. Break Enthalpy

Analyses the Power Level for DER

The following figures show the results according to the power level of 102, 70, 30, 0%.

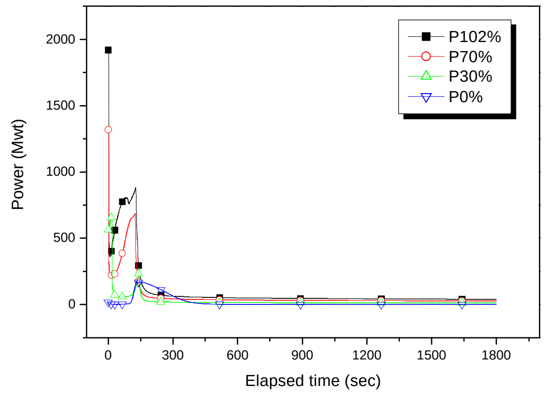

Figure 8. Core Power

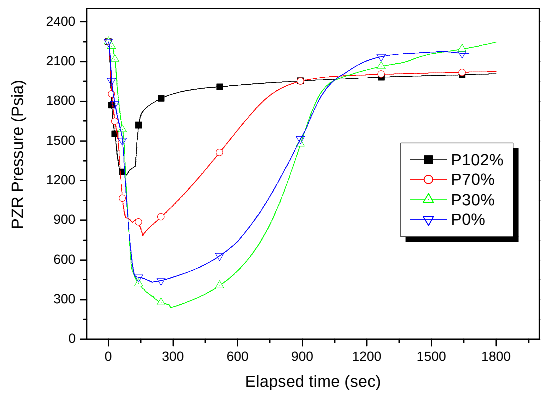

Figure 9. Pressurizer Pressure

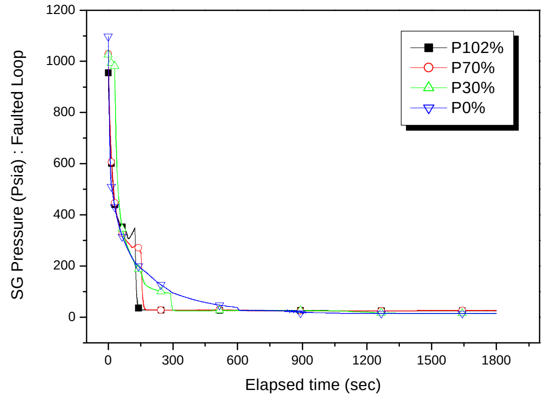

Figure 10. Steam Generator Pressure : Faulted Loop

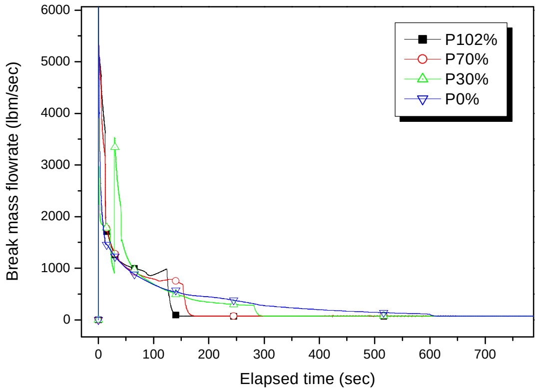

Figure 11. Break Mass Flowrate

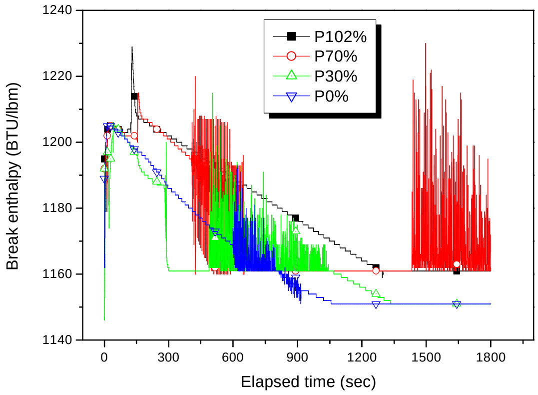

Figure 12. Break Enthalpy

Single Failure Assumptions

This analysis assumed three types of single failures (MSIV, RCP, One train of SI Failure). RCP failure of three cases was the least M/E release. It may be the small heat transfer from primary side to the secondary side. but M/E releases amount of MSIV & one train of SI failure was a similar.

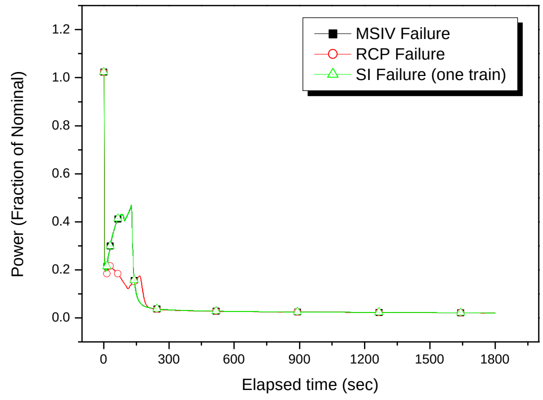

Figure 13. Core Power(Fraction of nominal)

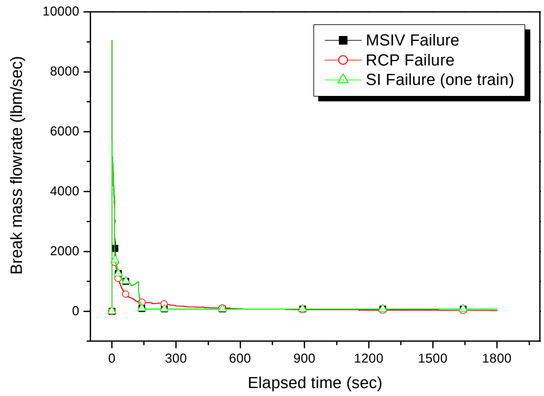

Figure 14. Break Mass Flowrate

Containment Pressure & Temperature (P/T) Analyses

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. To overcome the M/E data limit CONTEMPT/LT has been modified to accommodate more data sets. It is confirmed that the modified code calculated the P/T values as the same ones from the old code under the same M/E data sets. Design pressure of Kori-2 is 59.5 psia. The most limiting of this analysis at the viewpoint of pressure, on 1.4ft^2 break area, was 57.58 psia (104.0 sec) at 102% power level. About a temperature, it was 349.69 ^{o}F (120.0 sec) at 0% power level. Analysis for split break has not been done yet.

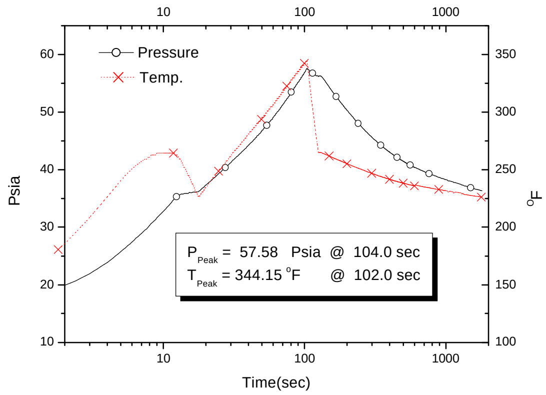

Figure 15. 102% Power, DER, CSS-1 Failure

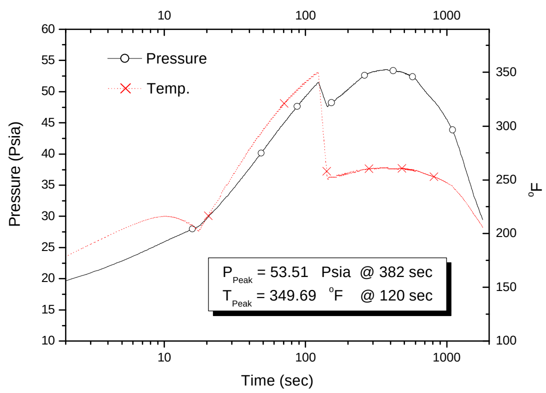

Figure 16. 0% Power, DER, CSS-1 Failure

Single Failure P/T

The most limiting of this analysis about pressure, on $1.4ft^2$ break area, was 57.60 psia (104.0 sec). About a temperature, was 344.00 °F (102.0 sec) at 102% power level.

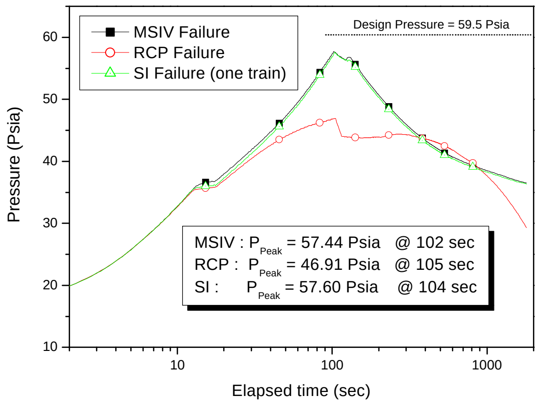

Figure 17. Single Failure (For Pressure)

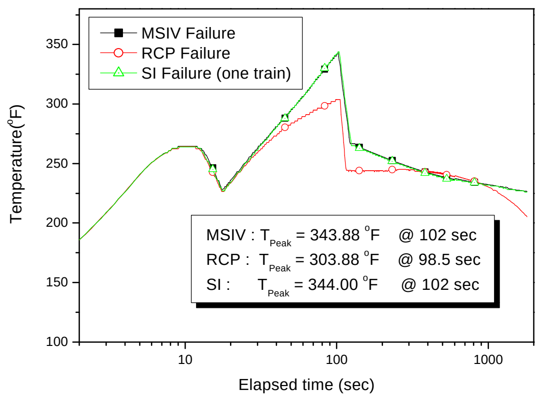

Figure 18. Single Failure (For Temperature)

An Effecting of Enrainment

The entrainment rolls low atmosphere temperature of the inside containment. One node of steam generator cannot appeal entrainment effect. So, in this study, a result data of LOFTRAN was referred. Entrainment data used was for F-Model value at SAS 12.2. As the results of the effects, the temperature of the containment decreases about 4 ^{o}F.

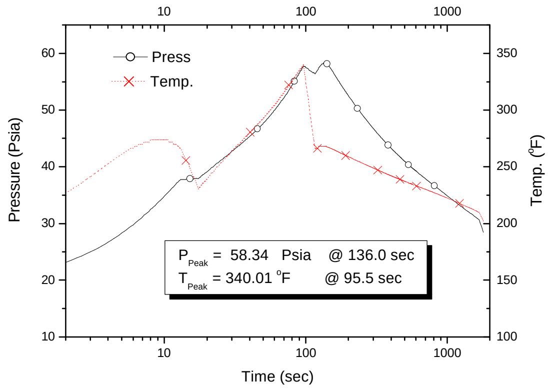

Figure 19. LOFTRAN : Without Entrainment

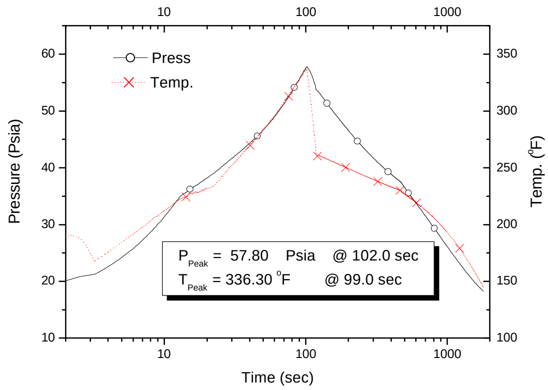

Figure 20. LOFTRAN : With Entrainment

4. Conclusion & future work

The analysis methodology for MSLB M/E release has been developed and have been performed transient analyses (Power level, Single Failure, etc) for some cases. And MSLB M/E release data calculated by developed methodology for LOFTRAN code have been compared. By the review of the results, the similarity in a trend between the results and those mentioned in FASR was confirmed.

In the next step, more various events will be analyzed. To investigate the effect of the nodalization, the more detail model of steam generator will be developed. And, the methodology for outside containment will be develop also.

Acknowledgments

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