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SAMPLING BASED UNCERTAINTY ANALYSIS OF 10 % HOT LEG BREAK LOCA IN LSTF

Samiran Sengupta
Bhabha Atomic Research Centre
Mumbai, Maharashtra, India

S. K. Dubey
Atomic Energy Regulatory Board
Mumbai, Maharashtra, India

R. S. Rao
Atomic Energy Regulatory Board
Mumbai, Maharashtra, India

S. K. Gupta
Atomic Energy Regulatory Board
Mumbai, Maharashtra, India

V. K. Raina
Bhabha Atomic Research Centre
Mumbai, Maharashtra, India

ABSTRACT

This paper describes the uncertainty analysis carried out for 10% Hot leg break LOCA of Large Scale Test Facility as a part of IAEA Coordinated Research Project on "Evaluation of Uncertainty in Best Estimate Accident Analysis". The best estimate code used for this analysis is RELAP5/MOD3.2. Initially the nodalisation of the test facility for carrying out the analysis is qualified for both steady state and transient level by systematically applying the procedures lead by Uncertainty Methodology based on Accuracy Extrapolation developed at University of Pisa. Subsequently the uncertainty analysis is carried out using sampling based Monte Carlo approach, which involves the generation and extrapolation of a mapping from uncertain inputs to the uncertain analysis results. The major steps followed in this methodology mainly includes screening sensitivity analysis for input parameters, design matrix generation using Latin Hypercube Sampling, representation of uncertainty analysis results based on best estimate thermal hydraulic code runs and importance /sensitivity analysis using regression analysis. The steps followed have been described in details in this paper.

INTRODUCTION

Thermal hydraulic system codes are complex tools developed to estimate the transient behaviour of NPPs during off-normal conditions. The evaluation of safety margins, the operator training, the optimization of the plant design and related emergency procedures are some of the major applications of these codes. The performance assessment and validation of these codes and their uncertainty evaluation are among some of the major objectives of international research programs. As a part of a similar coordianted research program, uncertainty analysis is carried out for 10% Hot leg break loss of coolant accident (LOCA) simulation experiment on the Large Scale Test Facility (LSTF) using RELAP5 /MOD3.2 code. Total failure of high pressure injection system and auxiliary feed water as well as loss of off-site power concurrent with scram is assumed as per experimental boundary conditions. The primary pressure decreases fast and core dry out takes place. The accumulator coolant injection occurs twice. Long term core cooling takes place by the actuation of low pressure injection system. This paper describes the test facility, experiment, methodology of qualification, steady state and transient level qualification and the uncertainty & importance analysis of the small break LOCA in LSTF.

LARGE SCALE TEST FACILITY

The Large Scale Test Facility [1] of ROSA-IV simulates a Westinghouse-type four-loop 3423 MWt PWR, namely Tsuruga Unit-2 of Japan Atomic Power Company, by a full-height and 1/48 volumetrically scaled two loop system as shown in Fig.1. Each loop has an active steam generator (SG) with 141 full-size U-tubes (inner-diameter of 19.6 mm each). Hot and cold legs, 207 mm in inner diameter, are sized to conserve the volumetric scaling (2/48) and the ratio of the length to the square root of the diameter to simulate the flow regime transitions in the horizontal legs. The LSTF simulated fuel rod assembly consists of 1064 heater rods and 104 unheated rods. The LSTF initial core power of 10 MW corresponds to 14% of the volumetrically scaled (1/48) PWR nominal core power because of limitation in the capacity of power supply. To obtain prototypical initial fluid temperatures with this core power, core flow rate is set to 14% of the scaled nominal flow rate. The LSTF instrumentations provide detailed information on thermal-hydraulic conditions through measurement of temperature, level, pressure, differential pressure, flow rate, fluid density, etc. The experiment conducted in this facility, which is considered for the uncertainty analysis is described below.

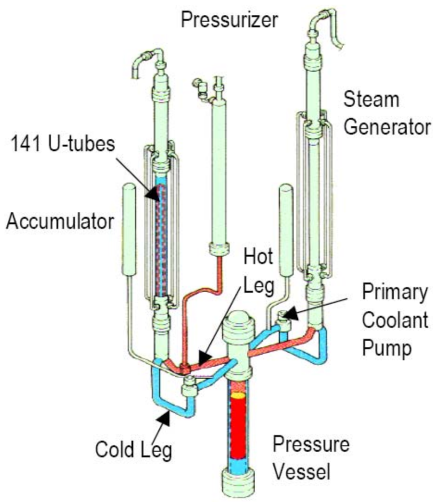

Fig.1 Schematic view of LSTF

EXPERIMENT OF SMALL BREAK LOCA

The break is simulated by using a 31.9 mm inner-diameter sharp-edge orifice mounted at the downstream of a horizontal pipe that is connected to hot leg horizontal break nozzle in the loop without PZR [2]. The orifice flow area corresponds to 10% of the cold leg cross-sectional area of the reference PWR. The experiment is initiated by opening a break valve located downstream of the break orifice. Scram and safety injection signals are generated at the PZR pressures of 12.97 and 12.27 MPa respectively. Initial conditions such as PZR pressure, fluid temperatures in hot and cold legs are 15.5 MPa, 599 K and 563 K respectively, according to the reference PWR conditions. The axial profile of the core power is a 9-step chopped cosine with a peaking factor of 1.495 while the radial profile is a distribution with a peaking factor of 1.51. Based on the decay power curve of the prototype 3423 MWt PWR with 1/48 volumetric scaling factor, the core power decays down to 10 MW after 42 sec. Since, maximum power in the LSTF is limited to 10 MW, LSTF core power is kept constant upto 42 sec in the experiment. Afterwards, LSTF core power is decreased according to the power decay curve of the prototype PWR. Initial pump speed is about 780 rpm. For better simulation of pressure and temperature transient of the reference PWR, the pump speed is increased to 1440 rpm after the break and dropped according to the predetermined coast down curve following the scram signal generation. Initial secondary pressure is raised to 7.3 MPa to limit the primary to secondary heat transfer rate to 10 MW, while 6.1 MPa is the nominal value in the reference PWR. Initial SG secondary side collapsed liquid level is 9.7 m. Set point pressures for opening and closure of SG relief valves (RVs) are 8.18 and 7.82 MPa respectively. Flow area of the RVs is simulated by using a 19.4 mm inner-diameter sharp-edge orifice. Emergency core cooling system (ECCS) injection from accumulators is actuated at primary pressure of 4.51 MPa. Low pressure injection (LPI) is actuated at lower plenum pressure of 1.29 MPa. Coolant injection temperatures from the accumulators and LPI are 320 K and 310 K respectively. Coolant injection volume in the accumulator tank is 1.68 m^3 in the loop with PZR and 0.56 m^3 in the loop without PZR. Proportional heaters in the PZR are used to trim the pressure, while backup heaters are used to mitigate system heat losses. Initially, powers to the proportional and backup heaters are 4.4 kW and 21.5 kW respectively. They increase upto 6.6 kW and 75.7 kW after the break. Initial PZR liquid level is 2.7 m. Heaters are turned off soon after the PZR liquid level falls below 1 m.

MODELLING

The nodalisation of primary and secondary sides of LSTF used for carrying out small break LOCA analysis using RELAP5/MOD3.2 code [3] is shown in Fig.2. The reactor core is modelled with four parallel channels with 9 volumes each using pipe component. The axial power distribution of the fuel simulators is specified as per 9-step chopped cosine distribution. To account for the radial distribution, four fuel rod heat structures with appropriate radial peaking factors are incorporated in modelling. The unheated instrument rods within the core are also modelled. The pressure vessel is modelled with downcomer, lower plenum, core, upper plenum and upper head along with vessel internals such as core barrel, upper plenum internals, control rod guide tubes, etc. Each loop is modelled with hot leg, cold leg, crossover leg, pump, SG plenum and SG U tubes. Loop-A is connected to pressuriser through surge line. Each pump is modelled with four quadrant curves. During transient, time dependent pump speed is specified as per the data from the experiment.

The break location (915) is modelled with a trip valve in the hot leg of Loop-B (i.e., loop without PZR) and connected to a time dependent volume 920. The pressure measured in the downstream of the break from the experiment is an input to volume 920. The break area is modelled with cross-sectional area of 8 cm^2, hydraulic diameter 31.9 mm and discharge coefficient of 1.0.

Appropriate volume and junction control flags is selected for simulating the physical behaviour of these components. Interfacial friction along with wall friction and thermal non-equilibrium effects is included for all the volumes. Vertical stratification model is also applied. Chocking and non-homogeneous options are applied for all the junctions. Abrupt area change option is activated at locations where sharp change in flow area takes place such as junctions between Pressure vessel & piping, loop piping & SG plenum, SG tubes & SG plenum, pressuriser & surge line, loop piping & pressuriser spray line etc. In all the valve locations and break location also it is applied. Momentum flux option is used for all the junctions except for locations where large variation in flow area is seen e.g. hot & cold leg piping to pressure vessel (PV). For the junction from upper plenum of PV to hot leg, momentum flux is used for the “to” cell and not used for the “from” cell, whereas for the junction from cold leg to downcomer of PV momentum flux is used for the “from” cell and not used for the “to” cell. Side oriented horizontal stratification vapour pull through/liquid entrainment model is used in the break location. Counter current flow limitation model is applied for the vertical junctions at downcomer annulus.

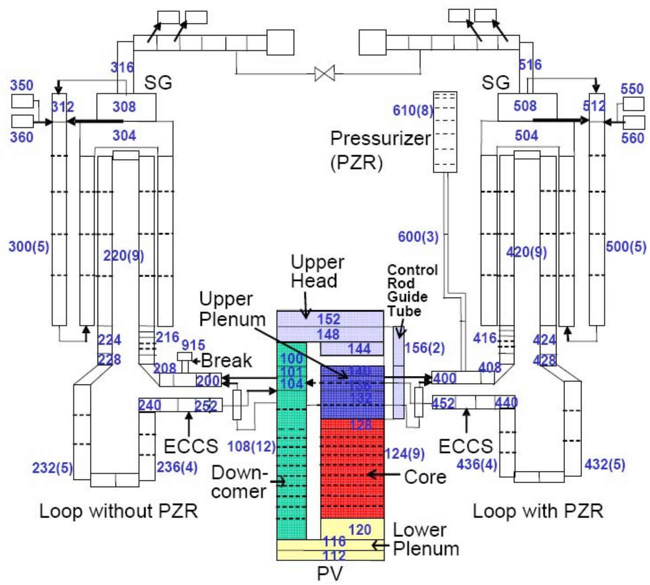

Fig.2 Nodalisation scheme of LSTF for small break LOCA

The emergency core cooling system (ECCS) is connected from accumulator-A (ACC-Cold) to volume 448 of loop-A and accumulator-B (ACC-Hot) to volume 248 of loop-B. Pressuriser heater is modelled with the help of heater power as a function of time available form the experiment. Pressuriser safety valve is modelled with its specific control logic of opening and closure.

Nodalisation of the secondary side of SG includes downcomer, steam generator, separator, separator bypass, steam dome, steam header line. Steam line relief valves, MSIVs are modelled using motorized valve option with specific opening and closure logic.

All the components of primary and secondary sides are modelled with proper insulation and material properties to account for the heat losses from them to the atmosphere. Various heat structures considered in the simulation includes i) Reactor vessel wall, upper head, vessel bottom, core barrel, upper plenum internals, guide tubes, upper core support plate, unheated instrument rods, unheated section of heater rods ii) Pressuriser wall, top head, bottom flange, heaters iii) Loop piping iv) SG primary side, tube bundle and v) SG secondary side boiler wall, separator, external downcomer pipe, steam dome, piping.

The nodalisation scheme is qualified by systematically applying the procedures lead by UMAE [4] for ‘steady state level’ and ‘on transient level’, which is described in the following sections.

STEADY STATE LEVEL QUALIFICATION

Steady state level qualification of the nodalisation scheme [5] is carried out by comparing overall geometrical parameters (volume, elevation, heat transfer area, metal volume, flow area, etc.) of the nodalisation input with the data of the test facility. It is seen that all the geometrical parameters are meeting the acceptance criteria. Volume Vs. Height curves for the pressure vessel, SG-A and SG-B are compared and it is found that volume distribution in the code and the experiment is well within acceptable error band (10%). Acceptance criteria for boundary conditions (such as core power, PRZ power, core bypass flow, pump initial velocity, pump coast down curve, valves opening closing logics, timings, thermo physical properties, pressure setting for injection, volume of injected liquid, etc.) are checked and satisfied with input nodalisation. All significant thermal-hydraulic parameters necessary to identify the facility/plant status are selected from the experiment (such as heat balance, absolute pressure, fluid temperature, clad temperature, heat losses, flow rate, level and mass inventory) and compared with the steady state parameters obtained from the code. The pressure distribution of Loop-A, Loop-B and pressure vessel are also compared and found to be within acceptance criteria (10%).

ON TRANSIENT LEVEL QUALIFICATION

Transient level qualification of the nodalisation scheme [5] is carried out by comparing the experimental and the code calculation resulting time sequence of significant events. It is demonstrated that time of occurrence for most of the events obtained from code are in good agreement with the experimental value. Identification of CSNI phenomena validation matrix applicable for the experiment is prepared and gradation of the test facility & the code is made by observing a phenomenon in the experiment and predicting the similar phenomenon in the computer simulation. A number of Phenomenological Windows (i.e., time spans in which a unique relevant physical process mainly occurs) is identified from the experiment and compared with the results obtained from the code. Key phenomena and Relevant Thermal hydraulic Aspects are defined for this transient and characterized by numerical values of significant parameters such as single value parameters, time sequence of events, integral parameters, etc. Visual comparisons between experimental and code calculated relevant parameters time trends for various thermal hydraulic parameters show that they are in good agreement for the most of the parameters except some of the parameters, having minor disagreement as described below.

The pressure at the top of the pressuriser shown in Fig.3 agrees well to the experimental data. The results indicate that the fast depressurization of primary side takes place due to large flow through the break (Fig.4) during the early stage of subcooled liquid blowdown phase. However, predicted flow rate through the break during two phase flow and single phase vapour flow show some discrepancy with experimental data.

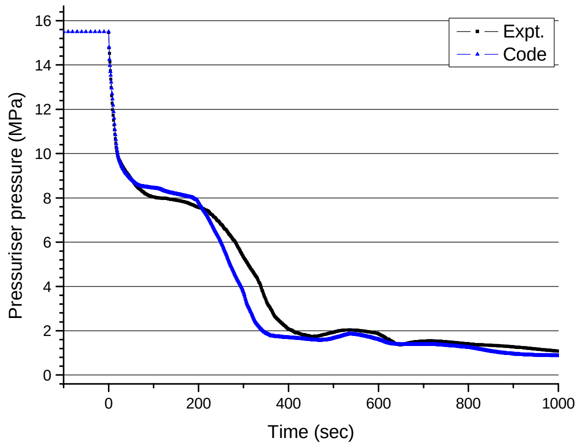

Fig.3 Pressuriser pressure

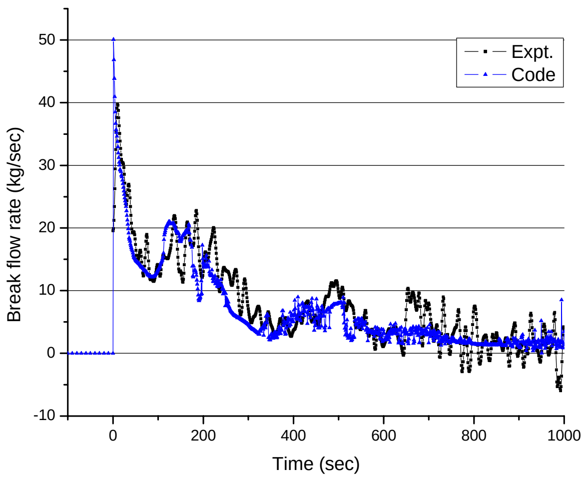

Fig.4 Break flow rate

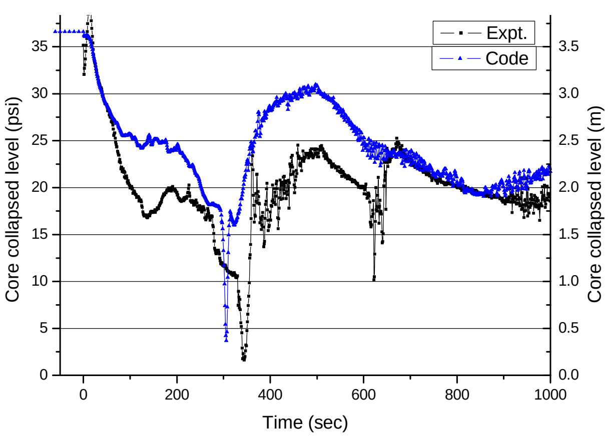

Fig.5 Core collapsed level

Under-prediction of the two phase break flow results in lower mass discharge from the primary system prior to loop seal clearing. Therefore calculated core liquid level prediction is higher than the experimental data as shown in Fig.5. Again, over-predicted vapour phase break flow causes fast primary pressure loss and an earlier accumulator injection following loop seal clearing. This results to a short uncovered time for the

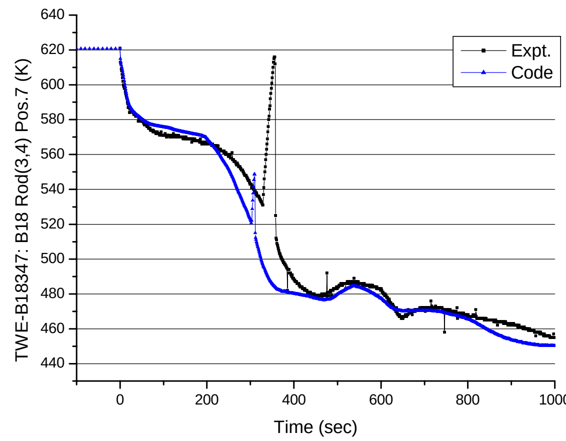

Fig.6 Clad surface temperature

fuel rods and lower temperature rise of the fuel rod surface during dryout as shown in Fig.6.

The pressure prediction at the SG dome shown in Fig. 7 is in good agreement with the experimental data. During fast depressurization of primary side, the scram signal is generated when the PZR pressure decreases to 12.97 MPa. The scram signal generation causes the closure of SG main steam isolation valves (MSIVs) and the coastdown of primary coolant pumps. The SG secondary side pressure increases rapidly after the closure of the MSIV till it reaches the SG relief pressure setting. The SG secondary pressure fluctuates between 8.18 and 7.82 MPa by opening and closure of the relief valves (RVs). The SG secondary side collapsed liquid level (Fig. 8) also fluctuates in response to the RV opening. The SG secondary side collapsed liquid level is maintained since the primary pressure falls lower than the secondary-side pressure and SG no longer acts as a heat sink.

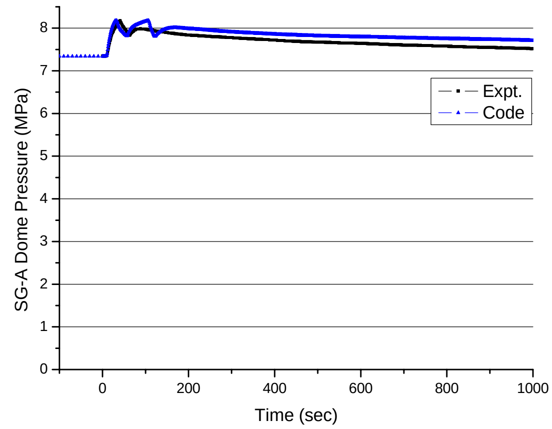

Fig.7 Pressure of SG-A

The ECCS system is initiated when the primary pressure decreases to 4.51 MPa. The accumulator coolant injection occurs twice in the experiment (Fig.9). However, code calculation results show injection occurs twice for accumulator-A only. The ECCS actuation takes place earlier than that of the experiment because the primary pressure is lower predicted during this period. The maximum injection flow rate from the accumulator is predicted less than that of the experiment during second time injection. This may be due to sudden decrease in core pressure due to condensation, which is not well predicted by the code. The coolant injection from the accumulator system is completed when the primary pressure decreases to about 1.6 MPa.

The LPI system in the loop A is actuated when the Pressure Vessel lower plenum pressure decreases to 1.29 MPa. Further cooling of the core is continued by LPI system and fluid temperature gradually comes down as shown in Fig.10.

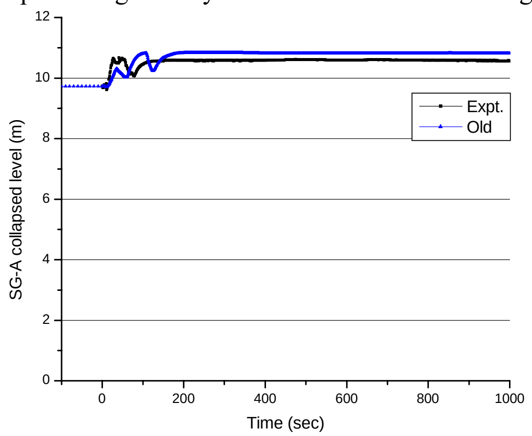

Fig.8 Collapsed level of SG-A

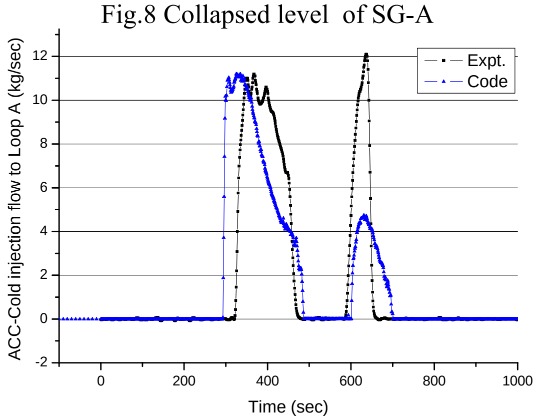

Fig.9 Accumulator-A injection flow rate

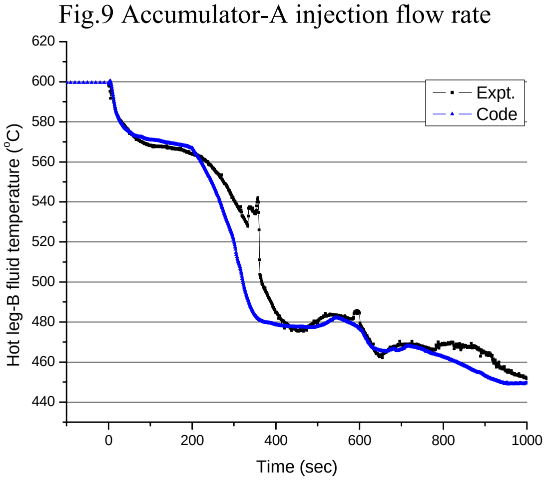

Fig.10 Hot leg- B fluid temperature

From the results of the steady state and transient, it is observed that the most of the code calculated parameters are in good agreement with the experimental one. Therefore, overall simulation of this transient is qualified as per qualitative qualification procedure.

UNCERTAINTY ANALYSIS

The qualified nodalisation (mentioned in the previous sections) is used to carry out the uncertainty and importance analysis based on Monte Carlo sample based approach. Screening sensitivity analysis is carried out for various uncertain input parameters, which may affect the results of the transient analysis. These parameters are selected based on the expert judgement and literature survey. The screening sensitivity analysis is done to determine the relative significance of each input parameter in order to reduce the number of model input parameters for which an extensive uncertainty analysis is needed [6]. As an example, break flow rate variation with respect to three uncertain input parameters - discharge coefficient at break location, accumulator isolation set level and SG relief valve set pressure are shown in Fig. 11 to Fig.13. For each uncertain input parameter with minimum value (1), maximum value (2) and nominal value (n), the results are compared with the experimental data.

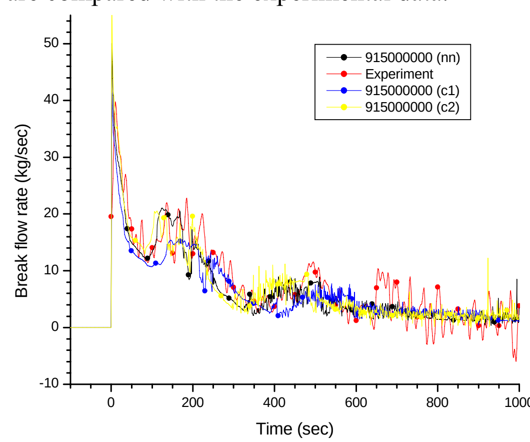

Fig. 11 Effect of break valve discharge coefficient on break flow rate

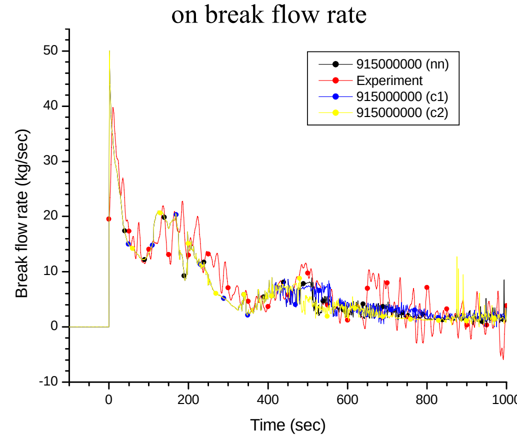

Fig. 12 Effect of accumulator isolation set level on break flow rate

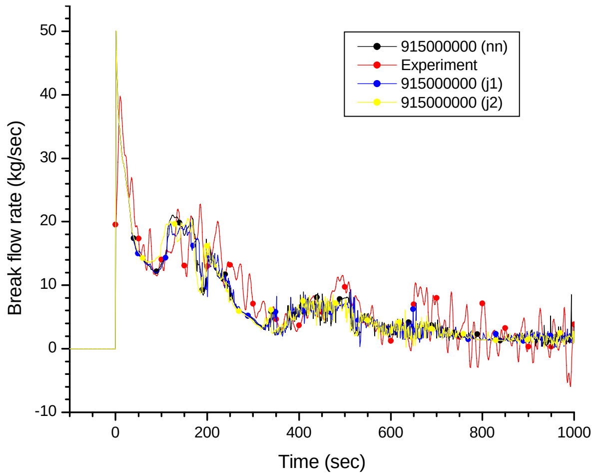

Fig. 13 Effect of SG relief set pressure on break flow rate

Based on the observations of screening sensitivity analysis, the key input parameters, which have significant impact on the required figure-of-merits, are decided to carry out the uncertainty analysis. The key input parameters and their nominal values are indicated in Table 1 in the column (Nom). The minimum (Min) and the maximum (Max) possible values are also indicated in the table. The ranges of these parameters are selected based on the extensive literature survey, code defaults, expert judgments and experimental uncertainties.

Table 1 : Variation in input parameters

Input Parameters	Min	Nom	Max
Discharge coefficient of SG relief valve	0.85	1.0	1.15
Set point of Accumulator injection pressure (MPa)	3.9	4.1	4.3
Accumulator-B injection stop level (m)	5.2	5.4	5.6
Discharge coefficient of accumulator	0.85	1.0	1.15
ACC-Cold fluid temperature (K)	314	319	324
ACC-Hot fluid temperature (K)	319	324	329
Discharge coefficient at break location	0.85	1.0	1.15
Primary heat loss coefficient ($W/m^2/K$)	2.25	3.0	3.75
Secondary heat loss coefficient ($W/m^2/K$)	2.25	3.0	3.75
Relief valve set pressure (MPa)	8.03	8.18	8.33

Using these above parameters RELAP5/MOD3.2 runs are taken and sixteen important output parameters (Pressuriser pressure, SG-B Pressure, SG-A pressure, SG-A collapsed level, SG-B collapsed level, Loop-A flow rate, Loop-B flow rate, Flow through break, Down comer fluid temperature, Differential pressure in pressure vessel, Differential pressure in heated core, ACC-Cold/Accumulator-A pressure, ACC-Hot/Accumulator-B pressure, Accumulator-A injection rate, Accumulator-B injection rate, Clad surface temperature) are selected from the code output. These output parameters are selected such that the transient can be mainly represented by these parameters and uncertainty analysis of these parameters can be carried out.

In the present study, the uncertainty in the selected model parameters mentioned in Table 1 is characterized by the uniform distribution. A stratified Monte Carlo sampling method known as the Latin hypercube sampling (LHS) is used in uncertainty propagation analysis. This method is commonly used because its efficient stratification properties allow for the extraction of a large amount of uncertainty and sensitivity information with relatively small sample size [7]. In this sampling technique, design matrix of order (n X k) is prepared, where n is the number of code runs to be taken and k is the number of input variables. In LHS technique, number of sampling for k input variables is sufficient if it is 4/3 k. However, it is better to obtain as many samples as possible (2k to 5k). Accordingly, 50 code runs are performed for 10 input parameters and which is considered to be adequate.

Based on the upper bound and lower bound of the input parameters mentioned in Table 1, 50 random samples are generated to form the design matrix using LHS technique. Subsequently 50 sets of code runs are performed with taking one set of input parameters from design matrix and time trends of sixteen output parameters are extracted from the code output for each run. All these output parameters for 50 runs are stored. Afterwards for each time, all these data are sorted in ascending order in a separate data file. Then rank is given to all these 50 values for each time. From these ranks the mean, median, 5th and 95th percentiles are evaluated. The mean, median, 5th & 95th percentiles, output for nominal input and experimental values are compared as shown in Fig.14 to Fig.24. Although the continuous graphs are shown for the mean, 5th percentile, 95th percentile and median output but it should be noted that all the points from one figure is not from same set of input.

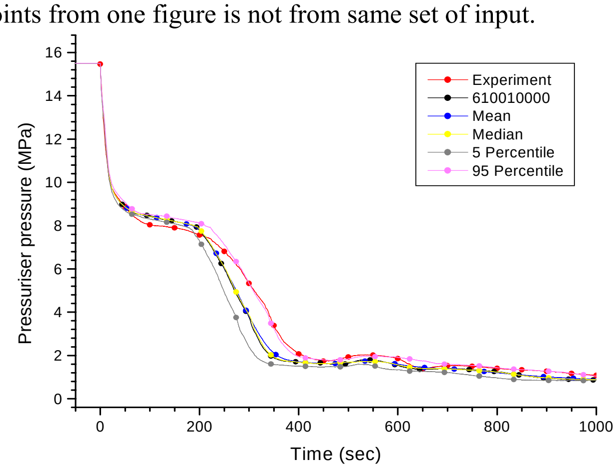

Fig.14 Uncertainty in pressuriser pressure

Figure 14 shows the uncertainty in PRZ pressure. The results show that during the two-phase blowdown, magnitude of uncertainty band is more as compared to remaining part of the transient. In this figure, experimental value is plotted in red colour. The mean & median of the output results is shown in blue & yellow colour respectively. It is clear that mean & median values lie between the uncertainty band and the experiment data matches well with these results.

The uncertainty in SG-A dome pressure prediction is shown in Fig.15. Similar trend of results is observed for SG-B dome pressure. Though mean and median results show similar trend with respect to the experimental data, but beyond 150 sec of transient, the experimental data shows a lower steam dome pressure than the values of output parameter between the uncertainty band. This may be due to lower prediction of release of steam through SG relief valve in the code calculation. Figure 16 shows the plot for SG-A collapsed level. As mentioned, due to lower steam release rate prediction in the analysis, the collapsed level predicted is higher than that of the experimental data. Similar results are observed for SG-B collapsed level.

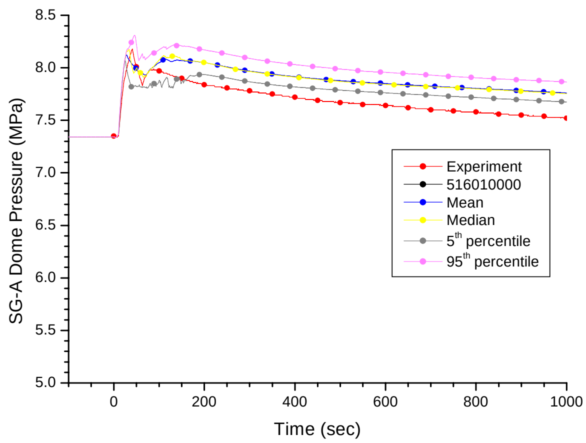

Fig.15 Uncertainty in SG-A dome pressure

Figure17 shows the uncertainty in flow rate of Loop-A. Predicted flow rates within the uncertainty band match well with the experimental data except in the region where injection from accumulator takes place. During first time injection there is an increase in flow rate as was observed from the experiment. However, the amount of increase predicted is less. Since the initiation of injection takes place in the analysis is earlier, there is a time shift also. Accumulator injection starts early in the analysis because decrease in primary pressure is more during two phase blow down (200 sec to 400 sec) in the analysis than the experimental observation. During second time accumulator injection, experimental data shows increase in Loop flow rate again. However, this phenomenon is not observed in the analysis. For Loop-B flow rate also similar discrepancy in results between the experiment and the analysis is observed.

Figure18 shows the plot of flow rate through break location. It is clearly seen that very good agreement in trends between experimental value and output values is obtained.

The results of fluid temperature in the downcomer show that experimental values are within the uncertainty band (Fig.19) during most of the time except between 350 to 700 sec. This may be due to the fact that loop flow rate and heat transfer rate is not well predicted during this time which decides the fluid temperature of the downcomer.

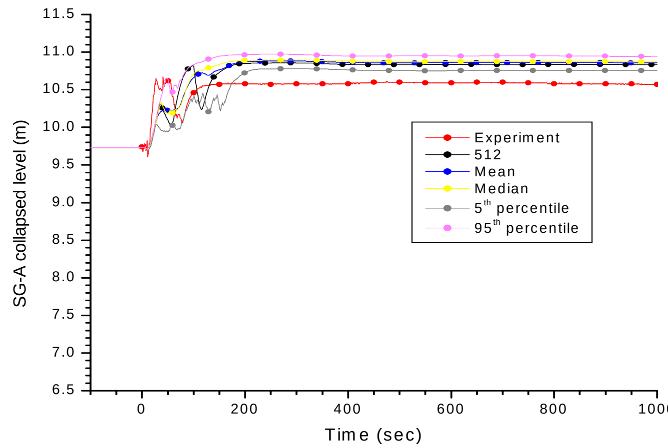

Fig.16 Uncertainty in SG-A collapsed level

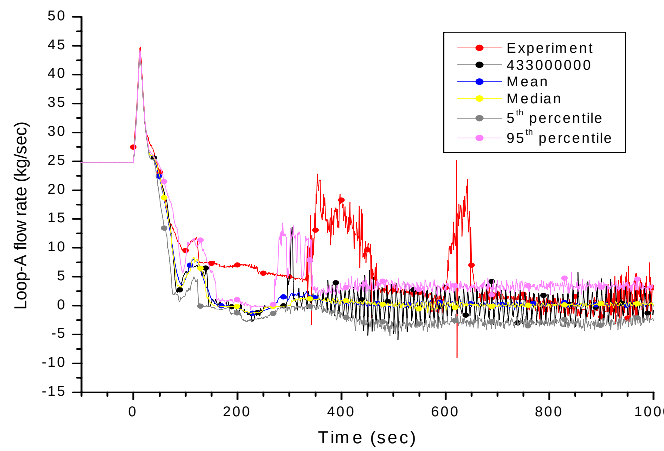

Fig.17 Uncertainty in loop-A flow rate

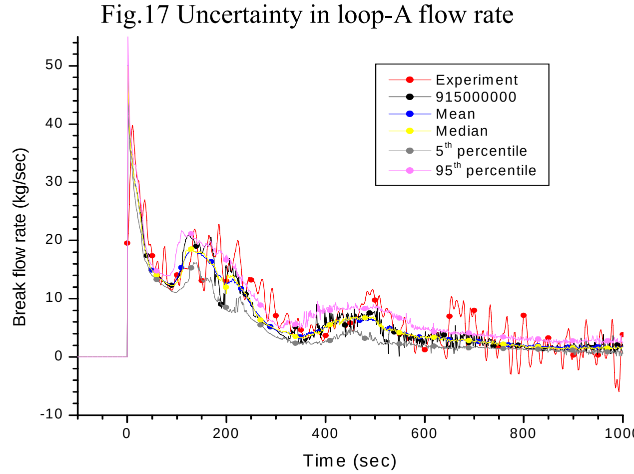

Fig.18 Uncertainty in flow rate through break location

Figure 20 shows the uncertainty plot of pressure drop across the core. From the output results, it is seen that the experimental value is not always within the uncertainty band of code prediction. However, the time trends are similar to that observed in the experiment. Differential pressure in the pressure vessel also shows similar trends.

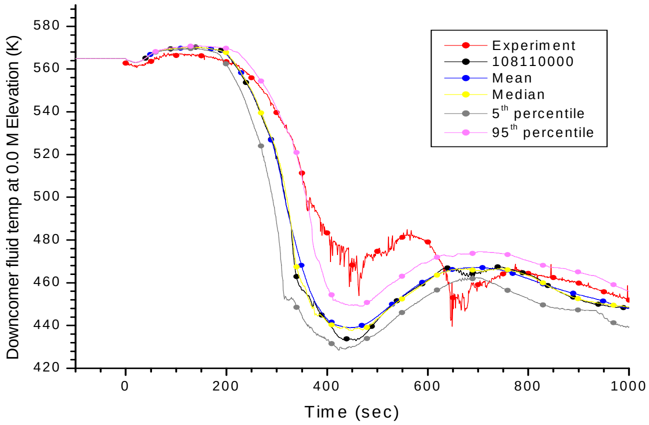

Fig.19 Uncertainty in downcomer fluid temperature

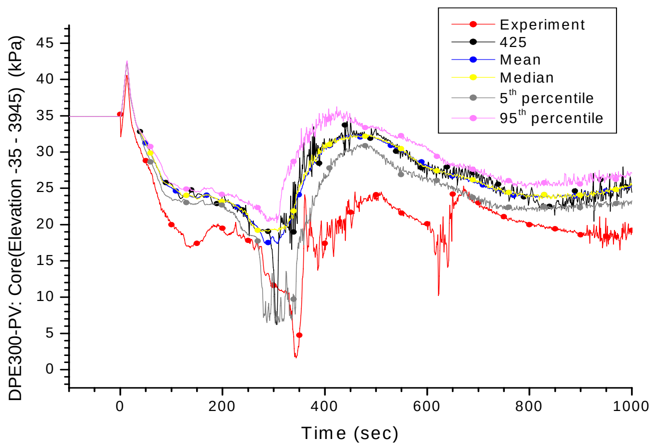

Fig.20 Uncertainty in Core pressure drop

The Uncertainty in pressure of Accumulator-A (Fig.21) shows that experimental data & output for nominal value of input have the same trends. It is also observed that the experimental data are well in the uncertainty band except for limited period at the last part of the transient. The uncertainty in pressure of Accumulator-B also shows similar trend of results.

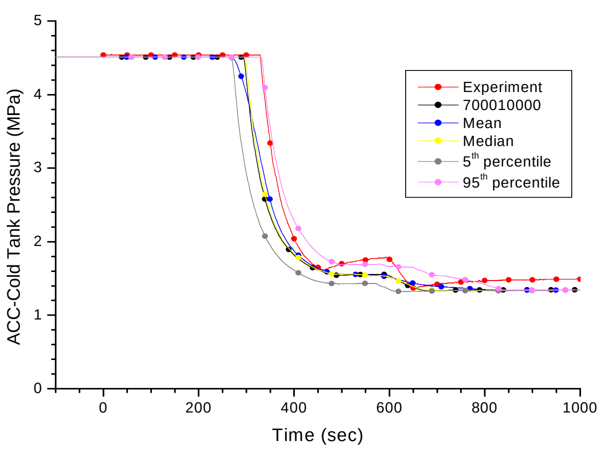

Fig.21 Uncertainty in accumulator-A pressure

Figures 22 & 23 show the uncertainty of injection flow rate prediction from Accumulator-A & Accumulator-B respectively. The results indicate that the accumulator injection takes place earlier than that of the experiment because the primary pressure is lower predicted during this period. The maximum injection flow rate from the accumulator is predicted less than that of the experiment during second time injection. This may be due to sudden decrease in core pressure due to condensation, which is not well predicted by the code.

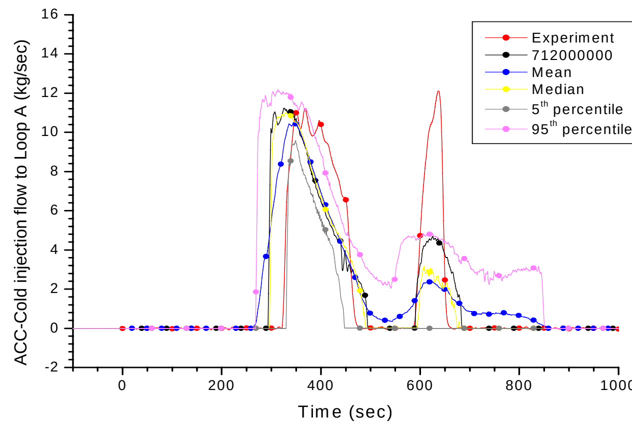

Fig.22 Uncertainty in accumulator-A flow rate

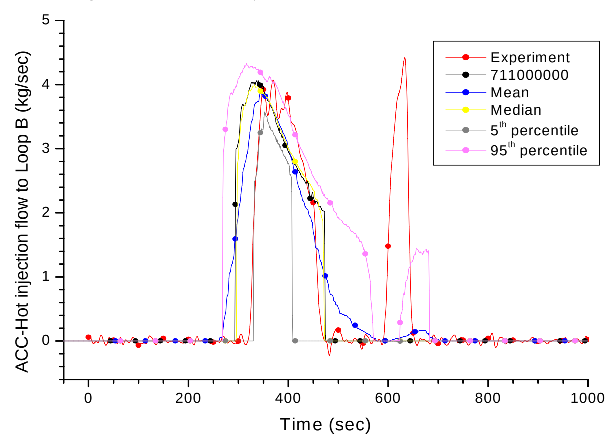

Fig.23 Uncertainty in accumulator-B flow rate

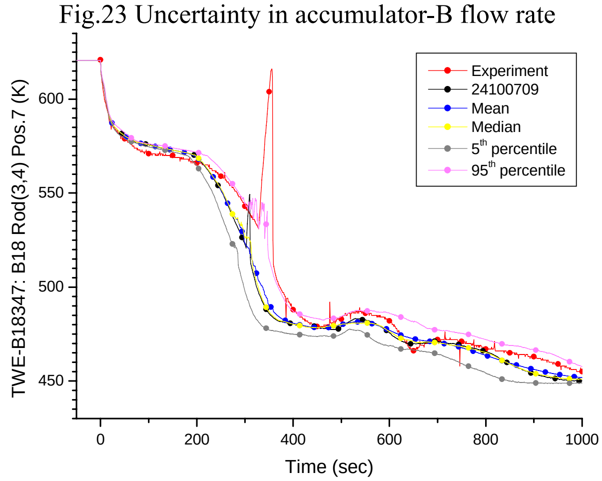

Fig.24 Uncertainty in clad surface temperature

Figure 24 shows the plot of clad surface temperature. It is observed that the experimental data are well in the uncertainty band except for limited period during core uncovery causing dryout condition. The predicted value is much lower than the experimental data. This may be due to short uncovered time for the fuel rods predicted in the analysis.

IMPORTANCE ANALYSIS

Based on the results obtained from the 50 runs mentioned in the previous sections, importance analysis is carried out to evaluate the degree to which an input parameter affects the model output results. A number of approaches in conjunction with a sampling based uncertainty analysis are available to carry out the importance analysis [8]. In the present study, regression analysis and partial correlation are used to determine the importance analysis results. Regression analysis provides an algebraic representation of the relationships between an output parameter and one or more of the input parameters. In the present study the linear relationship between output parameter and input parameters is assumed and standardised regression coefficients (SRCs) are evaluated. The SRCs provide a useful measure of variable importance with (i) the absolute values of the coefficients providing a comparative measure of variable importance and (ii) the sign of the coefficient indicates whether input and output parameters tend to move in the same direction or in the opposite direction as long as the input parameters are independent.

The main output parameter considered is the break flow, which finally dictates the primary pressure and clad temperature. These output parameters are compared during the initiation of accumulator injection (at 300 sec in the experiment). To know the behavior of output parameters after the reflood phase (at 400 sec) the parameters considered are ACC-clod & ACC-Hot flow rate and Core pressure differential. To compare the secondary side parameters, pressure of SG-A and SG-B is considered. The SRCs for all these parameters are shown in Table-2. The goodness of fit value R^2 is also inducated in Table 2. This value provides a measure of the extent to which the regression model can match the observed data. Specifically, when the variation about the regression model is small, then the corresponding R^2 value is close to 1, which indicates that the regression model is accounting for most of the uncertainty on the output variable. Conversely, a value close to 0 indicates that the regression model is not very successful. The values indicated in Table 2 below shows R^2 value more towards 1.

Similar to SRCs, Partial correlation coefficients (PCCs) are evaluated as shown in Table 3. The PCC has a value between –1 and 1, with a positive value indicating that input and output parameters tend to increase and decrease together and a negative value indicating that they tend to move in opposite directions. The absolute value of PCC between 0 and 1 correspond to a trend from no linear relationship between input and output parameters to an exact linear relationship between them.

Both types of coefficients essentially give the same meaning when using ranks. The numerical values may be different but both exhibit the same pattern of sensitivity ranking. The benefit of using PRCCs is that they tend to be spread out in value more than SRRCs and thus produce results that are easier to read. However, the demerit is that a variable can appear to have a larger effect on the uncertainty in output parameter than is actually the case.

CONCLUSION

Steady state and transient levels qualifications for the hot leg break LOCA in LSTF has been carried out using thermal hydraulics system code RELAP5/MOD3.2. From the results of the steady state and transient, it is observed that the most of the code calculated parameters are in good agreement with the experimental one. However certain discrepancies are observed during injection from accumulator into Loop-B during second time injection due to system pressure not lowering below accumulator-B pressure.

Uncertainty and importance analysis has been carried out by using order statistics with LHS technique. Uncertainty plots in the output parameters indicate that uncertainty band for primary pressure during two phase blowdown (200 to 400 sec) is more than the remaining period. Similarly, larger uncertainty band is observed relating to accumulator injection flow during reflood phase. Standard rank regression coefficient and partial correlation coefficients are computed. The value of R^2 is also evaluated and found to be more towards 1 which indicates that the regression model is able to account for most of the uncertainty on the output variables. Based on the standard regression coefficients and partial correlation coefficients, it is observed that the break discharge coefficient is the most important uncertain parameter relating to the prediction of all the primary side parameters and the SG relief pressure setting is the most important parameter in predicting the SG secondary pressure.

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Table 2 Standard regression coefficients and R^2

Parameter	Break flow at 300 sec	Primary pressure at 300 sec	SG-A Pressure at 300 sec	SG-B Pressure at 300 sec	Clad temp at 300 sec	ACC-Cold flow rate at 400 sec	ACC-Hot flow rate at 400 sec	Coe Δ P at 400 sec
SG relief valve discharge coefficient	0.04365	0.02758	0.04490	-0.24185	-0.05771	0.00445	0.01373	0.01823
Accumulator injection pressure	0.05990	-0.00848	0.10937	-0.04716	-0.02149	-0.18158	-0.24441	-0.12608
Injection stop level	0.00368	-0.01291	-0.05767	-0.09635	0.03132	-0.01751	-0.05336	-0.07510
Accumulator discharge coefficient	-0.02565	-0.01249	0.10619	0.02042	-0.00816	-0.05370	-0.06816	0.09718
ACC-Cold fluid temperature	-0.00283	-0.02553	-0.06672	0.16830	-0.07136	-0.10052	-0.12673	-0.21882
ACC-Hot fluid temperature	0.00933	-0.05049	-0.04494	0.04117	-0.07282	-0.07863	-0.10723	0.02719
Break discharge coefficient	-0.94780	-0.97890	-0.05065	-0.21163	-0.93624	-0.91082	-0.88749	0.79867
Primary heat loss	0.06912	0.03446	-0.02192	-0.12743	-0.04463	0.06001	0.06229	-0.00646
Secondary heat loss	0.02162	0.03273	-0.03974	-0.16202	-0.03112	-0.01812	-0.02549	-0.01599
SG relief pressure	-0.01132	-0.04629	0.85761	0.76223	0.01036	0.02606	-0.00390	0.00564
R^2	0.89141	0.97131	0.76953	0.7652	0.87621	0.87133	0.87346	0.70707

Table 3 Partial correlation coefficients

Parameter	Break flow at 300 sec	Primary pressure at 300 sec	SG-A pressure at 300 sec	SG-B pressure at 300 sec	Clad temp at 300 sec	ACC-Cold flow rate at 400 sec	ACC-Hot flow rate at 400 sec	Coe Δ P at 400 sec
SG relief valve discharge coefficient	0.13302	0.15994	0.09413	-0.44537	-0.15640	0.01791	0.04474	0.03407
Accumulator injection pressure	0.17078	-0.04980	0.22035	-0.08354	-0.06006	-0.44988	-0.56419	-0.22627
Injection stop level	0.00071	-0.07576	-0.12084	-0.17499	0.08784	-0.05618	-0.15601	-0.13614
Accumulator discharge coefficient	-0.08904	-0.07301	0.21163	0.05880	-0.02057	-0.14923	-0.18975	0.17667
ACC-Cold fluid temperature	-0.03048	-0.14851	-0.14609	0.31812	-0.20492	-0.27010	-0.33484	-0.36021
ACC-Hot fluid temperature	0.00143	-0.28517	-0.09444	0.09950	-0.21020	-0.21485	-0.28460	0.06863
Break discharge coefficient	-0.94040	-0.98516	-0.10133	-0.40908	-0.93300	-0.92651	-0.92401	0.81882
Primary heat loss	0.16173	0.19878	-0.05063	-0.24619	-0.16920	0.10071	0.10046	-0.00792
Secondary heat loss	0.08802	0.18851	-0.07137	-0.32293	-0.05118	0.01143	0.00583	-0.00355
SG relief pressure	-0.05756	-0.26323	0.87337	0.83850	0.00005	0.04246	-0.04113	0.02834

