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An Application of Realistic Evaluation Methodology for Large Break LOCA of KSNP 2 loop Plant

H.Y. Jun and Y. Jo
KEPCO Korea Electric Power Research Institute
103-16 Munji-dong, Yusong-gu
Taejon 305-380, Korea

B.D. Chung and Y.J. Lee
Korea Atomic Energy Research Institute
P.O. Box 105, Yusong
Taejon 305-600, Korea

Abstract

This report presents a demonstration of application of realistic evaluation methodology to a postulated cold leg large break LOCA in a KSNP two-loop pressurized water reactor with 16x16 fuel. This analysis can be divided into three distinct steps : 1) Best Estimate Code Validation and Uncertainty Quantification 2) Realistic LOCA calculation 3) Limiting Value LOCA Calculation and Uncertainty Combination. RELAP5/MOD3.1/K[1], which was improved from RELAP5/MOD3.1, and CONTEMPT4/MOD5 code were used as a best estimate thermal-hydraulic model for realistic LOCA calculation. The code uncertainties which will be determined in step 1) were quantified already in the previous study[2], and thus steps 2) and 3) for plant application were presented in this paper. The application uncertainty parameters are divided into two categories, i.e. plant system parameters and fuel statistical parameters. Single parameters sensitivity calculations were performed to select system parameters which would be set at their limiting value in Limiting Value Approach(LVA) calculation. LVA calculation generated 81 PCT data according to the various combinations of fuel parameters and the critical flow. These data provided input to response surface generation. The probability distribution function was generated from Monte Carlo sampling of a response surface and the upper 95th percentile PCT was determined.

1. Introduction

Since the NRC approval of a revised rule on the acceptance of ECCS in 1988, many demonstration and different methods have been proposed[3,4,5]. CSAU (Code Scaling, Applicability and Uncertainty) method proposed by INEL[6] is the one of the successfully demonstrated method. Although CSAU methodology and its demonstration give[7] a very comprehensive base on the uncertainty quantification strategy, a considerable amount of subjective engineering judgement must be involved in CSAU analysis process. The phenomena studied and mathematical models involved are too complicate to standardize it in a simple and straightforward engineering procedure. Methodologies developed by KINS and KAIST have similar problems too. In the light of this, it has been developed a practical LBLOCA realistic evaluation methodology, hereafter it is called by KREM (Korean Realistic Evaluation Methodology), designed to evaluate ECCS performance, which is simple in structure and based on a sound logical reasoning, while satisfying the requirements of the ECCS regulations. This methodology can be divided into three distinct steps : 1) Best estimate code validation and uncertainty quantification, 2) Realistic LOCA calculation and 3) Limiting value LOCA calculation and uncertainty combination. The code uncertainties which are determined in step 1) were quantified already in the previous study[2], and thus the steps 2) and 3) for plant calculation were presented in this paper.

2. Realistic LOCA Calculation

Ulchin 3/4 units with 16x16 CE fuel were selected for the demonstration of KREM. Realistic PWR LOCA calculations are performed using the best-estimate thermal hydraulic computer code RELAP5/MOD3.1/K and plant input conditions which are at their nominal values. The realistic calculation at nominal conditions represents the more probable operating conditions for the reactor at the time the postulated LOCA occurs. Unlike a traditional LOCA analysis in which all of the uncertainties were compounded in the analysis, the realistic calculation at nominal conditions attempts to use the nominal or best estimate plant operating and initial conditions. RELAP5/MOD3.1/K nominal calculation has used nominal inputs for several parameters particularly for the core power and stored energy. Nominal conditions have also been used for the safety injection tank(SIT) volume, pressure and water temperature. However, there were several bounding conditions which have been set at more conservative assumptions, namely, the single failure which reduces the pumped safety injection flow, and the worst break. The assumed bounding conditions will degrade the ECCS performance beyond that expected for a nominal situation, such that there is some unquantified PCT margin even in the nominal calculation.

3. Sensitivity Studies to Determine Effects of Variation in Plant Parameters

Plant behavior is not equally influenced by all processes and phenomena that occur during a transient. A phenomena identification and ranking table(PIRT) is established in CSAU methodology to guide the subsequent uncertainty quantification. Among those parameters listed in PIRT, the parameters related to code models and correlations : i.e. heat transfer coefficient, minimum stable film boiling temperature, interfacial drag, break flow model and phenomena related to noncondensibles were not considered in KREM because those parameters would be dealt with as code uncertainty or bias which were treated separately. Added parameters are based on experiences of the experts in LOCA analysis. Those parameters are fuel conductivity, total power, decay heat power, RCS flow, pressurizer pressure, SIT gas pressure, SIT water volume, SIT water temperature, SI flow rate and SI flow temperature. Uncertainty range for each parameter was listed on Table 1.

Table 1. Relevant Parameters for Sensitivity Study

Parameters	Uncertainty Ranges
Fuel Gap Conductance	±3σ
LHGR	±5.6 %
Fuel Thermal Conductivity	±10 %
Axial Power Shape	Top-Skewed/Chopped Cosine
Reactor Power	±2 %
Decay Heat	±6.6 %
Clad Oxidation Model	Cathcart-Pawel/Baker-Just
SIT Gas Pressure	570/610/632 psig
SIT Water Volume	1790/1858/1926 ft^3
Safety Injection Flow Rate	Max/Min on a Diesel Generator Failure

Most uncertainty ranges were obtained from the design data of Ulchin nuclear power units 3/4[8,9,10] and Reference 11. Sensitivity results provide the basis for determining the system parameters which would be set at their limit value in LVA calculation. Table 2 shows the effect of each parameter on the blowdown and reflood peak cladding temperatures (PCTs).

Table 2. Effect on PCT for each single parameter

	Case	Blowdown		Reflood	
		PCT (K)	PCT (K)	PCT (K)	PCT (K)
Base Calculation	0	1172.18		695.82	
Gap Conductance	1	1306.97	+ 134.79	780.61	+ 84.79
LHGR	2	1196.28	+ 24.10	716.93	+ 21.11
Fuel Thermal Cond.	3	1194.18	+ 22.00	703.69	+ 7.87
Axial Power Shape	4	1160.20	- 11.98	668.11	- 27.71
Reactor Power	5	1181.99	+ 9.81	718.22	+ 22.4
Decay Heat	6	1174.87	+ 2.69	724.17	+ 28.35
Oxidation Model	7	1172.04	- 0.14	712.80	+ 16.98
SIT Gas Pressure	8	1172.25	+ 0.07	730.70	+ 34.88
SIT Water Volume	9	1172.15	- 0.03	701.80	+ 5.98
SI Flow Rate	10	1172.18	0.00	693.35	- 2.47
Swell/Rupture Model	11	1172.18	0.00	695.82	0.00

4. Limiting Value LOCA Calculation and Uncertainty Quantification

1) Limiting value LOCA calculation

As discussed in Section 3, a limit value approach(LVA) calculation is performed in KREM. Since limit values for system parameters are applied to the plant calculation, a PCT, which consists of the best estimate calculated PCT and the application uncertainties for system parameters, is produced by LVA. This LVA calculation will yield higher PCT than the 95% probability limit because the uncertainties of major LOCA parameters such as total power, decay heat, axial power shape and SIT gas pressure are not combined together in a statistical fashion. But LVA is less expensive than the statistical approach because only one calculation is performed for a given break size.

2) Response surface generation and statistical analysis

The purpose of the response surface is to replace the code by a fit to the output of interest (here the PCT). The PCT response surface was generated from 81 PCT results for 81 hot rods modeled from a full 4-level experimental design on three fuel parameters and the critical flow selected for statistical treatment, and it could be viewed simply as polynomial least square fitting process of the calculated PCT. The selected fuel parameters were gap conductance(h_g), fuel thermal conductivity(k_f) and LHGR(F_q), respectively. The uncertainty range of C_d was based on Marviken Test data(Table 3).

Table 3. Marviken Test Data

	Mean	1σ
single phase	0.89	±0.03491
two phase	1.07	±0.1189

In order to produce a decent estimate of the probability distribution function from a response function, the surface must be sampled in a statistically acceptable way. Because the surface is only algebraic, a crude Monte Carlo sampler is used. A program called PCTxMON (Peak Cladding Temperature by Monte Carlo sampling) was developed to generate response surface from the calculated PCT data and to carry out the Monte Carlo calculations on the response surface. The program randomly selects a set of parameters using the ranges and distributions of parameters and generates a surrogate PCT. The probability distribution function(PDF) has been computed for both blowdown and reflood peaks of the cladding temperature. A large number of surrogate PCTs are generated and a statistical analysis is carried out in the program.

3) Calculation results

Double ended guillotine break in the cold leg was selected for this calculation. The results of LVA calculations for 4 parameters are shown on Table 4.

Table 4. The results of LVA calculations

No	C_d	h_g	k_f	F_q	Blowdown	Reflood	No	C_d	h_g	k_f	F_q	Blowdown	Reflood
1	1	0	0	0	1161,21	789,59	42	0	1	1	-1	1169,95	716,89
2	1	0	0	1	1210,76	821,73	43	0	1	-1	0	1218,71	770,50
3	1	0	0	-1	1139,36	757,15	44	0	1	-1	1	1287,90	805,24
4	1	0	1	0	1148,58	778,27	45	0	1	-1	-1	1196,59	744,01
5	1	0	1	1	1189,27	811,50	46	0	-1	0	0	1195,11	737,75
6	1	0	1	-1	1131,27	747,17	47	0	-1	0	1	1288,81	765,32
7	1	0	-1	0	1181,41	805,51	48	0	-1	0	-1	1150,20	701,92
8	1	0	-1	1	1239,62	834,39	49	0	-1	1	0	1174,29	726,10
9	1	0	-1	-1	1155,58	772,32	50	0	-1	1	1	1202,67	753,11
10	1	1	0	0	1179,98	803,09	51	0	-1	1	-1	1129,88	690,01
11	1	1	0	1	1181,43	792,92	52	0	-1	-1	0	1222,67	753,53
12	1	1	0	-1	1161,39	771,08	53	0	-1	-1	1	1263,05	782,18
13	1	1	1	0	1154,51	746,59	54	0	-1	-1	-1	1172,01	722,22
14	1	1	1	1	1213,37	822,45	55	-1	0	0	0	1223,32	842,01
15	1	1	1	-1	1151,13	760,96	56	-1	0	0	1	1264,44	863,70
16	1	1	-1	0	1187,08	814,40	57	-1	0	0	-1	1180,68	819,89
17	1	1	-1	1	1247,69	840,24	58	-1	0	1	0	1200,40	834,71
18	1	1	-1	-1	1170,44	785,30	59	-1	0	1	1	1288,88	854,16
19	1	-1	0	0	1153,86	779,51	60	-1	0	1	-1	1167,09	813,71
20	1	-1	0	1	1200,85	813,01	61	-1	0	-1	0	1262,23	853,63
21	1	-1	0	-1	1129,30	745,87	62	-1	0	-1	1	1306,34	927,68
22	1	-1	1	0	1136,29	766,27	63	-1	0	-1	-1	1206,21	828,99
23	1	-1	1	1	1181,73	801,83	64	-1	1	0	0	1249,32	849,00
24	1	-1	1	-1	1111,56	735,33	65	-1	1	0	1	1232,90	842,71
25	1	-1	-1	0	1172,66	794,80	66	-1	1	0	-1	1204,87	827,98
26	1	-1	-1	1	1225,70	826,85	67	-1	1	1	0	1189,58	802,31
27	1	-1	-1	-1	1148,37	761,59	68	-1	1	1	1	1259,89	861,64
28	0	0	0	0	1203,86	747,55	69	-1	1	1	-1	1187,02	822,02
29	0	0	0	1	1241,70	776,12	70	-1	1	-1	0	1270,24	856,86
30	0	0	0	-1	1160,43	712,65	71	-1	1	-1	1	1316,19	929,53
31	0	0	1	0	1186,07	736,47	72	-1	1	-1	-1	1225,57	835,39
32	0	0	1	1	1212,04	763,17	73	-1	-1	0	0	1213,58	837,67
33	0	0	1	-1	1149,92	704,61	74	-1	-1	0	1	1250,51	859,68
34	0	0	-1	0	1235,16	764,15	75	-1	-1	0	-1	1170,42	813,97
35	0	0	-1	1	1278,99	794,49	76	-1	-1	1	0	1187,93	829,13
36	0	0	-1	-1	1179,84	732,07	77	-1	-1	1	1	1218,51	849,77
37	0	1	0	0	1227,66	760,56	78	-1	-1	1	-1	1148,09	802,37
38	0	1	0	1	1212,18	750,78	79	-1	-1	-1	0	1248,52	849,86
39	0	1	0	-1	1183,18	731,65	80	-1	-1	-1	1	1289,39	920,66
40	0	1	1	0	1175,36	717,80	81	-1	-1	-1	-1	1197,01	824,49
41	0	1	1	1	1241,23	776,33	-	-	-	-	-	-	-

Using the LVA values and PCTxMON program, the resulting forms of the response surfaces for blowdown and reflood PCTs are obtained as follow,

$$\begin{aligned} PCT(u,x,y,z)_{blowdown} = {} & 1198{,}2237 - 31{,}5261u + 4{,}4598x - 25{,}1081y + 34{,}6033z - 4{,}3589uu - 0{,}6922ux \\ & + 6{,}2072uy - 2{,}4464uz - 1{,}3150xx + 1{,}9461xy - 4{,}4928xz + 6{,}0939yy - 5{,}5992yz \\ & + 3{,}4111zz + 1{,}3939uux - 0{,}5039uuy - 2{,}2508uuz + 0{,}3567uxx + 1{,}0862uxy \\ & - 0{,}3396uxz - 0{,}5283uyy - 1{,}2433uyz + 7{,}6075uzz - 1{,}0261xxy - 4{,}3417xxz \end{aligned}$$

$$+4.2106xyy -0.2258xyz +3.6056xzz +8.8175yyz +2.1769yzz$$

$$\begin{aligned}PCT(u,x,y,z)_{reflood} = {} & 741.3567 -23.9700u +3.7533x -15.2676y +24.0656z -71.4607uu -2.0036ux \\ & +2.5622uy +0.2064uz -3.5509xx -2.0061xy -4.1133xz +6.0341yy -4.2775yz \\ & +4.2141zz -3.6508uux -1.5139uuy +0.7625uuz -0.3125uxx -0.3358uxy \\ & -0.8267uxz -3.4950uyy +7.1492uyz -3.9542uzz -2.7172xxy -3.2100xxz \\ & +1.8950xyy -0.2238xyz +4.2767xzz +9.6708yyz +1.9603yzz\end{aligned}$$

And the produced PDFs are shown in Figure 1. The blowdown and reflood PCT PDFs are drawn by the light and solid lines, respectively.

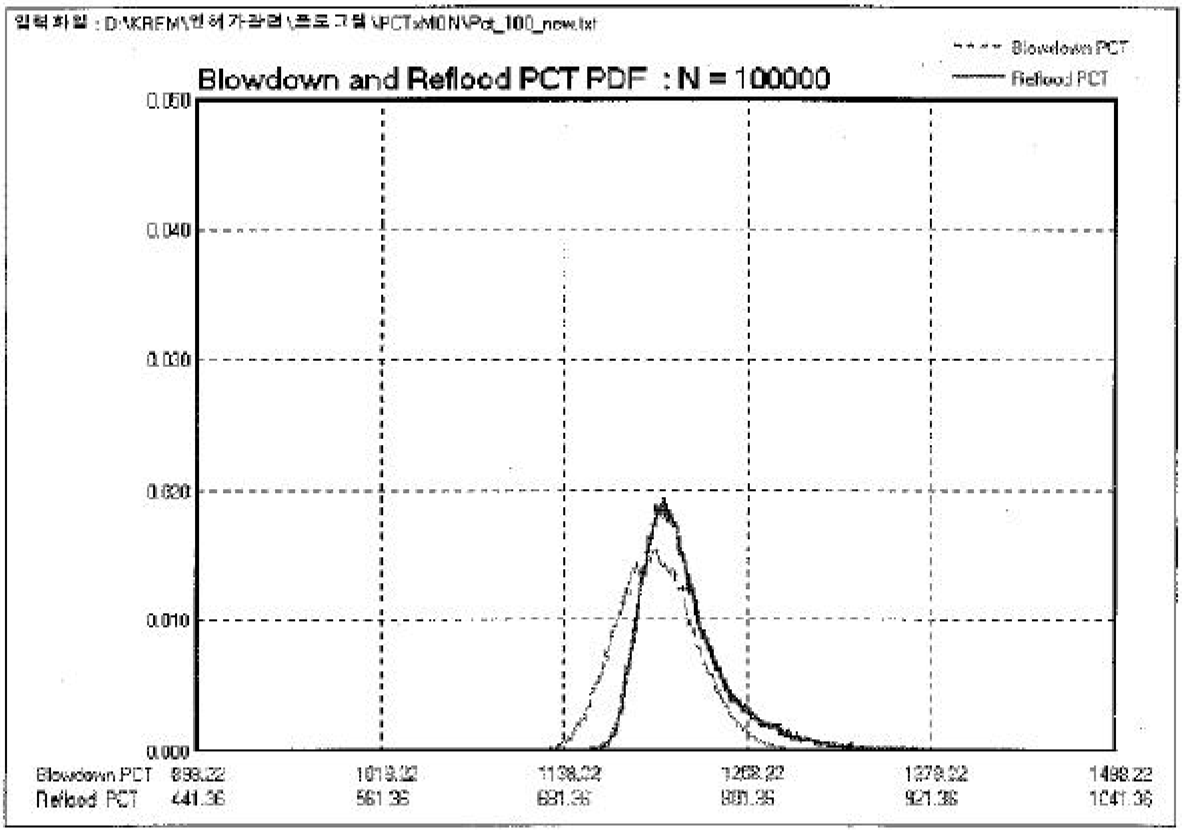

Fig. 1 : Blowdown and Reflood PDFs

The $PCT_{licence}$ is listed in Table 5.

Table 5. Final $PCT_{licence}$

Blowdown PCT	Reflood PCT
PCT(nominal, data) = 1203.860	PCT(nominal, data) = 747.550
PCT(nomunal, fit) = 1198.224	PCT(nomunal, fit) = 741.357
PCT(mean, appl) = 1199.397	PCT(mean, appl) = 761.303
PCT(mean, final) = 1199.538	PCT(mean, final) = 751.225
sigma code = 61.960	sigma code = 55.580
sigma appl. = 26.695	sigma appl. = 32.496
PCT(95%, final) = 1312.000	PCT(95%, final) = 900.000
Code bias = -9.770	Code bias = 7.560
Response surface bias = 16.794	Response surface bias = 16.887
Time step bias = 0.0	Time step bias = 20.0
PCT(Licence) = 1319.024	PCT(Licence) = 944.447

5. Conclusion

For a demonstration of KREM application to analysis of LBLOCA, Ulchin units 3/4 which are KSNP two-loop pressurized water reactor with 16x16 CE fuel core were selected. Single parameter sensitivity calculations were performed to select system parameters which would be set at their limiting value in LVA calculation, and the selected system parameters were total power, decay heat, axial power shape and SIT gas pressure. LVA calculation generated 81 PCT data with 3 fuel parameters and the critical flow. These data provided input to response surface generation. The probability distribution function was obtained by using Monte Carlo sampling. Thus, best estimate PCT calculation and plant application uncertainty evaluation were made by LVA calculation. This work shows that plant application uncertainty can be quantified and demonstrates the applicability of KREM.

6. References

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