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Quantification of Reactor Safety Margins for Large Break LOCA with Application of Realistic Evaluation Methodology

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최적평가 방법론의 적용에 의한 대형냉각재 상실사고시의 원자로 안전여유도의 정량화

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Abstract

The USNRC issued a revised ECCS rule that allows the use of best estimate computer codes for safety analysis. The rule also requires an estimation of uncertainty in calculated system response when applying the best estimate computer codes. A practical realistic evaluation methodology to evaluate the ECCS performance that satisfies the requirements of the ECCS rule has been developed and this paper describes the application of new realistic evaluation methodology to large break LOCA for the demonstration of the new methodology. The computer code RELAP5/MOD3/KAERI, which was improved from RELAP5/MOD3.1, was used as the best estimate code in the application. The uncertainty of the code was evaluated by assessing several separate and integral effect tests, and for the application to actual plant, Kori 3 & 4 was selected as the reference plant. Response surfaces for blowdown and reflood PCTs were generated from the results of the sensitivity analyses and probability distribution functions were established by random sampling or Monte-Carlo method for each response surface. Final uncertainties were quantified at 95% probability level and safety margins for large break LOCA were discussed.

요 약

미국원자력규제위원회에서는 최근 안전해석에 최적전산코드의 사용을 허용하는 개정된 비상노심냉각계통 평가 규정을 제시하였다. 당 규정에서는 계통해석에 최적전산코드를 사용할 경우 불확실성 평가를 수행할 것을 요구하고 있다. 본 논문에서는 이러한 비상노심냉각계통의 규제요건을 만족하는 실제적인 최적평가방법론을 개발하여 대형냉각재상실사고에 적용하였다. 최적평가전산코드로는 RELAP5/MOD3.1을 개선한 RELAP5/MOD3/KAERI를 사용하였으며, 코드의 불확실성은 수개의 분리효과 및 총체효과 실험에 대한 평가를 수행함으로써 정량화 하였다. 적용대상 발전소로는 고리 3 & 4호기를 선정하였다. 민감도 분석을 통하여 응답방정식을 구성하였으며 각 응답방정식에 대하여 무작위 추출방식,

Monte Carlo 방식으로 확률밀도함수를 구하였다. 최종 불확실성은 95%의 신뢰도로 정량화 하였으며 대형냉각재 상실사고시의 안전여유도에 대하여 논의하였다.

1. Introduction

In the past decade, the benefit of regulating to realistic plant performance rather than to artificial conservative performance became obvious. And in August 1988, the United States Nuclear Regulatory Commission (USNRC) approved a revised rule on the acceptance of Emergency Core Cooling Systems (ECCS) Evaluation Method[1]. The revised rule allows an alternative ECCS performance analysis, based on best estimate methodology to be used to provide more realistic estimates of plant safety margins. The rule requires the licensee to quantify the uncertainty of the estimates and include the estimated uncertainty when comparing the calculated results with the acceptance limits. To support the revised ECCS rule, the USNRC formed a small group of experts, called the Technical Program Group (TPG) to develop a method called the Code Scaling, Applicability, and Uncertainty (CSAU) evaluation methodology.[2-8] The CSAU Methodology was demonstrated for Westinghouse four-loop pressurized water reactor with 17 ×17 fuel using TRAC-PF1/MOD1 code. A similar realistic evaluation methodology for ECCS was developed by Korea Institute of Nuclear Safety (KINS) and demonstrated for Kori 3&4 using RELAP5/MOD2 [9, 10]. In another development, a method was developed and demonstrated for two loop Westinghouse PWR using RELAP5/MOD2[11].

The CSAU methodology gives a detailed reference on the uncertainty quantification strategy but the methodology requires many experts in the initial phase when importance judgments need to be made with regard to the complex mathematical models in the code. In light of this, a practical LBLOCA realistic evaluation methodology, which is simple in structure and satisfying the requirement of ECCS regulation, was proposed and demonstrated by applying it to Kori 3&4 PWR.

2. Realistic Evaluation Methodology

In developing the methodology, the emphasis was placed on providing a practical engineering approach to quantify code uncertainties.

The methodology can be summarized by the following equation;

$$PCT_{LIC} = PCT_{BE} + \Delta PCT_{CODE} + \Delta PCT_{SCALE} + \Delta PCT_{APPL} + \Delta PCT_{BIAS} \quad (1)$$

The Licensing PCT (PCT_{LIC}) is calculated by adding to the realistically calculated PCT (PCT_{BE}), the uncertainties in the calculated PCT propagated from various uncertainty sources in the calculation and the plant application.

The code uncertainty (ΔPCT_{CODE}) is quantified by evaluating the calculation results for the separate effect test (SET) assessment matrix. The resulting code uncertainty is then validated by demonstrating that it bounds or embraces the code uncertainty evaluated using the calculation results for the integral effect test (IET) assessments. The scaling uncertainty (ΔPCT_{SCALE}) represents the capability of the code to scale the LBLOCA phenomena up to the full sized nuclear power plant (NPP). The application uncertainty (ΔPCT_{APPL}) deals with the sources of uncertainties specific to the individual plant design and operation. The PCT bias (ΔPCT_{BIAS}) is added to compensate for the deficiencies of the analytical technique in predicting the LBLOCA phenomena for the given plant due to such factors as the code deficiencies or lack of code modelings.

The main feature of above methodology is that the licensing PCT is separated into two independent sets of terms. The first set of terms, consisting of

ΔPCT_{CODE} and ΔPCT_{SCALE}, is concerned with the capability of the code to simulate the individual and overall LBLOCA phenomena and each term can be calculated independent of plant design and operations. The other set of terms, consisting of PCT_{BE}, ΔPCT_{APPL} and ΔPCT_{BIAS}, relates to the plant-specific values. This feature makes the procedure to be a simple and practical methodology for LBLOCA application, while complying to the requirements specified in the ECCS regulations.

3. Preparation for the Analysis

3.1. Selection of Nuclear Power Plant and Best Estimate Code

The double ended cold leg guillotine break was selected and the two main phases of accident (blowdown, refill/reflood) were considered. The selection of a particular plant is crucial to the process because the resulting uncertainty is dependent on the plant configuration and operation. The Kori Unit 3&4 which are Westinghouse design 3-loop PWRs were chosen and the identification and ranking of LOCA phenomena and the results of TPG's efforts with the CSAU method was used since the CSAU was demonstrated for Westinghouse design 4-loop PWR.

The RELAP5/MOD3.1 computer code[12] was chosen as the base code for the analysis since the code had been extensively assessed in the past and modified through International Code Assessment Program (ICAP). Although the main emphasis of the RELAP5/MOD3.1 development was on the large break LOCAs, several deficiencies in relation to LOCA analysis were identified during the independent assessment of separate effect tests. Subsequently, the heat transfer package and hydraulic model related to reflood model were improved from RELAP5/MOD3.1[13]. The improvements consist of the modification of CHF correlation and transition boiling correlation. The drop size in the dispersed flow regime were adjusted according to the FLECHT experimental observations. The time smoothing of wall vaporization and level tracking of trasition flow are also added to eliminate the pressure spikes and level oscillation during reflood phase. For the plant LOCA calculations to be best-estimate, realistic description of the interaction between the containment and the reactor coolant systems become important. CONTEMPT4/MOD5 [14] was chosen for the containment analysis and it was coupled to RELAP5/MOD3. The merged version consists of a supervisory process and two child processes, RELAP5 and CONTEMPT. The processes run in parallel mode, and the supervisory process controls the child processes and the exchange of necessary data between the two coupled codes. This coupled version of RELAP5 and the CONTEMPT4 is named RELAP5/MOD3/KAERI and it is used as the best estimate code and frozen throughout the whole analysis of uncertainty quantification.

3.2. Establishment of Calculation Matrix for Code Uncertainty Quantification

The objective of code uncertainty assessment is to examine the code predictability by direct comparison of PCT measurements in Separate Effects Test (SET) and Integral Effect Test (IET) with RELAP5/MOD3/KAERI predictions. The overall code uncertainty assessment involves the combined uncertainties of the code models/correlations and experimental uncertainties. The assessment matrices are made separately for blowdown and for reflood PCTs, because the two different LBLOCA phases are governed by different sets of phenomena. The blowdown PCT assessment matrix consists of various THTF blowdown experiments[15] and reflood matrix consists of FLECHT-SEASET 161 unblocked rod experiments[16]. In both cases the ranges of test conditions were selected to cover the conditions expected to occur during the full-sized NPP accident, and the test conditions are summarized in Tables 1 and 2. In the present methodology, the resulting code uncertainty is validated by demonstrating that it bounds or embraces the code uncertainty evaluated using the calculation results for the IET assessments. Selected IET sets for LBLOCA were LOFT L2-3 [17], L2-5[18] and Semiscale S-06-03[19]. The best-estimate break discharge coefficients were determined through assessments of RELAP5/MOD3/KAERI against Marviken test data[20] and they were applied to IET and the plant calculations. The impact on PCT due to the uncertainty in discharge coefficient was confirmed through IET assessment.

3.3. Preparation of the Standard Input Deck for Best Estimate Plant Calculation

The standard input deck for Kori 3&4 had been developed over the past several years and was used in the LBLOCA analysis. The nodalization scheme is shown in Fig. 1. In order to eliminate the uncertainty

Table 1. Assessment Matrix for Code Uncertainty Quantification of Blowdown Phase (THTF Test)

Test Number	Break Area(m^2)	Break (Ratio)	Tin (K)	Tout (K)	Pressure (MPa)	Mass Flow ($kg/m^2/hr$)	Power (KW/rod)
105	12.54	0.4/0.6	558	607	15.5	12.2	122.0
151	12.54	0.4/0.6	558	606	15.7	11.2	122.0

Table 2. Assessment Matrix for Code Uncertainty Quantification of Reflood Phase (FLECHT-SEASET 161 Bundle Test)

Test Number	Pressure (Mpa)	Rod Maximum Temperature (K)	Rod Peak Power (kw/m)	Flooding Rate (cm/sec)	Coolant Temperature (K)
31701	0.28	1145	2.3	15.5	326
31302	0.28	1142	2.3	7.65	325
31203	0.28	1145	2.3	3.84	325
31504	0.28	1136	2.3	2.4	324
31805	0.28	1144	2.3	2.1	324
34006	0.27	1155	1.3	1.5	324
31108	0.13	1144	2.3	7.9	306
34209	0.14	1162	2.4	2.72	305
32013	0.41	1160	2.3	2.64	339
30817	0.27	804	2.3	3.86	326
30518	0.28	529	2.3	3.86	326
34420	0.27	1392	2.4	3.89	324
31021	0.28	1153	1.3	3.86	325
34524	0.28	1151	3.0	3.99	325
36026	0.28	1173	2.42	2.5	324
32333	0.28	1162	2.3	(1)	325
32235	0.14	1161	2.3	(2)	304
33338	0.28	1144	2.3	(3)	325

(1) 162kg/sec until 5sec, 21kg/sec onward

(2) 166kg/sec until 5sec, 25kg/sec until 200sec, 16kg/sec onward

(3) 5.9kg/sec until 15sec, 0.807kg/sec onward

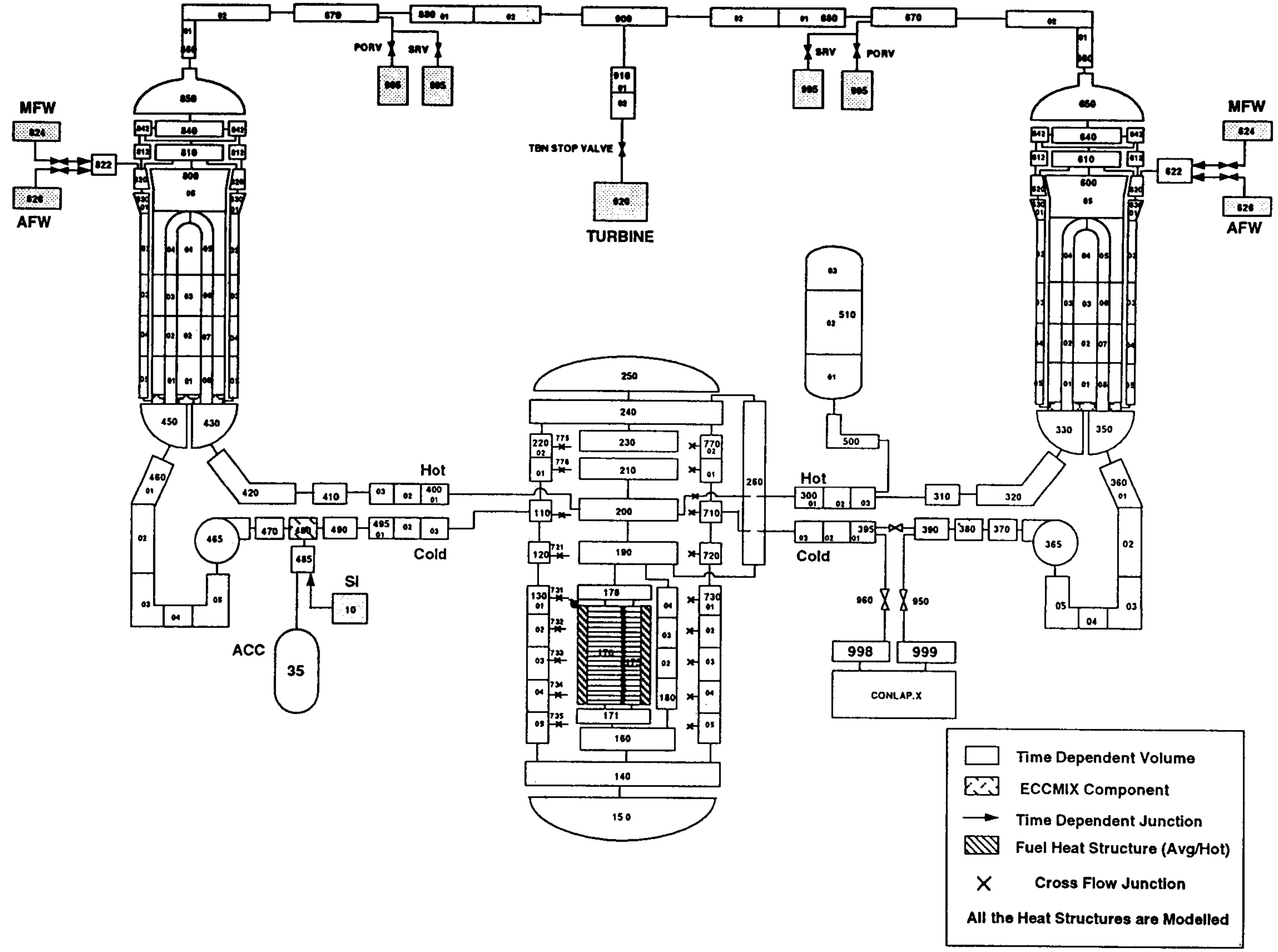

Fig. 1. Nodalization Scheme of RELAP5/MOD3 for Kori Unit 3 & 4 LBLOCA Analysis

related to the nodalization, nodalization was made as closely as possible to that used in the IET (LOFT and Semiscale) simulations. The nodalization schemes and options of safety injection point, downcomer and S/G U-tube were identical to IET. The number of nodes for the core was taken to be same as SET (THTF and FLECHT) nodalization. The number of core nodes was different to that used in the IET assessments because the IET facilities were scaled down from actual plant, but the ratio of volume length to the hydraulic diameter was taken to be same. The hydraulic volumes and heat structures of primary and secondary systems were modeled on a best estimate basis. The initial conditions and assumptions are shown in Table 3. The effects upon uncertainty due to imprecise knowledge of the reactor state and operating conditions were treated by limit value approach. The target value for the best-estimated power peaking factor was 2.5, although the current limit value in the FSAR is 2.32.

3.4. Selection of Plant Application Uncertainty Parameters

No single method provides the uncertainty range or bias for all the input and modeling parameters that affect the PCT uncertainty. The conclusions in CSAU methodology and demonstration of KINS were used as guides in selecting the parameters, and establishing the ranges and bias related to the parameters. The parameters related to code model and correlation; i.e. heat transfer coefficient, minimum temperature and break flow model were not considered because the code uncertainty is treated independent of the plant design and parameters and quantified separately in this paper. List of the final selected uncertainty parameters with their assumed distributions are provided in Table 4. The power peaking factor, fuel conductivity and gap conductance were used with uncertainty ranges used in the demonstration of CSAU methodology. The decay heat uncertainty range was extracted from KINS demonstration[9]. Since there are insufficient data to estimate the uncertainty of pump degradation in two phase condition, the range of variation was selected in the full range; from no degradation to full degradation.

In the plant application, the containment pressure calculation was coupled with the system calculation by merging the containment code CONTEMPT and the systems code RELAP. Therefore the uncertainties of parameters related to containment analysis were included as shown in Table 4. For other parameters which are not included in Table 4, the limiting values were used.

Table 3. Initial Conditions and Assumptions for Nominal Case of Plant Calculation

Major Parameters	Value or Assumptions
Reactor Power	102%
Power Peaking Factor	2.5
Axial Power Profile	1.5 chopped cosine
Decay Power	ANS-79 Model
No. of HPSI and LPSI pump	1
Accumulator Pressure	42.4 bar
Pressurizer Pressure	155.26 bar
Pressurizer Level	58%
Steam Generator Level	50%
Steam Generator Tube Plugging	0%

Table 4. The Ranges and Distribution for the Selected Uncertainty Parameters

Parameter	Notation	Ranges	Distribution
Fuel Conductivity	x_1	±10%	Normal Gaussian
Fuel Gap Conductance	x_2	±80%	Uniform
Peaking Factor	x_3	±5.6%	Normal Gaussian
ANS Decay Heat	x_4	±6.6%	Normal Gaussian
RCP Degradation	x_5	±100%	Uniform
Containment Wall Heat Transfer	x_6	±68%	Uniform

* Above ranges are 2σ for Normal Gaussian Distribution and Min./Max.value for Uniform Distribution

4. Results of Calculation

4.1. Code Uncertainty

All THTF and FLECHT-SEASET data in the USNRC Data Bank[21] are provided as clad temperature versus time. In many cases, the raw data contained failed or spuriously measured data. There are many thermocouples for clad temperature measurement since both test facilities have multi rod array configuration and thus it is impossible to treat the data manually. All raw data were scanned using "DATA ANALYZER" program developed at KAERI. The program has the capability to reject, upon visual examination or otherwise, those data which deviate seriously compared to other data.

The clad temperature computed by RELAP5/MOD3/KAERI for any computational cell was paired with the temperature measured in that computational cell. For each computational cell in RELAP calculation, there are many corresponding experimental thermo-couple measurements but the center of a computational cell does not always match the elevations of measurement points. Since the exact solution of field equation in a computational cell is not known, linearly interpolated calculational results were compared with the experiment data. The 231 pairs of THTF measured PCT values and computed values are plotted in the scatter diagram of Fig. 2. For the reflood PCT, 2793 pairs of FLECHT data and computed value are plotted as shown in Fig. 3. The values of the mean of differences between the measured and the calculated PCTs ($PCT_{MEAN,DIFF} = PCT_{EXP} - PCT_{RELAP}$) are $-15.3K$ for blowdown and 7.56K for reflood, while the sample standard deviation from the mean are 66.6K for blowdown and 55.7K for reflood PCT. Thus approximations to the deviation range of 95% of all data pairs are 94.3K for blowdown and 99.2K for reflood. However this reflood uncertainty does not take into account the uncertainty in predicting the initial condition for the refill period, that is the uncertainty propagated from blowdown process. In order to validate the above uncertainties justifiably represent the code uncertainty, the values were confirmed by assessing the LOFT L2-3, L2-5 and Semiscale S-06-03. Fig. 4 shows that the experimental data are bounded by the PCT value obtained by adding the code uncertainty to the calculational result. In the assessment of LOFT test, the data at the lower flux region were excluded because the measurement of nuclear flux in the nuclear test facility becomes uncertain in the low flux region. The peripheral assembly data were also excluded in LOFT assessment due to the strong 2D/3D effects in the test results.

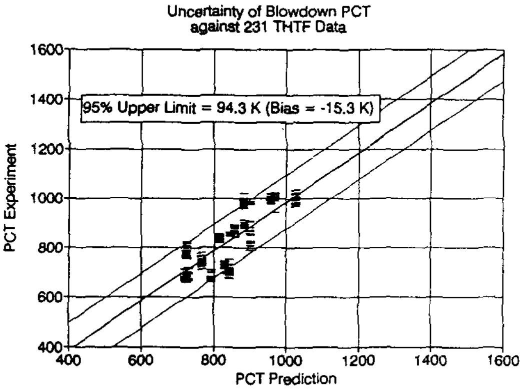

Fig. 2. Comparison of RELAP5/MOD3 Computed PCT With THTF Data

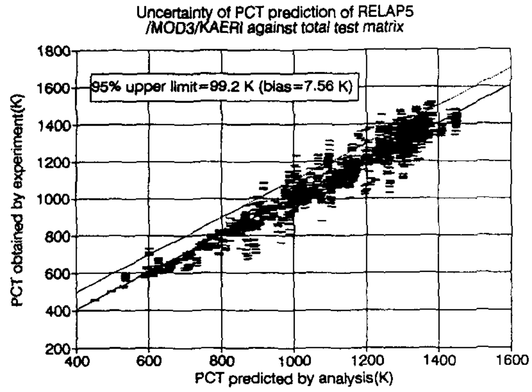

Fig. 3. Comparison of RELAP5/MOD3 Computed PCT With FLECHT-SEASET Data

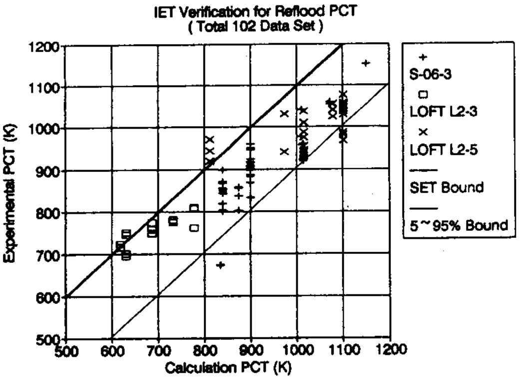

Fig. 4. Comparison of RELAP5/MOD3 Computed PCT With IET Data

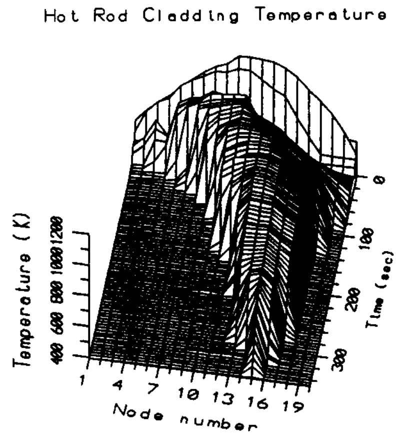

Fig. 5. Cladding Temperature Behavior of the Hottest Rod in Core After LBLOCA

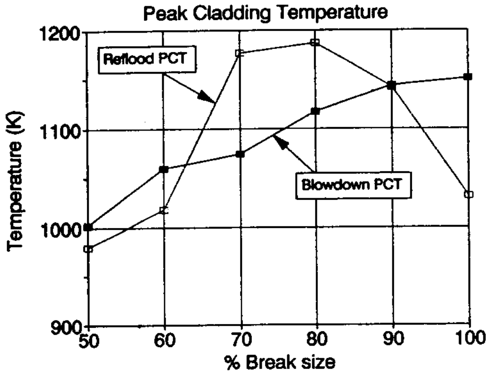

Fig. 6. PCT Behaviors With Respect to the Break Sizes

4.2. Plant Application Uncertainty

4.2.1. Base Calculation and Break Spectrum Analysis

Results of peak clad temperature of 100% LBLOCA with initial conditions and assumptions as shown in Table 3 are presented in Fig. 5 with respect to axial elevation and time after break. Two distinct peaks around the center of core are observed, first during the blowdown and second during the reflood process. According to regulatory requirement the plant calculation should be performed on the critical break size. To find the critical break size the plant calculation were performed for 6 break sizes;i.e. 100%, 90%, 80%, 70%, 60% and 50% guillotine break. The calculated peak temperature at center node are presented in Fig. 6 with respect to break size and time after break. In this methodology, different experimental data base sets are used for the quantification of blowdown and reflood PCTs and thus uncertainties are separately calculated for each phase. As shown in Fig. 6, the critical break size is 100% for blowdown and 80% for reflood. For the above two critical break sizes, the blowdown and reflood PCT uncertainties were quantified.

4.2.2. Influence of Single Parameter and Response Surface Generation

A calculational matrix with respect to the selected parameters in section 3.4 was constructed. The total number of calculations is 24 and each calculation required about 11 CPU hours using HP-715 workstation. The calculation results of blowdown and reflood PCTs at the hottest fuel rod are presented in Table 5.

The statistical quantification of application uncertainty with respect to variation in each parameter's combination would require a great number of plant calculations(more than 50,000). Such a large number of calculation runs using RELAP5 would be prohibitively expensive. Thus an algebraic approximation of the response of RELAP5 to a set of

Table 5. Results of Blowdown and Reflood PCT for Calculational Matrix of Plant

Uncertainty Parameters	100% Blowdown	break Reflood	80% Blowdown	break Reflood
Nominal	1151.0	1031.5	1117.0	1186.9
$x_1 = +10\%$	1128.8	998.0	1090.7	1177.6
$x_1 = -10\%$	1174.7	1060.6	1147.0	1217.6
$x_2 = +80\%$	1114.1	978.5	1074.2	1165.6
$x_2 = -80\%$	1320.9	1150.0	1210.5	1256.6
$x_3 = +5.6\%$	1181.6	1048.6	1147.8	1233.0
$x_3 = -5.6\%$	1123.2	994.2	1086.5	1132.2
$x_4 = +6.6\%$	1154.1	1058.1	1122.4	1255.7
$x_4 = -6.6\%$	1144.2	1006.3	1112.9	1152.1
$x_5 = +100\%$	1154.6	971.9	1163.1	1212.1
$x_5 = -100\%$	1144.2	1050.5	1080.1	1112.4
$x_6 = +68\%$	1151.0	1087.5	1117.0	1216.8
$x_6 = -68\%$	1151.0	1006.3	1117.0	1161.0

Table 7. Calculated Coefficients of Response Surface

Coefficient	100% Blowdown	Break Reflood	80% Blowdown	Break Reflood
PCT_0	1151.0	1031.5	1117.0	1186.9
α_1	−229.5	−312.8	−281.5	−200.0
α_2	−129.3	−107.2	−85.2	−56.8
α_3	521.2	485.7	547.7	900.2
α_4	44.9	392.8	71.7	785.2
α_5	5.2	−39.3	41.5	49.9
α_6	0.0	59.7	0.0	41.0
β_1	75.0	−218.0	185.0	1070.0
β_2	103.9	51.2	39.6	37.9
β_3	451.2	−3220.6	44.6	−1377.5
β_4	31.0	159.6	149.2	3903.8
β_5	−1.6	−20.3	4.6	−24.7
β_6	0.0	33.3	0.0	4.3

parameters(response surface) is used in place of RELAP5 in the statistical treatment. The purpose of the response surface is to replace the code by an algebraic fit to the output of interest(here PCT). There are a number of ways to formulate the response surface. Some require more calculational effort than others. In this paper, second order polynomial response surfaces were generated by applying the single parameter sensitivity results of Table 5, assuming independence of each parameters. The resulting form of the response surfaces for blowdown and reflood PCTs is as follow.

$$PCT(x_{i,\, i=1,6}) = PCT_0 + \sum \alpha_i x_i + \sum \beta_i x_i^2 \qquad (2)$$

where the x_i is the fraction of deviation from each parameter's mean value as noted in Table 4. The calculated values of coefficient α_i and β_i are listed in Table 6 for each break size.

4.2.3. Statistical Analysis for Uncertainty Quantification

In order to produce an estimate of probability distribution function from a response surface we must sample the surface in a statistically acceptable way. Because the surface is only algebraic, use of a crude Monte Carlo sampler was deemed adequate. 100, 000 samples were collected with random variations of input parameters. For the input parameters the corresponding probability distribution had been assumed as shown in Table 4. The resulted probability distribution functions of blowdown and reflood PCT for 100% and 80% break are shown in Fig. 7 and 8. The probability distribution function is used for the generation of the mean values and 95% upper bound values. Results are summarized in Table 7.

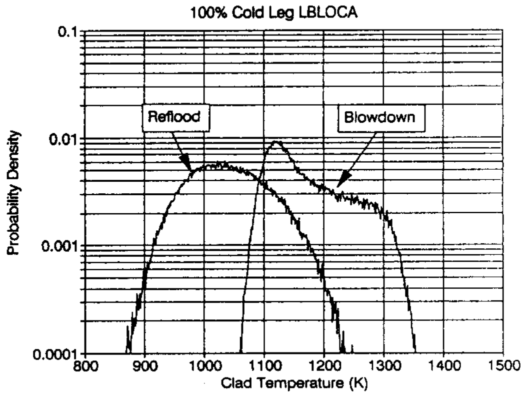

Fig. 7. Probability Distribution Function of PCTs for 100% Break

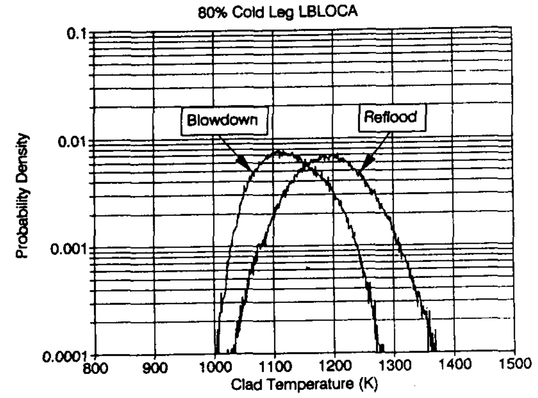

Fig. 8. Probability Distribution Function of PCTs for 80% Break

4.3. Consideration of Biases and Final Uncertainty Estimation

In the plant application, the nitrogen gas effect from accumulator injection process was not considered because of the run failure of RELAP5/MOD3. The uncertainty related to the above was not assessed in this paper, but assumed that conclusion of CSAU are applicable and the value in the CSAU results is used as the bias in the final adjustment of results. The scale-up capability of RELAP5 and associated uncertainty was not quantified at this stage due to the lack of scaled data, however we believe that the models and correlations in RELAP5/MOD3 has the scale-up capability with respect to most of the important processes of the LBLOCA.

By applying the realistic evaluation methodology described in section 2, the final results combined from code uncertainty, plant application uncertainty and bias are given in Table 8. The least PCT margin is calculated as 76.9K for 80% break during reflood period.

5. Conclusion

This work is a further contribution to the CSAU methodology development and application. In this paper, a new practical and traceable methodology for the realistic evaluation of ECCS for the LBLOCA was proposed by separating the code uncertainty from other application uncertainty. By following the

Table 8. Estimation of Total LBLOCA Uncertainties and Licensing PCT

Temperatures (K)	100% break		80% break	
	Blowdown	Reflood	Blowdown	Reflood
Mean value of PCT	1173.2	1040.7	1127.8	1193.8
Uncertainties				
−Application Uncertainty	125.8	115.8	88.2	97.1
−Code Uncertainty	94.3	99.2	94.3	99.2
−Code Bias	−	10	−	10
Final Licensing PCT	1393.3	1256.7	1310.3	1400.1
LOCA PCT Margine ($PCT_{Limt} - PCT_{Licen}$)	83.7	220.3	166.7	76.9

Table 7. Results of Plant Application Uncertainties and 95% Upper Bound PCT Determined by Statistical Method

	100% Break						80% Break					
Number of	Blowdown			Reflood			Blowdown			Reflood		
Sampling	Mean	σ	95%	Mean	σ	95%	Mean	σ	95%	Mean	σ	95%
1,000	1172.5	67.9	1302.0	1041.1	68.1	1155.5	1128.1	52.2	1216.0	1194.4	60.7	1294.9
5,000	1173.1	65.2	1297.0	1040.6	66.5	1157.5	1128.1	52.1	1218.0	1193.8	60.0	1291.9
10,000	1173.2	65.6	1299.0	1040.3	67.6	1155.5	1127.1	50.4	1215.0	1193.0	58.1	1289.0
50,000	1173.2	65.6	1298.0	1040.8	67.6	1156.5	1127.5	51.1	1216.0	1193.7	59.1	1289.9
100,000	1173.2	65.7	1299.0	1040.7	67.7	1156.5	1127.8	51.2	1216.0	1193.8	59.1	1290.9

new methodology, the determination of the best-estimate PCT and the quantification of associated uncertainty can be accomplished within a practical amount of man power, whereas the original CSAU requires many experts in the initial phase of analysis for the importance judgement of complex mathematical models in the code.

The demonstration effort shows that the uncertainties in the complex phenomena occurring during accident condition in nuclear power plant can be quantified. The results indicates the existence of PCT margin although the hot spot factor was increased to 2.5 from current limit value 2.32. The confirmed LOCA margin in the current design of Kori 3&4 could be utilized to the power upgrading or increasing the fuel burn-up and flexibility of plant operation.

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