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An Application of Realistic Evaluation Methodology for Large Break LOCA of Westinghouse 3 Loop Plant

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Abstract

This report presents a demonstration of application of realistic evaluation methodology to a posturated cold leg large break LOCA in a Westinghouse three-loop pressurized water reactor with 17x17 fuel. The new method of this analysis can be divided into three distinct step: 1) Best Estimate Code Validation and Uncertainty Quantification 2) Realistic LOCA Calculation 3) Limiting Value LOCA Calculation and Uncertainty Combination. RELAP5/MOD3/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 previous study [2], and thus the step 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 parameter sensitivity calculations were performed to select system parameters which would be set at their limiting value in Limiting Value Approach (LVA) calculation. Single run of LVA calculation generated 27 PCT data according to the various combinations of fuel parameters and 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. Break spectrum analysis was also made to determine the critical break size. The results show that sufficient LOCA margin can be obtained for the demonstration NPP.

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 in U.S and Europe[3]. CSAU (Code Scaling , Applicability and Uncertainty) method proposed by INEL[4] is the one of the successfully demonstrated method. Although the CSAU methodology and demonstration [5,6] gives a very comprehensive base on the uncertainty quantification strategy, a considerable amount of subjective engineering judgment must be involved in the CSAU analysis process. The phenomena studied and mathematical models involved are too complex, to be able to standardize it in a simple and straightforward engineering procedure. In light of this, it has developed a practical LBLOCA realistic evaluation methodology (K-REM) designed to evaluate ECCS performance, which is simple in structure and based on the sound logical reasoning, while satisfying the requirements of the ECCS regulations. The new method of this analysis can be divided into three distinct step: 1) Best Estimate Code Validation and Uncertainty Quantification 2) Realistic LOCA Calculation 3) Limiting Value LOCA Calculation and Uncertainty Combination. The code uncertainties which will be determined in step 1) were quantified already in previous study, and thus the step 2) and 3) for plant application were presented in this paper.

2. Realistic LOCA Calculation

The Kori 3&4 Unit with 17x17 Vantage-5H fuel were selected for the demonstration of realistic evaluation methodology. Realistic PWR LOCA calculations are performed using the best-estimate thermal hydraulic computer code RELAP5 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 nominal calculation has used nominal input for several parameters particularly for the core power and stored energy. Nominal conditions have also been used for the accumulator volume, pressure, and water temperature. However, there are several bounding conditions which have been set at a 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. The peaking factor 2.6 was selected as target value in demonstration 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 paramters listed in PIRT, the parameters related to code model and correlation ; i.e. heat transfer coefficient, minimum stable film boiling temperature, interfacial drag, break flow model and phenomena related to noncondensibles were not considered in the K-REM because those parameters would be dealt with as code uncertainty or bias which were treated separately. Parameters are added based on experiences of the experts in LOCA analysis. Those parameters are fuel thermal conductivity, total power, decay heat power, RCS flow, pressurizer pressure, accumulator gas pressure, accumulator water volume, accumulator water temperature, SI flow rate and SI water temperature. Uncertainty range for each parameter was looked up and listed in Table 1. Most uncertainty range was obtained from design data of Vantage 5H[19]. Sensitivity results provides the basis on determination of system parameters which would be set at their limit value in LVA calculation. Table 2 presents the effect of each parameter on blowdown and reflood PCT.

4. Limiting Value LOCA Calculation and Uncertainty Quantification

Limiting Value LOCA Calculation

As discussed in Section 1, the K-REM approach to the realistic LOCA analysis is to use a limit value approach (LVA) calculation which would yield a peak cladding temperature (PCT) which adds application uncertainty of system parameters to the best estimate calculated PCT by applying limit value for system parameters to plant calculation. This LVA calculation will yield PCT greater than the 95% probability limit because the uncertainties in the key LOCA parameters such as total power, decay power, RCS flow and accumulator gas pressure are combined together in a single calculation rather than in a random statistical fashion. LVA is also less expensive than the statistical approach, because for a given break size only one calculation is performed.

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 27 PCT results for 27 hot rods modeled from full three-level experimental design on three fuel parameters selected for statistical treatment, and it could be viewed simply as a polynomial least squares fitting process of the calculated PCT. The selected fuel parameters were gap conductance, fuel thermal conductivity and power peaking factor, respectively.

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 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.

Break Spectrum Calculation Results

Break spectrum analysis was made to determine the critical break size. The plant calculations were carried out for 4 break sizes, and variation of break size was realized by varying discharge coefficient at the break. The analyzed break sizes were with break discharge coefficient of 0.6, 0.8, 1.0 and 1.2. The range of break discharge coefficient analyzed was based on the result from previous study on finding best estimate discharge coefficient against Marviken test data. The calculation results were presented in Table 3 with uncertainties. The application uncertainty was combined statistically with code uncertainty and the resultant PCT were presented in Fig. 1 and 2.

Table 1. Relevant Parameters for Sensitivity Study

Parameter	Uncertainty Range
Gap conductance	gap width of 0.050 mm to 0.360 mm
Power peaking factor	-5.6% to +5.6%
Fuel thermal conductivity	-10% to +10%
Total power	102 % power
Decay heat power	+6.6%
RCS flow	TH design flow of 94700 gpm/loop
Pressurizer pressure	+30 psia
Accumulator gas pressure	-24 psia
Accumulator water volume	-15 ft^3
Accumulator water temperature	120°F (uppermost value)
SI flow rate	EM curve
SI water temperature	120°F (uppermost value)

Table 2. Effect on PCT for each single parameter

Parameter	Blowdown PCT (K)	Reflood PCT (K)	Effect on Blowdown PCT (K)	Effect on Reflood PCT (K)
Gap conductance	1367.77	1175.17	+197.72	+62.77
Power peaking factor	1196.15	1136.91	+25.10	+24.51
Fuel thermal conductivity	1197.49	1125.62	+27.44	+13.22
Total power	1182.92	1147.34	+12.87	+34.94
Decay heat power	1173.30	1124.60	+3.25	+12.20
RCS flow	1171.87	1127.19	+1.82	+14.79
Pressurizer pressure	1169.36	1117.73	-0.69	+5.33
Accumulator gas pressure	1170.00	1125.53	-0.05	+13.13
Accumulator water volume	1169.85	1114.60	-0.20	+2.20
Accumulator water temp.	1169.71	1114.47	-0.34	+2.07
SI flow	1169.80	1114.58	-0.25	+2.18
SI water temperature	1169.86	1109.89	-0.19	-2.51

Table 3. Results of Plant Application Uncertainty and 95th Percentile PCT from Break Spectrum Analysis

Break	Blowdown PCT			Reflood PCT		
C_d	Mean	σ	95 %	Mean	σ	95 %
0.6	1102.122	29.211	1155.8	1233.019	18.636	1264.5
0.8	1166.712	38.899	1239.2	1321.637	22.880	1360.2
1.0	1196.742	46.481	1284.0	1205.792	22.627	1245.5
1.2	1185.115	44.411	1268.1	1049.070	10.679	1066.5

Note) All the results are obtained from 100,000 random sampling.

5. Conclusion

For a demonstration of K-REM application to analysis of LBLOCA, Kori Unit 3 & 4 which are Westinghouse three-loop pressurized water reactor with 17 x 17 Vantage 5H fueled 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, devay heat power, RCS flow and accumulator gas pressure. Single run of LVA calculation generated 27 PCT data and 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 single run of LVA calculation.

Break spectrum analysis was made to determine the critical break size, and it was found out that critical break size for blowdown PCT and reflood PCT was break with C_d of 1.0 and break with C_d of 0.8, respectively. The resulting PCT is 1317.23 K for blowdown PCT and 1427.56 K for reflood PCT. There is 50 K margin when applying K-REM to LBLOCA analysis with power peaking factor of 2.60. This work shows that plant application uncertainty can be quantified and demonstrates the applicability of K-REM.

6. References

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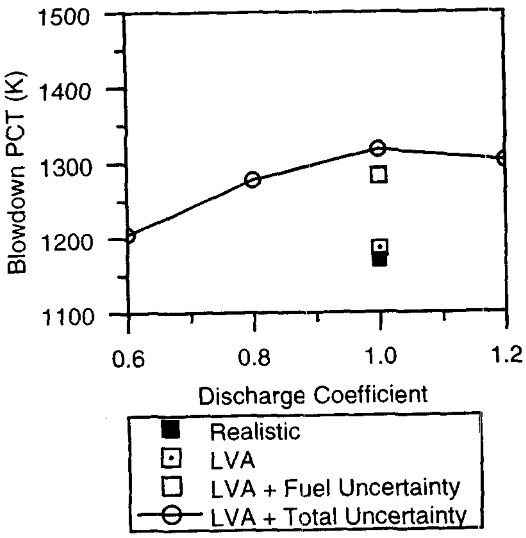

Fig.1. Blowdown PCT Trends with Cd

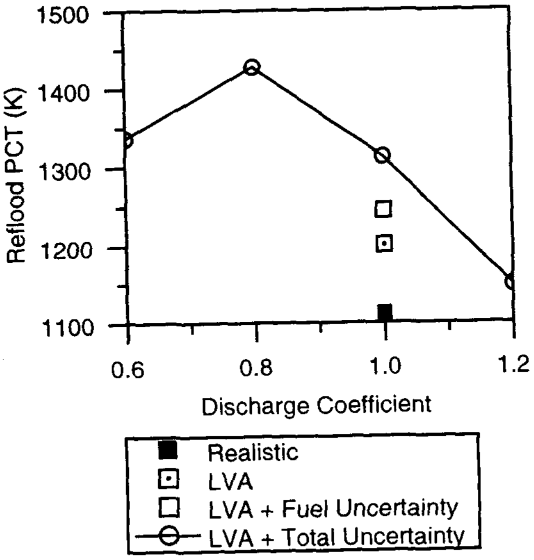

Fig.2 Reflood PCT Trends with Cd