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An Application of Realistic Evaluation Model to the Large Break LOCA Analysis of Ulchin 3&4

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Abstract

K-REM [1], which is under development as a realistic evaluation model of large break LOCA, is applied to the analysis of cold leg guillotine break of Ulchin 3&4. Fuel parameters on which statistical analysis of their effects on the peak cladding temperature (PCT) are made and system parameters on which the concept of limiting value approach (LVA) are applied, are determined from the single parameter sensitivity study. 3 parameters of fuel gap conductance, fuel thermal conductivity and power peaking factor are selected as fuel related ones and 4 parameters of axial power shape, reactor power, decay heat and the gas pressure of safety injection tank (SIT) are selected as plant system related ones. Response surface of PCT is generated from the plant calculation results and on which Monte Carlo sampling is made to get plant application uncertainty which is statistically combined with code uncertainty to produce the 95th percentile PCT. From the break spectrum analysis, blowdown PCT of 1350.23 K and reflood PCT of 1195.56 K are obtained for break discharge coefficients of 0.8 and 0.5, respectively.

1. Introduction

In August 1988, the Nuclear Regulatory Commission (NRC) approved the final version of a revised rule on the acceptance of ECCS entitled "Emergency Core Cooling System; Revision to Acceptance Criteria" [2]. The revised rule permits licensee or applicant to use either Appendix K features or realistic evaluation model. These realistic evaluation models must include sufficient supporting justification to demonstrate that the analytic techniques employed realistically describe the behavior of the reactor system. It also requires that the uncertainty in the realistic evaluation model be quantified and considered when comparing the results of the calculations with the applicable limit in 10CFR50.46 so that there is a high probability that criteria will not be exceeded.

Also, the Regulatory Guide 1.157 [3] provides detailed descriptions of best estimate (BE) calculation and the features that a best estimate code should exhibit, and suggests methods for estimating the calculation uncertainties that need to be quantified with respect to the requirements laid out in the 10CFR50.46. In addition, the CSAU (Code Scaling, Applicability and Uncertainty) evaluation method developed for LBLOCA by the USNRC [4] gives a very detailed reference on the development of a uncertainty evaluation methodology. However, the methodologies described in CSAU contain a number of weaknesses for them to be practical in the actual plant application. K-REM is developed to overcome the weaknesses of CSAU and is simple in structure and sound in logical reasoning.

This paper addresses the evaluation of plant application uncertainty and its combined results with code uncertainty. Plant application uncertainty is comprised of the uncertainty from the limit value approach on plant parameters and the uncertainty from a statistical approach on fuel parameters. In the K-REM, statistical approach is used for fuel related parameters which have some inter-dependency and the full 3-level experiment design is applied to. For other plant parameters identified to be important, the limit value approach is used.

2. Single Parameter Sensitivity Study

Thermal hydraulics of a LBLOCA is influenced by many parameters. Candidate parameters which can influence the PCT should be identified and ranked to reduce the number of parameters for sensitivity study. Relevant parameters are collected from evaluation method reports [5, 6] and CSAU study instead of parameter identification by the authors themselves. Collected 76 parameters related with LBLOCA analysis are ranked using the opinions of LOCA experts in Korea Atomic Energy Research Institute. Top ranked 11 parameters with their uncertainty ranges are shown in Table 1. Variation of the parameters from the nominal condition is studied with respect to the PCT impact and the result is shown in Fig. 1. Parameters which have considerable effect on the blowdown PCT are found to be fuel gap conductance, power peaking factor, fuel thermal conductivity, axial power shape and reactor power. Parameters which have considerable effect on the reflood PCT are fuel gap conductance, power peaking factor, axial power shape, reactor power, decay heat and SIT pressure if 20 K difference is set to a selection criterion. Fuel parameters are fuel gap conductance, fuel thermal conductivity and power peaking factor and plant system parameters are axial power shape, reactor power, decay heat and SIT pressure.

3. PWR Calculation at Limiting Value Conditions

Four system parameters are set to their conservative bounds for the calculation at limiting value conditions. Combined effect of the other minor parameters is neglected in the present analysis. Employing 27 hot fuel rods in the core to cover cross-combination of the minimum, nominal and maximum values of 3 fuel parameters, 27 PCT's are obtained in a calculation and they are used to generate a least square fitted response surface.

Monte Carlo sampling of 100,000 times on the surface showed stable converged values of surrogate PCT's. Results of 100,000 samplings for the break discharge coefficient (Cd) of 1.0 are shown in Table 2. The response surface deviated from the data by less than 1.5 K and was on slightly conservative side. Standard deviation of the sampling on the response surface of plant application calculation is 25.7 K and 10.7 K for blowdown and reflood PCT's, respectively. 95th percentile PCT's which are calculated from the statistically combined probability density function of code uncertainty and application uncertainty are 1347.0 K and 975.0 K for blowdown and reflood phases, respectively. Code uncertainties and related standard deviations were obtained from previous study [7]. Licensing PCT is calculated by adding code bias to the 95th percentile PCT.

Result of break spectrum analysis is shown in Fig. 2. Critical break sizes are found to be the breaks with Cd of 0.8 and of 0.5 for blowdown and reflood PCT's, respectively. The resulting PCT's are 1350.23 K and 1195.26 K for blowdown and reflood phases, respectively. PCT margin of 127 K is obtained when compared with the acceptance criterion of 1477 K as a PCT limit. Present analysis introduces additional PCT margin of 107 K when compared with conventional evaluation model calculations.

4. Conclusion

Parameters which affect the blowdown PCT by more than 10 K are found to be fuel gap conductance, power peaking factor, fuel thermal conductivity, axial power shape and reactor power. Parameters which have more than 20 K effect on the reflood PCT are fuel gap conductance, power peaking factor, axial power shape, reactor power, decay heat and SIT pressure. Fuel parameters are fuel gap conductance, fuel thermal conductivity and power peaking factor and plant system parameters are axial power shape, reactor power, decay heat and SIT pressure.

Response surface was generated from the plant calculation by least square fitting of 27 PCT's. Random sampling of 100,000 times on the response surface produced probability density function of plant application PCT. When combined with code uncertainty, 95th percentile licensing PCT's were 1350.23 K for Cd of 0.8 and 1195.26 K for Cd of 0.5 for blowdown and reflood phases, respectively.

References

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Table 1. Relevant Parameters for Sensitivity Study

Parameter	Uncertainty Range
Fuel Gap Conductance	± 3 sigma
Power Peaking Factor	± 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
Time Step Size	

Table 2. Final Results of LVA Calculation

	Blowdown PCT	Reflood PCT
PCT (Nominal , Data)	1234.660	882.240
PCT (Nominal, Fit)	1236.096	882.466
PCT (Mean,Appl.)	1237.458	882.402
PCT (Mean, Final)	1236.854	881.869
1σ (Code)	61.960	55.680
1σ (Appl.)	25.695	10.703
Code Bias	-9.770	7.560
PCT (95 %, Final)	1347.000	975.000
PCT (License)	1337.230	982.560

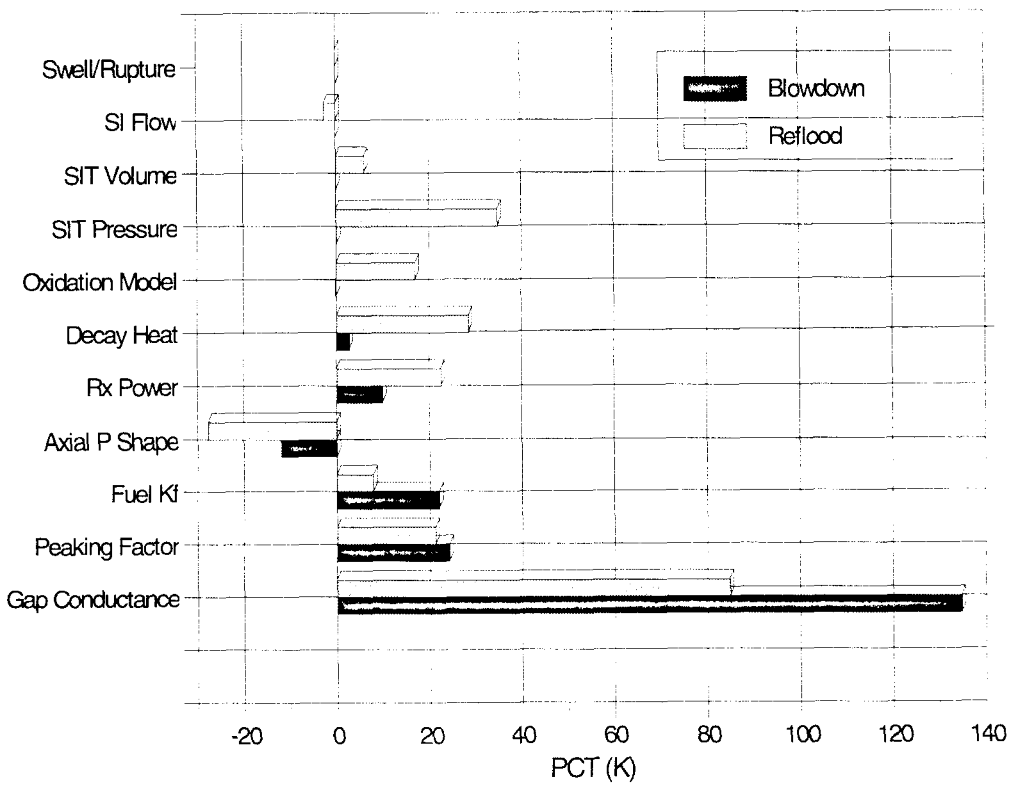

Fig. 1. Results of Single Parameter Sensitivity Study

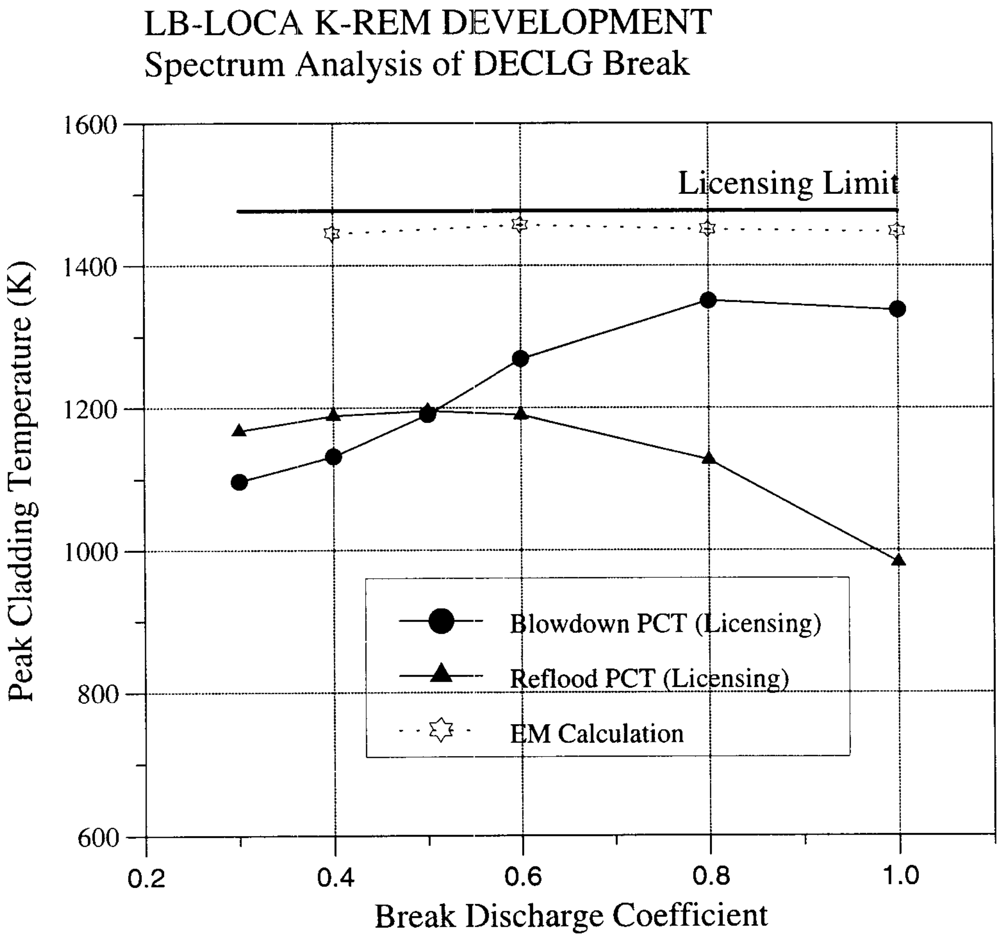

Fig. 2. Results of Spectrum Analyses