Uncertainty Evaluation of a Postulated LBLOCA for APR+ using KINS Realistic Evaluation Methodology and MARS-KS

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1. Introduction

Korea Institute of Nuclear Safety(KINS) developed a best estimate plus uncertainty evaluation methodology, KINS-REM(KINS Realistic Evaluation Methodology), for the regulatory evaluation of a postulated LBLOCA(Large Break Loss Of Coolant Accident)[1] based on the USNRC(United States Nuclear Regulatory Commission) Code, Scaling, Applicability, and Uncertainty(CSAU) methodology [2]. Recently, as a part of the regulatory safety research, KINS also developed a best estimate safety analysis regulatory audit code, MARS-KS[3], to realistically predict and better understand the physical phenomena of the design basis accidents. KINS improved uncertainty propagation methodology[4,5] using MARS-KS and applied the improved uncertainty evaluation method for the Shinkori Units 3&4 LBLOC[6]. This study is to evaluate the uncertainty propagation of a postulated LBLOCA and quantify the safety margin using KINS-REM and MARS-KS code for the APR+ (Advanced Pressurizer Reactor Plus) Standard Safety Analysis Report(SSAR) which is under regulatory review by the KINS for its design approval.

2. New Design Features of the APR+

Ever since the Nuclear Power Plant (NPP) started commercial operation, advanced NPPs have been developed and evolved to enhance performance and safety as well as the economics of the plant. APR+[7] is currently under development by the KHNP(Korea Hydro & Nuclear Co., Ltd.) and has been evolved from the APR1400 through upgrading the power and improving the SIS(Safety Injection System) as well as the active AFWS(Auxiliary Feedwater System). Total power was increased to 4,290 MWt and thus the NSSS (Nuclear Steam Supply System) design has been upgraded accordingly. Due to safety concerns of the active AFWS, PAFS(Passive AFS) has been adapted as a new design feature for the ultimate heat sink instead of the active AFWS of the APR1400. Four train SISs have been implemented as the new design features with four Direct Vessel Injection (DVI) nozzles and four Safety Injection Tanks(SITs) equipped with the flow control fluidic devices. ECCS Core Barrel Duct (ECBD) has been adapted to reduce the ECC bypass flow of the SI coolant to the break during reflood phase of the LBLOCA. The APR+ Standard Safety Analysis Report(SSAR)[7] has been submitted to the regulatory authority for the design certification and it is currently under review by the KINS.

3. Uncertainty Propagation of a postulated LBLOCA for APR+

In order to evaluate the uncertainty propagation of a postulated LBLOCA for the APR+, KINS-REM uncertainty evaluation methodology was applied using MARS-KS APR+ NSSS nodalization as shown in Fig. 1. The uncertainty variables and their ranges were selected from previous regulatory evaluation of the LBLOCA for the APR1400[5]. Due to new design features of the APR+ and model improvement of the MARS-KS code, additional biases should be considered especially for the effects of the blowdown quenching, ECC bypass, fuel conductivity degradation with extended fuel burnup, and recently improved reflood model of the MARS-KS code[9]. These biases were not explicitly accounted in the previous KINS-REM uncertainty evaluations. The uncertainty variables and their ranges for the APR+ LBLOCA and for the reflood model are listed in Tables 1 and 2, respectively.

3.1 MARS-KS APR+ Nodalization

As shown in Fig. 1, the MARS-KS APR+ NSSS nodalization simulates APR+ new design features of the four ECBDs in the downcomer, 4 trains of the SITs with the fluidic devices, 4 trains of the DVIs as well as the 4 trains of the PAFSs. However, PAFS does not actuate during the LBLOCA. Double-ended cold leg guillotine break LBLOCA was simulated as the most limiting LBLOCA as identified in the APR+ SSAR[7]. And according to the N+2 design of the APR+, two units of the EDG(Emergency Diesel generator) among 4 EDGs were conservatively assumed to fail and thus only two SIPs(Safety Injection Pumps)s were assumed to be operable during LBLOCA.

3.2 Uncertainty Variables for the APR+ LBLOCA

Table 1 shows the uncertainty variables, ranges and distribution functions used for the APR+ LBLOCA uncertainty evaluation in this study. These uncertainty variables were selected based on the key safety parameters and the phenomena important during a postulated LBLOCA. Among the 23 uncertainty variables, 18 variables are identical to those of the previous studies[6] for the APR1400 LBLOCA uncertainty propagation evaluation. Vessel upper head temperature, upper plenum loss coefficient and ECBD inlet/outlet loss coefficients are added to account for the blowdown quenching and ECC bypass, during reflood phase, respectively. A. The effect of the extended fuel burnup on the fuel thermal conductivity is implemented through the fuel thermal conductivity uncertainty variable.

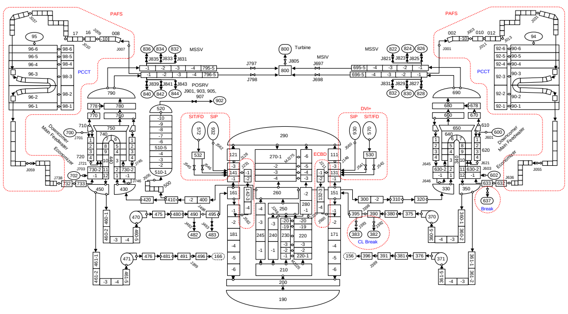

Fig. 1. MARS-KS APR+ Nodalization

Table 1. Uncertainty Variables for APR+ LBLOCA

No.	Models/parameters	Associated Phenomenon	Mean	Range	D[1)
1	Gap conductance (Clad roughness)	Gap conductance	0.95	0.4~1.5	N
2	Fuel thermal conductivity	Stored Energy	1	0.847~1.153	U
3	Core power	stored energy	1	0.98~1.02	N
4	Decay heat	Decay Heat	1	0.934~1.066	N
5	Groeneveld-CHF	Rewet	0.985	0.17~1.8	N
6	Chen-nucleate boiling HTC	Reflood heat transfer	0.995	0.53~1.46	N
7	Transition Boiling Criteria	Rewet	1	0.54~1.46	N
8	Dittus-Boelter HTC (liquid)	Reflood heat transfer	0.998	0.606~1.39	N
9	Dittus-Boelter HTC (vapor)	Reflood heat transfer	0.998	0.606~1.39	N
10	Bromley film boiling heat transfer	Reflood heat transfer	1.004	0.428~1.58	N
11	Break C_D	Critical Flow	0.947	0.729~1.165	N
12	Pump 2-phase head multiplier	pump 2-Φ performance	0.5	0.0~1.0	U
13	Pump 2-phase torque multiplier	pump 2-Φ performance	0.5	0.0~1.0	U
14	SIT actuation pressure (*MPa*)	Reflood	4.307	4.03~4.46	N
15	SIT water inventory (m^3)	Reflood	52.63	45.31~54.57	N
16	SIT water temp. (*K*)	Reflood	302.55	294.1~321.9	U
17	SIT loss coefficient (stand pipe & FD+)	Reflood	20.5 110.5	10.8~25.2 66.3-154.7	N
18	HPSI water temp. (*K*)	Reflood	302.5	283~321.89	U
19	Upper Head Temperature	Blowdown Quenching	603	586~620	N
20	Upper plenum to Core reverse loss coefficient	Blowdown Quenching	20.5	1 ~ 40	N
21	ECBD inlet loss coefficient	ECC bypass	0.25	0.0 ~0.5	N
22	ECBD outlet loss coefficient	ECC bypass	0.5 10.0	f : 0.0~1.0 r : 0.0~20.0	N
23	ECBD Air holes loss coefficient	ECC bypass	5.5	1.0~10.0	N

1) Distribution

Table 2 shows the reflood uncertainty variables and their uncertainties for the MARS-KS global input parameters required for the improved LBLOCA realistic evaluation methodology. The MARS-KS code version used in this study is the improved version for the reflood model[10].

Table 2. Reflood Uncertainty Variables for APR+ LBLOCA

No.	Input Global Parameters	Uncertainty
1	Chen nucleate boiling heat transfer coefficient	±50%
2	AECL CHF Lookup table	±80%
3	Pool boiling CHF(Zuber)	±62%
4	Modified Wesmann correlation	±100%
5	Bromley void weighted QF heat transfer	±50%
6	Forslund-Rohsenow equation	±50%
7	Convection to superheated vapor	±50%
8	Droplet enhancement factor	±50%
9	Interfacial Drag for Bubbly flow	+100%, -50%
10	Ishii-Mishama entrainment	+100%, -50%
11	Weber number	+100%, -50%
12	Interfacial HT of subcooled liquid	+100%, -50%
13	Interfacial area of Inverted annular	+100%, -50%
14	Dry/wet wall criteria	+100%, -50%

15	Transition criteria for void fraction	+100%, -50%
16	Interfacial HT of drop-steam	+100%, -50%

3.3 Result and Discussion

The peak cladding temperature during the LBLOCA with 95% probability at 95% confidence level is determined as the third PCT from the results of the 124 calculations for the 124 random sampling input accounting for the uncertainties of the uncertainty variables. Figure 2 shows the Peak Cladding Temperature of 124 random sampling calculations. Reflood $PCT_{95/95}$ is 1363.2 K and higher than the blowdown $PCT_{95/95}$ of 1275.3 K. Figs. 3 and 4 show the frequencies of the blowdown and reflodd PCTs for the 124 random sampling calculations, respectively.

4. Conclusions

KINS-REM LBLOCA realistic evaluation methodology was used for the regulatory assessment of the APR+ LBLOCA using MARS-KS to evaluate the uncertainty propagation of the uncertainty variables as well as to assess the safety margin during the limiting case of the APR+ double ended guillotine cold leg LBLOCA.

Uncertainty evaluation for the APR+ LBLOCA shows that the reflood PCT with upper limit of 95% probability at 95% confidence level is 1363.2 K and is higher than the blowdown $PCT_{95/95}$ of 1275.3 K. The result shows that the current evaluation of APR+ LBLOCA PCT is within the acceptance criteria of 1477 K ECCS.

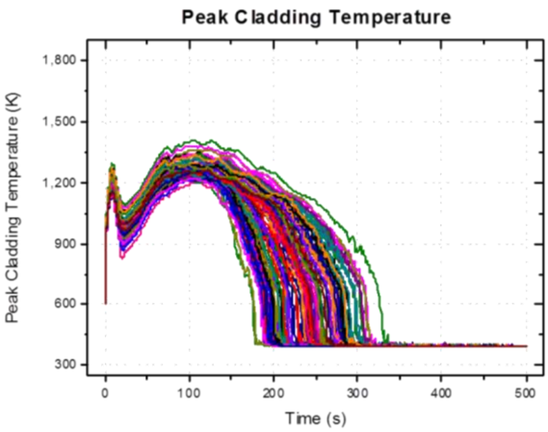

Fig. 2. Peak Cladding Temperature, K

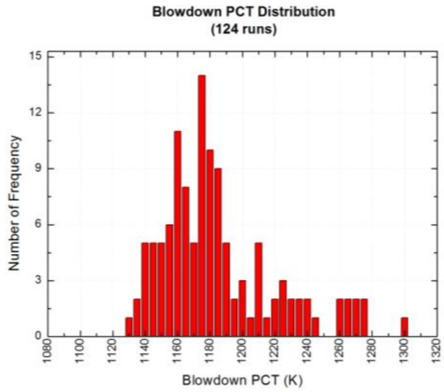

Fig. 3. Frequency of Blowdown PCT, K

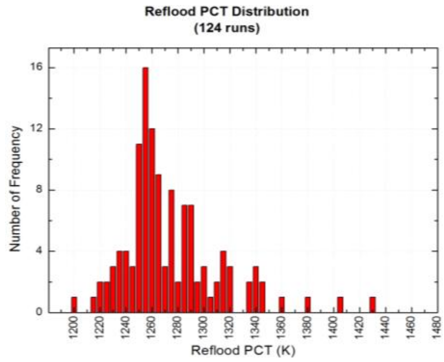

Fig. 4. Frequency of Reflood PCT, K

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