Estimation of Conditional Exceedance Probability for LBLOCA using Monte-Carlo and Alternative Method

Dong Gu Kang*, Do Kyun Lim, Il Suk Lee, Deog Yeon Oh, Yong Seok Choi

Korea Institute of Nuclear Safety, 62 Gwahak-ro Yuseong-gu Daejeon Korea

***littlewing@kins.re.kr**

Introduction

❖ Integrated approach of deterministic and probabilistic method

- Functional failure probability or a Conditional exceedance probability (CEP)
- Requires a lot of computational costs or additional statistical techniques
- Some have used the statistical method, but the direct Monte-Carlo (MC) method has been widely used to calculate the CEP as the computational capability improves.

❖ Direct Monte-Carlo (MC) approach

- Increasingly applied to BEPU and integrated method as an alternative uncertainty propagation and quantification method
- Most of the previous studies using the MC method have not made statistical estimations
- Still being debated that how many samples are required to obtain the result with low uncertainty and high convergence

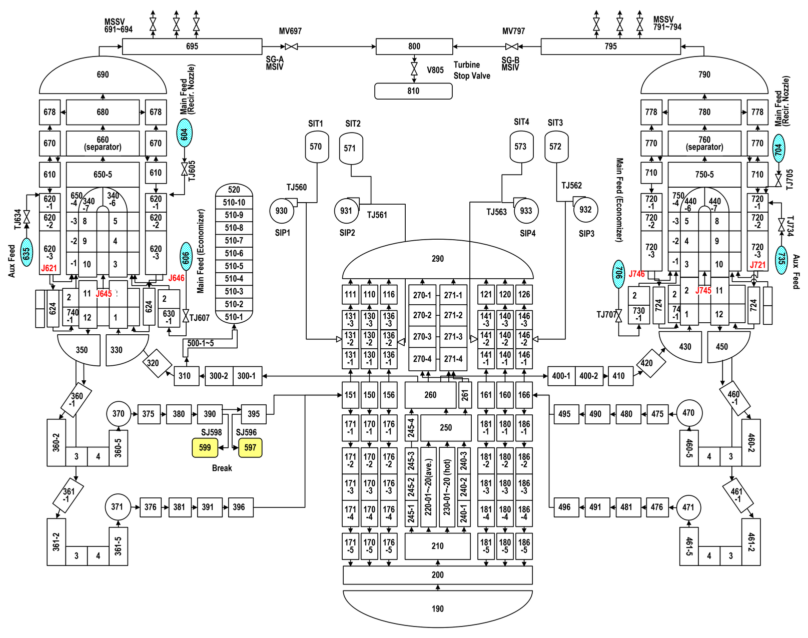
❖ Objective

- LBLOCA calculation using the direct MC method
- Estimation of CEP and their 95% confidence intervals
- Comparison with statistical method for CEP

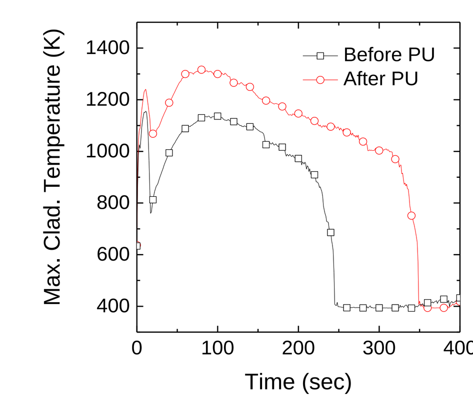
Model Description and MC Calculations

❖ Model description

- 10% power uprate of APR-1400
- LBLOCA by 100% DEGB at RCP Discharge Leg using MARS-KS
- Two SIPs and two SITs were assumed to be available reflecting previous PSA result



Parameter	Before PU	After PU
Core power (MW)	3983.0	4381.3
RCS pump flow (kg/s)	5248.0	5248.0
Primary pressure (MPa)	15.5	15.5
Cold leg temperature (K)	568.0	571.2
Hot leg temperature (K)	600.5	605.8
Upper dome temperature (K)	588.3	593.3
Secondary pressure (MPa)	6.93	7.19
Steam flow (kg/s)	1153.7	1245.3



Model Description and MC Calculations

❖ MC calculations

- 100, 200, 500, 1000, 2000 samples were made by simple random sampling (SRS) and latin hypercube sampling (LHS)
- Calculations using 5000 samples with SRS were performed as the reference of MC calculations
- 18 uncertainty parameters were considered

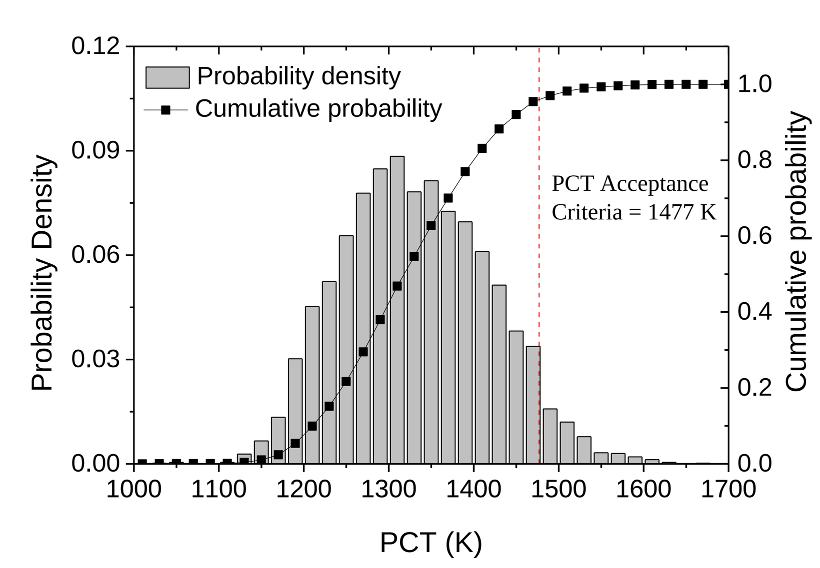
No	Models/Parameters	Distribution	Mean	Uncertainty [a)]
1	Gap conductance	Uniform	0.95	0.55
2	Fuel conductivity	Uniform	1.0	0.153
3	Core power	Normal	1.0	0.01
4	Decay heat	Normal	1.0	0.033
5	Groeneveld CHF lookup table	Normal	0.985	0.2638
6	Chen nucleate boiling correlation	Normal	0.995	0.1505
7	Chen transition boiling correlation	Normal	1.0	0.149
8	Dittus-Boelter liquid convection correlation	Normal	0.998	0.127
9	Dittus-Boelter vapor convection correlation	Normal	0.998	0.127
10	Bromley film boiling correlation	Normal	1.004	0.1864
11	Break CD	Normal	0.947	0.0706
12	Pump 2-f head multiplier	Uniform	0.5	0.5
13	Pump 2-f torque multiplier	Uniform	0.5	0.5
14	SIT actuation pressure (MPa)	Uniform	4.245	0.215
15	SIT water inventory (m^3)	Uniform	49.95	4.65
16	SIT water temperature (K)	Uniform	308	14.0
17	SIT loss coefficient	Normal	18.0	2.33
18	IRWST water temperature (K)	Uniform	302.5	19.5

Results and Discussion

❖ Direct Monte-Carlo method

- The 95% confidence interval for CEP from samples

$$CI_{P_{exc},0.95} = P_{exc} \pm 1.96 \cdot SE_{P_{exc}} = P_{exc} \pm 1.96\sqrt{\frac{P_{exc}\cdot(1-P_{exc})}{n}}$$



<Reference calculation result>

Sample size	SRS		LHS	
	P_{exc}	$SE_{P_{exc}}$	P_{exc}	$SE_{P_{exc}}$
100	0.0600	0.0237	0.0700	0.0255
200	0.0700	0.0180	0.0750	0.0186
500	0.0520	0.0099	0.0780	0.0120
1000	0.0720	0.0082	0.0680	0.0080
2000	0.0715	0.0058	0.0690	0.0057
5000	0.0662	0.0035		

- 95% CI for CEP can be calculated

Results and Discussion

❖ Johnson's normal distribution transformation method

$$z = \gamma + \eta \cdot f_i(x, \epsilon, \lambda)$$

$$f_i(x,\epsilon,\lambda) = \ln\left(\frac{x-\epsilon}{\lambda+\epsilon-x}\right): \quad S_B \text{ distribution}$$

$$f_i(x,\epsilon,\lambda) = \ln(x-\epsilon): \quad S_L \text{ distribution}$$

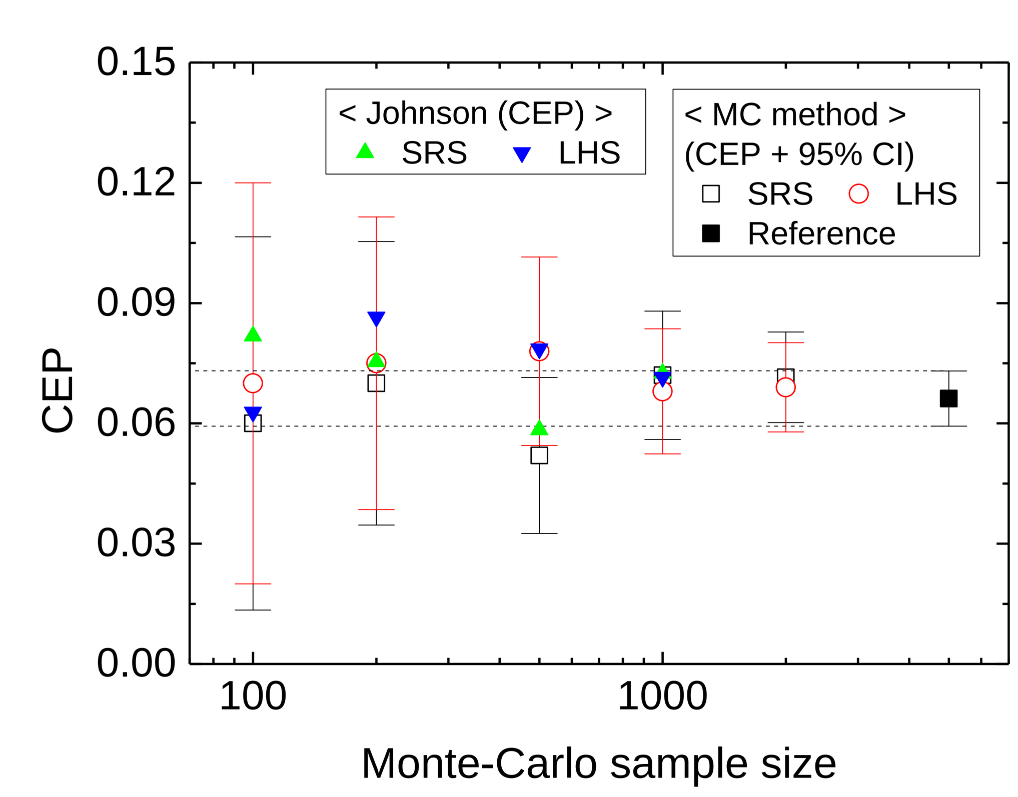
$$f_i(x,\epsilon,\lambda) = \text{asinh}\left(\frac{x-\epsilon}{\lambda}\right): \quad S_U \text{ distribution}$$

Sample size	SRS						LHS					
	type	η	γ	λ	ϵ	p-value	type	η	γ	λ	ϵ	p-value
100	S_B	1.08	-0.03	450	1130	0.73	S_B	1.01	0.22	413	1153	0.59
200	S_L	5.71	-34.9		888	0.96	S_B	1.55	0.81	641	1099	0.98
500	S_B	1.11	-0.03	442	1132	0.65	S_B	2.68	2.44	1178	999	0.92
1000	S_B	3.15	2.67	1328	942	0.36	S_B	3.25	2.51	1320	925	0.52
2000	S_B	3.21	1.87	1209	910	0.55	S_B	1.75	0.75	674	1074	~ 0.00
5000	S_B	2.14	1.08	840	1022	~ 0.00						

- For example, for 100 sample size case with SRS, the transformed data followed a normal distribution with a mean of -0.068 and a standard deviation of 0.967
- $P_{exc} = P(PCT > 1477\ K) = P(z > 1.278) = 0.0818$

Results and Discussion

❖ Comparison of CEPs by Monte-Carlo and Johnson transformation method



- Large variation and not within 95% CI of reference for Johnson method less than 500 samples
- Too large CI for small samples
- Narrow CI for 1000 and more samples
- CEP values of MC method also were within the 95% CI of the reference result and tended to converge
- Too small standard error decrease for 1000 or more samples

- Considering both computational cost and benefit of increase in sample size, the MC method using 1,000 samples could yield reasonable CEP result.