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Estimation of PCT95/95 for LBLOCA using Monte-Carlo and Wilks Method

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Introduction

❑ Direct Monte-Carlo (MC) approach

- Increasingly applied to BEPU methodology 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.

❑ Objectives

- LBLOCA calculation using the direct MC method
- Statistical evaluation of PCT data with respect to sample size and sampling method
- Estimation of PCT95 and their 95% confidence intervals
- Comparison with Wilks' method for PCT95/95.

Model Description and MC Calculations

❑ Model Description

- 10% power uprate of APR-1400 nuclear power plant
- 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

❑ 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

Model Description and MC Calculations

❑ MC Calculations

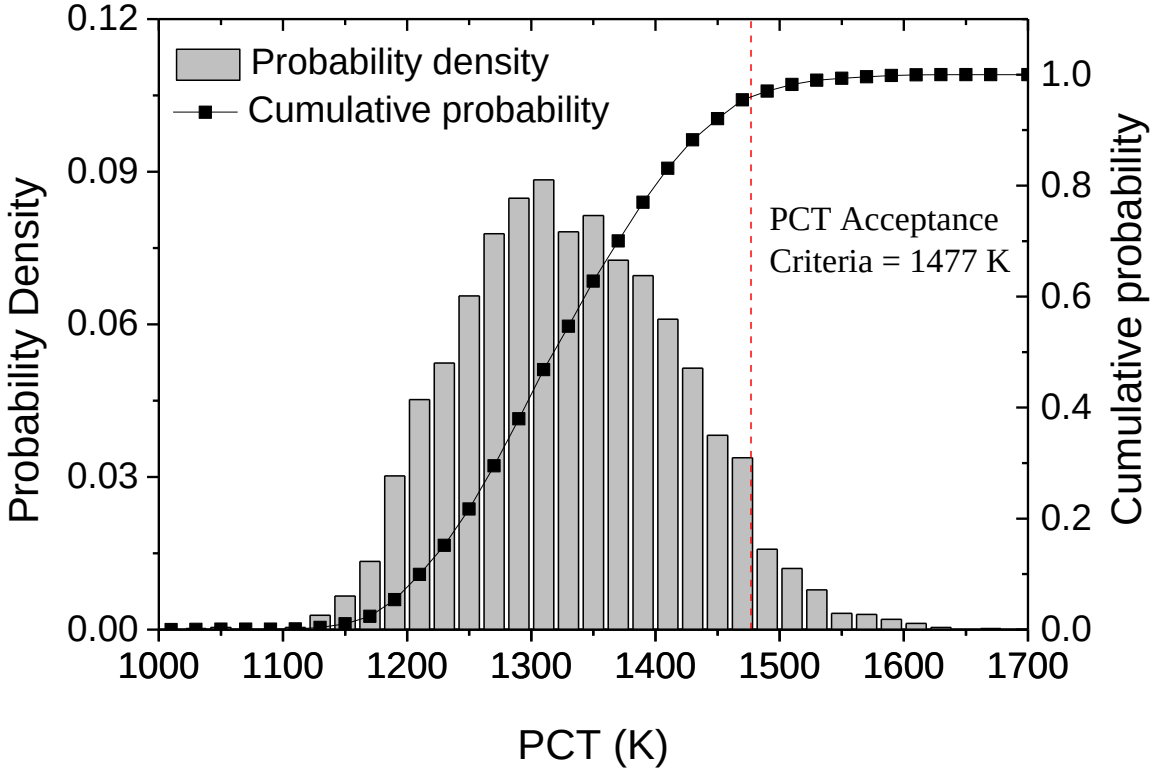
- 18 uncertainty parameters were considered

No	Models/Variables	Distribution	Mean	Uncertainty
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	Normal	0.985	0.2638
6	Chen nucleate boiling	Normal	0.995	0.1505
7	Chen transition boiling	Normal	1.0	0.149
8	Dittus-Boelter liquid convection	Normal	0.998	0.127
9	Dittus-Boelter vapor conv.	Normal	0.998	0.127
10	Bromley film boiling	Normal	1.004	0.1864
11	Break CD	Normal	0.947	0.0706
12	Pump 2-f head	Uniform	0.5	0.5
13	Pump 2-f torque	Uniform	0.5	0.5
14	SIT pressure (MPa)	Uniform	4.245	0.215
15	SIT inventory (m^3)	Uniform	49.95	4.65
16	SIT temperature (K)	Uniform	308	14.0
17	SIT loss coefficient	Normal	18.0	2.33
18	IRWST temperature (K)	Uniform	302.5	19.5

Model Description and MC Calculations

❑ MC Calculations

- Probability density and cumulative probability of PCT for the reference calculation



Direct Monte-Carlo Method

❑ Normality of PCT Data

- Shapiro-Wilk normality test (p-values of MC calculations)

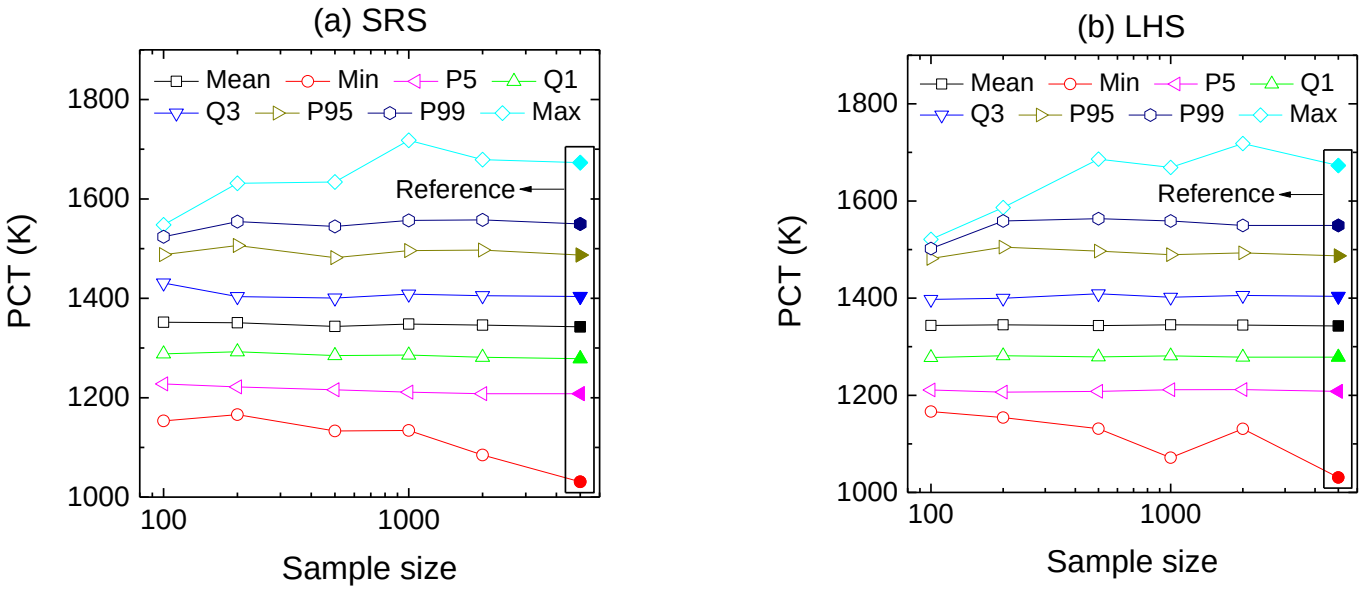
Sample size	SRS	LHS
100	0.209	0.102
200	0.015	0.066
500	0.078	5.44E-4
1000	2.444E-5	1.824E-4
2000	1.833E-6	3.063E-9
5000	2.271E-13	

- For both SRS and LHS, if the sample size is more than 1000, the normality was not satisfied.
- Especially for LHS, the p-value decreased as the sample size increases

Direct Monte-Carlo Method

❑ Trends of Descriptive Statistics

- Trends of mean and some quantiles of PCT for the SRS and the LHS

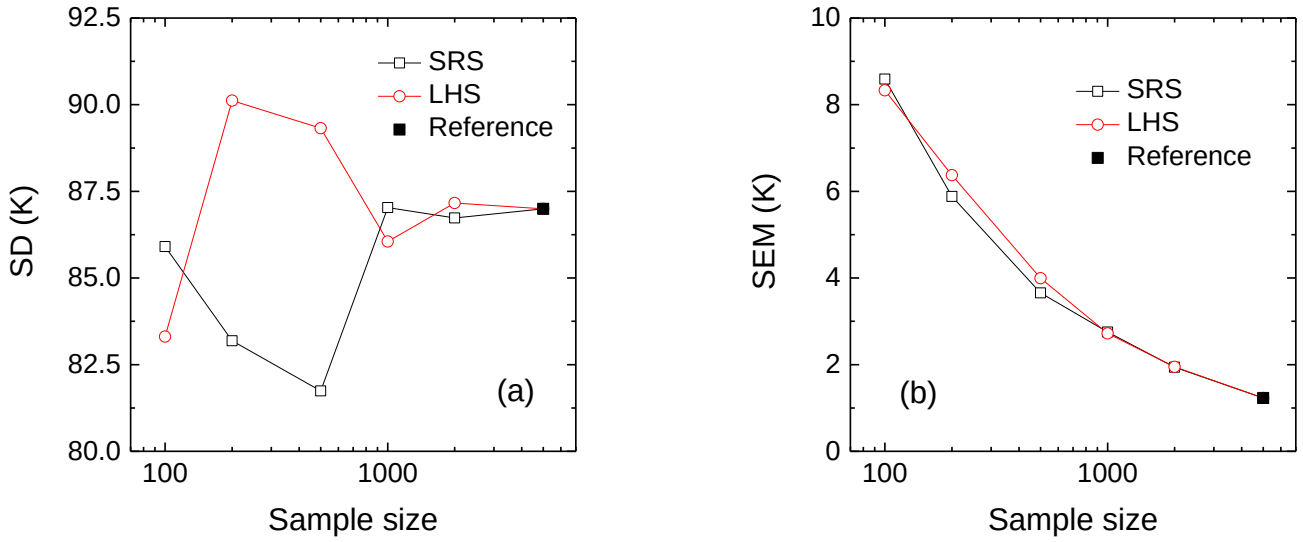


- The statistics except for the minimum and the maximum, almost converged after calculations with 500 and 200 samples for the SRS and the LHS, respectively

Direct Monte-Carlo Method

❑ Trends of Descriptive Statistics

- Trends of standard deviation (SD) and standard error of mean (SEM) of PCT



- SD tended to converge from 1000 sample size, and the SEM decreased as the sample size increases.

Direct Monte-Carlo Method

PCT95 and its 95% CIs

- the 95% CI of PCT95 ($\mathrm{CI}_{PCT95,0.95}$)

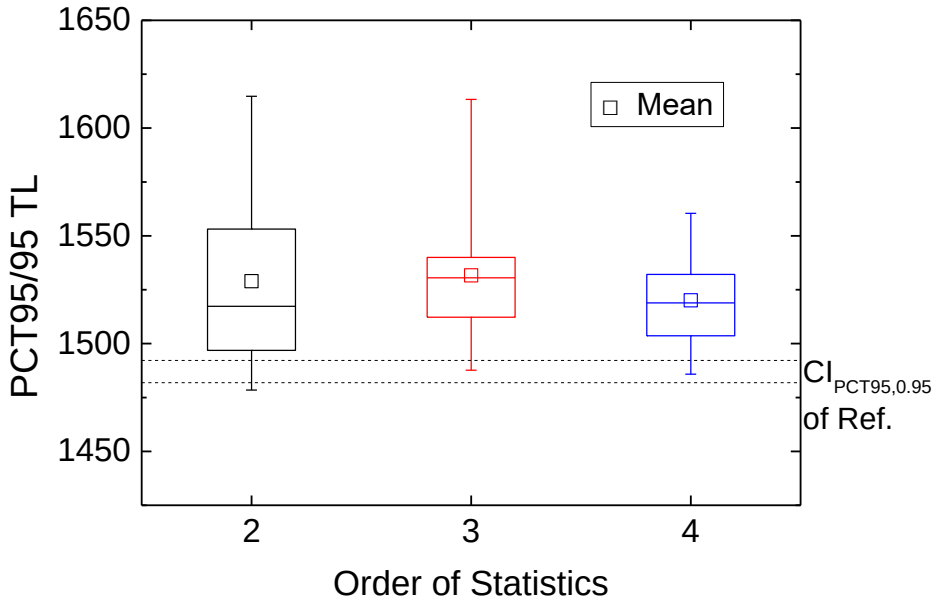
$$\mathrm{CI}_{PCT95,0.95} = PCT95 \pm 2 \cdot SE_{Q_{0.95}}$$
$$\approx PCT95 \pm 2 \cdot 2.11 \cdot SEM$$

  - where $SE_{Q_{0.95}}$ is the standard error of 95 percentile and SEM is the standard error of mean.
  - The SEM is defined as $\mathrm{SD}/\sqrt{n}$ where n is the sample size

Comparison with Wilks' Method for PCT95/95

❑ PCT95/95 Tolerance Limit (TLs) with Wilks' Method

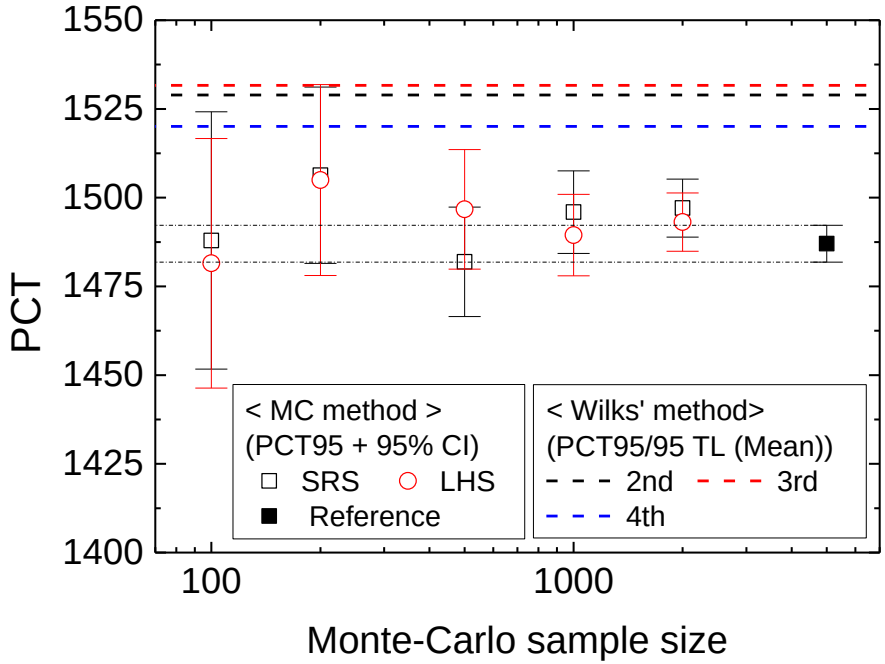
- 30 newly sampled PCT95/95 TLs for the 2nd, 3rd, and 4th order



- Means of PCT95/95 TLs by Wilks' method were not within the reference result, showing more conservative
- For better accuracy and less variability, the higher order of statistics should be used.

Comparison with Wilks' Method for PCT95/95

❑ Comparison of PCT95/95 by MC and Wilks' method



- Only when using 500 or more samples in the MC calculations, the upper confidence limit (CL) could be lower than the mean of PCT95/95 TL using the 4th order of Wilks' method.

Comparison with Wilks' Method for PCT95/95

❑ Comparison of PCT95/95 by MC and Wilks' method

- When the sample size increases from 1000 to 2000 and from 2000 to 5000, the SE of PCT95 decreased only by less than ~ 2 K
- When the sample size is more than 1000, the PCT95 did not fluctuate significantly
- Considering both computational cost and benefit of increase in sample size, the MC method using 1,000 samples could remedy the shortcomings of Wilks' method (i.e., considerable conservatism and substantial variability) and provide reasonable PCT95/95 result.

Conclusions

- When using direct MC method, a statistical estimation and sensitivity studies need to be made to obtain reliable result with low CI and high convergence.
- The limitations of the Wilks' method (i.e., considerable conservative bias and substantial variability) was identified, and it was confirmed that the MC method could replace them.
- Considering all of computational cost, benefit of increase in sample size and statistics convergence, the MC method using 1000 samples could remedy the shortcomings of Wilks' method and yield reasonable PCT95/95 results.
- In addition, when the sample size was 1000 or more, the effect of sampling methods was not significant.