Evaluation of Pin Power Distribution Uncertainty for KRITZ-2:13 and KRITZ-2:19 critical experiment benchmarks by McCARD

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Introduction and Objective

- ❖ KRITZ reactor operated at Studsvik, Sweden, during the first half of the 70s.
- ❖ KRITZ benchmark is to investigate the predictive capability of various codes and nuclear data libraries and to compare the accuracy of the predictions.
- ❖ KRITZ-2 reactor included light water moderated rectangular lattices with uranium oxide and mixed-oxide fuel rods at cold and hot temperatures.
  - UO2 fuel based three critical experiments (KRITZ-2:1h, KRITZ2:13c, and KRITZ-2:13h) , MOX fuel based two critical experiments (KRITZ-2:19c and KRITZ-2:19h).

❖ Objective

- To estimate the accuracy of the criticality and pin power distribution capability for Monte Carlo (MC) particle transport code, McCARD
- To examine the sensitivity due to the evaluated nuclear data library, ENDF/B-VII.1, ENDF/B-VIII.0, JENDL-4.0, and JENDL-5.0 cross section libraries were used for the benchmark analyses. (KRTIZ-2:13c, KRITZ-2:13h, and KRITZ-2:19c)

Modeling and Monte Carlo simulation

❖ Modeling

- McCARD eigenvalue calculations were conducted on 1,000 cycles including 50 inactive cycles with 10,000 neutron histories per cycle.
  - ➢ Table I shows the specification of the KRITZ-2:13 and KRITZ-2:19c benchmarks.
  - ➢ Figures 1 and 2 present horizontal and vertical cross sections of the KRITZ-2:13c benchmark by the McVIEW.

Table.1 Configuration of the KRITZ-2:13, 2:19c core

Parameters	KRITZ-2:13c	KRITZ-2:13h	KRITZ-2:19c
Rod number	44×44		25×24
Rod type	UO_2		MOX
Pin pitch (mm)	16.3500	16.4150	18.000
Water height (mm)	961.7	1109.6	665.6
Temperature (°C)	22.1	243.0	21.1

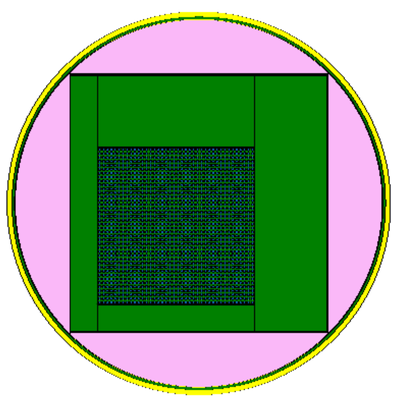

Fig.1 Horizontal (X-Y plane) cross section

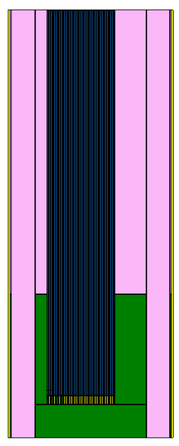

Fig.2 Vertical (X-Z plane) cross section

❖ Criticality capability

- Table II shows the k_{eff} values of the KRITZ-2:13 and KRITZ-2:19c benchmarks by the McCARD with various evaluated nuclear data library.
  - ➢ Measured benchmark k_{eff} is 1.0, the maximum error of compared with benchmark was 0.35% in KRITZ-2:19c with JENDL-4.0.

Table.2 k_{eff} for KRITZ-2:13, KRITZ-2:19c by McCARD

Core	KRITZ-2:13c	KRITZ-2:13h	KRITZ-2:19c
ENDF/B-VII.1	0.99950	0.99779	1.00228
ENDF/B-VIII.0	0.99830	0.99835	0.99819
JENDL-4.0	0.99953	0.99761	1.00348
JENDL-5.0	0.99980	0.99900	0.99874

❖ Pin power distribution capability

- Figures 3 and 4 presents pin power distributions calculated by the McCARD code with four evaluated nuclear data libraries.
  - ➢ Calculated pin power values normalized to the maximum pin power.
  - ➢ It was calculated by averaging the value of the pin symmetrical in the core.

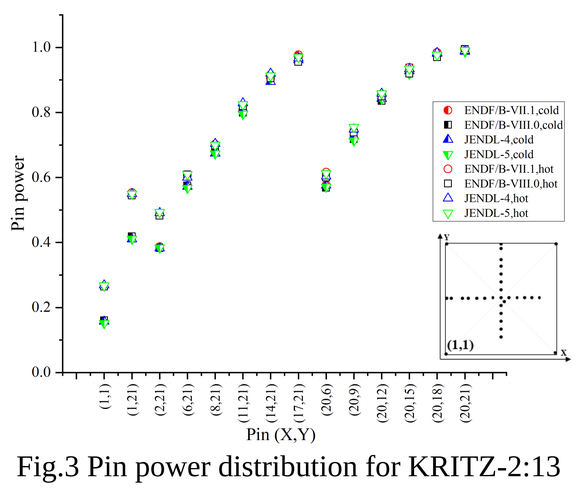

Fig.3 Pin power distribution for KRITZ-2:13

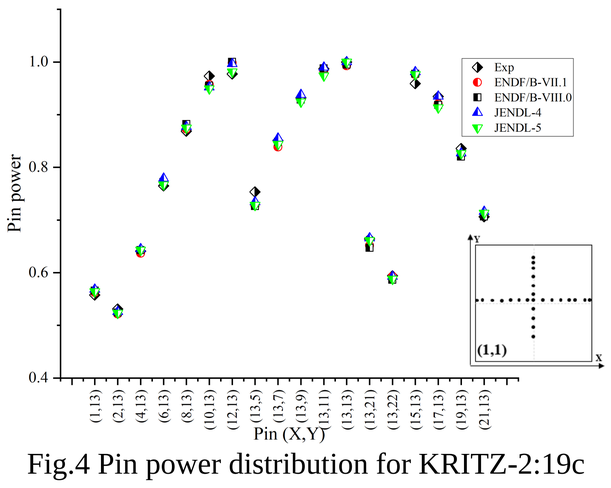

Fig.4 Pin power distribution for KRITZ-2:19c

Results

❖ RMS error of pin power distribution by the McCARD

- Table III represents the root mean square (RMS) errors for the fuel pin power distributions using the ENDF/B-VII.1, ENDF/B-VIII.0, JENDL-4.0 and JENDL-5.0 evaluated nuclear data libraries.
  - ➢ Maximum RMS errors of KRITZ-2:13c and KRITZ-2:13h were 1.00% and 1.43 % in ENDF/B-VII.1.
  - ➢ In the KRITZ-2:19c, maximum RMS error was 1.32% with ENDF/B-VIII.0.
  - ➢ Overall, the results were good agreement between the measurements and McCARD.

Table.3 RMS error of pin power distributions by the McCARD with various evaluated nuclear data libraries

RMS error (%)	ENDF/B-VII.1	ENDF/B-VIII.0	JENDL-4.0	JENDL-5.0
KRITZ-2:13c	1.00	0.87	0.78	0.66
KRITZ-2:13h	1.43	0.70	1.30	1.37
KRITZ-2:19c	1.22	1.32	1.13	1.19

❖ Uncertainty analysis of pin power distributions by Wilk's formula

- Wilk's formula can apply the estimation of their uncertainties regardless of the population.
  - ➢ Equation (1) shows the one-sided order Wilk's formula to obtain the number of input sample to calculate β×100 (%) confidence that will be located above the α×100 (%).
  - ➢ 78 samples were used in this study, the Wilk's formula considering the first-order one sided 95% confidence 95% upper limit $X^{95\times95}$ by Eq. (2) was used.

$$\sum_{k=0}^{n-p} nC_k\, \alpha^k (1-\alpha)^k \geq \beta \qquad (1)$$

$$X^{95\times95} = \bar{X} + k_s^{95\times95} \cdot \sigma_s(X) \qquad (2)$$

- Figures 5~8, observed that uncertainties of the pin power distribution by the McCARD code with ENDF/B-VII.1, ENDF/B-VIII.0, JENDL-4.0, JENDL-5.0 are 2.62 %, 2.71 %, 2.76 % and 2.37 %, respectively.

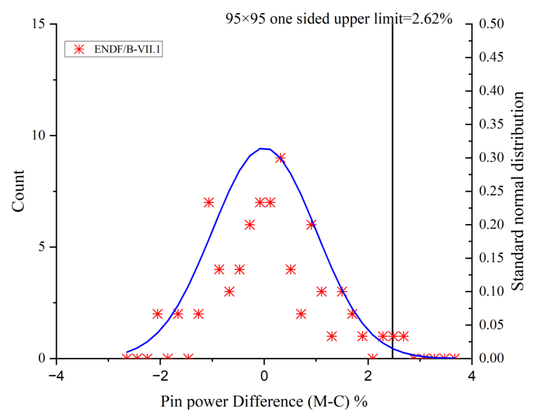

Fig.5 Uncertainty of pin power with ENDF/B-VII.1 library

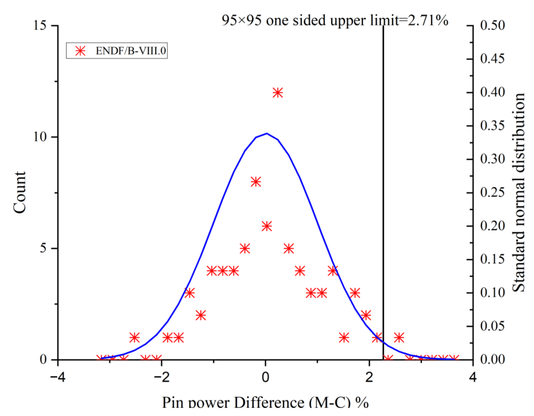

Fig.6 Uncertainty of pin power with ENDF/B-VIII.0 library

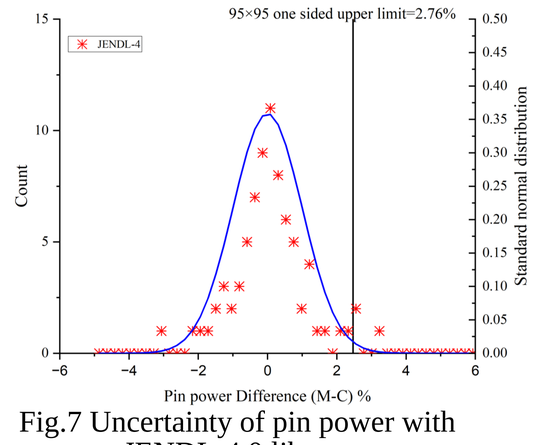

Fig.7 Uncertainty of pin power with JENDL-4.0 library

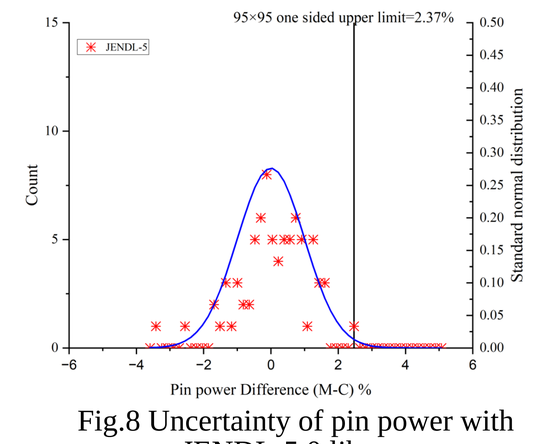

Fig.8 Uncertainty of pin power with JENDL-5.0 library

Conclusion

- ❖ The k_{eff} errors from reference data to measured data were less than 0.35 % while the RMS errors of the pin power distributions are less than 1.43%.
- ❖ Up-to-date libraries (i.e., ENDF/B-VIII.0 and JENDL-5.0) predict the criticality better than the existing libraries (i.e., ENDF/B-VII.1 and JENDL-4.0).
- ❖ Uncertainty analyses for the pin-power prediction by the McCARD were performed with the one-sided order Wilk's formula. Maximum uncertainty is 2.76%.

❖ Future work

- A further in-depth analysis on the effect for variance bias will be carried out to confirm the source of the errors in the pin power distribution.