Procedure for an Uncertainty Evaluation in the Nuclear Peaking Factor Measured by SPND System

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1. Introduction

The principal in-core instrumentation in CE-type fuel assembly reactors is provided by a string of four or five short rhodium Self-Powered Neutron Detectors (SPNDs) arranged axially in the central water holes of about 20~30% of all fuel assemblies. The purpose of this paper is to describe how to quantify the numerical uncertainties associated with the use of the SPND system when the signals are processed through the INCA/CECOR systems in inferring the core power peaking factors(F_q, F_r, F_{xy}) [1]. The overall uncertainties determined for these peaking factors are in the form of 95%/95% probability/confidence one-sided tolerance limits.

In this paper, a conventional procedure for an uncertainty evaluation of a nuclear peaking factor measured by fixed rhodium SPND is described and a direct 3-D power connection method developed in KAERI for the synthesis of a detailed power distribution is introduced briefly.

2. Procedure for an Uncertainty Evaluation

Uncertainty evaluation is classified as three parts, i.e., measurement, synthesis and combined uncertainty. Measurement uncertainty means that an uncertainty associated with the measurement of an assembly average power in instrumented locations. This can be obtained by comparing detailed calculations of the fuel assembly box power with those inferred from in-core measurements with the INCA system using SPNDs.

Synthesis uncertainty, called a software dependent uncertainty is caused by the radial coupling from instrumented to un-instrumented assemblies and by the axial expansion of the power profile and by the translation of an assembly power to pin power using the pin-to-box factors. Then combined uncertainty is determined by a statistical combination of the measurement uncertainty with the synthesis uncertainty.

2.1 Core Peaking Factors

For the axially arranged rhodium detector slices, core peaking factors are defined by Eq. (1) to Eq. (3) and measurement and synthesis uncertainties are evaluated for those core peaking factors, respectively. Figure 1 shows the calculational method for the core peaking factors in the INCA/CECOR system

- 3-Dimensional Peaking Factor

$$F_q = \frac{\underset{x,y,z}{Max}\left[P(x,y,z)\right]}{\frac{1}{V}\iiint P(x,y,z)dxdydz} \quad (1)$$

- Axially Integrated Radial Peaking Factor

$$F_r = \frac{\underset{x,y}{Max}\left[\frac{1}{H}\int P(x,y,z)dz\right]}{\frac{1}{V}\iiint P(x,y,z)dxdydz} \quad (2)$$

- Planar Radial Peaking Factor

$$F_{xy}(z_i) = \frac{\underset{x,y}{Max}\left[P(x,y,z_i)\right]}{\frac{1}{V}\iint P(x,y,z_i)dxdy} \quad (3)$$

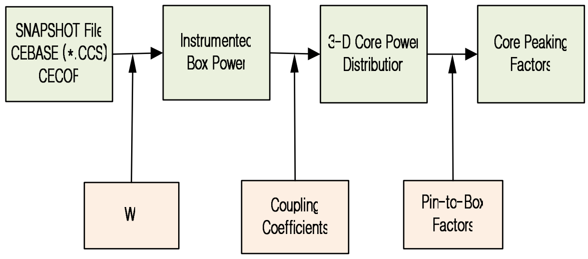

Fig. 1. Calculational method for the core peaking factors in the INCA/CECOR system.

2.2 Poolability Test

Pooling of data can be undertaken for the purpose of combining data from all levels (F_{xy} only), all time points and/or all cycles. In those cases where pooling of data is undertaken, physical assessment of poolability is judged. If the variation of the sample variance is indeed small compared to their magnitude, pooling is deemed to be justified on physical grounds. Thus confirmation of the justification is obtained by applying various statistical tests, i.e., Bartlett test which assumes normality.

If pooling is not confirmed on the basis of the Bartlett test, worst case values are taken instead of pooled values. The worst case is taken as the one with the largest variance. For those cases that do pass the Bartlett test for a time point pooling and also are worst cases for a cycle pooling, a test on normality is done. If this test does not refute normality, the data is accepted as the final estimate of the variance. If the normality test is not passed, the poolability is tested on the basis of a χ^2 test of homogeneity. A general flow diagram of this procedure is shown in figure 2.

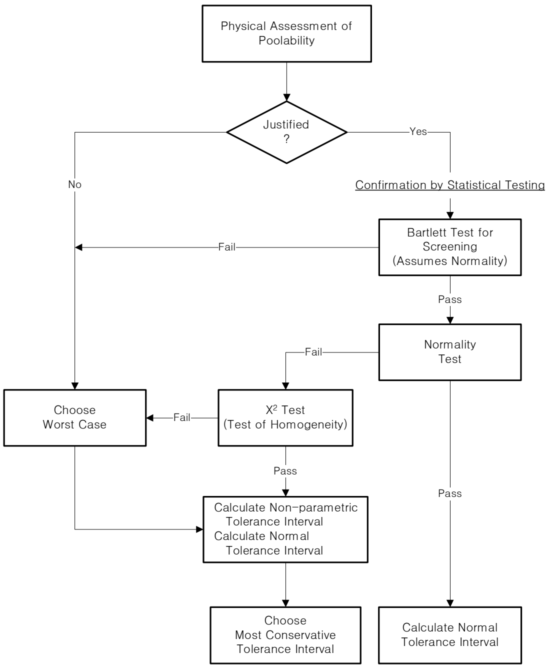

Fig. 2. General procedure for justifying and a confirmation of a poolability.

2.3 One-sided Tolerance Limits Computing

For a normal distribution the one-sided tolerance limit, when needed, is obtained from the total sample size and the appropriate number of degrees of freedom (N_{DEG}). For a distribution that does not pass normality tests, one-sided tolerance limit is calculated by a non-parametric method [2]. An equivalent k value is then obtained by dividing the tolerance limit by the sample standard deviation and the equivalent number of degrees of freedom is obtained from a table [3]. In cases where the method for normal distributions provides a more conservative estimate of the one-sided tolerance limit, its values for N_{DEG} and k are taken instead of the values obtained by the non-parametric method. The values of S and N_{DEG} obtained for core peaking factors are used in the combined uncertainty analysis.

2.4 Combination of Box Synthesis and Measurement Uncertainties

Overall combined uncertainty is determined by a statistical combination of the basic measurement uncertainty, synthesis uncertainty and pin-to-box uncertainties. Final form for the overall combined uncertainty is as follows:

$$\overline{D} = \overline{D}_{BM} + \overline{D}_{BS} + \overline{D}_{PC} + \overline{D}_{PS} \quad (4)$$

$$S^2 = S^2{}_{BM} + S^2{}_{BS} + S^2{}_{PC} + S^2{}_{PS} \quad (5)$$

where, $\overline{D}$, S^2 mean the average bias and sample variance for the power differences(CECOR-3D Code) and lowercase BM, BS, PC, PS mean the box power measurement, box power synthesis, pin-to-box calculation and pin-to-box synthesis, respectively. Then overall degrees of freedom, f is determined by Eq. (6)

$$\frac{S^4}{f} = \frac{S^4_{BM}}{f_{BM}} + \frac{S^4_{BS}}{f_{BS}} + \frac{S^4_{PC}}{f_{PC}} + \frac{S^4_{PS}}{f_{PS}} \quad (6)$$

The 95%/95% probability/confidence multiplier, $k_{95/95}$ is determined according to the degrees of freedom and then lower one-sided tolerance limit for the deviation between INCA/CECOR and the true power then is determined by Eq. (7)

$$\overline{D} - k_{95/95} S \ \ (for\ F_q,\ F_r,\ F_{xy}) \quad (7)$$

These uncertainties are applicable to reactors employing axially sliced fixed rhodium. Also these uncertainties may be used in conjunction with Technical Specification limits for a plant operation and safety analysis.

3. Direct 3-D Power Connection Method

In KAERI, 3-dimensional power distribution synthesis method has been developed using measured SPND data and a neutronics code [4]. In this method, instrumented node powers are determined from the detector powers by using power sharing factors and the un-instrumented node powers are determined by using power connection factors. A coefficient library for the 3-D power synthesis is functionalized as a function of the burnup, core power and control rod position.

By employing a 3-D power connection method, it is expected that a core power distribution could be synthesized more accurately when compared with the conventional CECOR method which uses coupling coefficients and a Fourier expansion method. In addition, a synthesis uncertainty will be evaluated with the 3-D power connection method for commercial Korean nuclear power plants and compared with that of the CECOR method in the future.

Acknowledgements

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REFERENCES

[1] A. Jonsson et al., "Evaluation of Uncertainty in the Nuclear Power Peaking Measured by the Self-Powered, Fixed In-Core Detector System", CENPD-153-P, Rev. 1-P-A, Combustion Engineering, Inc. 1980.
[2] W.J. Conover, "Practical Non-parametric Statistics", J. Wiley and Sons, Inc., 1971.
[3] D.B. Owen, "Factors for One-Sided Tolerance Limits and for Variables Sampling Plans", Sandia Corporation Monograph, SCR-607, 1963.
[4] J.Y. Cho et al., "3-D Power Synthesis Methodology for SMART Core Monitoring System", KAERI/RR-3399, 2007.