# Uncertainty Evaluation for SMART Synthesized Power Distribution

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## 1. Introduction

A synthesized power distribution for SMART core is produced by SSUN (SMART core SUpporting system coupled by Nuclear design code). SSUN runs coupled with the MASTER [1] neutronics code and generates the core 3-D synthesized power distribution using DPCM3D. DPCM3D is similar to the 3DPCM [2] except for the coefficient library. The MASTER code plays a role to provide the DPCM3D constants to the SSUN code at core state. DPCM3D produces the 3-D power distribution by using the detector signals and the power coupling coefficients. The synthesized power distribution generated by the SSUN code is not a true solution and contains uncertainties originated from the measurement and the DPCM3D coefficient errors. In this paper, the overall uncertainty of the synthesized power distribution of the SSUN code is evaluated.

## 2. Methods and Results

Fig. 1 shows the uncertainty evaluation procedure. A 3-D power distribution generated by the MASTER code is used both to produce a virtual power distribution and to generate the DPCM3D coefficients. Virtual power distribution which is inferred as a true power distribution is produced by adding CASMO/MASTER uncertainty [3] statistically and used to generate detector signals. A synthesized 3-D power distribution is generated by using the DPCM3D coefficients and the detector signals. Uncertainty of the synthesized power distribution is evaluated using the error distribution.

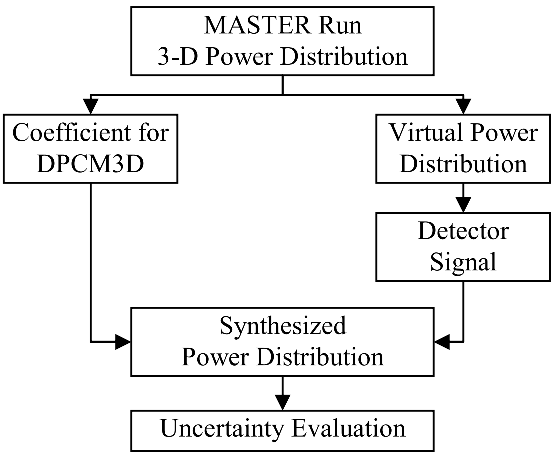


Fig. 1. uncertainty evaluation procedure

### *2.1 Virtual Power Distribution*

Reference 3 lists the uncertainties not only for the 3-D power distribution but also for the axially integrated and the planar power distributions. To satisfy the three power distribution uncertainties for the virtual power distribution, the following procedure is used.

(1) Virtual axial power distribution: $P'(z) = P(z) + \delta P$

(2) Axially integrated virtual power distribution:
$$P'(r) = P(r) + \delta P$$

(3) Ratio distribution: $F(r) = P'(r)/P(r)$

(4) Planar virtual power distribution:
$$P'(x,y) = F(r)P(x,y) + \delta P$$

(5) 3-D virtual power distribution:
$$P'(x,y,z) = P'(z)P'(x,y)$$

In this procedure, the MASTER power error distribution is assumed to be normal, and $\delta P$ 's in procedure (1), (2) and (4) are all generated by the random numbers within the uncertainties. The standard deviation in procedure (1) is determined to be:

$$\frac{\sigma_{Fz}^2}{\overline{P(z)^2}} = \frac{\sigma_{Fq}^2}{\overline{P(z)^2}\,\overline{P(x,y)^2}} - \frac{\sigma_{Fxy}^2}{\overline{P(x,y)^2}}, \tag{1}$$

where $\overline{P(z)^2}$ and $\overline{P(x,y)^2}$ mean the square averages of the axial and the planar power distributions. The standard deviation in procedure (4) is determined as:

$$\delta\sigma_{Fxy}^2 = \sigma_{Fxy}^2 - \sigma_{Fr}^2 . \tag{2}$$

### *2.2 Uncertainty Evaluation Procedure*

The $\chi^2$ goodness of fit test is used to determine if the error distribution is normal. This test calculates the quantity:

$$\chi_m^2 = \sum_{i=1}^{K} \frac{(O_i - E_i)^2}{E_i}, \tag{3}$$

where $O_i$ and $E_i$ are the observed and expected distribution. If the calculated $\chi^2$ value is less than the critical value, the hypothesis of the normal error distribution is accepted.

If the error distribution turns out to be normal distribution, the Bartlett test would be used for data pooling, or KRUSKAL WALLIS test [4] would be used. The Bartlett test calculates the following quantity:

$$\chi^2_{K-1} = \frac{\nu_e \ln S_p^2 - \sum_{i=1}^{K} \nu_i \ln S_i^2}{1 + \frac{1}{3(K-1)}\left(\sum_{i=1}^{K} \frac{1}{\nu_i} - \frac{1}{\nu_e}\right)}, \quad (4)$$

where, $\nu_i$ and $S_i^2$ are the degree of freedom and the variance of sample *i*, and $K$ , $\nu_e$ and $S_p^2$ are the number of samples, total degree of freedom and the pooled variance.

The KRUSKAL WALLIS test calculates the following quantity:

$$K = \frac{12}{N(N+1)} \sum_{i=1}^{J} n_i \left( \frac{R_i}{n_i} - \overline{R} \right)^2 , \quad (5)$$

where $n_i$ and $R_i$ are the sample size and the rank average of sample *i* and $\overline{R}$ is the pooled rank average. If the calculated values are less than the corresponding critical $\chi^2$ values, the data pooling would be performed.

Uncertainty is quantified by the one-sided tolerance limit. If the error distribution turns out to be normal, the one-side tolerance limit would be obtained from the normal distribution table, or non-parametric method would be used.

### *2.3 Results*

Fig. 2 shows the in-core detector positions in SMART core. Total 29 detector assemblies are loaded in radial, and each detector assembly contains 4 detector units in axial.

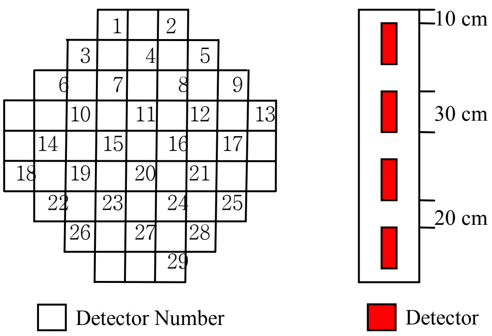


Fig. 2. SMART Detector Position

Power distribution error analysis is performed from the initial core to the 5th cycle which is considered to be equilibrium cycle. In each cycle, 5 burnup points of BOC, 240, 480, 750 and EOC are analyzed. In each burnup point, total 16 cases are analyzed by varying the power level and the control rod positions. In each case, 10 virtual power distributions are generated. In the generation of the virtual power distribution, the uncertainties of 6.0 %, 5.0 % and 4.0 % [3] are used for the 3-D, the planar and the axially integrated power distributions, respectively.

The synthesized power error distribution turns out to be non-normal, which is mainly due to the detector signal. The errors for the detected nodes are less than those for the undetected nodes, and the error distribution is slim compared with the normal distribution. Therefore, the KRUSKAL WALLIS test is used for the data pooling and the non-parametric method is applied to the uncertainty evaluation.

The pooling test shows that the 10 error distributions can be pooled because the K value is less than critical $\chi^2$ value of 16.92. Also the error distributions for 16 cases are pooled because the K value is less than critical $\chi^2$ value of 25.0. The pooling tests for the burnup points and cycles are not performed because the error standard deviation for the pooled data over 10 sets and 16 cases is sufficiently flat, and the pooled data showing the maximum standard deviation is used to evaluate the uncertainties.

Table 1 shows the evaluated uncertainties for the synthesized power distribution. Uncertainties for the 3-D, the planar and the axially integrated node power distributions are evaluated to be 5.40 %, 4.89% and 3.67 %, respectively. In the uncertainty evaluation for the node-wise pin peaking factor distribution, the CASMO uncertainty of 2.0 % [3] is used. Uncertainties for the 3-D, the planar and the axially integrated pin peaking factor distributions are turned out to be 5.76 %, 5.29% and 4.18 %, respectively.

Table I: Uncertainties of the Synthesized Power Distribution for SMART Core (%)

| Parameters | Node | Pin |
|---|---|---|
| 3-D Power Distribution | 5.40 | 5.76 |
| Planar Power Distribution | 4.89 | 5.29 |
| Axially Integrated Power Distribution | 3.67 | 4.18 |

## 3. Conclusions

The uncertainty evaluation was performed for the SMART synthesized power distribution. The results showed that uncertainties for the 3-D, the planar and the axially integrated node power distributions are 5.40 %, 4.89% and 3.67 %, respectively, and those for the peaking factor distributions are 5.76 %, 5.29% and 4.18 %, respectively. The uncertainties in this paper are the form of 95%/95% probability/confidence one-sided tolerance limits

## REFERENCES

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