REACTOR CORE CALCULATIONS WITH MCNP4A THE DIMPLE S01A CRITICAL ASSEMBLY

A. Hogenbirk and T.J.M. Peeters

ECN
PO Box 1
NL - 1755 ZG Petten
The Netherlands

tel.: +31 224 56 40 51
fax: +31 224 56 34 90
e-mail: hogenbirk@ecn.nl

1 Introduction

The JEF-2.2 evaluation is the most recent European general-purpose nuclear data evaluation. Validation of this evaluation is an important item, which is taken care of in the framework of the JEF-project.

In order to validate the JEF-2.2 evaluation for use in LWR criticality and reactivity analyses it is essential to use a relevant experimental benchmark, in which a description of a complete LWR core is given. Recently such high-quality data referring to the DIMPLE S01A benchmark became available [1].

In this paper the results are given of benchmark calculations performed with the Monte Carlo neutron transport code MCNP4A [2] for the DIMPLE S01A geometry using cross-section data from the EJ2-MCNPlib library.

Continuous-energy Monte Carlo calculations of neutron transport are a very useful tool to validate cross-section data. They offer the big advantage that much detail of the original evaluation is retained in the cross-section library. Few approximations are needed and self-shielding in the resolved resonance range is explicitly taken into account. Besides, very few limitations exist in the field of the geometric modelling of a problem.

In this context it is essential to note, that a validation of nuclear data *alone* is not possible, as always a combination of a *processed* nuclear data library and a neutron transport code is validated.

2 Geometry

The DIMPLE reactor, located at the Winfrith site of AEA Technology, is a versatile, water moderated reactor used to investigate performance, safety and safeguards issues relevant to the entire nuclear fuel cycle.

The S01A assembly comprises 1565 3% enriched uranium dioxide fuel pins arranged on a square pitch of 1.32 cm to provide a cylindrical, light water moderated core 59 cm in diameter and just under 50 cm high. It is a high-leakage assembly, with over 20% of the neutrons leaking from the core.

In an experiment [1] a range of core physics parameters, such as the critical moderator level and water height reactivity coefficient, was measured in the assembly. Reaction rate measurements were performed to provide diagnostic data. The critical water level was determined to be 49.26 cm at room temperature. This distance is measured with respect to the bottom of the fuel in the fuel pins.

A detailed description of the DIMPLE S01A geometry and of the composition of the assembly is given in [1].

3 Calculational model

3.1 Method

Neutron transport calculations for this benchmark were performed using the Monte Carlo code MCNP4A [2]. JEF-2.2 based cross-section data for all isotopes were taken from the EJ2-MCNPlib library [3], processed at ECN Petten.

3.2 Geometry

A detailed model of the DIMPLE S01A assembly for use in the MCNP4A calculations was made, which includes a detailed description of the fuel pins and

- the core,
- the upper lattice plate,
- the lower lattice plate and
- the part of the fuel support plates and fuel beam bases that sustains the lower lattice plate and the core.

The geometrical model is illustrated in fig. 1. All dimensions and material data were taken from [1].

In the MCNP-model not the complete reactor was modelled, as only the core region needs to be taken into account for the calculation of k_{eff} and reaction rates. As mentioned in [4], in the DIMPLE S01A assembly 13 cm of water forms an effectively infinite reflector. Thus, features more than 13 cm away from the edge of the outermost pin could be ignored.

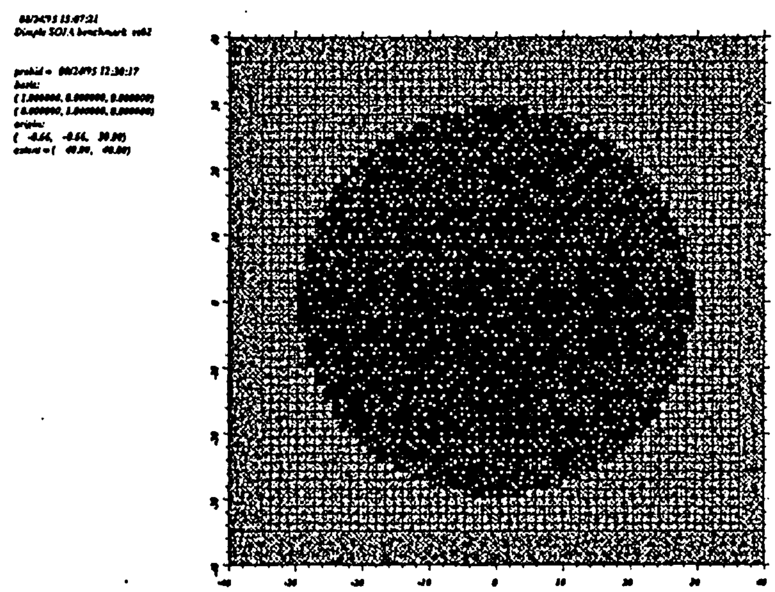

Figure 1: *MCNP4A model, overview of S01A assembly, cross section at 30 cm above fuel base*

3.3 Reaction rate calculations

Reaction rates for the central core position were measured by foil activation techniques. Foils were inserted between the fuel pellets of fuel pins inside the central area of the core lattice [5]. The central core measurements were performed are at mid water height (measured from the base of the fuel [6]).

In the MCNP4A calculations, reaction rates were determined in the central fuel pin and 20 surrounding fuel pins. In order to study the axial behaviour of the reaction rates, reaction-rate calculations were performed in 6 axial zones.

4 Results and discussion

The calculated value of k_{eff} for the model of the DIMPLE S01A assembly amounts to 0.99996 $\pm$ 0.00021. Hence, an excellent agreement between measured and calculated value of k_{eff} is observed.

In table 1 calculated reaction rate ratios are given. The ratios were calculated in axial bins ("levels" in table 1) in order to study the axial dependence. For each level, the reaction rates are averages of the 21 central fuel pins. Reaction rate ratios were measured in the core centre, which corresponds to level 2.

Measured and the calculated (in axial level 2) values of the reaction rate ratios are compared in table 2. From this table it is clear that a very good agreement is obtained between measured and calculated values of $F9/F5$ and $C8/F5$. However, the measured and calculated values of $F8/F5$ strongly disagree, as the experimental value is underpredicted by 10%. Although the experimental uncertainty in the determination of $F8/F5$ is rather large, the difference is clearly outside the error-band.

This difference may be due to

- errors in cross-section data;
- errors in the calculational model;
- experimental errors in the determination of $F8/F5$
- photo-fission in ^{238}U.

Because of the good agreement between measured and calculated values of $F9/F5$ and $C8/F5$ errors in the cross-section data for ^{235}U may be excluded. Hence, if the difference is due to errors in cross-section data it should be due to errors in cross-section data for the fission cross section of ^{238}U. Using ENDF/B-VI.2 cross-section data for ^{238}U instead of JEF-2.2 cross-section data leads to statistically indistinguishable results for the reaction rate ratios. This implies that errors in cross-section data are an unlikely source for the observed difference. One should bear in mind, however, that cross sections in the resonance ranges in the JEF-2.2 and ENDF/B-VI.2 ^{238}U evaluations are essentially identical up to E_n = 149 keV, which decreases the sensitivity to ^{238}U fission cross section in a thermal spectrum.

Errors in the calculational model may safely be excluded because of the good agreement obtained between the measured and calculated values of k_{eff}, $F9/F5$ and $C8/F5$.

Therefore, the remaining possibilities for the discrepancy observed are either experimental errors in the determination of $F8/F5$ or the effect of photo-fission in ^{238}U. Several experimental difficulties are encountered in the determination of $F8$. However, it is known that photo-fission in ^{238}U is an important effect [7,8] and may amount to 8% of the measured fission rate. This effect is not included in analyses with MCNP, which may very well be the reason of the observed discrepancy. Further analysis is needed in order to make a firm decision.

Table 1: *Calculated reaction rate ratios based on reaction rates averaged over the central 21 fuel pins*

level	distance to fuel base [cm]	$F8/F5 \pm\sigma$ [%]	$F9/F5 \pm\sigma$ [%]	$C8/F5 \pm\sigma$ [%]
0	0.00 - 9.63	2.57E−03 ± 0.83	2.17 ± 0.96	1.90E−02 ± 0.96
1	9.63 - 19.63	2.73E−03 ± 0.67	2.21 ± 0.79	2.02E−02 ± 0.78
2	19.63 - 29.63	2.73E−03 ± 0.63	2.21 ± 0.73	2.03E−02 ± 0.72
3	29.63 - 39.63	2.73E−03 ± 0.66	2.22 ± 0.78	2.01E−02 ± 0.77
4	39.63 - 49.26	2.81E−03 ± 0.87	2.21 ± 1.0	2.12E−02 ± 1.0
5	49.26 - 69.285	1.10E−02 ± 1.5	2.28 ± 2.6	4.40E−02 ± 1.6

Table 2: *Comparison of measured and calculated central reaction rate ratios. The calculated data are based on reaction rates averaged over the central 21 fuel pins.*

ratio	measured $\pm\sigma$ [%]	calculated $\pm\sigma$ [%]	$C/E \pm\sigma$ [%]
F8/F5	3.02E−03 ± 3.4	2.73E−03 ± 0.63	0.904 ± 3.5
F9/F5	2.19 ± 0.9	2.21 ± 0.73	1.009 ± 1.2
C8/F5	2.03E−02 ± 0.5	2.03E−02 ± 0.72	1.000 ± 0.9

5 Conclusions

In this paper the results are presented of a detailed Monte Carlo analysis of the DIMPLE S01A critical assembly. The analysis was carried out with MCNP4A, whereas JEF-2.2 based cross-section data from the EJ2-MCNPlib library were used.

An excellent agreement between measured and calculated values is obtained for k_{eff} and the reaction rate ratios $F9/F5$ and $C8/F5$. This validates the JEF-2.2 ^{235}U cross-section data, and especially the data from the EJ2-MCNPlib library, for LWR-applications.

A strong discrepancy is observed between the measured and calculated value of $F8/F5$ (the measured value is underpredicted by 10% in the calculations). This is probably due to the effect of photo-fission in ^{238}U. This is not included in MCNP-analyses. Further analysis is needed to make a proper calculation of this effect.

References

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