A COMPARISON OF UK CODES FOR ANALYSING DIMPLE S01A WITH JEF2.2 DATA

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ABSTRACT

The S01A core of the DIMPLE experimental reactor at Winfrith has been suggested as a computational benchmark to study differences and hopefully improve methods. Descriptions and computer models have been made available. This paper describes tests of their use with JEF2.2 data in UK codes.

INTRODUCTION

Modern evaluated nuclear data are usually validated using simple models of critical systems. A benchmark programme for the combined European/Japanese nuclear data library JEF2.2[1], commenced this "tendency research[2,3] " using simplified systems. Results were obtained from several European countries but it soon became apparent that differences in methods led to as large effects as those seen between experiment and any one calculation with the JEF2.2 data.

A method benchmark programme was then initiated by the "JEFF community" and co-ordinated by J Rowlands[4]. This study included typical PWR cell models with significant leakage of neutrons. There was a large spread in results due to different treatment of buckling. This could not be modelled in the available point Monte Carlo codes to give a reference theoretical result. Two experiments were then proposed for study. This paper describes one of these - DIMPLE S01A - and presents models and results with UK codes .

THE DIMPLE REACTOR

DIMPLE (Fig. 1) was one of the low power reactors run by the United Kingdom Atomic Energy Authority at Winfrith. It is currently being decommissioned. The zero energy assembly consisted of a large aluminium primary vessel in which a wide range of experimental cores could be assembled. The reactor was controlled by varying the height of the light water moderator allowing study of the experiments without the introduction of perturbing control media. Assembly S01/A was built in 1983 as a re-commissioning experiment. It is a rebuild of an earlier benchmark, R1/100H studied in 1966 in the JUNO reactor and in 1967 in DIMPLE[5].

THE DIMPLE S01A CORE

The DIMPLE S01A assembly is light water moderated with a core consisting of 3% enriched UO_2 fuel pellets wrapped in adhesive aluminium foil and stacked in stainless steel cans. The fuel pins are supported on a square pitch of 1.32 cm by aluminium lattice plates. There are 1565 pins (Fig. 2) which are arranged to form a cylindrical core of approximately 59 cm diameter and 69 cm fuelled height. The critical water height for the core is approximately

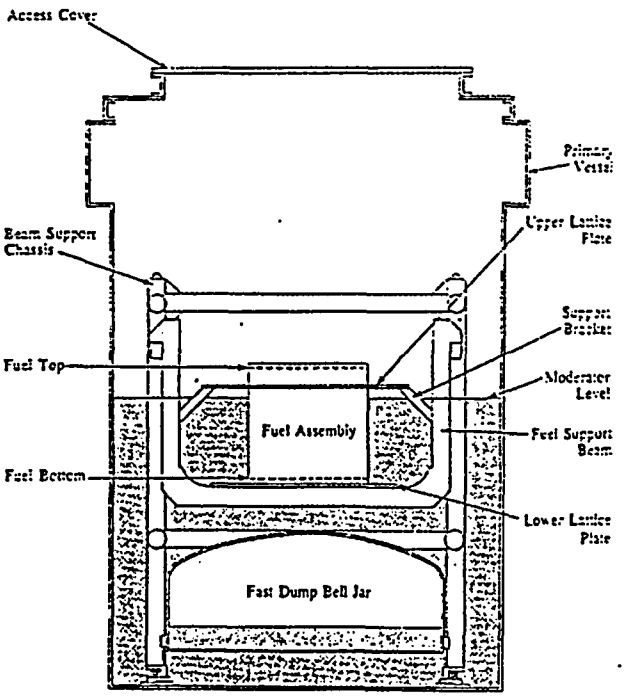

Figure 1 General Sectional Elevation View of DIMPLE

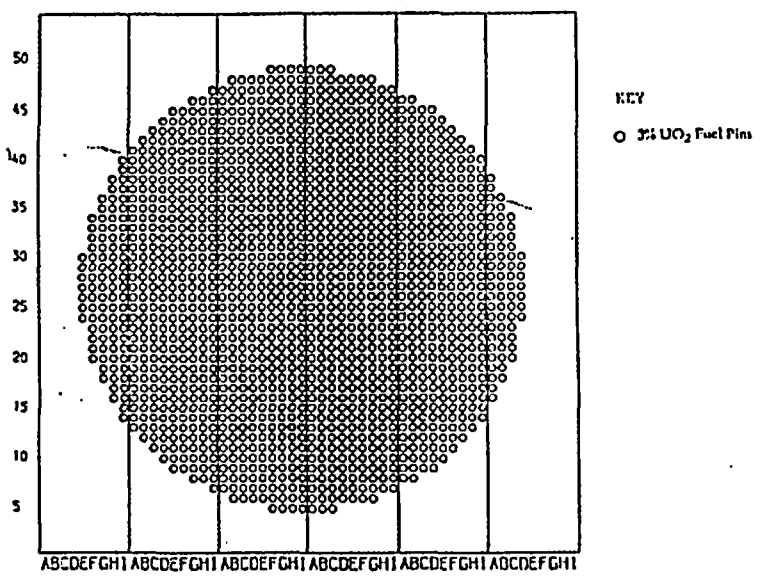

Figure 2 DIMPLE Assembly S01A

50 cm. The aluminium lattice plates are secured to aluminium support beams which are in turn supported by a stainless steel chassis. This is a high leakage core with more than 20% of neutrons leaking from the core. The clean core and high leakage make it an ideal base assembly for studying methods for computer modelling of leakage.

When the JEFF community considered using DIMPLE S01A as a reference, the reactor was still operational. More importantly, the reactor team was still assembled. The opportunity was taken to revisit experimental and analytical documentation and for Knipe to issue definitive specifications[6].

Despite the availability of these specifications two types of computational model were requested. Firstly, we constructed a three dimensional model of the full core with enough of the surround structure to model all nuclear effects. Secondly, a model of a typical pin cell was created and coupled with experimental bucklings. The models were made available to the JEFF community[7] after testing in the WIMS computer code.

NUCLEAR DATA PROCESSING

The JEF2.2 evaluated nuclear data have been processed through NJOY[8] to form two nuclear data libraries. Firstly, a 13,193 hyper-fine DICE library has been assembled for use with the point Monte Carlo tracking code MONK7[9]. Secondly, 172 group data in the XMAS group scheme have been assembled in a DATAGRAM library for use by WIMS7[10]which has both deterministic and group Monte Carlo options. The availability of these libraries and codes enables the full three dimensional and pin cell representations of DIMPLE S01A to be modelled.

MODELS AND CALCULATIONS

The reference 3D full core model was set up using the MONK5W Monte Carlo code from within WIMS7. Knipe's specification gives composition details and dimensions (including necessary approximations) for all relevant core structures. We made no further approximations. Early calculations indicated 13 cm of water gives an effectively infinite reflector. This has now been confirmed internationally[11]. All structures further than 13 cm from the edge of the core were ignored . Thus the model components were the fuel pins, the upper and lower lattice plates and the lower lattice plate support beams together with water/air as appropriate. The lattice plates were modelled exactly while, for the fuel pins and support beams, Knipe made certain approximations (e.g. the geometry of some components in the pins was simplified whilst retaining the correct overall volume).

Once the model was complete, it was verified in a two stage process. First, the material compositions and component dimensions were checked against the specification, and then the geometry was checked by using the VISAGE[12] graphics code to generate pictures of a number of radial and axial sections through the model. Figure 3 shows the whole core elevation generated by VISAGE when supplied with the WIMS/MONK5W input data. The picture is to scale and is viewed in colour on a SUN computer screen. Colours can be selected to enhance different aspects of the elevation. Misplaced colour or shape can highlight input problems. Figure 4 compares the VISAGE picture of the fuel pin with a sketch of the actual pin. This shows some of the aspects smeared by Knipe during his specification. The 3% enriched fuel pellets are assembled into packs of 8 or 9. Each pack is wrapped in adhesive aluminium foil which is crimped over the pack ends. The packs are stacked to give 68 UO_2 pellets. During material specification checks we were surprised to see hydrogen present in the aluminium wrapper composition. The experimental team were able to show us models of the wrapped pellets and to explain how hydrogen from the adhesive was smeared across the wrapper region and even how the crimped wrapper was included. Further, they explained how packing density

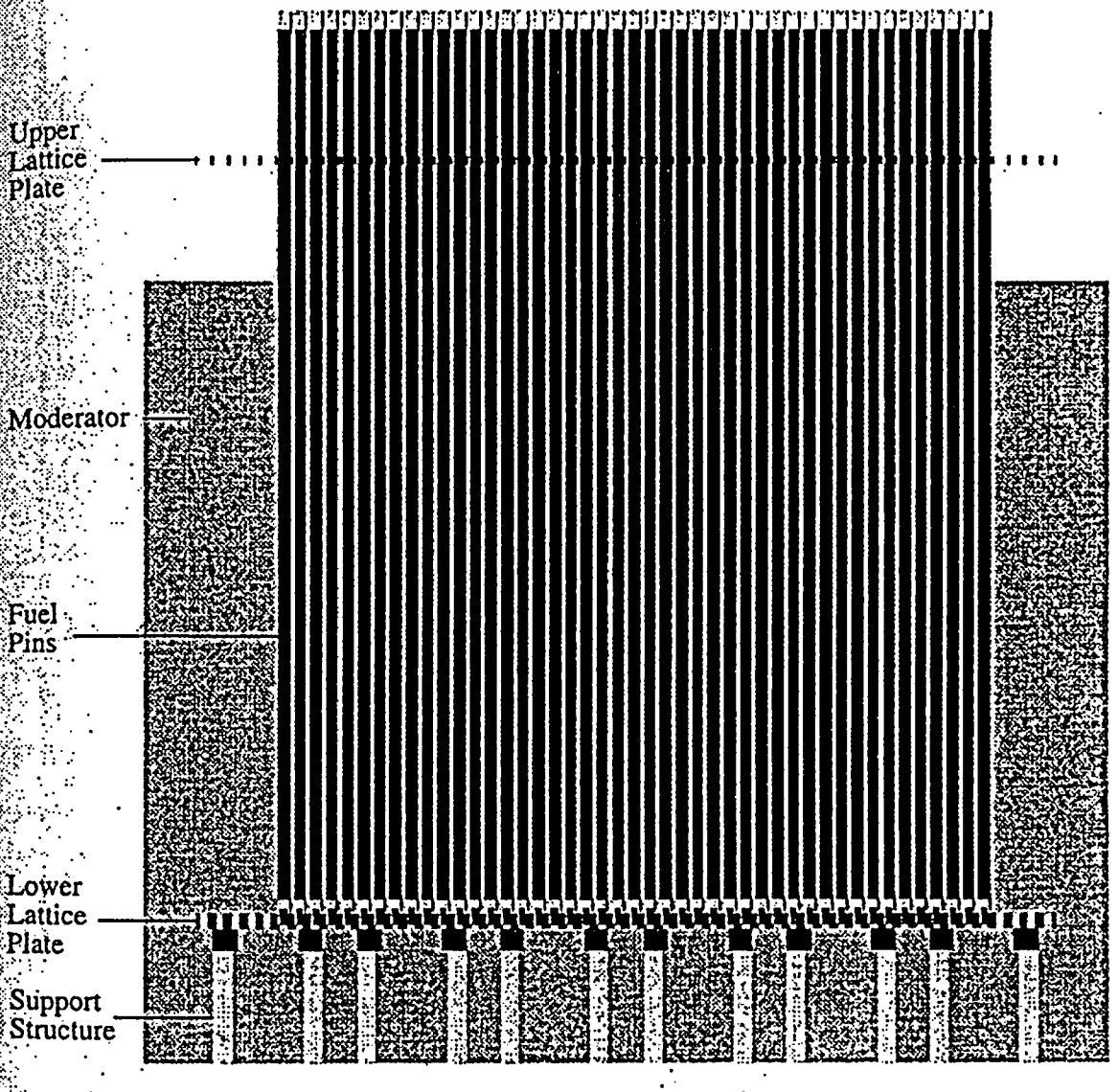

Figure 3. VISAGE Whole Core Elevation

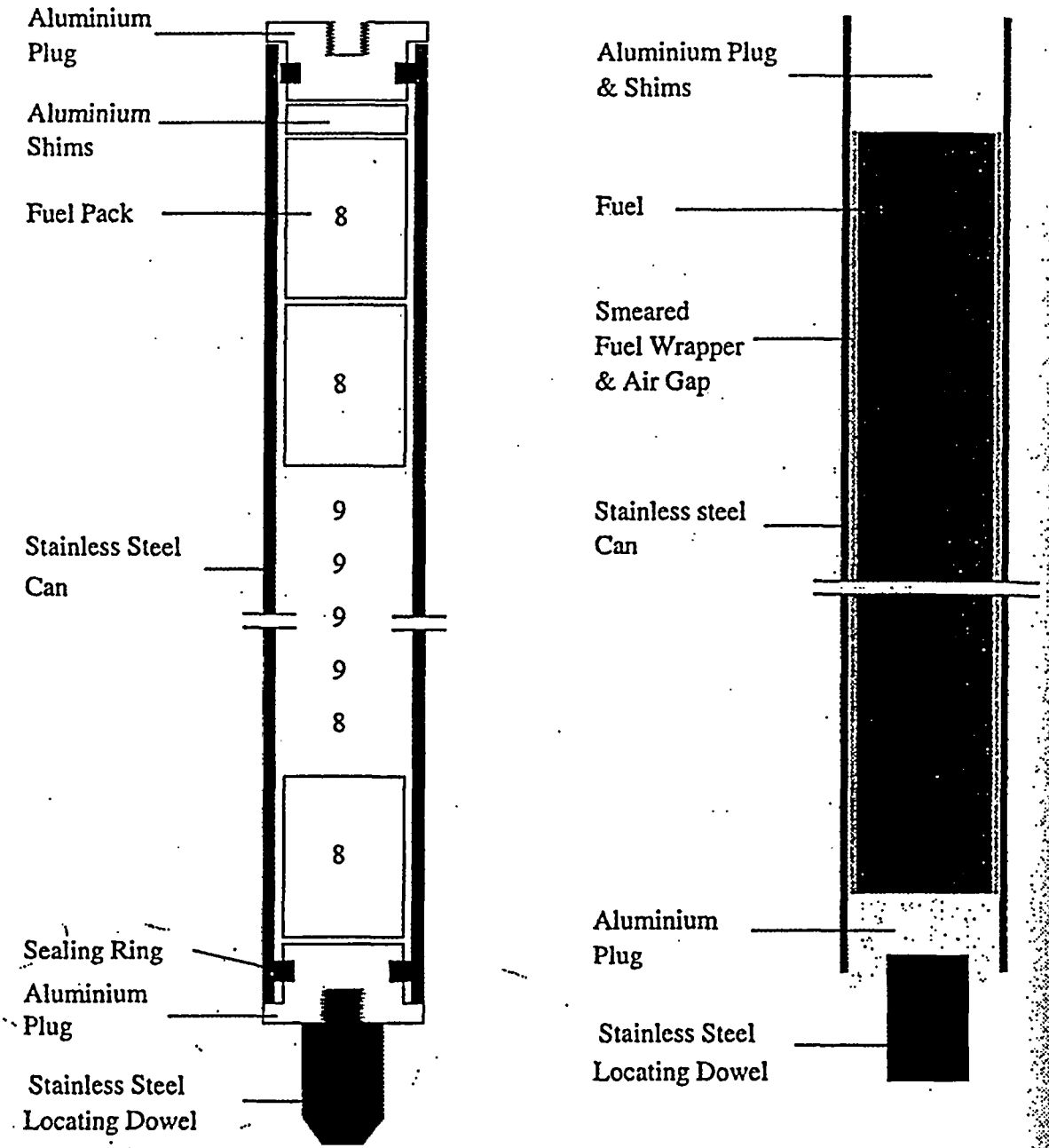

Figure 4. Fuel Pin Compared to MONK Model (Not to Scale)

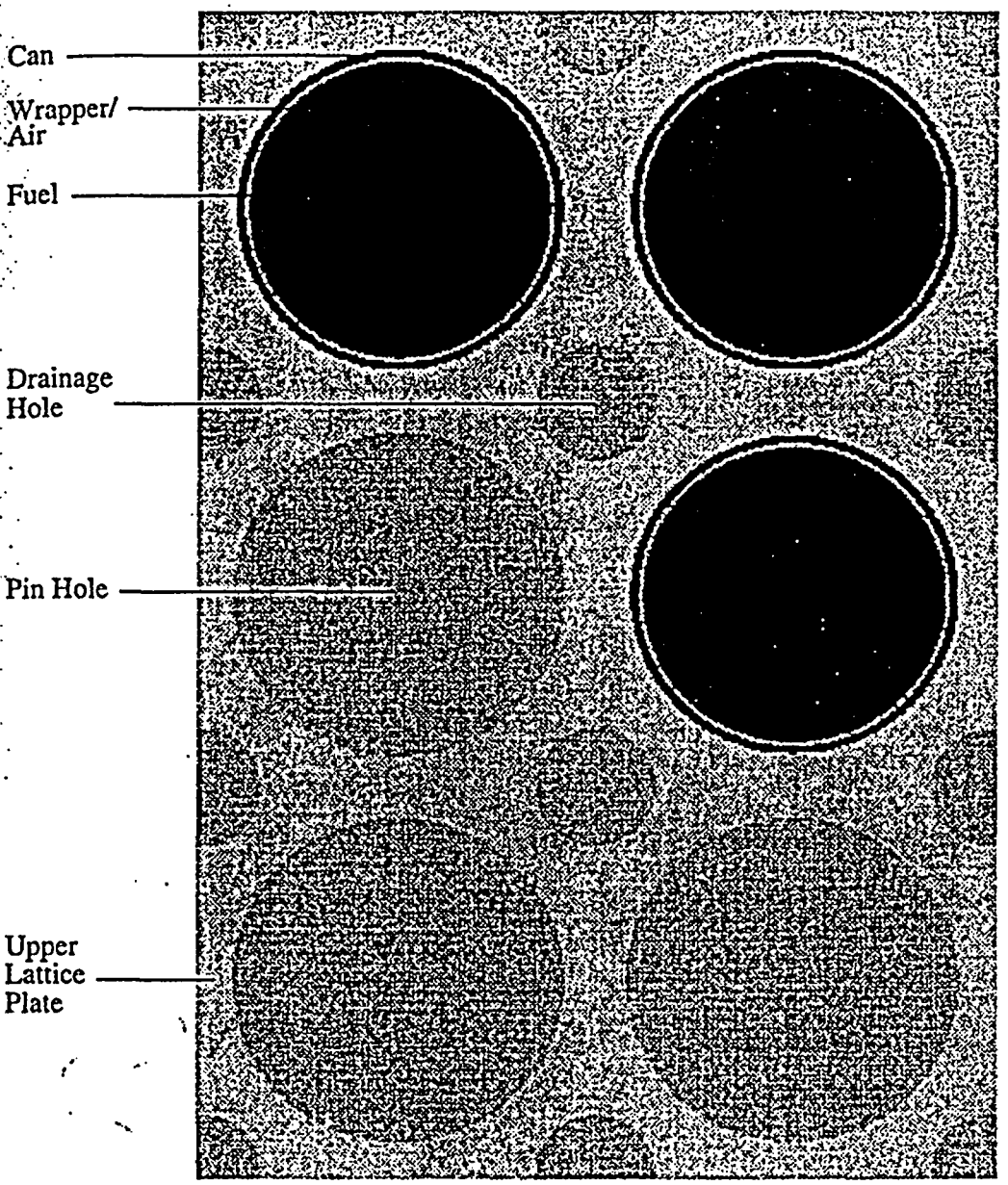

Figure 5. Detail of Fuel Pin Arrangement

measured in different pins meant that modelling individual pellets was impractical. The ability to consult the experimental team was invaluable in answering this kind of detailed question and is not possible for older benchmarks. Figure 5 is a VISAGE picture of the upper lattice plate at the edge of the fuelled region. The MONK model includes empty pin holes and water drainage holes although for DIMPLE S01 the water level is well below the plate concerned (see Fig. 3). The fuel, wrapper/air and can are seen. The wrapper/air region comprises wrapper + adhesive compositions smeared over the interstitial region between fuel pellet and can, assuming void where wrapper + adhesive are not present. Again the experimental team explained that, during loading, some pellet packs touch the can at different points so further breakdown is invalid.

The case was run from within WIMS7 using the modules WHEAD and WMONK. In WHEAD the NOVICE subgroup treatment prepares the cross sections for the MONK5W group Monte Carlo tracking (WMONK). The case was run with three different random number seeds and the results averaged to give a more reliable measure of standard deviation than a single calculation with the same number of neutron histories.

The reference pin cell model was also set up using the MONK5W Monte Carlo code from within WIMS7. This was a highly simplified case in which the material compositions and radial structure of the pin were taken from a slice through a single pin in the water region of the 3D model. All other structures were ignored. The core was represented by an infinite lattice of pins with leakage approximated by radial and axial bucklings calculated from the experiment. Verification was carried out as for the 3D model but in this case a single radial VISAGE representation was sufficient. The case was run from within WIMS7 using the same options as in the three dimensional case.

In practical PWR design and load following calculations in the UK, parameters are calculated using WIMS in a production mode. It was thus appropriate to model DIMPLE S01 in this way. The production pin cell model was also set up in WIMS7 but this time as a deterministic case with no complex representation of the geometry. The same pin cell as in MONK5W was used. The case was verified by checking input values against the specification. We used the alternative WIMS7 subgroup method (WPRES-WPIJ-WRES) to obtain effective broad group shielded cross-sections and a square cell boundary (WPIJ-WPIP) to form collision probabilities and $k_{infinity}$. This was followed by WSMEAR to generate transport cross sections suitable for the B1 flux solution in WCRITIC which applies the experimental bucklings to form $k_{effective}$.

WIMS7 results for all three models were further validated using the previous UKNDL based 1986 WIMS library and the 69 group version of the JEF2.2 based library to confirm that those quoted for the 172 group 1996 WIMS library were realistic.

The 3D geometrical model for MONK7 uses much of the data from the MONK5W design. MONK7 uses 13,193 energy groups to represent the JEF2.2 cross sections. Secondary data are represented as 20 equi-probable emergent energy/angle bins given wherever such data are present in the evaluation. Tracking of particles is in continuous energy. This Monte Carlo calculation is again validated using VISAGE. A pin cell calculation is not appropriate due to the lack of buckling representation although k-infinity results could be formed. The calculations are again validated using an earlier UKNDL library. MONK7 and WIMS7 UKNDL based libraries were each adjusted to fit their own contemporary benchmark results. JEF2.2 libraries are not adjusted.

RESULTS

Table I summarises results from four UK methods.

TABLE I

DIMPLE S01A k Values from UK Codes

Model	Code	k-effective	1 standard deviation uncertainty
3D	MONK7	0.9987	+/-0.0006(convergence only)
3D	WIMS7 (MONK5W)	0.9983	+/- 0.0008 (convergence only)
Pin cell	WIMS7 (MONK5W)	1.0023	+/- 0.0006 (convergence only)
Pin cell	WIMS7 Deterministic	1.0003	N/A
Experiment		1.0	+/- 0.001 to 0.002*

* Calculated from uncertainties in the bucklings and other measurements.

ANALYSIS

The $k_{effective.}$ values from UK codes using JEF2.2 reproduce the experimental value within 2 standard deviations and 230 pcm. MONK7 is the UK reference code for criticality assessment, and, with its 13,193 energy group representation, should give the best result and show how well JEF2.2 can predict $k_{effective.}$ for DIMPLE S01. The result is within the standard deviations on experiment. The $k_{effective.}$ values for three MONK7 runs were 0.9989, 0.9990 and 0.9983 all with standard deviations of 0.001. This small spread gives further confidence.

In an idealised analysis, one would expect results to converge on the MONK7 value. As cross sections are averaged over wider energy groups and simplified geometrical models are used, results might be expected to become worse. The 3D MONK5W result uses 172 energy groups instead of MONK7's 13,193, yet results differ by only 40 pcm . It uses effectively the same geometric model. In moving to a pin cell model with MONK5W we see a 400 pcm change. When the much faster deterministic method is used the difference from MONK7 is only 160 pcm. However the MONK5W pin cell solution is within the standard deviation of the experimental result.

The MONK7 solution is 130 pcm lower than the value quoted by Peeters[11] . This work uses MCNP4A based on UK models and tracks ~14,000,000 neutrons in an attempt to get a definitive result for both $k_{effective.}$ and reaction rate ratios. It is not thought that this calculation included treatment of the unresolved resonance region, which is included in MONK7. In view of this 130 pcm difference in two reference codes we feel the MONK5W pin cell solution is very acceptable.

It is proposed to use the DIMPLE S01 calculational model to compare results between different computer codes. The accuracy of the Monte Carlo calculations in this paper is designed to give practical results relative to known experimental error. In comparing methods we may need to improve our convergence although the actual result will then not truly be to the accuracy indicated. The use of tighter accuracy may indicate the presence of some of the small effects shown by Rowlands[4]. These can then be explored using sensitivities etc. They may not be seen with our current Monte Carlo accuracy.

CONCLUSIONS

The DIMPLE S01A assembly has been modelled in three dimensional and pin cell forms. Computer calculations have been run with UK codes as a prerequisite for international benchmarking.

The UK models have been used in MCNP4A calculations showing that the benchmark description and sample inputs can be run with non-UK codes.

JEF2.2 data reproduces $k_{effective}$ within the experimental standard deviation (200 pcm).

DIMPLE S01A is a suitable benchmark for studying leakage models in computer codes.

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