Contributions to the IRPhE Database from Experiments on the UK Dimple Reactor

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Abstract

A paper presented earlier in this session described the launch of the **I**nternational **R**eactor **Ph**ysics Experimental Benchmarks **E**valuation (IRPhE)[1] database of experimental benchmarks. This paper describes two experiments that have been evaluated and accepted for inclusion in the first release of the database. The experiments were performed on the DIMPLE low power reactor at the U.K.A.E.A's Winfrith site in 1983 and 1987 respectively. The two DIMPLE assemblies chosen for benchmarking are:

1. DIMPLE S01, two cores are considered S01A and S01B. These cores consisted of cylindrical assemblies containing $3^{w}/_{o}$ ^{235}U enriched fuel pins on a square lattice pitch of 1.32cm.

2. DIMPLE S06, again two cores are considered S06A and S06B. These cores were cruciform in shape and simulated 12 core edge PWR fuel elements. Here, the assemblies contained $3^{w}/_{o}$ ^{235}U enriched fuel pins on a square lattice pitch of 1.2507cm.

Sufficient information has been provided in the IRPhE benchmark description and evaluation to allow comprehensive modelling of the DIMPLE series assemblies and to allow comparisons with measurements that have well defined, evaluated, uncertainties.

This report gives an overview of the DIMPLE reactor, a description of the measurements made in the above experimental configurations and presents some selected results from a sample analysis of the defined benchmarks.

KEYWORDS: IRPhE, DIMPLE, PWR, UO2

1. Introduction

The DIMPLE facility consisted of a large aluminium primary vessel, 2.591m inner diameter, 4m high with a side-wall thickness of 0.65cm, surrounded by concrete shielding. The reactor core was supported inside the tank by a steel chassis. A number of 'U' shaped beams were accurately arranged within the chassis to support two sets of aluminium lattice plates which it turn supported the fuel pins. The lower lattice plates were secured to the 'U' beams by a tubular stainless steel chassis. The upper lattice plates, approximately 60cm above the lower lattice plates, were attached to the 'U' beams by two support brackets. Figure 1 gives a general view of the reactor which is shown diagrammatically in Figure 2.

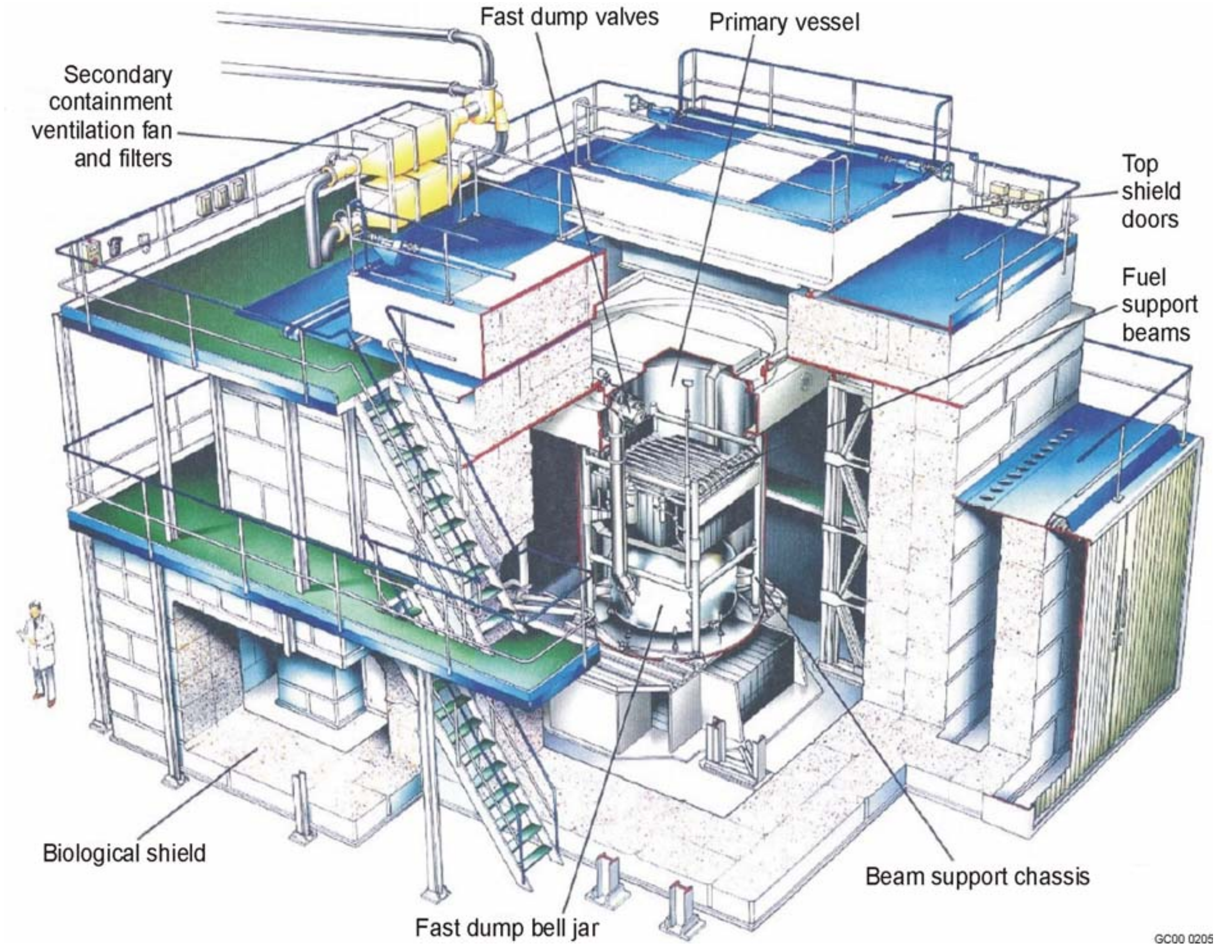

Figure 1. General View of the DIMPLE Reactor.

A series of neutron detectors for reactor control and monitoring were located in the primary vessel within submersible aluminium pods in the water reflector around the core. Three types of detector were used, polythene sleeved BF_3 chambers located centrally in two different sized outer aluminium cylinders and RC6 or RC7 ionization chambers also housed in outer aluminium cylinders. The detectors were located in various positions around the perimeter of the core. During reactor period measurements, used to obtain critical height and the water height reactivity coefficients the detectors were positioned at least 12 cm from the outer boundary of the fuel assembly.

The ability to control the reactor by means of moderator level alone permits subcritical and critical assemblies to be studied without the complicating perturbation of control rods. Shutdown could be achieved by means of a fast-dump system. When the reactor was operating, a 2 m-diameter stainless steel bell jar, situated approximately 25 cm below the core, sustained an air cavity. By venting the cavity through a pair of large valves, the water level could be dropped by 30 cm in about one second. During operation the surface level in the fast dump tank was maintained by feeding a steady flow of air into the dump tank and allowing this to bleed off through a small number of orifices mounted at the lower end of a vent pipe. The vent pipe carried the surplus air into the air space above the moderator in the reactor vessel. A large (coarse) compressor was used only when a large amount of water, supplied by the coarse pump, was being added, i.e. the initial load of water, up to a set limit 7 cm below the fuel pins. A fine compressor was operated at all times to maintain the air cavity in the fast dump tank. A fine pump was used to raise the moderator to the critical height. When the required moderator level was reached the fine pump was turned off and the fine compressor left running to maintain the level in the fast dump tank. The flow from the compressor could exit through the vent pipe to compensate for changes in barometer pressure, temperature, and leakage from the system.

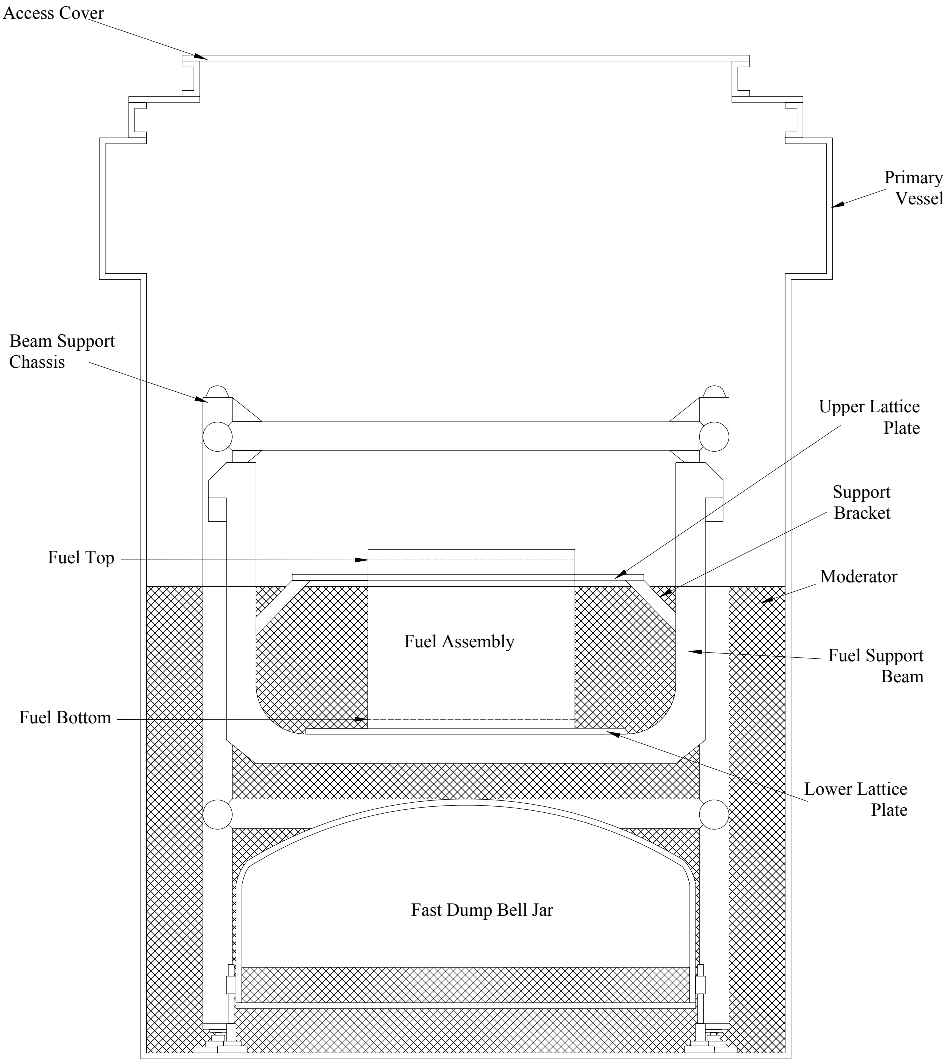

Figure 2. General Sectional Elevation View of the DIMPLE Reactor.

2. DIMPLE Assemblies S01A and S01B [2]

This experimental programme considered critical experiments with low enriched uranium dioxide fuel rods, arranged as a circular assembly, containing 3.0 wt.% ^{235}U with light water moderation and reflection. The S01A core consisted of an arrangement of 1565 pins on a 1.32cm pin pitch, Figure 3, while the S01B core contained 1441 pins, Figure 4. The specific purpose of the S01B configuration was to assess the reactivity worth of core edge rods.

Measurements made on these cores included axial and radial buckling determinations, spectral indices, water height reactivity coefficients $\Delta\rho/\Delta H$, and reaction rate distributions. These are listed in Table 1.

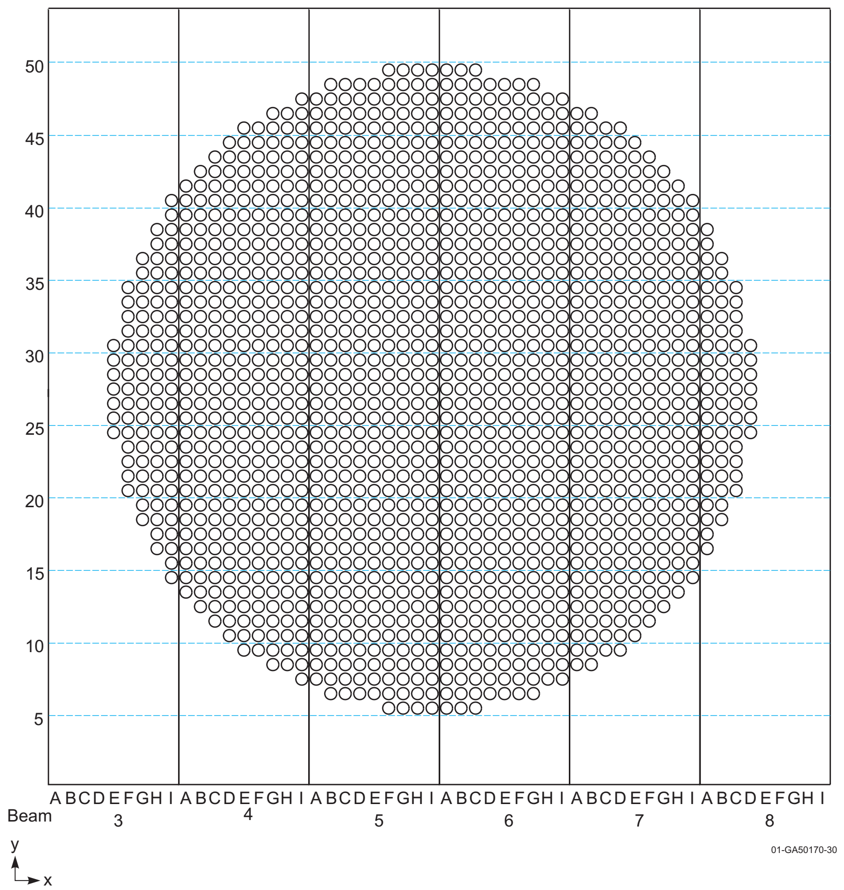

Figure 3: DIMPLE S01A (Case 1) 3%-Enriched Assembly of 1565 Fuel Pins.

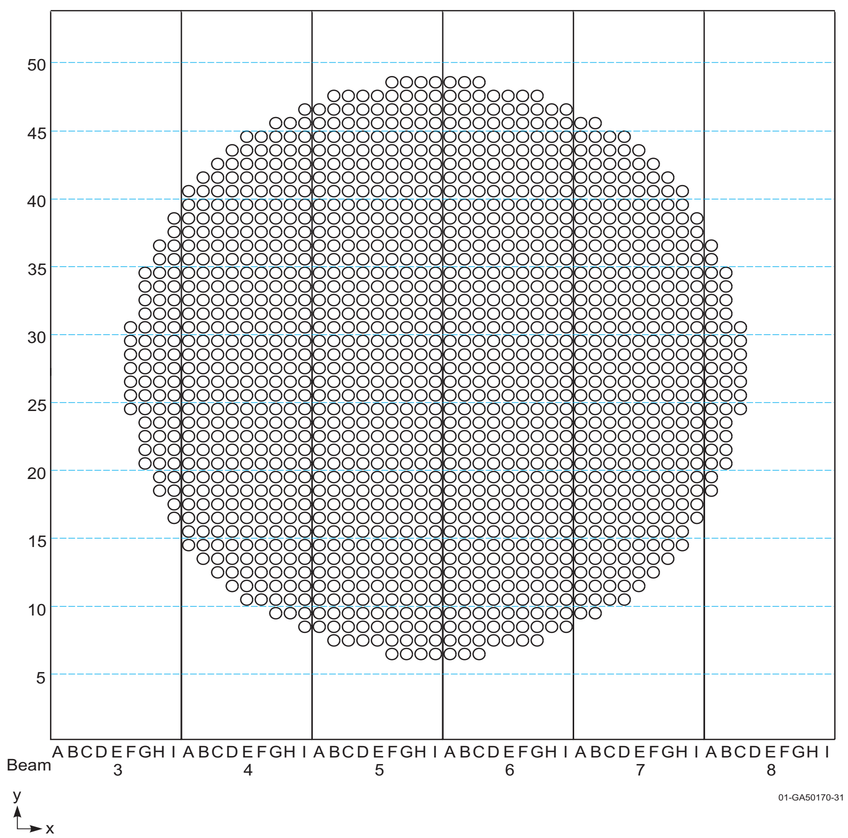

Figure 4: DIMPLE S01B (Case 2) 3%-Enriched Assembly of 1441 Fuel Pins.

Measurement	S01A	S01B
Critical Water Height	Measured	Measured
Water Height Reactivity Coefficient ($\Delta\rho/\Delta H$)	Measured	Measured
Axial fission Chamber Scans	^{235}U & ^{239}Pu Fission	^{235}U & ^{239}Pu Fission
Axial and Radial Foil Reaction Rate Distributions	^{238}U, ^{235}U & ^{239}Pu Fission and ^{238}U Capture	Not Measured
Buckling	Radial and Axial	Axial only
Fine structure Measurements in and around central pins.	^{235}U Fission	Not Measured
Central Reaction Rate Ratios	^{238}U Capture/^{235}U Fission ^{238}U Fission/^{235}U Fission ^{239}Pu Fission/^{235}U Fission	Not Measured

Table 1 Measurements made in DIMPLE assemblies S01A and S01B.

Recommended single infinite pincell and 2D representations of Assemblies S01A and S01B have been provided as benchmark models. Table 2 compares measurement with calculations performed using WIMS Version 8A with JEF2.2, 172 energy group, nuclear data. In general, with the possible exception of ^{238}U Fission/^{235}U Fission, there is good agreement between calculation and experiment.

Parameter	Experiment	WIMS8 Calculation
k-effective	1.00000 ±0.00120	1.00007 (using fitted bucklings)
Buckling (total)	65.7 ±0.2	65.67 ±0.4 (WIMS pincell)
Buckling (axial)	24.2 ±0.2	24.13 ±0.3 (WIMS 2D model)
^{238}U Fission/^{235}U Fission (Central Reaction Rate Ratio)	0.00302 ±3.4%	0.00278
^{239}Pu Fission/^{235}U Fission (Central Reaction Rate Ratio)	2.189 ±0.9%	2.214
^{238}U Capture/^{235}U Fission (Central Reaction Rate Ratio)	0.0203 ±0.9%	0.0205

Table 2 Comparison between Calculation and Experiment for DIMPLE assembly S01A.

Although no formally documented details are available, previous international analyses of the Fast Fission Ratio (^{238}U Fission/^{235}U Fission) in DIMPLE S01 have shown significant under-predictions. The reason for these under-predictions is not known and indicates that there are unidentified uncertainties associated with this measurement. However, extensive investigation of the experimental technique has not revealed any additional uncertainties.

3. DIMPLE Assemblies S06A and S06B [3]

This experimental programme comprised of critical experiments with low enriched uranium dioxide fuel rods, arranged as a cruciform assembly, containing 3.0 wt.% ^{235}U with light water moderation and reflection. The purpose of the experiments was to simulate the rectangular corner configuration of a Pressurised Water Reactor (PWR) and the re-entrance of neutrons at the core periphery. This assembly represented twelve PWR fuel assemblies, see Figure 5. Two versions of the cruciform assembly are included in the benchmark, the first S06A is water reflected, the second S06B is surrounded azimuthally by a stainless steel region simulating a PWR core baffle. The 3072 fuel pins were on a rectangular lattice with a 1.2507cm pin pitch.

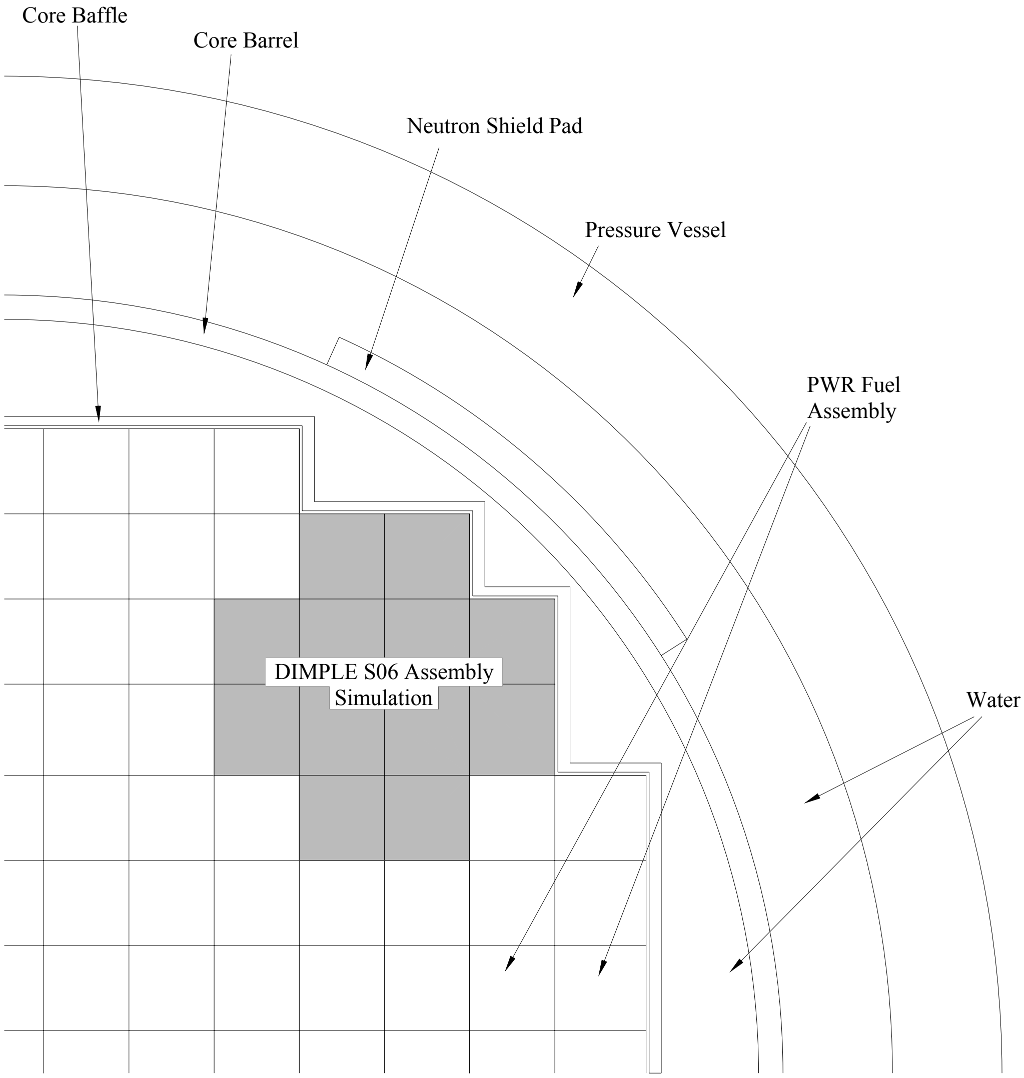

Figure 5: Sectional Plan View Within Quadrant of PWR Pressure Vessel Showing DIMPLE S06 Assembly Simulation.

Measurements made on these cores included axial buckling determination, spectral indices, water height reactivity coefficients Δρ/ΔH, and reaction rate distributions. These are listed in Table 3.

Measurement	**S06A**	**S06B**
Critical Water Height	Measured	Measured
Water Height Reactivity Coefficient (Δρ/ΔH)	Measured	Measured
Axial fission Chamber Scans	^{235}U Fission	^{235}U Fission
Axial and Radial Foil Reaction Rate Distributions	^{238}U and ^{235}U Fission and ^{238}U Capture	^{238}U and ^{235}U Fission and ^{238}U Capture
Buckling	Axial only	Axial only
Central Reaction Rate Ratios	Not Measured	^{238}U Capture/^{235}U Fission ^{238}U Fission/^{235}U Fission ^{239}Pu Fission/^{235}U Fission

Table 3 Measurements made in DIMPLE assemblies S06A and S06B.

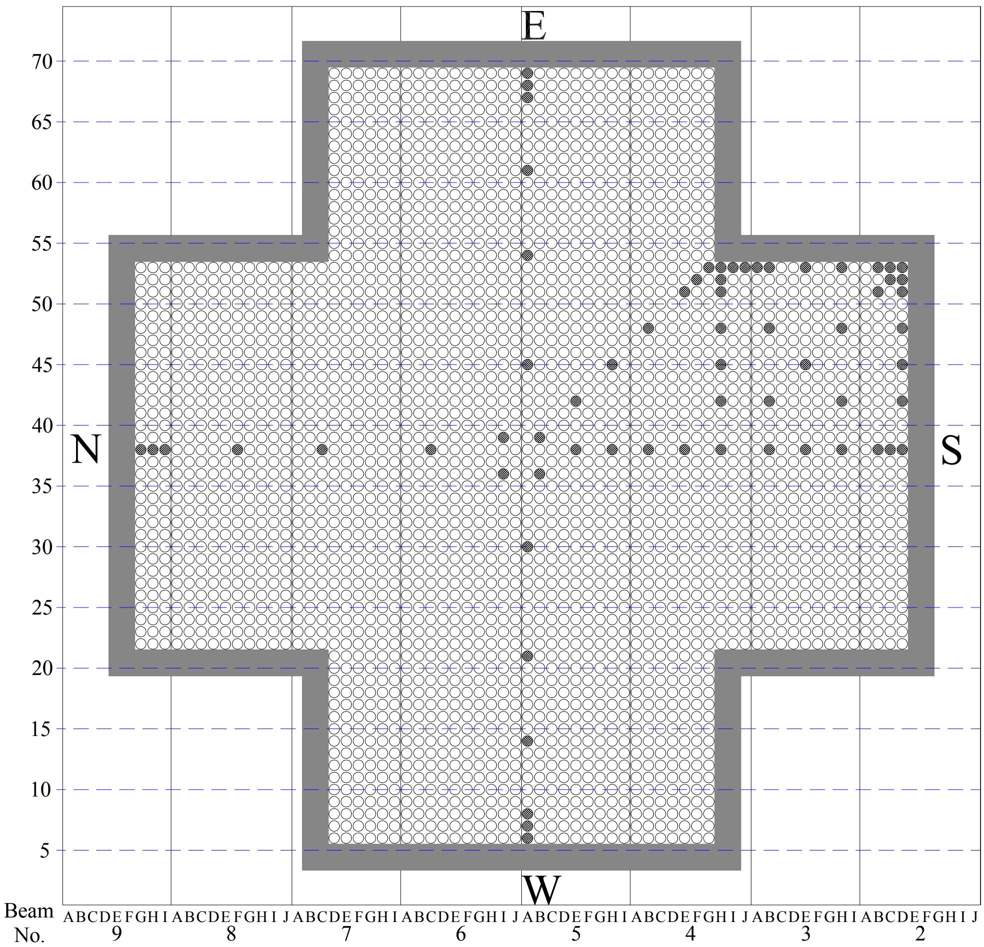

Figure 6: DIMPLE S06B 3%-Enriched Assembly of 3072 Fuel pins Showing Baffle and Radial Foil Measurement Positions.

Recommended 2D representations of Assemblies S06A and S06B have been provided as benchmark models. Table 4 compares measurement with calculations performed using WIMS Version 8A with JEF2.2, 172 energy group, nuclear data.

Parameter	**Experiment**	**WIMS8 Calculation**
k-effective	1.00000 ±0.00120	1.00039 S06A 0.99952 S06B (using fitted bucklings)
Buckling (axial)	24.7 ±0.2 S06A 21.1 ±0.2 S06B	24.8 ±0.4 S06A 21.2 ±0.3 S06B
^{238}U Fission/^{235}U Fission (Central Reaction Rate Ratio)	0.00343 ±3.4%	0.00332
^{239}Pu Fission/^{235}U Fission (Central Reaction Rate Ratio)	2.274 ±1.0%	2.312
^{238}U Capture/^{235}U Fission (Central Reaction Rate Ratio)	0.0236 ±1.0%	0.0238

Table 4 Comparison between Calculation and Experiment for DIMPLE assemblies S06A and S06B.

There is good agreement between calculation and experiment. Comparison of calculated radial reaction rates with experiment show good agreement at the centre of the assembly getting worse towards the edge, especially in S06A where the effects of the water reflector are greatest.

4. Conclusion

The lattice studies in DIMPLE have provided valuable benchmarks for the validation of calculational methods and data employed in the design and operation of thermal power reactors. Much of the data available is relevant to advanced reactor designs. Four of these lattices S01A, S01B, S06A and S06B have been evaluated and accepted as accredited benchmarks in the first edition of the International Handbook of Evaluated Reactor Physics Benchmark experiments.

References

1) NEA Nuclear Science Committee, “International Handbook of Evaluated Reactor Physics Benchmark Experiments”, NEA/NSC/DOC(2006)1 March 2006
2) D.Hanlon et Al, “Light Water Moderated and Reflected Low Enriched Uranium (3wt.%) Dioxide Rod Lattices – DIMPLE S01”, NEA/NSC/DOC(2006)1 Volume VII March 2006.
3) B.Franklin and D.Hanlon, “Light Water Moderated and Reflected Low Enriched Uranium (3wt.%) Dioxide Rod Lattices – DIMPLE S06”, NEA/NSC/DOC(2006)1 Volume VII March 2006.