DRAFT

UK Integral Benchmarking Programme for JEF

June 1994

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1 Summary of Results from 1993/94 Programme

1.1 MONK6 Benchmarks

(a) Uranium Systems

For well-thermalised low-enriched UO_2 systems there is strong evidence to suggest that the JEF2.2-based library with MONK can calculate k-effective close to the level of the experimental uncertainties. This evidence is provided by over thirty configurations studied from four different experimental programmes performed at three independent laboratories. Slightly larger differences between calculation and experiment are obtained for lower levels of moderation, with the divergence from measurement in general increasing with spectrum hardness. This suggests that the additional over-prediction for these under-moderated cases is due to epithermal uranium data effects.

There is good evidence that the JEF2.2/MONK combination produces more accurate results for low-enriched UO_2 systems than the current UKNDL/MONK6B combination.

The other uranium system studied comprised bare and natural uranium reflected metal spheres. The JEF2.2/MONK results show better internal consistency than the UKNDL/MONK6B results and better agreement with the experimental measurements - an under-prediction of about 0.5% compared with an experimental uncertainty at the one standard deviation level of the order of 0.1%.

(b) Plutonium Systems

The plutonium nitrate solution systems studied this year have served to consolidate our general impressions of the status of the JEF2.2 plutonium data. The conclusions last year were that although some improvements may have occurred in the intermediate range, problems with thermal Pu239 data were still causing significant differences between calculation and critical experiment measurements.

In order to extend the range of our database, plutonium nitrate experiments were considered which covered a broad range of solution concentrations, with H:Pu ratios from 124 to 1067. From these benchmark results it has been concluded that the JEF2.2/MONK calculations significantly over-predict k-effective for critical plutonium experimental systems (outside three standard deviations in most cases) for a range of moderation levels. The over-prediction is between 0.5% and 1.5% and it is considered that at least some part of this over-prediction is due to thermal plutonium data effects.

For metallic plutonium systems we see a different picture, where for the bare systems an under-prediction of about 0.5% was observed (compared with an experimental uncertainty

at the one standard deviation level of the order of 0.2%).
When a natural uranium reflector is included the agreement is worse and well-outside the three standard deviation level. This supports the above conclusion that there is some residual problem resulting from epithermal uranium data effects.

(c) Mixed Systems

The mixed nitrate solution systems that were studied this year support the conclusions for mixed systems observed last year The systems studied have contained depleted uranium so that the dominant fissile isotope is Pu239. However the presence of large quantities of U238 means that they are also sensitive to resonance absorption in that isotope.

For the higher H:Pu ratio mixed nitrate cases the agreement with experiment is broadly in line with that observed for the plutonium systems (0.5% to 1.5%), whereas the difference increases up to 2.5% for the harder spectrum cases. This latter figure is not far below that observed last year for mixed oxide compact cases, implying that some improvements can be made for the JEF2.2 resonance data, probably for both plutonium and uranium.

The mixed oxide pins systems studied this year tend to confuse the situation slightly. Agreement with experiment is generally good over a range of moderation levels, contradicting the evidence provided by the solution experiments. The mixed nitrate and mixed oxide pins experiments show a spread of results of about 3% in k-effective. Although some of this variation could be due to system differences, (such as Pu240 content, importance of Pu24, fuel heterogeneity), there is a strong possibility that significant sources of unreported experimental error exist in one or more of the experiments. It is concluded that there remains a need for further high quality plutonium benchmark data in the validation database.

1.2 WIMS Benchmarks

(a) Uranium Systems

The DIMPLE S03 High Leakage Assembly Lattice study has been analysed using the JEF nuclear data library, using both deterministic and Monte Carlo codes. This critical assembly was constructed from 7% enriched UO2 pins on a 1.32cm pitch to form a cylindrical system with high leakage.

Calculations performed using the recommended LWRWIMS lattice code with its standard WIMS86 69-group nuclear data library and a 172-group JEF nuclear data library show both libraries calculate k-effective for the system well, supporting the earlier conclusions drawn from the MONK6 benchmarks. The calculations also show a global tendency for the JEF2.2 values to be lower for ^{235}U fission, ^{238}U fission and ^{238}U capture. For all reactions the reduction increases from the centre of the assembly to the edge, with the JEF2.2 values 0.1% lower near the centre and approximately 2% lower at the edge.

MONK6 calculations predict the system multiplication to within 1.0% of unity using the DICE data library and within +0.5% of unity using the JEF2.2 library.

LWRWIMS Results:

Nuclear Data Library	k-effective
WIMS86	0.99893
JEF2.2	0.99698

MONK Results:

Nuclear Data Library	k-effective
DICE	1.0104±0.0011
JEF2.2	1.0050±0.0011

(b) CERES Phase I: Irradiated PWR Fuel

Phase I of the CERES programme in DIMPLE has been re-analysed using the JEF2.2 nuclear data library with WIMSE. This phase of CERES consisted of reactivity measurements in three critical assemblies on a set of irradiated PWR samples, (20-60GWd/t), and some unirradiated MOX samples, to provide validation for calculations of reactivity loss with burnup.

Measurements made in Assembly I are dominated by the fissile content of the samples. With the exception of two MOX samples with high-plutonium concentration, the reactivity of all samples was well predicted.

The characteristics of CERES Assembly II were such that typically 50% of the events in the samples occurred in the resonance region. Small discrepancies were evident from the mixed-oxide comparison where some dependence on ^{240}Pu content was observed.

CERES Assembly III has a predominantly thermal neutron spectrum sensitive to reactivity effects resulting from both fission and absorption. The reactivities of the mixed-oxide samples are generally over-predicted in this assembly, the high plutonium concentration sample giving the largest over-prediction. As in the other two assemblies, the irradiated samples show good agreement. The results for Assemblies I, II & III are summarised in Figures 1, 2, & 3.

(c) CERES Phase II: Fission Products

Preliminary analysis of the second phase of CERES has been completed. In this phase reactivity measurments were made on a set of samples doped with twelve of the major fission product absorbers; Sm147, Sm149, Sm152, Nd143, Nd145, Eu153, Gd155,

Rh103, Ru101, Mo95, Cs133, & Ag109. Typically these isotopes represent about 70% of the total fission product absorbtion in spent reactor fuel.

Until definative checks on the sample compositions have been made, the analysis and conclusions must be considered provisional. Briefly, WIMSE modelling of the experiments indicates that JEF2.2 absorbtion cross-sections for the Sm, Nd and Eu isotopes studied are about 10% low, with good agreement for the Gd155 &, Ag109 samples. This work will be reported in full when comparisons with the results for the same samples measured in the MINERVE reactor at CEA Cadarache have been completed.

(d) The representation of Uranium 238 for use in MONK7.

The K infinity result from John Rowland's PWR pincell benchmark using MONK6 with JEF2.2 was surprisingly high. (1.4026 compared with a mean of 1.3869+/-.0019 for broad group deterministic codes). Calculations with the fine group deterministic code ECCO and the Monte-Carlo MCNP code confirmed the MONK6 result to be about 1% high.

A study suggests the MONK6 result is incorrect due to too coarse representation of U238 resonances above 73eV. Special pre-shielded data, suitable for use only with the PWR pincell were generated in the current structure. The K infinity reduced to 1.3907. This is only 0.08% higher than the MCNP value of 1.38952.

The study notes that, for the PWR pincell, about 20% of U238 absorption occurs in the region between 73eV and 9.118KeV, where the improvement to data representation is required. MONK6 is normally used for criticality calculations where much softer spectra give significantly smaller effects. This explains why the problem was not recognised earlier.

Effects of this problem on reported JEF2.2 benchmarks for similar CEA Valduc experiments are estimated to reduce the mean K effective from being 0.5% high to being 0.5% low. Other reported MONK6 benchmarks are too dissimilar to prompt comment but usually have much softer spectra.

The study initiated a programme of work to improve the representation of U238 data above 73eV on DICE libraries for MONK and MCBEND. We have a target date of September 1994 for this work. Once the work is completed further JEF benchmarking is proposed using MONK7.

1.3 Summary of Conclusions from UK JEF Benchmarking Programme

In summary, benchmarking using the JEF2.2-based library for a range of applications yields the following conclusions.

-there is good agreement with critical measurements for a range of low-enriched UO_2 systems (between 0 and 1.0% over-prediction). The larger over-prediction (~1.0%) for low-enriched UO_2 systems occurs for less well-thermalised systems suggesting residual

problems with the U238 resonance data.

- poorer agreement is found for critical experiment measurements on plutonium systems, with over-predictions of between 0.5 and 1.5% using MONK6. The differences between calculation and measurement probably result from a combination of problems with thermal and resonance plutonium data.

-there are significant differences between calculation and experiment for mixed uranium/plutonium systems in the range 0 to 2.5% , probably due to problems with both plutonium thermal and resonance data and U238 resonance data.

-inconsistancies in the results for plutonium systems have highlighted the importance of high quality experimental data.

-global reactivity loss with burnup for PWR fuel is well predicted but significant adjustment for many of the major fission products is indicated.

- representation of U238 absorption on DICE libraries for use in MONK7 and MCBEND is to be improved before further JEF2.2 benchmarking takes place.

2 Future Programme

The UK JEF Benchmarking programme for 1994/95 is summarised in Table 1. This programme has a total funding of about £200k through the HSE & IMC Reasearch Programme and is designed to provide extensive validation of JEF data for applications in the UK user community. It is now envisaged that JEF application libraries will be released by about mid-1995, ie prior to the release of JEF3. If required, adjustments (eg to Pu data) will be made directly to the application libraries to improve accuracy.

The programme also includes provision for review of the JEF International Integral Benchmark Results for U238 and Iron.

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June 1994

Table 1 Summary of UK Validation Programme for JEF.

A) MONK6 Benchmarks:-

- high enriched uranyl nitrate solution
- high burnup plutonium nitrate solution cylinders (43% Pu240)
- plutonium nitrate cylinders (19% Pu240)
- mixed oxide fuel pins with various absorbers
- mixed nitrate solutions with various levels of moderation
- Japanese/US mixed oxide experiments with a range of fuel compositions.
- Low enriched UO_2 powder exponential experiments (LEMUR, Springfields).

B) Shielding Benchmarks:-

- ASPIS Steel/Graphite Experiment (new)
- Iron study peer review

C) WIMS Benchmarks:-

C1) Graphite Moderated

BICEP	22 Experiments U Metal (U nat. + some enrichment) Al clad, air cooled, pincell geometry. AEEW-R235
Hanford	5 Experiments Natural U rods in Al, air cooled, pincell geometry. Barclay (AEEW- R473) analysed 6 expts.
SCORPIO	Windscale AGR fuel cluster - enrichment 1.8%. CO_2 cooled. 2 ring cluster (7 and 14 rods) Studies temperature coefficients. (298 + 660K)
Hinkley B	CAGR 2.55% enrichment burnup to 25GWD/Te. Used to compare cross pin power tilts and compositions calculated with earlier libraries.
Dungeness B	Commissioning expts, including rod removal in stages.

C2) Light Water Moderated

ORNL	5 Experiments. Bare spheres of Uranyl nitrate spheres (93% U235) and H_2O adjusted to criticality by boric acid. (CESWG benchmarks)
TRX	1.3% enriched uranium metal clad in Al. Triangular pitch varied lattice spacings. TRX1 and 2 are included as pincells.TRX1-4 are included in CESWG.
DIMPLE	5 Experiments, 3% enriched UO_2 pins clad in stainless steel,varying moderator to fuel ratio. R1,R2,R3/100H and S01. R1 at 80 and 20K.
Brookhaven	10 experiments, 3% enriched UO_2 pins clad in stainless steel, varying moderator to fuel ratio and concentration of boric acid.
ESADA	11 experiments, PuO_2/UO2 pins clad in Zr, fixed pin size with varying pitch, boron poisoning, and Pu240 percentage.
KRITZ-1	46*46 UO_2 pins, Zircaloy clad at 20, 90, 160, and 210K. (1.35W% U235)
KRITZ 2.1	44*44 UO_2 pins (1.86W% U235) 19.7C and 248.5C boron poisoned.
KRITZ 2.13	40*40 UO_2 pins (1.86W% U235) 22.1 and 243C boron poisoned.
KRITZ 2.19	25*24 PUO_2/UO_2 pins 21.1 and 235C boron poisoned.

C3) Heavy Water Moderated

Wurenlingen — 3 experiments, natural uranium pins clad in Al, varying square pitch in pincell geometry.

Savannah River — 4 experiments natural uranium pins clad in Al, varying hexagonal pitch in pincell geometry.

C4) Un-moderated

Lemur — 4 sub-critical intermediate spectrum experiments, 2% enriched UO_2 with differing H/U ratios.

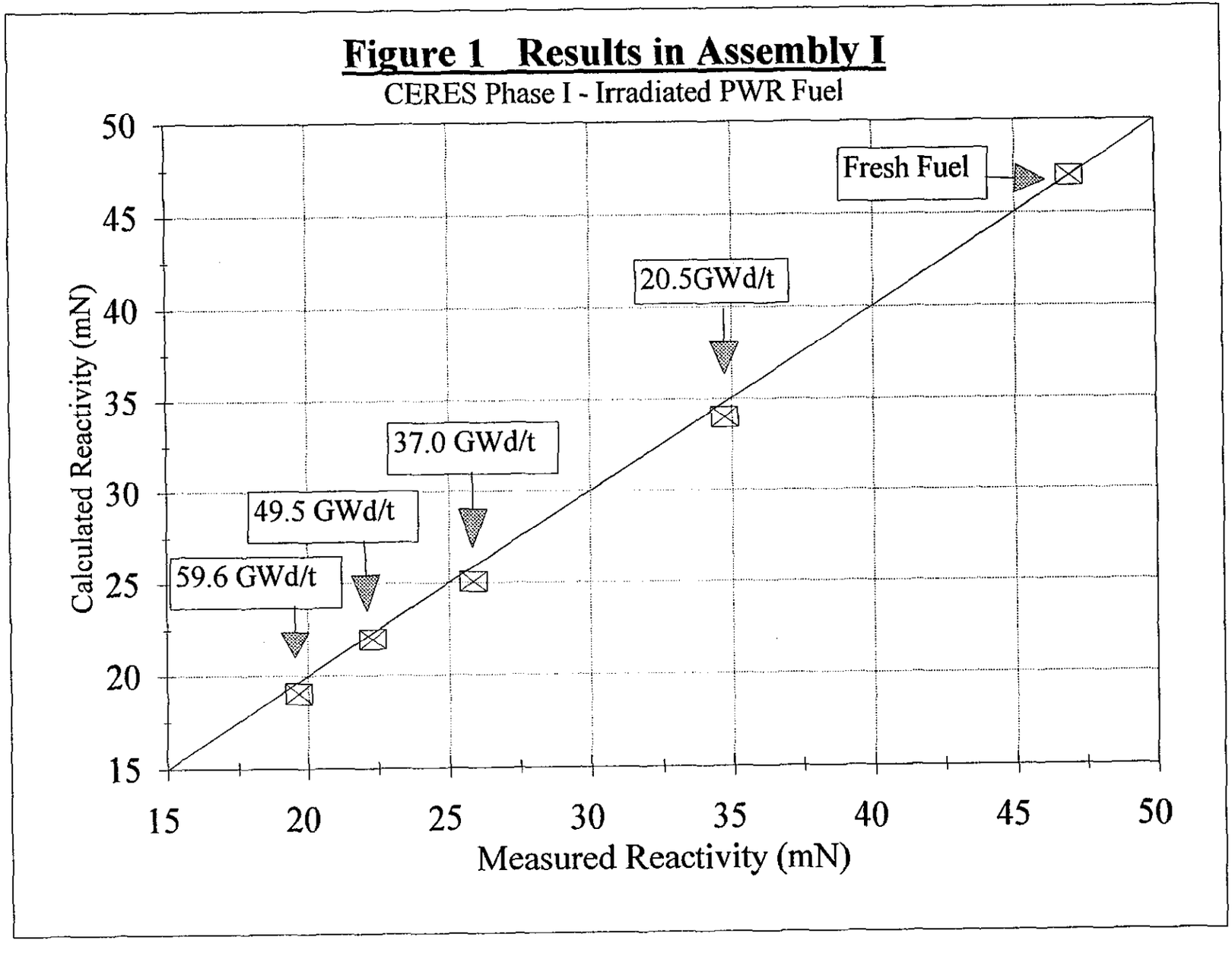
Figure 1 Results in Assembly I
CERES Phase I - Irradiated PWR Fuel
Calculated Reactivity (mN)
Measured Reactivity (mN)
50
45
40
35
30
25
20
15
15
20
25
30
35
40
45
50
Fresh Fuel
20.5GWd/t
37.0 GWd/t
49.5 GWd/t
59.6 GWd/t

Figure 2 Results in Assembly II

CERES Phase I - Irradiated PWR Fuel

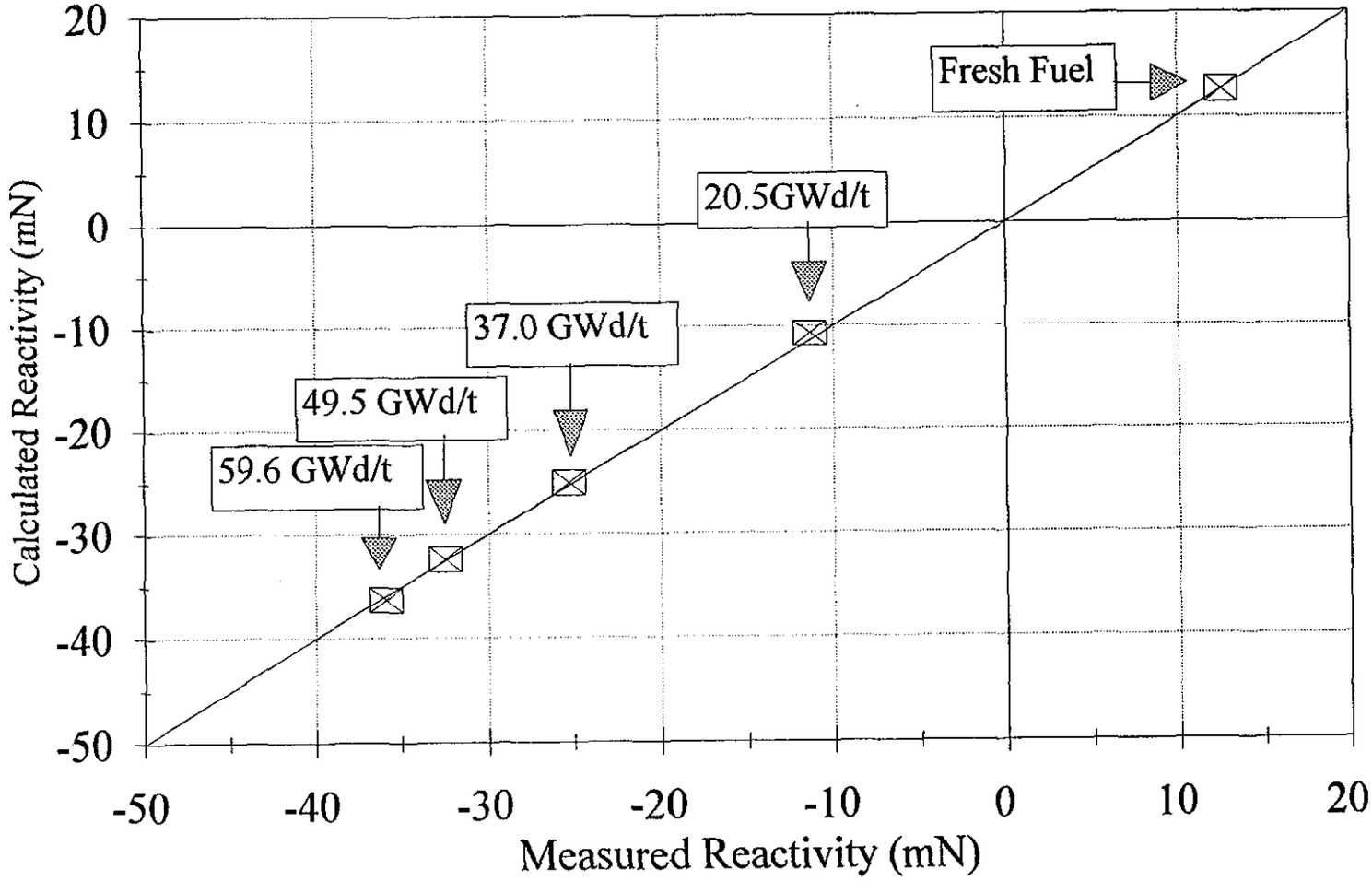

Figure 3 Results in Assembly III

CERES Phase I - Irradiated PWR Fuel