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VALIDATION OF THE ABBN/CONSYST CONSTANTS SYSTEM.

PART 2: VALIDATION THROUGH THE CRITICAL EXPERIMENTS ON CORES WITH URANIUM SOLUTIONS

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Abstract

VALIDATION OF THE ABBN/CONSYST CONSTANTS SYSTEM. P art 2: Validation through the Critical Experiments on Cores with Uranium Solutions Results of calculatins of critical asemblies with the cores of uranium solutions for the considered series of the experiments are presented in this paper. The conclusions about acceptability of the ABBN-93.1 cross sections for the calculations of such systems are made

Introduction

By analysing homogeneous solution critical assemblies the usefulness of the constants software system to be tested can be checked irrespective of how accurately this system takes account of heterogeneous effects. As long as the criticality calculation in all the instances below took detailed account of the geometry (in the majority of cases in a fairly simple form), the divergences between the calculation and the experiment can only be due either to the inaccuracy of the constants used for the calculation, or to the error levels of the evaluation of the critical experiments. The calculations employing the ABBN constants were carried out in a 299-group approximation using the KENO-Va program, and those employing ENDF/B-V

using the MCNP program. The calculation models for the experiments were based on the data given in the Handbook [1], and where the Handbook gave ready-made programs in the KENO-Va program language these were used directly. The calculations results using the MCNP program were, in the majority of cases, obtained by the authors of the evaluations and are taken from the Handbook [1].

1. Critical assemblies with high-enriched uranium solutions

The calculation results for critical assemblies with high-enriched uranium solutions are given in Table 1. In all cases the enrichment was at least 89% and is therefore not shown in the table. At the end of the table, as in Part 1, the mean characteristics of the divergences between the calculation and the experiment are given. The divergences between the experimental data and the calculation results are practically identical for both the ABBN-93 constants and ENDF/B-V.

Table 1: Critical assemblies with high enriched uranium solutions

Experiment index from the Handbook	Location carried out	Geometry and solution parameters	(k_C-k_E), % KENO ABBN-93	(k_C-k_E), % MCNP ENDF/B-V	k(MCNP-BIT)-k(KENO-93), %
Cylinders with no reflector HEU-SOL-THERM-001-1	Rocky Flats Plant	Ø27.9 cm (SS), h = 31.2 cm, C_U = 146 g/l	+0.25±0.25(10)	+0.47(21)	+0.22±0.23
HEU-SOL-THERM-001-2		Ø27.9 cm (SS), h = 28.9 cm, C_U = 367 g/l	+0.16±0.25(10)	+0.13(21)	-0.03±0.23
HEU-SOL-THERM-001-3		Ø28.0 cm (Al), h = 33.6 cm, C_U = 143 g/l	+0.73±0.25(11)	+0.64(20)	-0.09±0.23
HEU-SOL-THERM-001-4		Ø28.0 cm (Al), h = 30.9 cm, C_U = 358 g/l	+0.88±0.25(11)	+0.15(21)	-0.73±0.24
HEU-SOL-THERM-001-5		Ø33.0 cm (Al), h = 39.5 cm, C_U = 54.9 g/l	+0.19±0.25(9)	+0.27(16)	+0.08±0.18
HEU-SOL-THERM-001-6		Ø33.0 cm (Al), h = 36.7 cm, C_U = 59.7 g/l	+0.66±0.25(9)	+0.74(16)	+0.08±0.18
HEU-SOL-THERM-001-7		Ø33.0 cm (Al), h = 24.0 cm, C_U = 137.4 g/l	+0.19±0.25(10)	+0.51(20)	+0.32±0.22
HEU-SOL-THERM-001-8		Ø33.0 cm (Al), h = 23.7 cm, C_U = 145.7 g/l	+0.41±0.25(10)	+0.39(20)	-0.02±0.22
HEU-SOL-THERM-001-9		Ø33.0 cm (Al), h = 22.5 cm, C_U = 357.7 g/l	+0.37±0.25(11)	+0.06(22)	-0.31±0.25
HEU-SOL-THERM-001-10		Ø50.7 cm (Al), h = 20.5 cm, C_U = 64 g/l	-0.41±0.25(10)	-0.025(17)	+0.39±0.20

Experiment index from the Handbook	Location carried out	Geometry and solution parameters	(k_C-k_e), % KENO ABBN-93	(k_C-k_e), % MCNP ENDF/B-V	*k(MCNP-BV)-k(KENO-93)*, %
The same cylinders in the centre of a concrete cell 122x122x122 cm HEU-SOL-THERM-002-1	Rocky Flats Plant	Ø27.9 cm, h = 29.8 cm, C_U = 144.4 g/l	+0.55±0.20(10)	+0.47(21)	-0.08±0.23
HEU-SOL-THERM-002-3		Ø27.9 cm, h = 29.8 cm, C_U = 144.4 g/l	**+0.68±0.20(10)**	+0.66(24)	-0.02±0.26
HEU-SOL-THERM-002-9		Ø27.9 cm, h = 29.8 cm, C_U = 144.4 g/l	+0.33±0.20(9)	+0.66(23)	+0.33±0.25
The same cylinders in the centre of a plexiglass cell 123x123x123 cm HEU-SOL-THERM-003-3	Rocky Flats Plant	Ø27.9 cm (SS), h = 29.8 cm, C_U = 147.7 g/l	+0.36±0.50(10)	+0.73(25)	+0.37±0.27
HEU-SOL-THERM-003-5		Ø27.9 cm (SS), h = 27.6 cm, C_U = 345.33 g/l	+0.27±0.50(10)	+0.09(21)	-0.18±0.23
HEU-SOL-THERM-003-8		Ø28.1 cm (Al), h = 31.3 cm, C_U = 147.7 g/l	+0.69±0.50(10)	+0.65(23)	-0.04±0.25
HEU-SOL-THERM-003-10		Ø28.1 cm (Al), h = 28.8 cm, C_U = 345.3 g/l	+0.57±0.50(10)	0.00(23)	-0.57±0.25
HEU-SOL-THERM-003-12		Ø33.0 cm (Al), h = 34.3 cm, C_U = 60.3 g/l	+0.41±0.50(9)	+0.40(22)	-0.01±0.24
HEU-SOL-THERM-003-16		Ø33.0 cm (Al), h = 22.8 cm, C_U = 147.7 g/l	+0.31±0.50(10)	+0.27(23)	-0.04±0.25
HEU-SOL-THERM-003-18		Ø33.0 cm (Al), h = 21.7 cm, C_U = 345.3 g/l	+0.68±0.50(11)	-0.48(23)	-1.16±0.25
HEU-SOL-THERM-003-1	LANL	Cylinder Ø35.6 cm, h = 13.86 cm, C_U = 144.4 g/l	-1.10±0.50(10)	-1.05(14)	+0.05±0.17
HEU-SOL-THERM-003-8		The same with an H_2O reflector	-1.31±0.54(10)	-1.37(15)	-0.06±0.18
Sphere with UO_2F_2 solutions with an H_2O reflector HEU-SOL-THERM-009-1	ORNL	R = 11.52 cm (Al) C_U = 696.4 g/l	+1.16±0.57(10)	+0.44(7)	**-0.72±0.12**
HEU-SOL-THERM-009-2		R = 11.47 cm (Al) C_U = 543.0 g/l	+1.34±0.57(10)	+0.42(6)	**-0.92±0.12**
HEU-SOL-THERM-009-3		R = 11.52 cm (Al) C_U = 348.8 g/l	+0.88±0.57(10)	+0.60(7)	-0.28±0.12

Experiment index from the Handbook	Location carried out	Geometry and solution parameters	(k_C-k_e), % KENO ABBN-93	(k_C-k_e), % MCNP ENDF/B-V	*k(MCNP-BV)-k(KENO-93)*, %
HEU-SOL-THERM-009-4		R = 11.84 cm (Al) C_U = 213.2 g/l	+0.08±0.57(10)	-0.12(7)	-0.20±0.12
Sphere with UO_2F_2 solutions with an H_2O reflector HEU-SOL-THERM-010-1	ORNL	R = 13.2 cm (Al) C_U = 102.6 g/l; T = 27.5°C	+0.46±0.18(9)	+0.40(7)	-0.06±0.11
HEU-SOL-THERM-010-2		R = 13.2 cm (Al) C_U = 103.8 g/l; T = 39.5°C	**+0.65±0.18(10)**	+0.55(7)	-0.10±0.12
HEU-SOL-THERM-010-3		R = 13.2 cm (Al) C_U = 109.4 g/l; T = 74.0°C	+0.38±0.18(9)	+0.40(7)	+0.02±0.11
HEU-SOL-THERM-010-4		R = 13.2 cm (Al) C_U = 111.5 g/l; T = 85.5°C	+0.12±0.18(9)	+0.15(7)	+0.03±0.11
Sphere with UO_2F_2 solutions with an H_2O reflector HEU-SOL-THERM-011-1	ORNL	R = 17.0 cm (Al) C_U = 53.0 g/l	+0.62±0.20(8)	+0.83(5)	+0.21±0.09
HEU-SOL-THERM-011-2		R = 17.2 cm (Al) C_U = 52.1 g/l	+0.17±0.20(8)	+0.44(5)	+0.27±0.09
HEU-SOL-THERM-012-1 Sphere with UO_2F_2 solution with an H_2O reflector	ORNL	R = 27.9 cm (Al) C_U = 21.4 g/l	+0.05±0.58(6)	+0.37(5)	+0.32±0.08
HEU-SOL-THERM-013-1 Sphere with uranyl nitrate solutions with no reflector	ORNL	R = 34.6 cm (Al) C_U = 20.12 g/l	-0.31±0.26(6)	+0.01(4)	+0.32±0.07
HEU-SOL-THERM-013-2		R = 34.6 cm (Al) C_U = 23.53 g/l	-0.36±0.36(6)	-0.09(4)	+0.27±0.07
HEU-SOL-THERM-013-3		R = 34.6 cm (Al) C_U = 26.77 g/l	-0.51±0.36(6)	-0.40(4)	+0.11±0.07
HEU-SOL-THERM-013-4		R = 34.6 cm (Al) C_U = 28.45 g/l	-0.39±0.36(6)	-0.29(4)	+0.10±0.07
HEU-SOL-THERM-014-1	IPPE	Cylinder Ø40 cm, h = 19.3 cm with reflector C_U = 70 g/l	-0.51±0.27(9)	-0.31(19)	+0.27±0.21
HEU-SOL-THERM-015-1	IPPE	Cylinder Ø40 cm, h = 18.7 cm with reflector C_U = 100 g/l	-0.24±0.27(9)	+0.37(23)	+0.64±0.25
HEU-SOL-THERM-015-2 (Different reflector configuration)		Cylinder Ø40 cm, h = 16.6 cm with reflector C_U = 100 g/l	**-1.17±0.34(9)**	-0.35(21)	+0.57±0.23
HEU-SOL-THERM-016-1	IPPE	Cylinder Ø40 cm, h = 15.1 cm with reflector C_U = 156.5 g/l	-1.05±0.36(10)	-0.14(22)	+0.66±0.24

Experiment index from the Handbook	Location carried out	Geometry and solution parameters	(k_C-k_E), % KENO ABBN-93	(k_C-k_E), % MCNP ENDF/B-V	k(MCNP-BIV)-k(KENO-93), %
HEU-SOL-THERM-017-1	IPPE	Cylinder Ø24.8 cm, h = 22.6 cm with reflector C_U = 202 g/l	-0.55±0.28(10)	+0.16(23)	+0.01±0.25
HEU-SOL-THERM-017-2		Cylinder Ø40.0 cm, h = 15.6 cm with reflector C_U = 202 g/l	**-1.69±0.40(10)**	-1.41(25)	+0.13±0.27
HEU-SOL-THERM-017-3 (Different from the preceding reflector configuration)		Cylinder Ø40.0 cm, h = 14.3 cm with reflector C_U = 202 g/l	**-1.95±0.36(10)**	-1.09(23)	+0.36±0.25
HEU-SOL-THERM-018-1	IPPE	Cylinder Ø24.8 cm, h = 21.7 cm with reflector C_U = 300 g/l	-0.57±0.34(10)	-1.12(21)	-0.15±0.23
HEU-SOL-THERM-018-2		Cylinder Ø40.0 cm, h = 50.5 cm with reflector C_U = 300 g/l	-1.18±0.46(10)	-0.83(25)	+0.15±0.27
HEU-SOL-THERM-018-3 (Different from the preceding reflector configuration)		Cylinder Ø40.0 cm, h = 14.3 cm with reflector C_U = 300 g/l	-0.81±0.42(10)	-1.70(24)	-0.08±0.26
HEU-SOL-THERM-019-1	IPPE	Cylinder Ø24.8 cm, h = 22.6 cm with reflector C_U = 447 g/l	+0.34±0.40(10)	+0.08(23)	-0.16±0.25
HEU-SOL-THERM-025-1	IPPE	Cylinder Ø40.0 cm, h = 23.8 cm with reflector C_U = 51.2 g/l	+0.01±0.25(8)	+0.31(8)	+0.30±0.11
HEU-SOL-THERM-025-2 (Different from the preceding reflector configuration)		Cylinder Ø40.0 cm, h = 23.8 cm with reflector C_U = 51.2 g/l	-0.02±0.25(8)	+0.31(8)	+0.33±0.11
HEU-SOL-THERM-025-4		Cylinder Ø40.0 cm, h = 23.1 cm with reflector C_U = 53 g/l	+0.06±0.27(8)	+0.66(8)	+0.60±0.11
HEU-SOL-THERM-025-5		Cylinder Ø40.0 cm, h = 18.8 cm with reflector C_U = 77 g/l	+0.11±0.30(8)	+0.67(9)	**+0.56±0.12**
Expected root-mean-square spread (δk_{exp})			±0.30	±0.33	±0.20
Observed mean divergence ($\Delta k \pm \delta k_{cal}$)			+0.12±0.57	+0.23±0.51	+0.04±0.37

As may be seen, the calculations agree well on average with the experimental data. However, the root-mean-square spread was one and a half to two times higher than expected using either of the constants systems under consideration. Hence it follows that the value

± 0.3% can hardly be viewed as a realistic evaluation of the mean error level of one experiment. There is every reason for assuming that the experimenters underestimated the error levels and, most probably, that systematic error common to the whole series of experiments was not taken into account. Figure 2 shows the divergences between the calculation and the experiment as a function of the uranium concentration. There is clearly no statistically significant dependence either in the calculations using the ABBN-93 constants (circles) or in those using ENDF/B-V (crosses).

At the same time it is clear that the results obtained for an identical uranium concentration in the solution (i.e. within one experimental series) deviate from the calculated values in one direction if not as a rule, then often. The important point here, however, is not the concentration of the solution but that the experiments belong to the same series. Thus, in the HEU-SOL-THERM-002 and -003 experiments, almost all the k_{eff} values were below the calculated values, even though the concentration ranged from 50 to 350 g/l. Both results in the HEU-SOL-THERM-006 experiment are significantly higher than the calculated values. Also higher than the calculated values were the majority of the data measured at the IPPE in series HEU-SOL-THERM-014, ... , -019, -025.

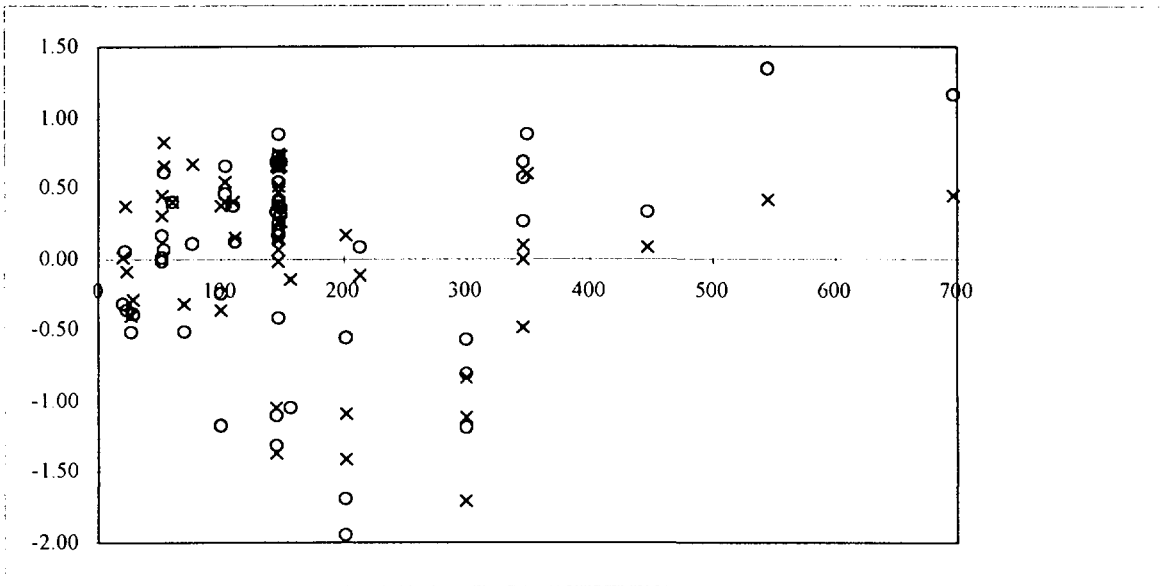

Fig. 1. Divergences between the calculation and experiment in dependence on the uranium concentration in the solution. Solution critical experiments with high-enriched uranium are considered. Circles - calculations using KENO-CONSYST; crosses - calculations using MCNP-ENDF/B-V.

Owing to the presence of unidentified systematic errors (i.e. strongly correlated for the results of one series), the root-mean-square spread would seem to be a more realistic evaluation of the mean error level of one experiment. However, even using this more cautious evaluation, in view of the lack of any systematic dependence for the divergences on concentration it is hardly possible to view all 52 experiments as independent measurements of the same value (k_{eff} of the high enriched uranyl nitrate solution) and take the mean error level of the calculated result to be $\pm 0.6/\sqrt{52} \approx \pm 0.08\%$. This evaluation would be unduly optimistic. It would be more realistic to divide by the square root of the number of experimental series (there are 16 of them). In this case, we would have to adopt an error level of ±0.15% for the calculated prediction of k_{eff} for solution systems similar to those above. However, even this error level is unduly optimistic since it can be applied with equal success to calculations employing both ABBN-93 and ENDF/B-V, though the results of these calculations (they are compared with one another in the last column of Table 1) diverge on average from one another by only 0.04%, whereas their root-mean-square spread is 0.37% which is twice as high as the divergence which would be expected on the basis of the statistical error level of the calculated results. This wide spread is caused by certain anomalously high divergences between calculation results for comparable systems. In six cases the divergences between the results of comparable calculations exceed the statistical error level by a factor of more than 3. These divergences are bolded in Table 1. Thus, for example, in the HEU-SOL-THERM-003 series, at a uranium concentration of 345.3g/l, when the tank diameter is increased from 28cm to 33cm the error level of the calculations using KENO-CONSYST rises from +0.2% to +0.7%, whereas the divergence from the calculations employing MCNP-ENDF/B-V moves in the opposite direction - from +0.1% to -0.5%, so the divergence between these calculations for the experiment with a tank radius of 33cm is 1.2%. In the same experimental series, at a uranium concentration of 147.7g/l, the divergences in the calculated results do not significantly exceed the statistical error level (which is ±0.27% for the difference in the calculated results). It should be noted that, on comparing the results obtained using the KENO program with the ABBN-93 and ENDF/B-IV constants, similar large differences are not observed: the divergences do not exceed the statistical error levels either in the above-mentioned HEU-SOL-THERM-003 series of experiments or in the HEU-SOL-THERM-009 series of experiments where, for variants 1 and 2, the divergences between the calculations using KENO-CONSYST and MCNP-ENDF/B-V are anomaly high. One possible cause of the anomalous divergences noted is hidden errors in the calculation programs. If this is in fact the case, after these errors have been identified and eliminated we might expect the calculation results for comparable constants software packages to agree with one another to within statistical error limits. In this case, the evaluation of ± 0.15% for the error level of calculated k_{eff} would acquire credibility.

Until the causes of the anomalous divergences found is clarified, on the basis of the above data we can assert at this point that, in future high-accuracy critical experiments on high-enriched uranium solutions, we can expect that the divergence from the calculated results using any of the above constants systems will not exceed 0.5%, if there are no errors in the calculation programs.

2. Critical assemblies with low-enriched uranium solutions

There are relatively few experimental data on criticalities of low-enriched uranium solutions. All the data included in the Handbook were analysed and the results are given in Table 2 below. Essentially, data are available for two enrichment levels only - 10% and 5%. The experiment with a 29% uranyl nitrate solution in a graphite reflector (IEU-SOL-THERM-001) was not taken into account here owing to the particularly complex geometry and the lack of any description of this geometry in the input language of the KENO program. Divergences (and agreement) between the calculation and the experiment under identical experimental conditions with a complex description can always be attributed to incorrect programming.

Table 2: Critical assemblies with low-enriched uranium solutions

Experiment index from the Handbook	Location carried out	Geometry and solution parameters	(k_C-k_E), % KENO ABBN-93	(k_C-k_E), % MCNP ENDF/B-V	*k(CNP-BV)-k(KENO-93)*, %
Spheres with no reflector, enrichment 10.2%; D = 65.9 cm; LEU-SOL-THERM-003-1	IPPE	D = 65.9 cm; truncated: h/D = 0.749; C_U = 296 g/l.	-0.16 ±0.39(7)	-0.06(4)	+0.1±0.08
LEU-SOL-THERM-003-2		D = 65.9 cm; truncated: h/D = 0.882; C_U = 264 g/l.	-0.42±0.42(7)	-0.12(4)	+0.3±0.08
LEU-SOL-THERM-003-3		D = 65.9 cm; full: h/D = 1.000; C_U = 260 g/l	+0.33±0.42(6)	+0.25(4)	-0.08±0.07
LEU-SOL-THERM-003-4		D = 87.3 cm; truncated: h/D = 0.545; C_U = 255 g/l	-0.58±0.42(7)	-0.52(4)	+0.06±0.08
LEU-SOL-THERM-003-5		D = 87.3 cm; truncated: h/D = 0.821; C_U = 203 g/l	-0.37±0.48(5)	-0.14(3)	+0.23±0.06
LEU-SOL-THERM-003-6		D = 87.3 cm; full: h/D = 1.000; C_U = 197 g/l	-0.22±0.49(5)	-0.12(3)	+0.10±0.06

Experiment index from the Handbook	Location carried out	Geometry and solution parameters	(k_C-k_e), % KENO ABBN-93	(k_C-k_e), % MCNP ENDF/B-V	*k(CNP-BV)*-*k(KENO-93)*, %
LEU-SOL-THERM-003-7		D = 119.8 cm; truncated: h/D = 0.538; C_U = 193 g/l	-0.40±0.49(5)	-0.25(3)	+0.15±0.06
LEU-SOL-THERM-003-8		D = 119.8 cm; truncated: h/D = 0.850; C_U = 171 g/l	-0.05±0.52(5)	+0.07(3)	+0.12±0.06
LEU-SOL-THERM-003-9		D = 119.8 cm; full: h/D = 1.000; C_U = 168 g/l	-0.29±0.52(5)	-0.17(3)	+0.12±0.06
LEU-SOL-THERM-001-1	LANL	Cylinder (Ø25cm) with uranium oxy-fluoride solution (5%) with no reflector; C_U = 1000 g/l	**+1.18±0.29(8)**	**+1.014(10)**	-0.17±0.13
LEU-SOL-THERM-002-1	ORNL	Sphere (Ø 69 cm) with uranium oxy-fluoride solution (4.9%) with an H_2O reflector; C_U = 450 g/l	-0.54±0.40(5)	-0.32(4)	+0.22±0.06
LEU-SOL-THERM-002-2		The same with no reflector, C_U = 492 g/l	-0.71±0.37(6)	-0.61(4)	+0.1±0.07
LEU-SOL-THERM-003-2		Truncated sphere with reflector H/D =0.740; C_U = 492 g/l	-0.34 ±0.44(6)	-0.12(4)	+0.22±0.07
Expected root-mean-square spread (δk_{exp})			±0.42	±0.42	±0.08
Observed mean divergence ($\Delta k \pm \delta k_{cal}$)			-0.10±0.17 -0.33±0.08*	±0.13 -0.20±0.09*	**+0.11±0.12** **+0.14**±0.09*

* The averaging results do not include the data from experiment LEU-SOL-THERM-001.

In Table 2 there is a satisfactory level of agreement between the calculated results and the experimental data on average. However, the fact that only two of the 13 experiments used yielded a k_{eff} value higher than the calculated value, and that the positive contribution of these two experiments (+0.2) was only a little less than the total negative contribution of the remaining 11 experiments (-0.3) is disturbing. This also caused the low mean divergence value. As was the case with the high enriched uranium solutions, there is every reason to assume that the experimental data contain systematic errors which are most probably common to experiments in the same series. Indeed, all three experiments carried out at ORNL and eight of the nine experiments carried out at IPPE yielded results higher than the calculated results, though they do agree with the calculation to within error limits; on the other hand, the experiment carried out at LANL yielded a k_{eff} value more than 1% lower than the calculated values. The fact that the root-mean-square spread of the data is significantly smaller than would be expected from the evaluated experimental error levels (assuming that these error levels are not correlated) would also indicate that there is systematic error. If experiment LEU-SOL-THERM-001 (whose result differs most markedly from the calculated data) is excluded, the mean divergences do rise, but they are still less than the divergences which would be expected from the evaluated experimental error levels (see Table 2 - mean values marked with an asterisk). The difference in the mean divergences (0.2%) calculated taking into account all the experiments except the one which differs most markedly from the calculated data can be taken as a measure of the error level of the calculated results.

It should be noted that, in contrast to the experiments with high-enriched uranium solutions, no unexpectedly high differences between the calculations using KENO-CONSYST and those using MCNP-ENDF/B-V were observed for this series of experiments: the mean divergence between them - expressed as a percentage of k_{eff} - is 0.11±0.12, and the maximum differences are only 0.22-0.23%.

3. Critical assemblies with uranium-233 solutions

The results of only two series of critical experiments on uranium-233 solutions have been published. Series U233-SOL-THERM-001 determined the dependence of the critical concentration on the boron additive levels. In all cases the additive level was fairly low, so the majority of fissions occurred in the thermal energy region. Series U233-SOL-THERM-008 included only one experiment on a uranium-233 solution with no absorber added. The calculation results are compared with the experimental data in Table 3.

Above all, the data in Table 3 show that calculations using the ABBN-93 constants underestimate k_{eff} by 0.7-0.8%, whereas the ENDF/B-V constants yield an excellent level of agreement with the experimental data. No dependence of the divergence on the boron concentration was found (which was to be expected considering the fact that, even at the maximum boron concentration, the vast majority of fissions and neutron absorptions were occurring in the thermal region (below 0.46 eV)). Attention is drawn to the correlation of the error levels for the results of the five experiments in the first series. This is understandable since the descriptions of the experimental data clearly show that the main sources of experimental error were inaccurate knowledge of the uranium concentration in the solution and the density of the solution; an error level of ±0.5% was ascribed to each of these, which is

at least twice as high as the spread of the measurement results relative to the continuous curve (straight line) drawn through them. The error level for the volume of the sphere also appears to be common to all these experiments, although its contribution is small. Owing to this correlation, it would seem wise to average only the results of the first and last experiments whose error levels, even though they are correlated, are of course much lower than the error levels of the other experiments belonging to the first series. As can be seen from the data in Table 3, this does not affect the nature and scale of the divergences.

The preferability of ENDF/B-V over the ^{233}U constants used in ABBN-93 was also apparent in the study of the metallic spheres, though not quite so clearly (see section 1.4). It would therefore seem wise to recalculate the ABBN constants using the ENDF/B-V data.

Table 3: Critical assemblies with Uranium-233 solutions

Experiment index from the Handbook	Location carried out	Geometry and solution parameters	(k_c-k_e) %, KENO ABBN-93	(k_c-k_e) %, MCNP ENDF/B-V	k(MCNP-BV)-k(KENO-93), %
U233-SOL-THERM-001-1	ORNL	Aluminium sphere D=70 cm with no reflector U concentration = 16.76 g/l B concentration = 0	+0.94±0.31(6)	+0.13(5)	-0.81(8)
U233-SOL-THERM-001-2		U concentration = 17.42 g/l B concentration = 0.0233 g/l	+0.92±0.33(5)	+0.08(5)	-0.83(7)
U233-SOL-THERM-001-3		U concentration = 18.03 g/l B concentration = 0.0453 g/l	+0.85±0.33(6)	+0.06(6)	-0.79(8)
U233-SOL-THERM-001-4		U concentration = 18.67 g/l B concentration = 0.0670 g/l	+0.91±0.33(6)	+0.03(6)	-0.88(8)
U233-SOL-THERM-001-5		U concentration = 19.27 g/l B concentration = 0.0887 g/l	+0.90±0.33(6)	+0.00(6)	-0.90(8)
U233-SOL-THERM-008	ORNL	U concentration = 13.05 g/l	+0.46±0.29(4)	-0.21(4)	-0.67(6)
Expected root-mean-square spread (Δk_{exp})			±0.32	±0.32	±0.08
Observed mean divergence ($\Delta k \pm \delta k_{cal}$)			+0.83±0.17 +0.70±0.24*	+0.02±0.10 -0.04±0.17*	-0.81±0.07

* Averaging results for only the first and last experiments (with no boron).

8. Conclusions

The analysis shows that the results of the calculations for critical assemblies with high-enriched uranium agree well on average with the experimental data.

In the series of experiments with low-enriched uranium solutions, the difference in the mean divergences of 0.2% calculated taking into account all the experiments except the one which differed most markedly from the calculated data represents a satisfactory level of agreement between the calculation results using the ABBN-93 constants and the experimental data on average. In this series of experiments, the calculations using ABBN-93 and ENDF/B-V show a high level of agreement with one another: the mean divergence between them - expressed as a percentage of k_{eff} - is 0.11-0.12.

The calculations for critical assemblies with ^{233}U solutions using the ABBN-93 constants underestimate k_{eff} by 0.7-0.8%. The preferability of ENDF/B-V over the ^{233}U constants in ABBN-93 indicates that it would be wise to recalculate the ABBN constants using the ENDF/B-V data.

REFERENCES

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