Benchmarking of ^{232}Th form INDL/Th-U

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1. Background

The purpose of the benchmarking exercise was to study the current status of ^{232}Th data and to validate the new ^{232}Th INDL/Th-U evaluation from the IAEA co-ordinated research project (CRP) on "Evaluated Nuclear Data Files for the Th-U Fuel Cycle".

2. Scope

Benchmarks from the ICSBE Handbook that were considered in the analysis are shown in Table 1. The RBMK benchmarks were not analysed because it was felt their sensitivity to thorium data is not very high. The benchmarks in which thorium appears only as an impurity were also excluded.

Table 1.: List of thorium-bearing lattices in ICSBEP.

Ident	Cases		Description
HEU-MET-FAST-068	1	KBR22	KBR22 (U/Th metal, polyethylene)
HEU-MET-INTER-008	1	KBR23	KBR23 (U/Th metal, polyethylene)
IEU-COMP-FAST-002	1	KBR18	KBR18 (90%235UO2+Th metal+36%235UO2)
IEU-COMP-INTER-001	1	KBR19	KBR19 (90%235UO2+Th metal+36%235UO2, polyethylene)
	1	KBR20	KBR20 (90%235UO2+Th metal, polyethylene)
IEU-COMP-THERM-005	1	KBR21	KBR21 (36%235UO2+Th metal, polyethylene)
PU-MET-FAST-008	1	THOR	THOR Pu sphere/Th-reflector
HEU-COMP-THERM-015	1	LWBR SB-1	LWBR SB-1 (93%235UO2+ZrO2, ThO2 blanket)
	1	LWBR SB-5	LWBR SB-5 (93%235UO2+ZrO2, ThO2 blanket)
U233-COMP-THERM-001	1	LWBR SB-2	LWBR SB-2 (97%233UO2+ZrO2, ThO2 blanket)
	1	LWBR SB-3	LWBR SB-3 (97%233UO2+ZrO2, UO2+ThO2 blanket)
	1	LWBR SB-4	LWBR SB-4 (97%233UO2+ZrO2, UO2+ThO2 blanket)
	1	LWBR SB-6	LWBR SB-6 (97%233UO2+ZrO2, ThO2 blanket)
	1	LWBR SB-7	LWBR SB-7 (97%233UO2+ZrO2, UO2+ThO2 blanket)
LEU-COMP-THERM-060	10	RBMK	RBMK (Th absorbers, cases 19-28)
U233-SOL-THERM-006	1	ORCEF	ORCEF (Th as impurity only)
U233-SOL-THERM-008	1	ORNL	ORNL (Th as impurity only)
U233-SOL-THERM-009	1	ORNL	ORNL (Th as impurity only)
U233-SOL-THERM-012	1	ORCEF	ORCEF (Th as impurity only)
U233-SOL-THERM-013	1	ORCEF	ORCEF (Th as impurity only)

The MCNP5 Monte Carlo code with various data libraries was used in the analysis. The inputs for MCNP5 were taken from the ICSBEP handbook, but the number of particle histories and the number of batches for k_{eff} determination were increased so that the statistical error in the calculations was negligible compared to experimental uncertainties. Sensitivity analysis on the source data library and separately on the ^{232}Th evaluated nuclear data was performed. Most of the libraries were available from the MCNPDATA package distribution. Additional libraries and ^{232}Th files in ACE format were generated at the IAEA and CIAE.

The following libraries were considered in the analysis

ENDF/B-V	The ".50c" series of materials in the RMCCS and RMCCSA files of the MCNPDATA set.
ENDF/B-VI Rel.2	The ".60c" series of materials in the ENDF60 file of the MCNPDATA set.
ENDF/B-VI Rel.4	The ".64c" series of materials in the URESA file of the MCNPDATA set.
ENDF/B-VI Rel.6	The ".66c" series of materials in the ENDF66 files of the MCNPDATA set.
ENDF/B-VI Rel.8	The ".62c" series of materials in the ACTI files of the MCNPDATA set.
ADS-Lib	The IAEA pilot library for Accelerator Driven Systems with limited number of nuclides, based on JEFF-3.1 data.
ADS/INDL	The ADS-Lib with ^{232}Th data from the INDL library (see below).

In addition to the ^{232}Th data in the libraries above, the following additional data sets for ^{232}Th were considered:

Maslov	Data file provided by V. Maslov, which include slight improvements compared to the data adopted for JEFF-3.1, as described in a paper by the author in Phys Rev C published in (2004).
Pre-ENDF/B-VII	Data file adopted from JEFF-3.1 provided by Maslov.
INDL/i3t	Preliminary INDL evaluation from the IAEA as a result of the co-ordinated research project on "Evaluated Nuclear Data for Th-U Fuel Cycle". The labels "i3t" and "i3t1" refer to the version numbers; the later differs only in the correctly represented delayed neutron spectra.

3. Results

The results are presented as the differences between the calculated multiplication factor k_c and the measured one k_m in units of parts per 100 000 (pcm). The spread in the results for the KBR series of benchmarks is very large and obscures the differences for other benchmarks, therefore separate plots for each set of benchmarks is also presented.

In Figures 1 and 2 the sensitivity of the results on different ^{232}Th data is presented. The reference data are from the ENDF/B-VI Rel.2 library, which does not contain probability tables to account for self-shielding in the unresolved resonance range.

In Figures 3 and 4 the sensitivity of the results on different libraries is presented.

Figure 1.: Sensitivity of the results for the KBR series of benchmarks on ^{232}Th data.

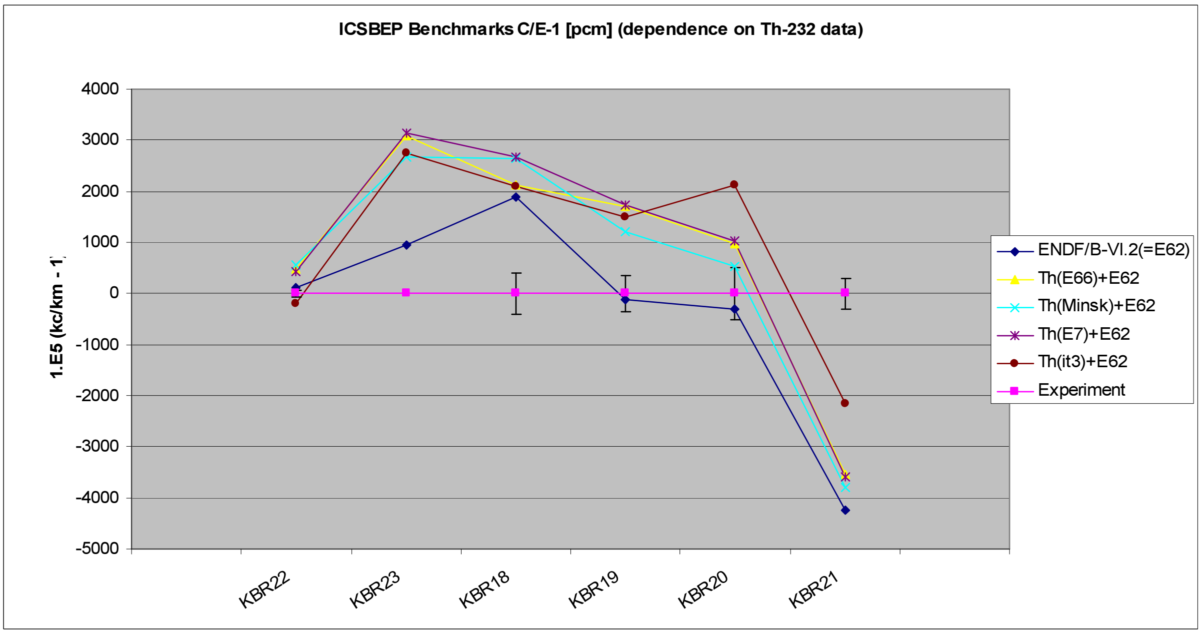


Figure 2.: Sensitivity of the results for the SB-n series of benchmarks on ^{232}Th data.

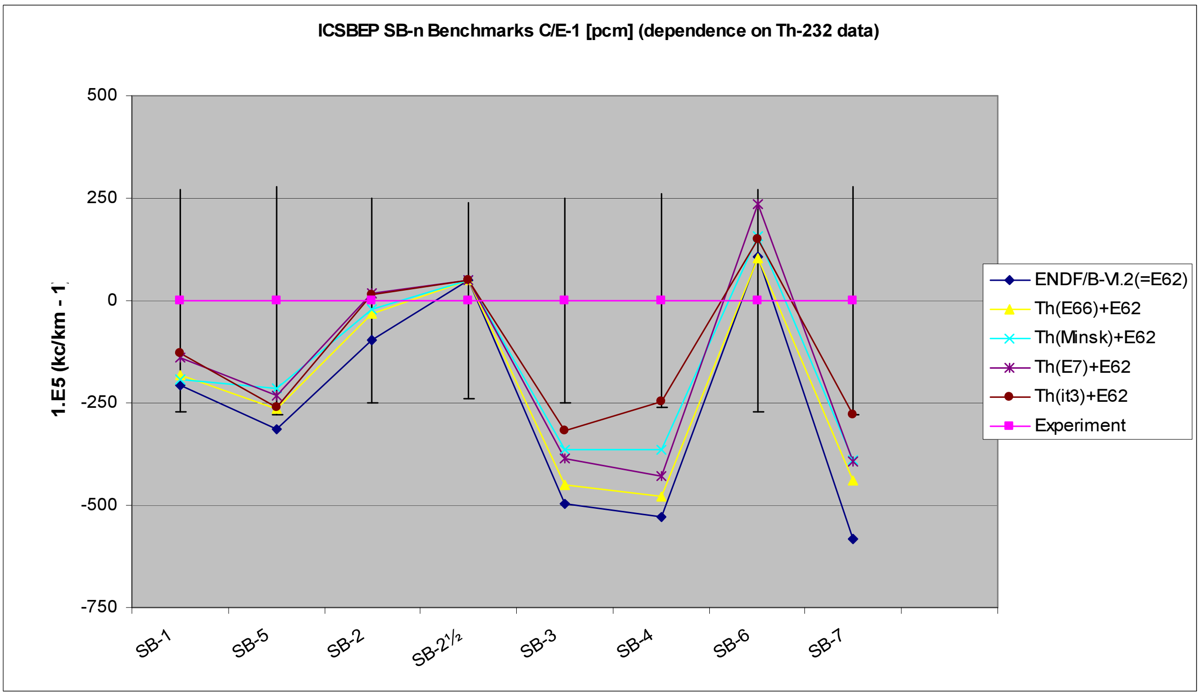


Figure 3.: Results of calculations for the KBR series of benchmarks with different libraries

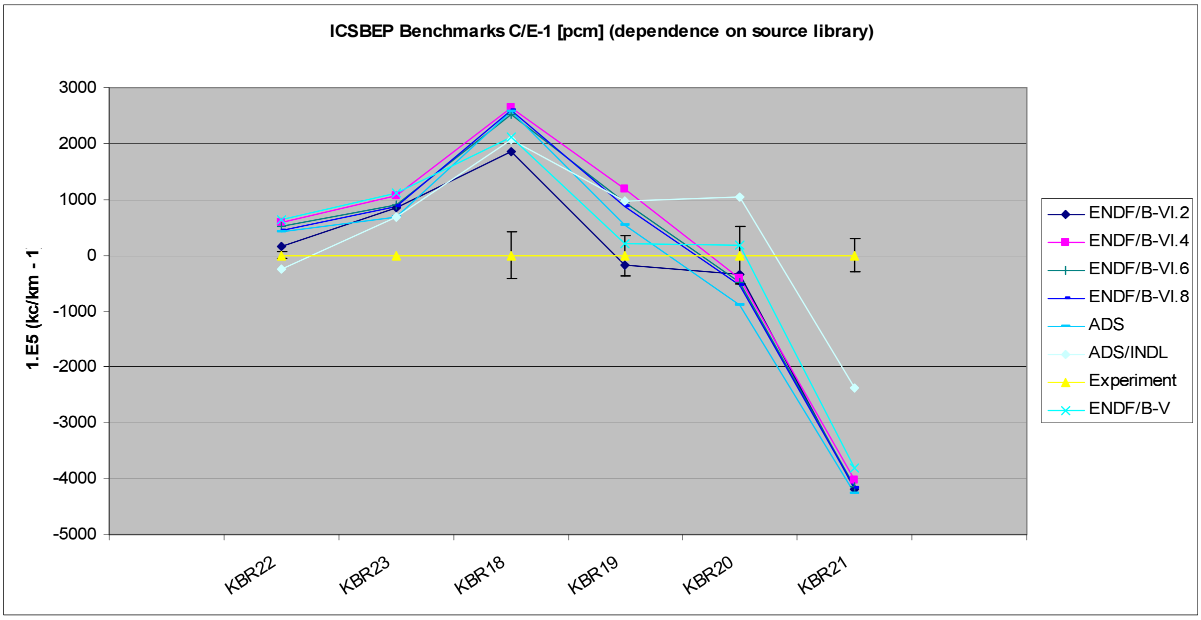


Figure 4.: Results of calculations for the SB-n series of benchmarks with different libraries

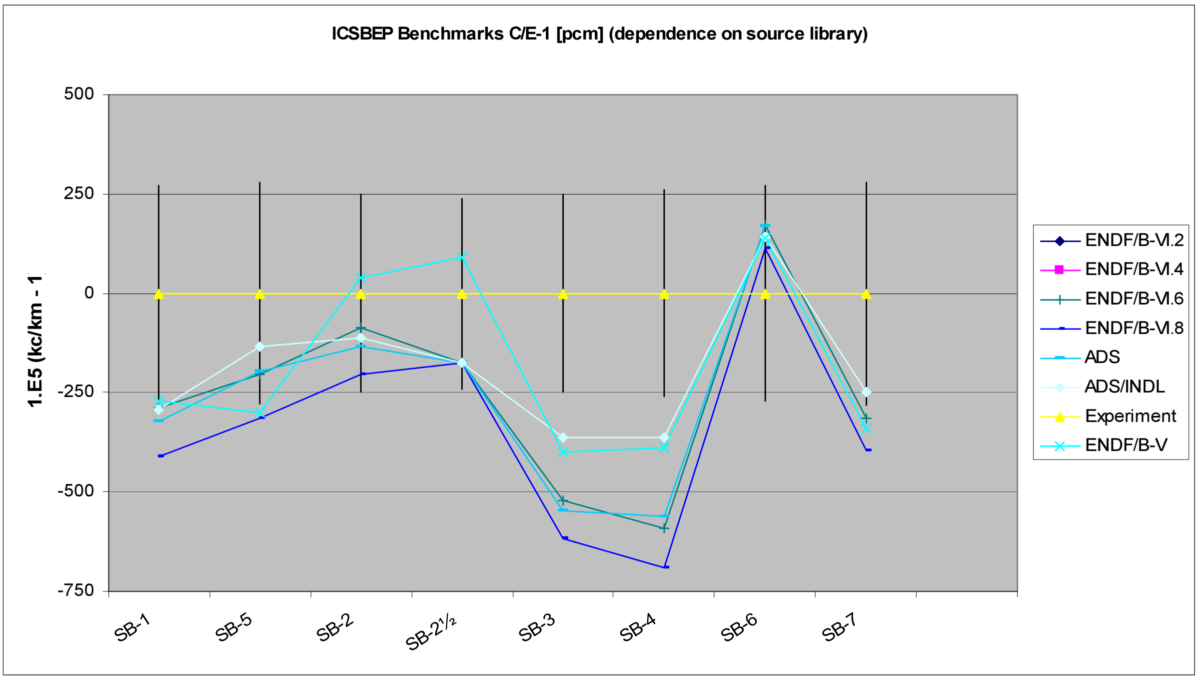
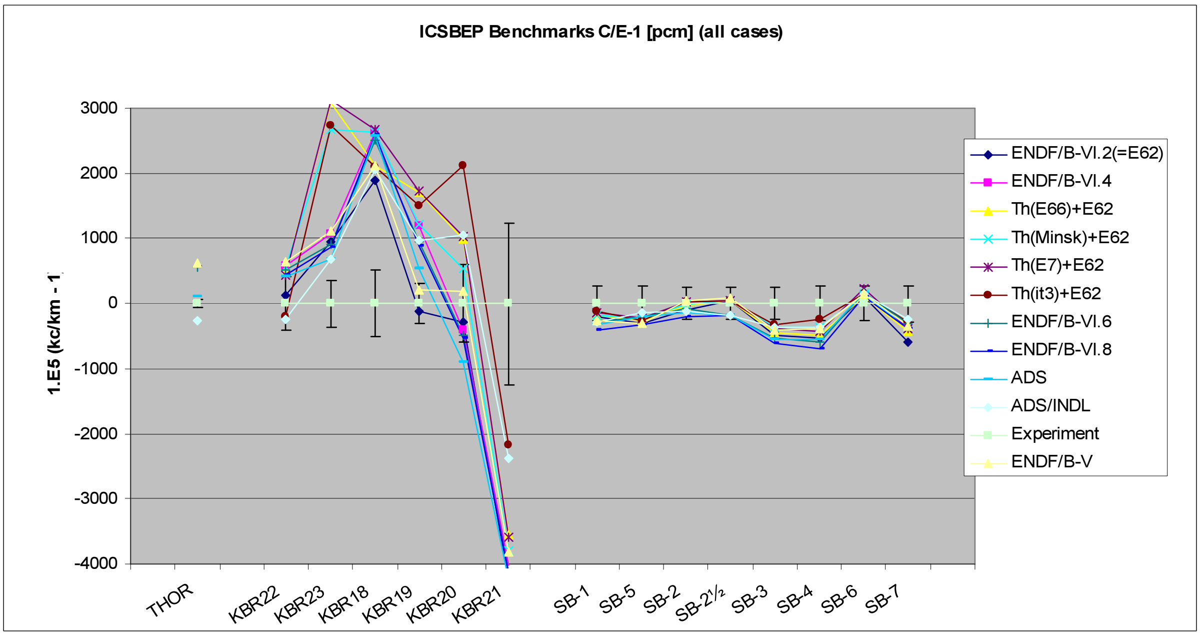


Figure 5.: Complete set of results



4. Discussion

4.1. Sensitivity on ^{232}Th data

The SB benchmarks are less sensitive to ^{232}Th data compared to the KBR benchmarks (see the scale in the Figures). Also, there seem to be large differences for data sets that include probability tables for self-shielding calculations in the unresolved resonance range; this is evident from the differences in the results using ^{232}Th data from ENDF/B-VI Rel.2 and Rel.6, respectively. In both cases the data are the same (adopted from ENDF/B-V), but the set based on ENDF/B-VI Rel.6 data contains probability tables. In the case of the SB series of benchmarks the largest differences due to ^{232}Th data occur for the SB-3, SB-4 and SB-7 benchmarks. Note that the SB-2½ benchmark contains no thorium.

4.2. Sensitivity on source data libraries

The calculations with different nuclear data libraries show better agreement compared to cases where only ^{232}Th data were varied. This suggests that there are strong interferences between cross sections, which compensate the effects of ^{232}Th data alone. It is interesting to note that following the evolutionary sequence of different releases of ENDF/B-VI library, the results seem to deteriorate compared to the reference values. At least for the SB-n series of benchmarks the ENDF/B-V library (without probability table treatment) seems to perform best, except for the ADS-Lib library based on JEFF-3.1 data (with missing nuclides taken from ENDF/B-VI Rel.8) and ^{232}Th data from the most recent IAEA evaluation.

The THOR assembly is a plutonium sphere reflected by cylindrical thorium reflector. The calculated results are sensitive to cancellation of errors in the plutonium and thorium data. Complementary results of a sphere of pure plutonium (such as the JEZEBEL assembly) should be added to the list of benchmarks.

Conclusions

The SB-n series of benchmarks indicates that the new INDL evaluated nuclear data file for ^{232}Th provides better agreement with measured data, especially when other materials are taken from the most recent data sources such as JEFF-3.1; unfortunately a full JEFF-3.1 library was not available for testing.

The KBR series of benchmarks generally indicates some improvement with the new ^{232}Th data, but the results are somewhat inconclusive due to the very large spread of about 7000 pcm in the results for different lattices. The more reliable seem to be KBR22 and KBR23, which refer to critical configurations.

The THOR assembly results should be compared with results for a bare plutonium sphere. This comparison has not been performed.