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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

UPDATE OF THE WIMS-D4 NUCLEAR DATA LIBRARY

Status Report of the IAEA WIMS Library Update Project

Compiled by S. Ganesan

December 1993

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

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Abstract

The WIMS-D4 code is one of the most widely used thermal reactor physics lattice-cell codes and is of interest especially to reactor physics groups in developing countries. The WIMS-D4 code has its working nuclear data library in processed form. The presently available nuclear data library of the WIMS-D4 code is outdated. The IAEA WIMS-D4 library update project is principally conceived to proceed through a series of thermal reactor benchmark calculations using the evaluated nuclear data libraries, nuclear data processing codes and the WIMS-D4 code. The final outcome of the project will be a reliable up-to-date nuclear data base for the WIMS-D4 code. This report presents a compilation of the papers related to the IAEA WIMS-D4 library update project. The project is expected to be completed by 1996.

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Introduction

by

S.Ganesan

The IAEA WIMS-D4 library update project was conceived with the goal of providing updated working nuclear data libraries for the users of the WIMS-D4 or compatible thermal reactor lattice-cell code. This report presents a compilation of papers related to the developments in the WIMS Library Update Project to highlight the progress achieved thus far.

The WIMS-D4 code is a freely available thermal reactor physics lattice-cell code used widely especially by scientists in developing countries for thermal research and power reactor application calculations. The presently available and widely used WIMS-D4 nuclear data library was generated more than 20 years ago using basic files available in the early sixties.

The recently released basic evaluated nuclear data files such as ENDF/B-VI, JENDL-3.1, BROND-2 and CENDL-2 are not directly used as input to neutronics or other applied calculations but are first converted to pre-processed files which are post-processed into multigroup files which are then cast into specially formatted working libraries that are compatible with neutronic codes. The urgent need to provide a consistent and correct multigroup data for core physics calculations of thermal research and power reactor applications derived from the recently released basic evaluated data files remain to be fulfilled.

Both the developed and developing countries are finding it difficult to sustain and fund adequately the nuclear data processing activities. The processing tasks demand specialized expertise using computer resources committed over a long period of time (several years) to execute the tasks. There has been no active common forum to bring the scientists, in particular in developing countries working in this area together. The field of study of nuclear data processing and preparation of processed nuclear data libraries form the connecting bridge between basic evaluated nuclear data files and application calculations. The subject involves development and validation of computer software using knowledge of ENDF/B formats and conventions, numerical reconstruction of resonance line shapes, calculations of Doppler broadening, thermalization effects, self-shielding factors in resolved and unresolved resonance regions, transfer matrices for various Legendre orders etc.

The nuclear data processing requirement must satisfy the very important requirement that errors due to processing of the basic data does not introduce unacceptable errors in the processed data which are the results of processing. The accuracy of the processed data should correctly reflect the quality of the basic evaluated data.

The present project assumes special importance because of the need to provide updated working libraries compatible with the WIMS code (or equivalent lattice cell codes that are compatible with WIMS-D4 nuclear data working library). The preparation of updated working WIMS library is an important practical step to enable

scientists use the updated nuclear data files, ENDF/B-VI, JENDL-3.1, BROND-2 and CENDL-2 which cannot be directly used in thermal research and power reactor calculations.

The task of updating the WIMS-D4 library involves the tasks of processing the basic neutron cross section files ENDF/B-VI, JENDL-3.1, BROND-2 and CENDL-2 using the nuclear data processing code system such the NJOY code system, taking care to ensure that the quality of the working library correctly reflects the quality of the basic evaluated data file from which the working library is derived, keeping the conventions and definitions of the group constants as expected by the lattice cell code system, WIMS-D4, without introducing unacceptable errors in processing.

In response to a letter dated 27 August 1990, inviting scientists to participate in the "WIMS Library Update Project, (WLUP)" and, subsequently to a second letter dated 8 September 1992 inviting scientists to participate in the extension of Phase I and in Stage 3 of the WLUP, over 23 laboratories from 18 countries together participated. It should be stressed that the participation was through correspondence and at no cost to the Agency. The results submitted by various scientists were tabulated and analyzed by A. Trkov and M. Ravnik of the Institute "Jozef Stepan" Ljubljana, Slovenia within the scope of an IAEA Research Contract No. 6291. The WIMSR module of the NJOY code system was closely examined for its consistency using initially the 1976 ENDF/B-IV data as experimental validation and comparison with other calculations in the published literature are available for ENDF/B-IV for comparison purposes. The NJOY code system with the updated WIMSR module has been successfully used, as a first attempt, to process the recently released (1992) basic evaluated nuclear data files ENDF/B-VI, JENDL-3.1, BROND-2 and CENDL-2 for a few selected isotopes. Some questions still remain as pointed out in section 2 and Section 3.

It is planned to continue to execute the IAEA WIMS-D4 library update project so that the goal of obtaining the updated WIMS working nuclear library for all the isotopes of interest can be attained.

Volunteers are invited to join the project at any time in any stage.

In order to help the newcomers to the WLUP, the letter dated 27 August 1990 inviting scientists to participate in the "WIMS Library Update Project," and also the letter dated 8 September 1992 inviting scientists to participate in the extension of Phase I and in Stage 3 of the "Wims Library Update Project," have been included in this compilation as item 6 and item 7.

Any enquiries regarding the IAEA WIMS-D4 library update project are most welcome and may be addressed to:

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Comparison of WIMS Results Using Libraries Based on New Evaluated Data Files

Primerjava rezultatov programa WIMS z uporabo različnih knjižnic presekov na osnovi novejših evaluiranih knjižnic podatkov

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ABSTRACT - A number of selected benchmark experiments have been modelled with the WIMS-D/4 lattice code. Calculations were performed using multigroup libraries generated from a number of newly released evaluated data files. Data processing was done with the NJOY91.38 code. Since the data processing methods were the same in all cases, the results may serve to determine the impact on integral parameters due to differences in the basic data. The calculated integral parameters were also compared to the measured values. Observed differences were small, which means that there are no essential differences between the evaluated data libraries. The results of the analysis cannot serve to discriminate in terms of quality of the data between the evaluated data libraries considered. For the test cases considered the results with the new, unadjusted libraries are at least as good as those obtained with the old, adjusted WIMS library which is supplied with the code.

POVZETEK - Nekaj izbranih testnih kritičnih eksperimentov smo modelirali s programom WIMS-D/4. Izračuni so bili narejeni na osnovi grupnih konstant dobljenih iz več različnih novejših knjižnic evaluiranih nevtronskih podatkov. Za procesiranje podatkov je bil uporabljen program NJOY91.38. Ker je bila priprava podatkov izvedena na enak način, so rezultati primerni za določitev vpliva razlik med knjižnicami na integralne parametre. Izračunani integralni parametri so bili primerjani tudi z izmerjenimi vrednostmi. Ugotovljeno je bilo, da so odstopanja majhna, zato na osnovi teh rezultatov ni mogoče ugotoviti bistvenih razlik v natančnosti podatkov v različnih evaluiranih knjižnicah. Za obravnavane testne primere smo ugotovili, da so rezultati z novimi, nepopravljenimi WIMS knjižnicami najmanj tako dobri kot tisti dobljeni s staro knjižnico, ki je bila popravljena na osnovi integralnih meritev

1 Introduction

The WIMS package [1] originating from the Winfrith laboratory is widely used for reactor calculations of a variety of thermal reactors. It consists of a lattice transport code and the associated library. The lattice code exists in a version, which is available from the NEA Data Bank at Saclay as WIMS/D-4, and versions LWR-WIMS and WIMS-E

which are distributed to the users through the ANSWERS service [2] on commercial terms. They all use basically the same multigroup data library [3], although the commercial versions allow some format extensions and their library is reported to include some further data adjustments [4] which improve the performance of WIMS.

The libraries that are supplied with different versions of the WIMS code are based on basic evaluated data files originating from the sixties. Considering that the source data base is very old and obsolete, the performance of WIMS has been shown to be remarkably good because of several adjustment to the multigroup data and particularly to the resonance integrals. The adjustments were performed through comparisons of the calculated integral parameters with measurements for a wide range of "benchmark" experiments.

With the welcomed release of several new evaluated data files [5,6] through the International Atomic Energy Agency (IAEA), such as JENDL-3.1, BROND-2, ENDF/B-VI, JEF-2 and CENDL-2, it was felt that the performance of WIMS for lattice calculations could be improved by updating its library from one of the new evaluated data files. With this objective in mind, the Nuclear Data Section of the IAEA has initiated the WIMS Library Update Project (WLUP) through international cooperation [7], which commenced in 1991. The work completed so far includes optimization of WIMS inputs to model some selected benchmark experiments as accurately as possible [8] and intercomparison of data entered into the WIMS library using different code systems [9]. Related to this work is also the upgrading of the WIMSR module of the NJOY code for nuclear data processing [10], so that it could be used reliably to prepare group constants for the WIMS library. The principal advantage of NJOY [11] is its versatility and its comprehensive capability to process data in ENDF-6 format, which is used for the ENDF/B-VI, JEF-2 and CENDL-2 evaluated data libraries.

A parametric study of the effect of different NJOY input options on integral results calculated by WIMS has been performed [12]. The ENDF/B-IV [13] library was used in the analysis. Using the updated library based on ENDF/B-IV data, WIMS calculations were done for a selection of benchmark lattices [14], considered in Stage-1 of WLUP. The results were compared to the highly accurate published results [15] for the same lattices (obtained mainly by Monte Carlo codes), which were used as numerical benchmarks In this way a consistent set of NJOY91.38 input instructions to process evaluated nuclear data files and generate an updated WIMS library have been obtained.

Once the optimized data processing procedures for generating the WIMS library from ENDF/B-IV data with NJOY91.38 have been established, they were applied to other libraries (JENDL-3.1, ENDF/B-VI, JEF-1, JEF-2 and CENDL-2) that can be processed by the same code. The results of such analysis are presented in this work.

2 Data processing verification

The data processing details and the sensitivity of the results to the selection of the input parameters have been reported elsewhere [10,12,16,9], so they will not

Table 1: Summary of WIMS results based on ENDF/B-IV data for selected benchmark lattices and comparison with reference results.

LATTICE	k_{eff}	ρ^{28}	δ^{25}	δ^{28}	C^*
TRX-1	0 98760(32)	1 382(43)	0 0994(50)	0 0955(63)	0 806(25)
ENDF/B-IV	0 98706(- 05)	1 380(- 14)	0 1002(+ 80)	0 0928(-2 8)	0 804(- 25)
TRX-2	0 99350(31)	0 863(58)	0.0609(49)	0.0676(44)	0.647(.31)
ENDF/B-IV	0 98916(- 44)	0 868(+ 58)	0 0615(+1 0)	0 0660(-2 4)	0 649(+ 25)
BAPL-1	0 99140(30)	1 433(2 0)	0.0835(1 6)	0.0735(95)	0 817(1 3)
ENDF/B-IV	0.99321(+ 18)	1 429(- 28)	0 0843(+ 98)	0.0717(-2.5)	0 814(-.31)
BAPL-2	0 99320(09)	1 188(1.3)	0 0678(1.8)	0 0631(79)	0 742(81)
ENDF/B-IV	0 99325(+ 01)	1 191(+ 25)	0 0688(+1 4)	0 0617(-2 3)	0 743(+ 08)
BAPL-3	0 99395(21)	0 936(1 7)	0.0522(38)	0 0516(78)	0 664(1 1)
ENDF/B-IV	0 99373(- 02)	0 938(+ 21)	0 0529(+1 3)	0 0506(-2.0)	0.664(0 00)

NOTE For each lattice the reference solution and the % uncertainty is given in the first row. The results using the updated ENDF/B-IV based library and the % difference from reference are given in the second row.

be repeated here. Integral measurements on thermal reactor lattices TRX-1, TRX-2, BAPL-UO_2-1, BAPL-UO_2-2 and BAPL-UO_2-3, which serve as standard benchmarks for testing nuclear data [14], have been selected for the analysis. For convenience, the comparison table of the calculated integral parameters [10] based on ENDF/B-IV data and the reference results is reproduced in Table 1. The measured integral parameters are listed below:

k_{eff} the effective multiplication factor,

ρ^{28} the ratio of the epithermal to thermal capture reaction rates in ^{238}U,

δ^{25} the ratio of the epithermal to thermal fission reaction rates in ^{235}U,

δ^{28} the ratio of the total fission reaction rates in ^{238}U and ^{235}U,

C^* the ratio of the capture reaction rates in ^{238}U and fission reaction rates in ^{235}U (i.e. the conversion ratio), measured in the TRX lattices only.

The thermal cutoff energy for the parameters defined above is $0.625\,eV$ where applicable.

The reference results [15] were obtained by averageing the results of 10 different contributors, 6 of them using sophisticated Monte Carlo methods. Very good agreement between different contributions was observed, so we believe the reference results to be highly reliable.

From the results in Table 1 it can be seen that WIMS predicts ρ^{28} and C^* quite well. The k_{eff} is generally predicted well, but there might be a trend to underpredict k_{eff} in lattices with metal fuel. Parameter δ^{25} lies at the upper end of the uncertainty interval of the reference results. This could be due to the differences in the treatment of the unresolved resonance parameters, which are used to describe the ^{235}U cross sections over most of the resonance range. There is a very clear underprediction of parameter δ^{28} of about 2.4%. This parameter was found to be

sensitive not only to the fission spectrum, but also to the cross section averageing spectrum This is an indication that the WIMS 69-group structure is inadequate in the fast resonance range. This problem cannot be overcome within the present scope of analysis.

The conclusions reached with ENDF/B-IV data must be considered when analysing the results obtained with other evaluated libraries, discussed in the next section.

3 Comparison of integral results using different recently released evaluated libraries

Evaluated data libraries that have been included in the analysis are the following

- CENDL-2 the Chinese evaluated nuclear data library,
- ENDF/B-VI the evaluated nuclear data files from USA,
- JEF-2 the revised joint European files,
- JEF-1 the original joint European files,
- JENDL-3.1 the Japanese evaluted nuclear data library.

The Russian BROND-2 library was also considered, but there arose problems with data processing. In the library some uncommon data formatting options are used to describe angular distributions which have not yet been incorporated into NJOY91.38, so a complete and consistent data set could not be produced.

The JENDL-3.1 and CENDL-2 libraries have no thermal scattering law data, therefore the ENDF/B-III file was used. The JEF-2 library also lacks thermal scattering law data, so the thermal scattering matrix for hydrogen bound in water processed from JEF-1 was used instead.

The results of all the calculations are summarized in Table 2. For each of the benchmark lattices the measured values of the integral parameters and the associated measurement % uncertainty are given. Then follow the calculated results using libraries generated from different evaluated data files. The calculated values and the % differences from the measurement are given. The results using the old WIMS library [3] are also presented. The result show that the maximum difference in k_{eff} never exceeds 0.58 % With most of the new libraries the parameter ρ^{28} is predicted well within the uncertainty interval of the measurements for all lattices except for BAPL-2, where a systematic overprediction of 3 to 4 % is observed. This could be an indication of an error in the measurement. The agreement of the calculated values of δ^{25} is also very good. There is a large experimental uncertainty in the measurements of δ^{28}. The calculated values are generally within the uncertainty interval of the measurements, except for the well thermalized BAPL lattices, where some underprediction of δ^{28} is observed. Part of this underprediction can be attributed to the coarseness of the energy mesh in the fast neutron range, as observed in the analysis with the ENDF/B-IV data summarized in the previous section. Parameter C^* is predicted well with all the new libraries.

Table 2. Summary of WIMS results using different evaluated data libraries for selected benchmark lattices and comparison with measured values

LATTICE	k_{eff}	ρ^{28}	δ^{25}	δ^{28}	C^*
TRX-1	1 00000(30)	1 320(1 6)	0 0987(1 0)	0 0946(4 3)	0 797(1 0)
CENDL-2	0 99997(- 00)	1 348(+2 1)	0 0980(- 72)	0.0960(+1 4)	0 789(-1 1)
ENDF/B-VI	0 99472(- 53)	1 345(+1 9)	0 0985(- 18)	0 0969(+2.5)	0 794(- 36)
JEF-1	0 99960(- 04)	1.336(+1 2)	0 0988(+ 12)	0 0978(+3 4)	0 793(- 53)
JEF-2	0 99682(- 32)	1.339(+1 4)	0 0985(-.23)	0 0958(+1.3)	0 798(+ 09)
JENDL-3 1	0 99457(-.55)	1.344(-1.8)	0.0970(-1.8)	0 0978(+3.3)	0 793(- 45)
WIMS-D/4	1 00227(+ 23)	1 279(-3 1)	0.0990(+ 30)	0 0965(+2.0)	0 780(-2 1)
TRX-2	1 00000(10)	0 837(1 9)	0.0614(1 3)	0.0693(5.1)	0 647(93)
CENDL-2	0 99911(- 09)	0.850(+1 6)	0.0603(-1.8)	0.0652(-1 6)	0 638(-1 4)
ENDF/B-VI	0 99429(- 58)	0 847(+1.2)	0.0606(-1.4)	0.0689(-.65)	0 643(- 68)
JEF-1	0 99844(- 16)	0.842(+ 60)	0 0608(- 99)	0.0699(+.81)	0 642(- 74)
JEF-2	0 99581(- 42)	0 844(+ 84)	0.0606(-1.3)	0 0684(-1 3)	0 646(- 12)
JENDL-3.1	0 99452(- 55)	0 847(+1 2)	0 0595(-2 9)	0 0697(+ 55)	0 642(- 77)
WIMS-D/4	0 99654(- 35)	0 808(-3 5)	0.0610(- 64)	0.0695(+ 30)	0 636(-1 7)
BAPL-1	1.00000(10)	1.390(72)	0.0840(2 4)	0.0780(5 1)	0 000
CENDL-2	1.00549(+ 54)	1.399(+ 63)	0.0825(-1.8)	0 0740(-5 2)	0 799
ENDF/B-VI	1.00052(+ 05)	1.392(+ 14)	0.0828(-1 4)	0 0747(-4 3)	0 804
JEF-1	1.00567(+ 56)	1.385(- 36)	0.0832(- 93)	0.0758(-2.8)	0 803
JEF-2	1 00286(+.28)	1.385(- 36)	0 0828(-1 4)	0 0741(-5 1)	0 808
JENDL-3 1	1 00137(+.14)	1.392(+ 14)	0.0816(-2 9)	0.0757(-3 0)	0 803
WIMS-D/4	1 00292(+.29)	1.358(-2 3)	0.0840(+.06)	0.0755(-3 2)	0 800
BAPL-2	1 00000(.10)	1 120(89)	0.0680(1.5)	0.0700(5.7)	0.000
CENDL-2	1 00424(+ 42)	1.167(+4 2)	0.0674(- 96)	0.0636(-9 1)	0.730
ENDF/B-VI	0 99936(- 06)	1 161(+3.7)	0 0676(- 66)	0.0642(-8.3)	0 734
JEF-1	1.00435(+.43)	1.156(+3.2)	0.0679(-.10)	0.0653(-6.7)	0.734
JEF-2	1.00157(+ 16)	1.155(+3.1)	0.0676(-.54)	0.0638(-8.8)	0.737
JENDL-3.1	1 00039(+ 04)	1 161(+3 7)	0.0666(-2 1)	0.0652(-6.9)	0.733
WIMS-D/4	1 00049(+ 05)	1.133(+1.2)	0.0687(+1 0)	0.0652(-6.8)	0 732
BAPL-3	1 00000(10)	0 906(1.1)	0.0520(1.9)	0.0570(5.3)	0.000
CENDL-2	1.00347(+.34)	0.919(+1 5)	0.0518(-.35)	0.0521(-8.5)	0.653
ENDF/B-VI	0.99885(- 12)	0 914(+ 88)	0.0520(+.04)	0.0527(-7.6)	0.658
JEF-1	1 00341(+ 34)	0 911(+.55)	0 0523(+ 48)	0 0536(-5.9)	0 657
JEF-2	1 00073(+ 07)	0 910(+ 44)	0 0520(+ 08)	0 0524(-8 0)	0 661
JENDL-3.1	1 00000(+ 00)	0 915(+.99)	0 0512(-1.5)	0 0535(-6 2)	0 657
WIMS-D/4	0 99807(- 19)	0 894(-1 3)	0.0529(+1 7)	0 0538(-5.6)	0 657

NOTE Measured values and their % uncertainty (in brackets) for each lattice are given in row-1. Then follow the results using libraries based on different evaluated data files and the old WIMS library, and in brackets the % difference from measurements.

To make the comparison clearer, averages over all the benchmark lattices were calculated and are presented in Table 3. The average measurement uncertainty was calculated as the root-mean-square of the uncertainties for each parameter over all the lattices. For each parameter, for each of the data libraries considered, the simple mean of the differences between the calculation and the measurement was calculated. As a measure of the spread of the results, the standard deviations were also calculated. For parameter ρ^{28} the results of the BAPL-2 lattice were excluded from averageing.

Table 3: Summary of average measurement uncertainties and average differences between calculated and measured values over all the benchmark lattices

LATTICE	k_{eff}	ρ^{28}	δ^{25}	δ^{28}	C^*
Average	0 16	1 32	1 69	5 12	0 97
CENDL-2	0 24(0 25)	1 46(0 53)	-1 13(0 59)	-4 60(4 04)	-1 22(0 15)
ENDF/B-VI	-0 25(0 26)	1 03(0 63)	-0 69(0 59)	-3 67(4 09)	-0 52(0 16)
JEF-1	0 23(0 28)	0 50(0 56)	-0 28(0.58)	-2.24(3.88)	-0 63(0 11)
JEF-2	-0 05(0 28)	0 58(0 64)	-0 68(0 59)	-4.39(3 88)	-0.02(0 11)
JENDL-3 1	-0 19(0.29)	1.03(0 59)	-2.23(0 57)	-2.43(3.91)	-0.61(0.16)
WIMS-D/4	0 00(0 24)	-2 55(0 84)	0 49(0 81)	-2 66(3 36)	-1.90(0 23)

NOTE Average uncertainty over all lattices for each of the parameters is given. Then follow the mean differences between the calculated values and the measurements and in brackets the standard deviation for each of the evaluated libraries considered.

On average the claculated k_{eff} with the new libraries differs by up to 0.25 % from criticality. The spread in the results is comparable to that obtained with the old WIMS library. This result is not disappointing, since we must consider, that the old WIMS library was adjusted to predict well the k_{eff}.

A significant improvement compared to the results with the old WIMS library is observed in predicting ρ^{28}. The average difference from the measured values lies within the uncertainty interval of the measurements with all libraries except CENDL-2 where it is slightly outside. The spread in the results is also reduced compared to the old WIMS library.

Parameter δ^{25} is predicted within the uncertainty interval of the measurements with all libraries except JENDL-3.1 where it is slightly outside. The spread of the results is smaller than with the old WIMS library.

On average, parameter δ^{28} is underpredicted by a few percent, but within the uncertainty interval of the measurements. The average difference from the measurements and the spread in the results are comparable to that obtained with the old WIMS library.

Since the measurements of parameter C^* are not available for the BAPL lattices, the comparison is limited to the two TRX lattices. Good agreement with measurements is observed with all the libraries except CENDL-2 where the difference slightly exceeds the measurement uncertainty. The average difference from the measurements and the spread of the results with the old WIMS library are considerably larger

4 Conclusions

Nuclear cross section data processing methods for generating a WIMS library from evaluated nuclear cross section data files have been established. They have been verified by comparing the results obtained with the ENDF/B-IV library to the published results of highly accurate Monte Carlo calculations, using the same basic data.

Using the same data processing methods, WIMS libraries have been generated from several recently available evaluated data files. A number of selected thermal reactor benchmark lattices have been analysed. The results show that there are no significant differences related to thermal reactor applications between the libraries

By comparing the calculated results for the benchmark lattices with the measured values, good agreement is observed. Almost all the parameters lie within (or very close to) the uncertainty interval of the measurements. Comparing the results with those obtained with the old WIMS library it can be concluded, that a significant improvement in predicting global lattice parameters has been achieved, even though the multigroup constants libraries for WIMS were generated from first principles. No empirical adjustments on the new data libraries were made. The work presented in this paper forms a sound basis for a systematic updating of the WIMS library.

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Due to adequate computer resources, the computationally intensive nuclear data processing was performed at the IAEA on the VAX4300 computer.

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NJOY Verification for WIMS Library Preparation

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1 Introduction

The NJOY code [1] has recently become the standard tool for processing nuclear data into multogroup libraries for various applications. Version NJOY91.38 has been released and it includes the WIMSR module which is of special interest to the WIMS [2] users community, because the standard WIMS library which is distributed with the WIMS/D-4 code is rather old and also deficient in some important reactor materials. With the availability of new evaluated data libraries it is felt that a significant improvement in WIMS performance could be achieved through the use of an updated multigroup library.

Unfortunately, the WIMSR module as distributed with NJOY91.38 does not meet the requirements for updating the WIMS library. For this reason, a project has been initiated by the International Atomic Energy Agency (IAEA) to improve this module so that it could be used to insert new data into the WIMS library based on one of the new evaluated data files. This project runs in parallel with the WIMS Library Update Project (WLUP), the aim of which is to prepare methods for verifying the WIMS library by comparison with integral experiments [3] and by comparing data entered into the WIMS libraries by different processing codes [4].

2 NJOY Processing verification

Verification of the data processed by NJOY was carried out in several stages:

- checking cross section reconstruction from resonance parameters,
- checking doppler broadening,
- checking group averageing and self-shielded cross section preparation,
- checking formatting the data according to WIMS definitions and formats specifications,

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The work was performed under a Special Service Agreement between the first author and the International Atomic Energy Agency, Vienna during the period Nov.24th to Dec.23rd 1992.

- checking for numerical roundoff errors (calculations on short word/long word machines),
- intercomparison with other codes,
- verification on integral results.

Since the integral results are not relevant for the verification of the data processing methods, to reduce the processing times and also to allow comparison with data processed by other codes, material ^{238}U (MAT 1262) form the ENDF/B-IV library was selected for testing. In later stages the ENDF/B-VI library will be used.

2.1 Resonance reconstruction

Analysis of resonance roconstruction using NJOY has already been reported by other authors [5]. The analysis repeated in this work serves only to investigate the propagarion of errors on the group constants. The pointwise data for ^{238}U from ENDF/B-IV prepared by NJOY were compared against those obtained by running LINEAR/92-1 and RECENT/92-1 [6]. A portion of the resolved resonance range for the elastic and capture cross sections is presented in Figure 1. From the figure it can be observed that there is a difference between the RECONR module of NJOY and the RECENT/92-1 code in the treatment of the negative cross sections which arise due to the use of the Single level Breit-Wigner resonance formalism. Otherwise, in the resonance peaks no significant differences are observed. The physical impact of the differences is discussed in the following sections.

2.2 Doppler broadening

In Figure 2 the Doppler broadened elastic and capture cross sections for ^{238}U from ENDF/B-IV are compared as calculated by the BROADR module of NJOY and by running SIGMA1/92-1 and FIXUP/92-1 [6] on the cross sections prepared by RECENT/92-1. From the figure it can be observed that the differences encountered before Doppler broadening are carried over to the broadened cross sections. No additional major discrepancies are noted.

2.3 Group averageing

The cross sections were group averaged in a $1/E$ spectrum by the GROUPR module of NJOY and by running GROUPIE/92-1 [6] on the cross section file prepared by SIGMA1/92-1. The narrow resonance approximation was assumed in both cases. Differences in the unresolved resonance region were ignored, since it is known that GROUPIE/92-1 can not do self-shielding and Doppler broadening in the unresolved resonance range.

At infinite dilution the agreement between the group constants calculated by the two codes is very good, especially for the capture cross section. Differences in the treatment of the small cross section values below the resonance energies is reflected by up to 0.6 % difference in the averaged elastic cross section (see Figure 3). This difference is not physically significant.

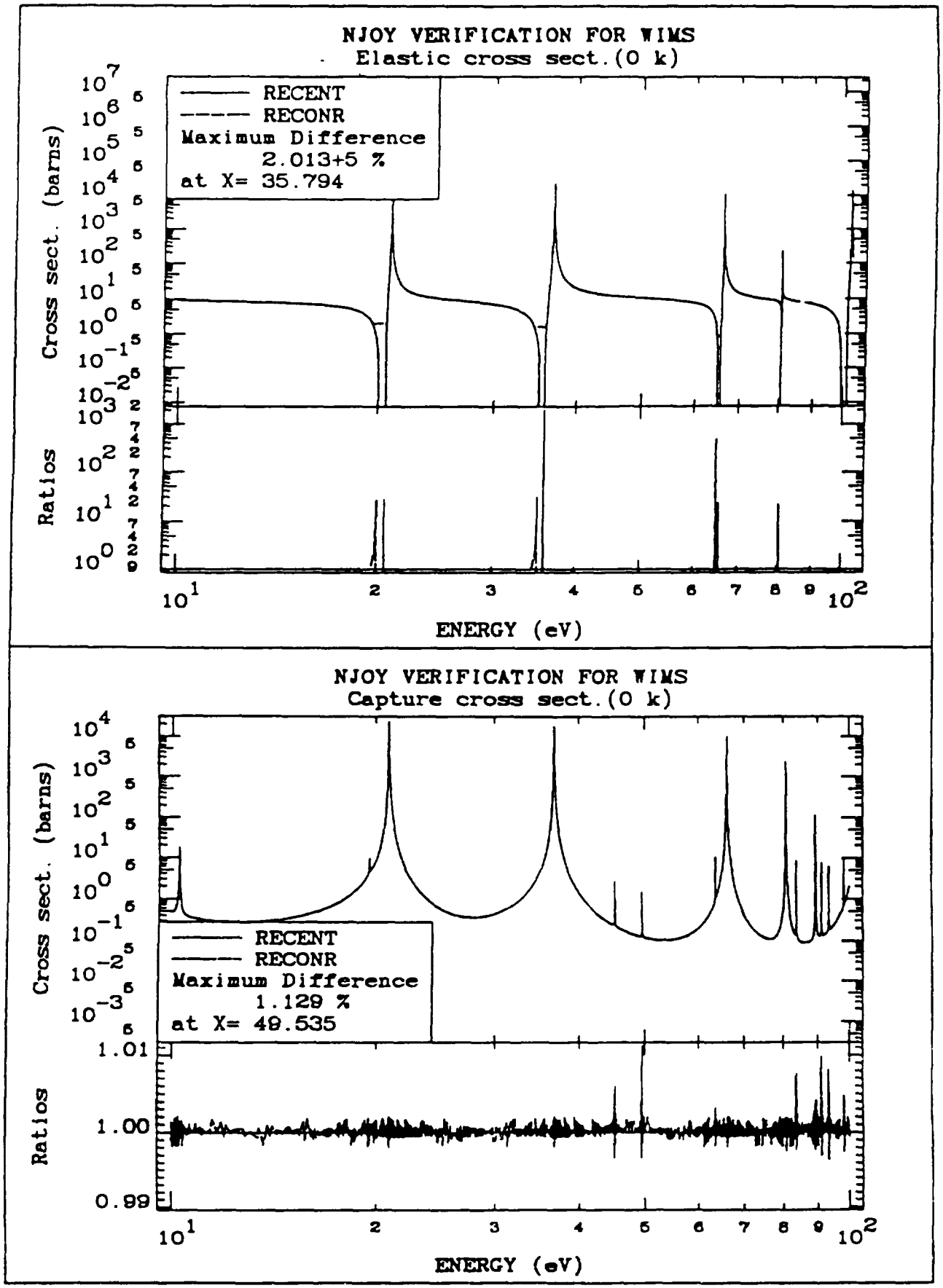


Figure 1: Comparison of the Uranium-238 elastic and capture cross sections from ENDF/B-IV reconstructed from resolved resonance parameters by NJOY91.38 and RECENT/92-1.

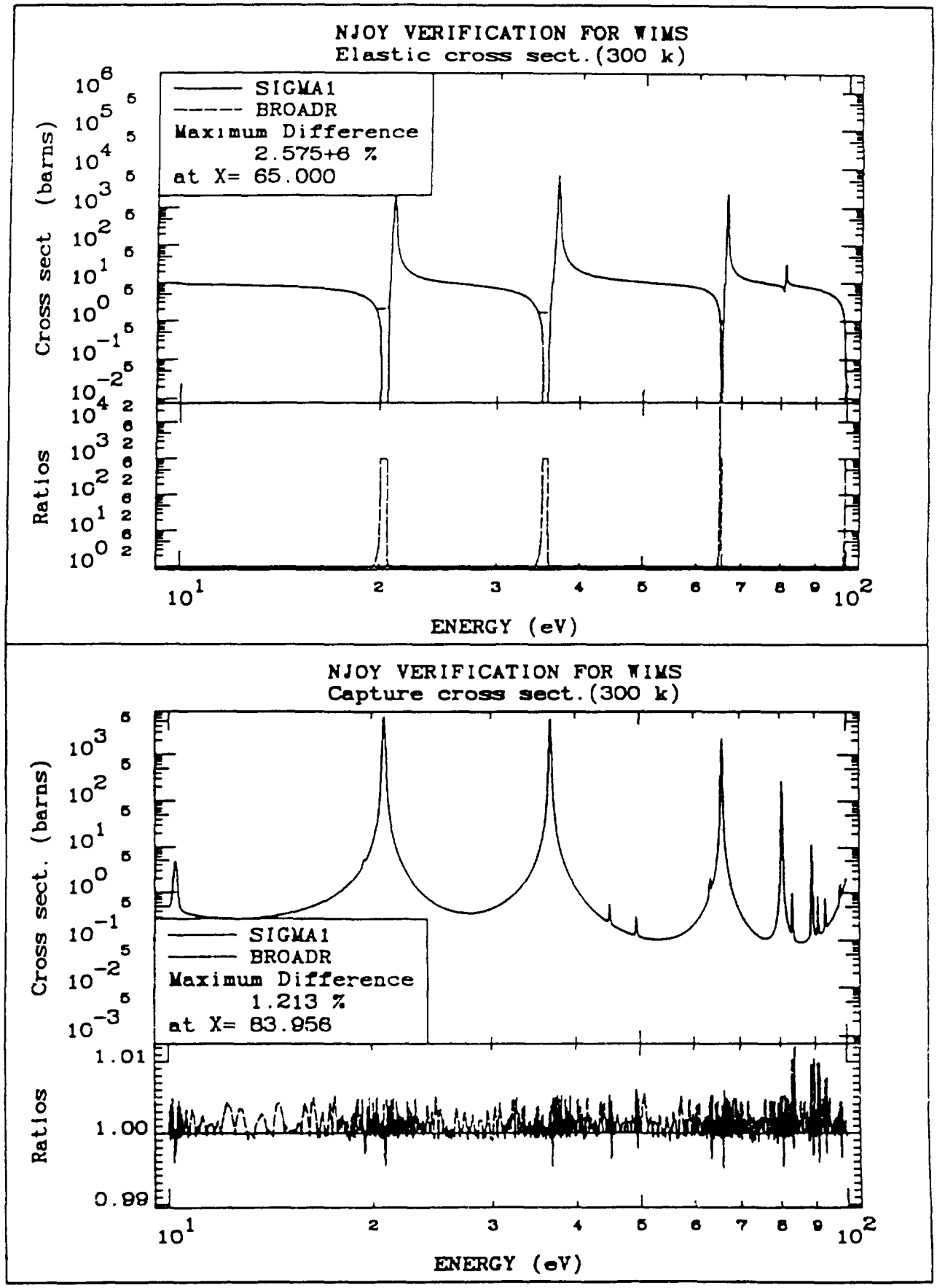


Figure 2: Comparison of the Uranium-238 elastic and capture cross sections from ENDF/B-IV Doppler-broadened by NJOY91.38 and SIGMA1/92-1.

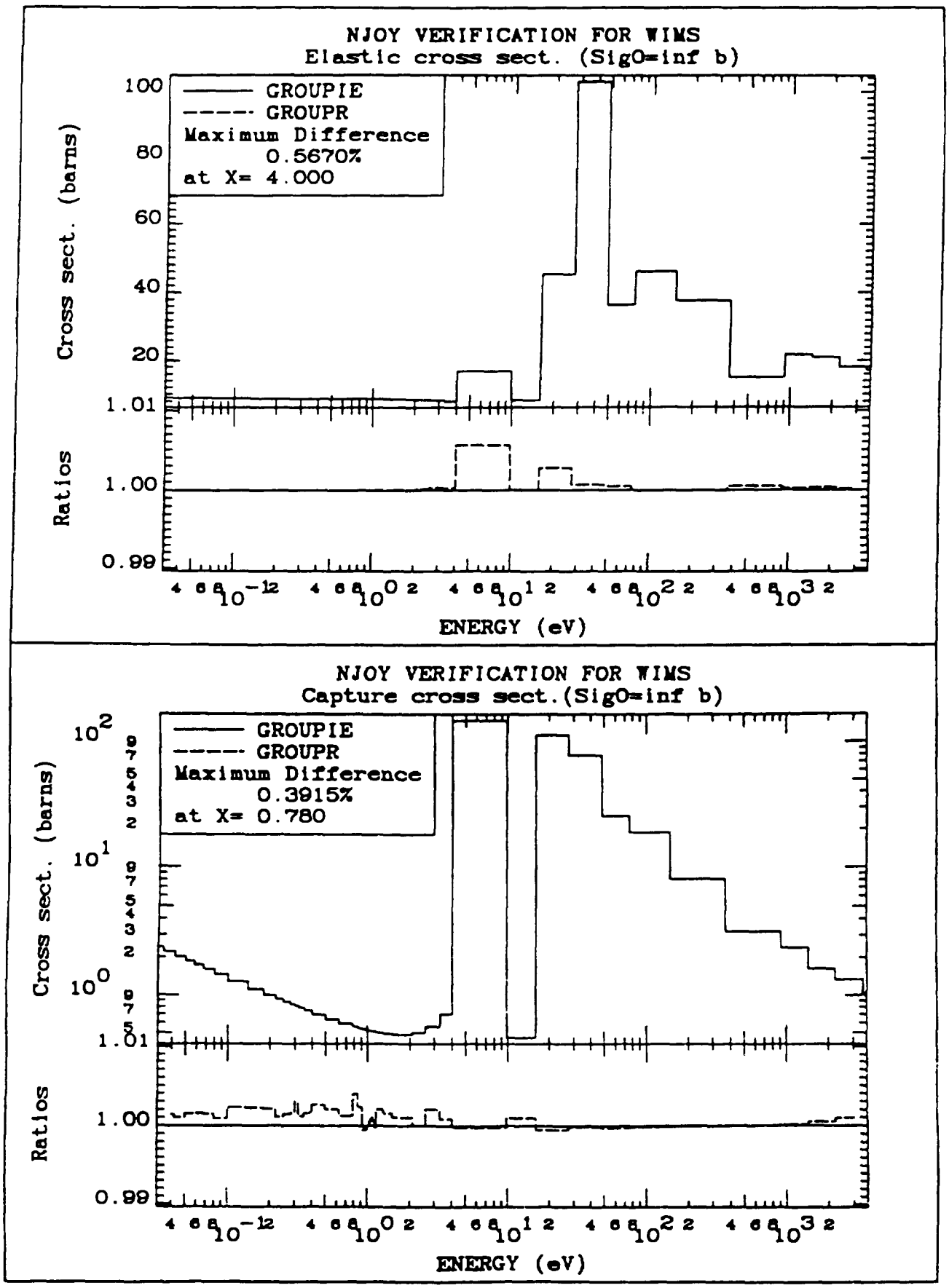


Figure 3: Comparison of the Uranium-238 elastic and capture cross sections from ENDF/B-IV group averaged by NJOY91.38 and GROUPIE/92-1 in a $1/E$ spectrum.

With increasing self-shielding the differences between the averaged cross sections calculated by the two codes gradually increase. At the value of σ_0 of $100\,barns$ the difference in the self-shielded elastic cross section increases to 1.4 %, while at $1\,barn$ it amounts to nearly 4 %. The difference in the capture cross section remains below 0.4 % at σ_0 of $100\,barns$, but at $1\,barn$ it reaches about 3 %. Some of the differences in the self-shielded elastic and capture cross sections are shown in Figures 4 and 5 for σ_0 values of 100 and $1\,barn$.

The above mentioned differences could originate either from the cross sections or from the group averageing modules. To eliminate the possibility of processing errors, the BROADR output was processed by GROUPIE/92-1 and compared to the GROUPR output. The results were practically the same, therefore it can be concluded, that the differences arise due to the differences in the resonance reconstruction and Doppler broadening procedures adopted by the two code systems.

2.4 WIMS library formatting

Before the WIMSR module of NJOY could be applied and tested, a number of obvious mistakes had to be eliminated. The necessary corrections are discussed and summarized in Appendix A.

When generating the data for WIMS, the WIMSR module allows the cross sections to be picked at different values of σ_0. The data are available in the so-called GENDF files prepared by the GROUPR module of NJOY. Since the data retrieval from GENDF files is coded in WIMSR for every reaction separately, data checking must be performed likewise. This was achieved by running WIMSR, retrieving data from the output and comparing systematically against the values retrieved independently from the GENDF file. Scattering matrices were checked only in the integral sense by comparing the total scattering cross section reconstructed from the scattering matrix.

All observed differences were insignificant and occured in cases where the cross sections were reconstructed from different reaction types. One such example is the neutron fission yield where the value calculated from the average number of neutrons per fission (MT452) and the fission cross section (MT18) differs from that reconstructed from the fission matrix by nearly 40 % in group 18, but the cross section there is less than $10^{-8}\,barns$. The differences can be attributed to the NJOY treatment of very small cross sections and can be ignored. (It has been verified on the ^{235}U data where no significant differences were observed).

An independent confirmation of the correct data formatting peformed by the WIMSR module is the comparison with the data contributed within the scope of WLUP by the Korean Atomic Energy Research Institute (KAERI), Choong-Nam, Republic of Korea, which were also calculated using NJOY91.38. These data were converted into WIMS format by an independent local code, starting from a GENDF file prepared by NJOY. Some unresolved discrepancies are discussed in the next section. It has been verified by a visual inspection of the GENDF file that they do not arise due to some error in the WIMSR module.

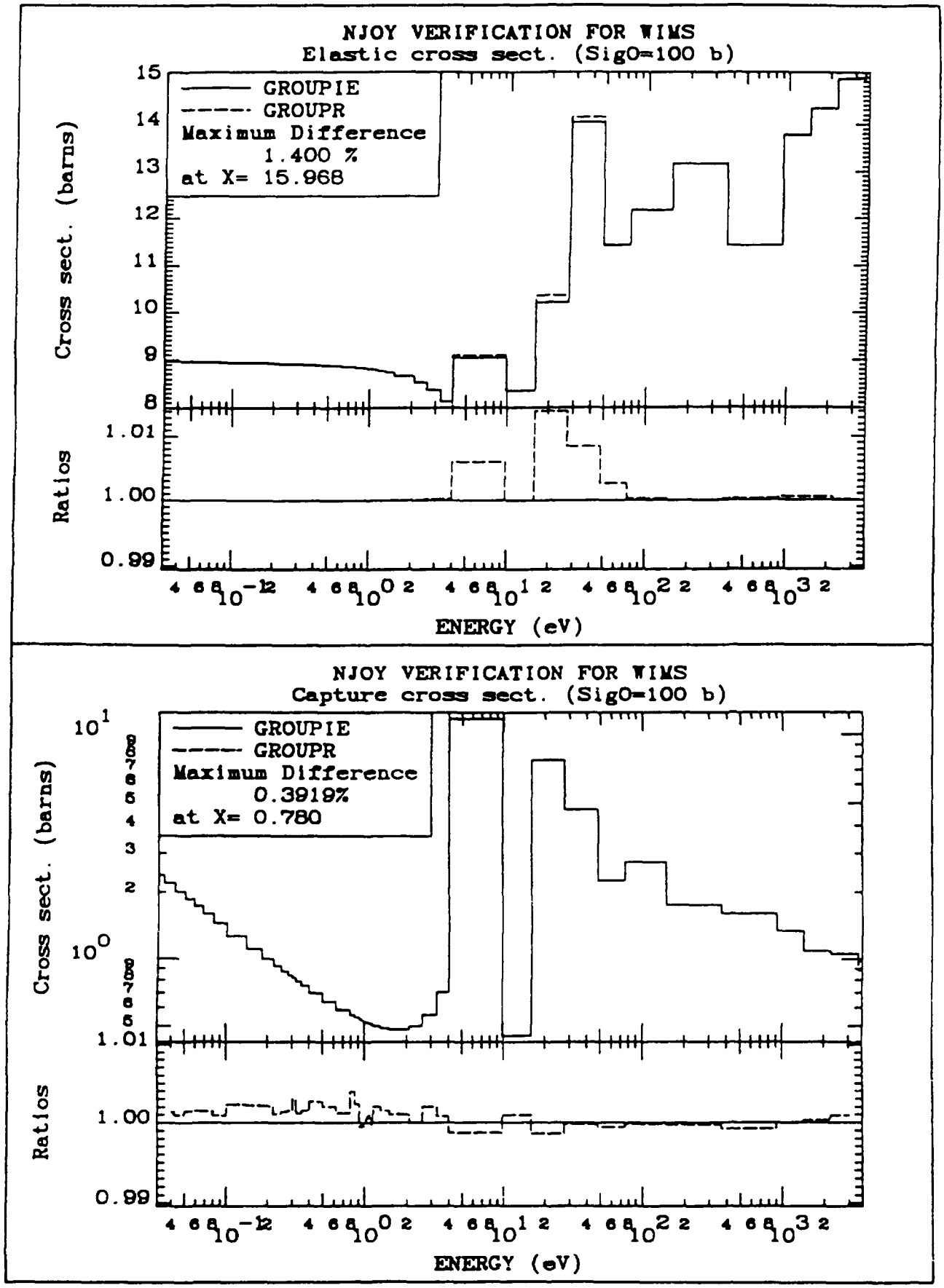


Figure 4: Comparison of the Uranium-238 self-shielded elastic and capture cross sections from ENDF/B-IV group averaged by NJOY91.38 and GROUPIE/92-1 in a $1/E$ spectrum at Bondarenko σ_0 of 100 *barns*.

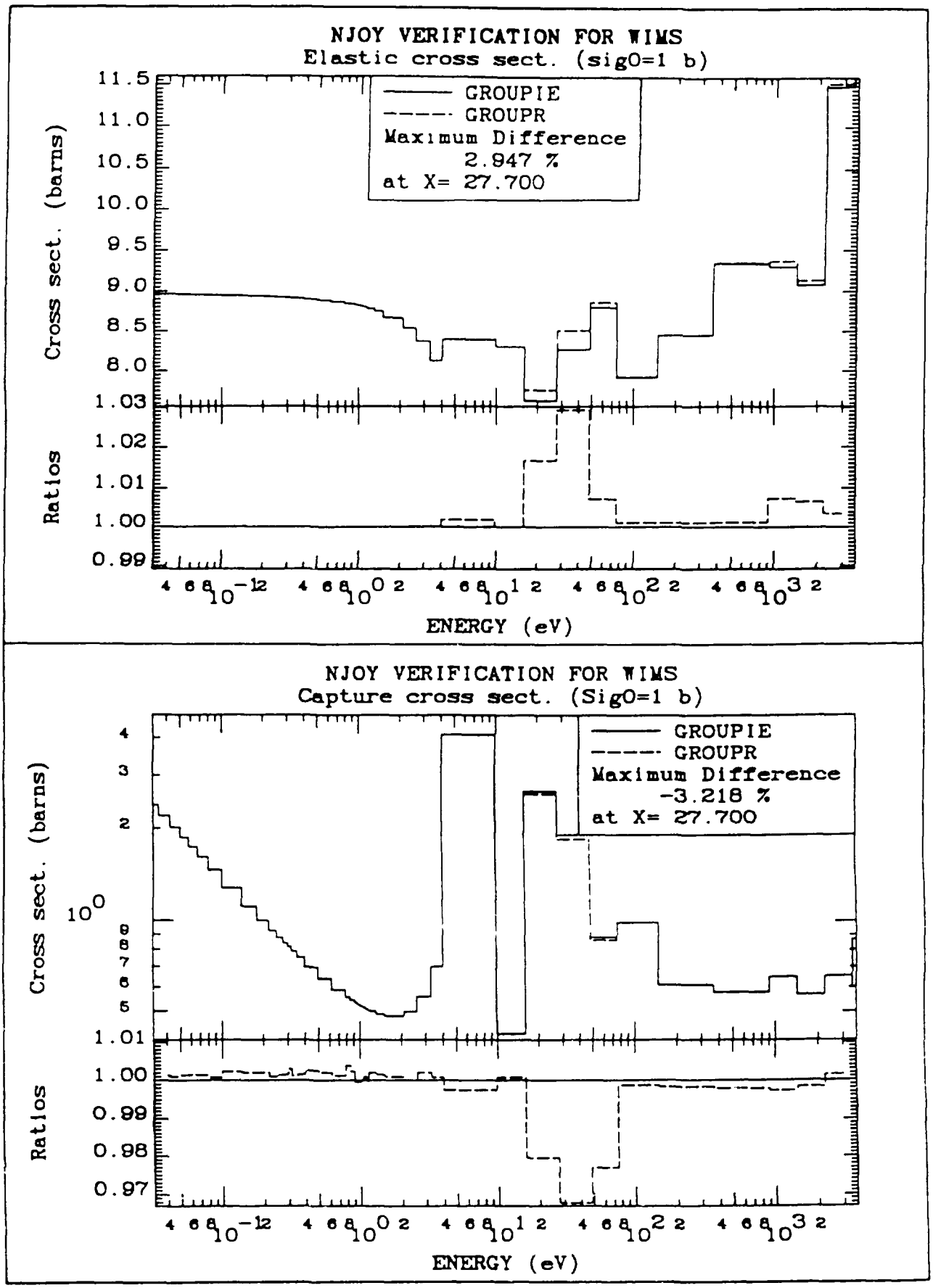


Figure 5: Comparison of the Uranium-238 self-shielded elastic and capture cross sections from ENDF/B-IV group averaged by NJOY91.38 and GROUPIE/92-1 in a $1/E$ spectrum at Bondarenko σ_0 of 1 *barn*.

2.5 Numerical roundoff errors

The KAERI data introduced in the previous section were calculated using NJOY91.38 on a workstation with a 64-bit word. A local code was used to extract the data from the GENDF file to format the WIMS library. At IAEA the input data for WIMSR were selected to simulate the general assumptions used in the KAERI data as closely as possible. Negligible differences were noted except for the following, which could not be resolved:

- 7 % difference in the slowing down power in group 27,
- up to 65 % differences in the outscattering cross section (i.e. the scattering cross section without the self-scattering term).

The possibility of a WIMSR processing error in constructing the slowing-down power in group-27 has been eliminated by a visual inspection and hand-calculation of the data from the GROUPR output.

The differences in the outscattering cross section between KAERI data and those processed at IAEA on VAX are given in Figure 6. Again, the possibility of a processing error in the WIMSR module has been eliminated. It is interesting to note that the outscattering cross section in the data contributed by IJS (Institute Jozef Stefan, Ljubljana, Slovenia) for WLUP Stage-2 and processed by FLANGE-AE (which has been incorporated into the FEDGROUP-C package [7]) does not exhibit any erratic behaviour, although the averageing spectrum is different and hence some differences are inevitable. In the energy ranges where the group mesh is refined, the peaks are observed just like in the data processed by NJOY, but in the ranges where the mesh is quite uniform, no unexpected oscillations in the outscattering cross section are encountered. Comparison between the IJS data and the NJOY calculation at IAEA is also shown in Figure 6.

2.6 Comparison with other codes

Within the scope of the WIMS Library Update Project (WLUP) a number of test WIMS libraries based on ENDF/B-IV data were received. The cross sections from following contributors were compared (in alphabetical order):

AEC Atomic Energy Corporation of South Africa Ltd., Pretoria, South Africa, using AMPX-II,

IAEA International Atomic Energy Agency, using NJOY91.38 with an updated WIMSR module,

IJS Institute Jozef Stefan, Ljubljana, Slovenia, using FEDGROUP-C86(Rev.3),

KAERI Korean Atomic Energy Research Institute, Choong-Nam, Republic of Korea, using NJOY91.38 and an independent interface module instead of WIMSR (revised contribution),

NRI Nuclear Research Institute, Rez, Czech and Slovak Federal Republic, using FEDGROUP-R (revised contribution).

The contribution from the Institute of Atomic Physics, Bucharest, Roumania, was excluded from the analysis because it was not presented in computer-readable form.

A reference data set was constructed using LINEAR/89-1, RECENT/89-1, SIGMA1/89-1, FIXUP/89-2 and GROUPIE/89-1 [6] for comparison purposes only. A Maxwellian-$1/E$-fission spectrum was used for averageing. It must be emphasized that the reference data set is not *the best* but merely served as a common basis against which other data could be compared. The differences batween the contributions were discussed in detail in reference [4]. The cross sections are presented in Figures 7-9. A summary with a special emphasis on the IAEA data set is given below. The choice of the input options for NJOY is discussed in the next section.

Potential cross section: all contributions apply a constant or weakly energy dependent potential cross section. IAEA data use the fully shielded elastic cross section.

Slowing down power: most contributions calculate the slowing down power from the elastic cross section at infinite dilution except IJS which uses the potential cross section. IAEA data set again applies the fully shielded scattering cross section to calculate the slowing down power.

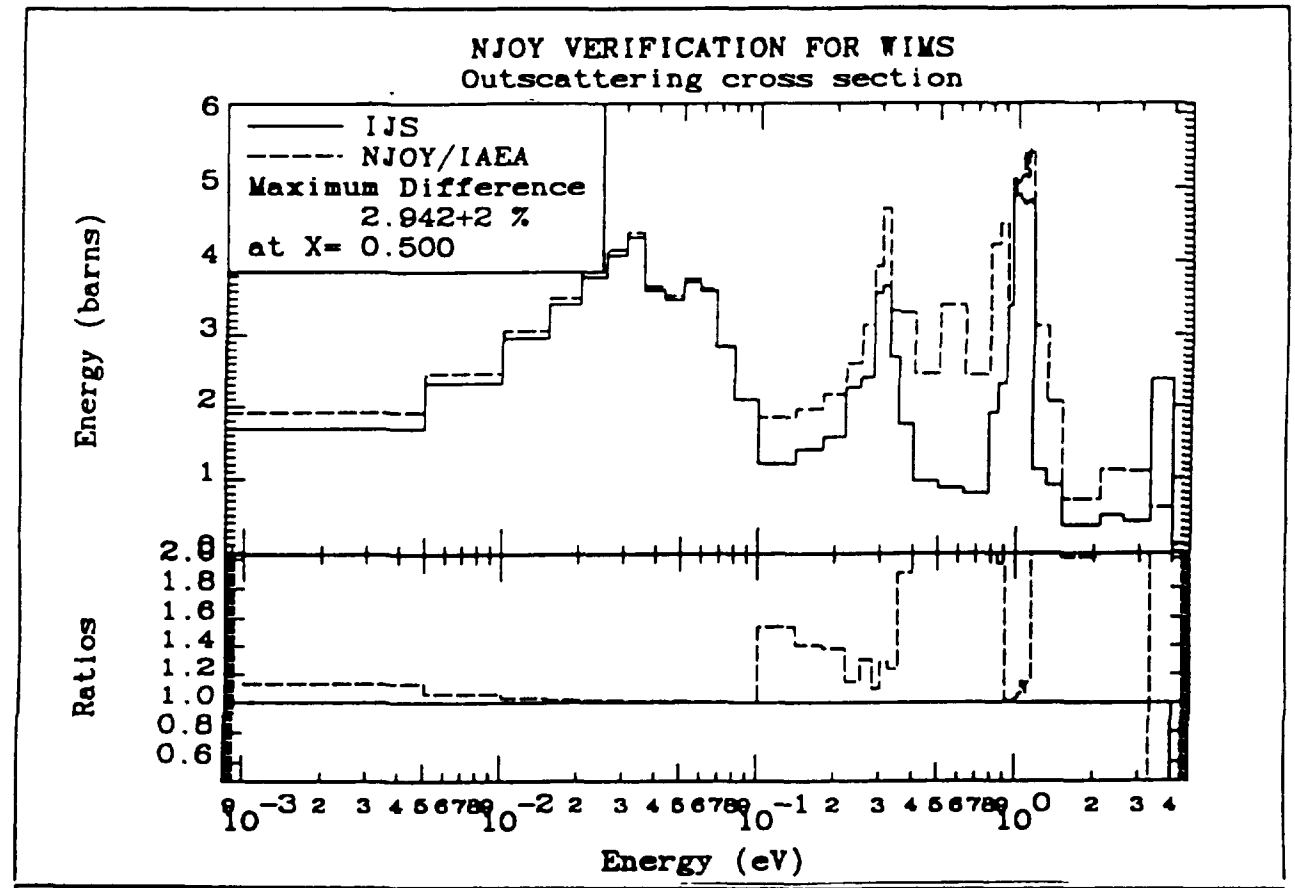
Transport cross section: In the epithermal range, AEC, KAERI and NRI use the scattering cross section at infinite dilution to define the transport cross section. The differences between them are small except for the AEC data which contain a trivial error in the unresolved resonance range. The reference solution is known to be incorrect because GROUPIE/92-1 can not process scattering matrices, which would enable a consistent definition of the transport cross section as required by WIMS. However, the observed differences are small due to the large mass of ^{238}U nuclei. The IJS data which use the potential cross section instead of the elastic resemble quite closely the IAEA data which use the fully shielded elastic cross section.

In the thermal range some oscillations are observed in the AEC data which are not physically realistic.

Absorption cross section: the AEC data show some differences in the upper end of the resolved resonance range and in the highest energy group (due to the omission of the (n,2n) correction). Other differences are small and can be attributed to the differences in the averageing spectra.

Fission cross section: below the threshold the ^{238}U fission cross section is unimportant. Differences in the treatment of small cross sections are observed between the code systems.

Scattering cross section: The same comments apply as for the transport cross section. The KAERI data were specially prepared for test purposes and do not contain the transport correction, hence the observed discrepancy.



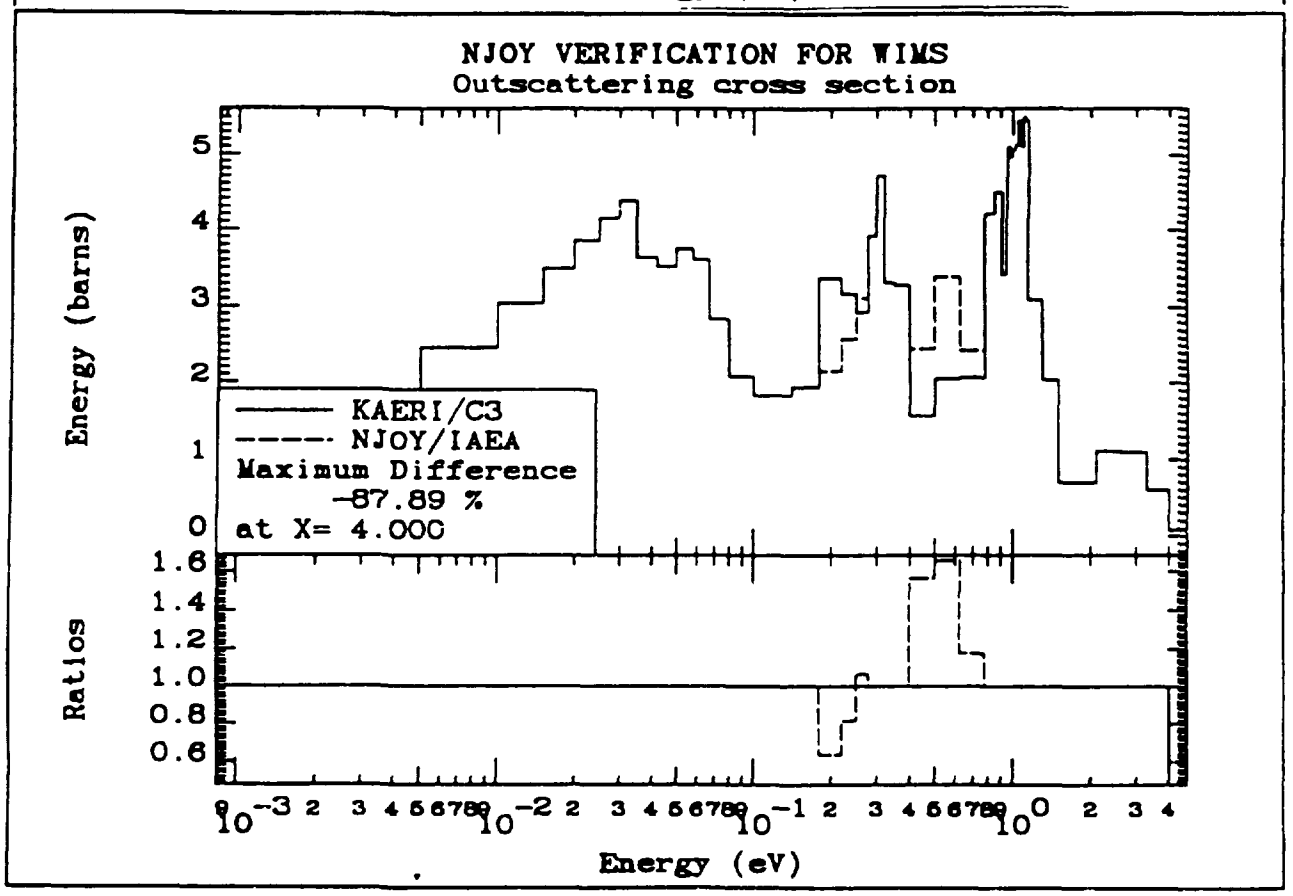


Figure 6: Comparison of the Uranium-238 outscattering cross section from ENDF/B-IV processed at KAERI, IJS and IAEA.

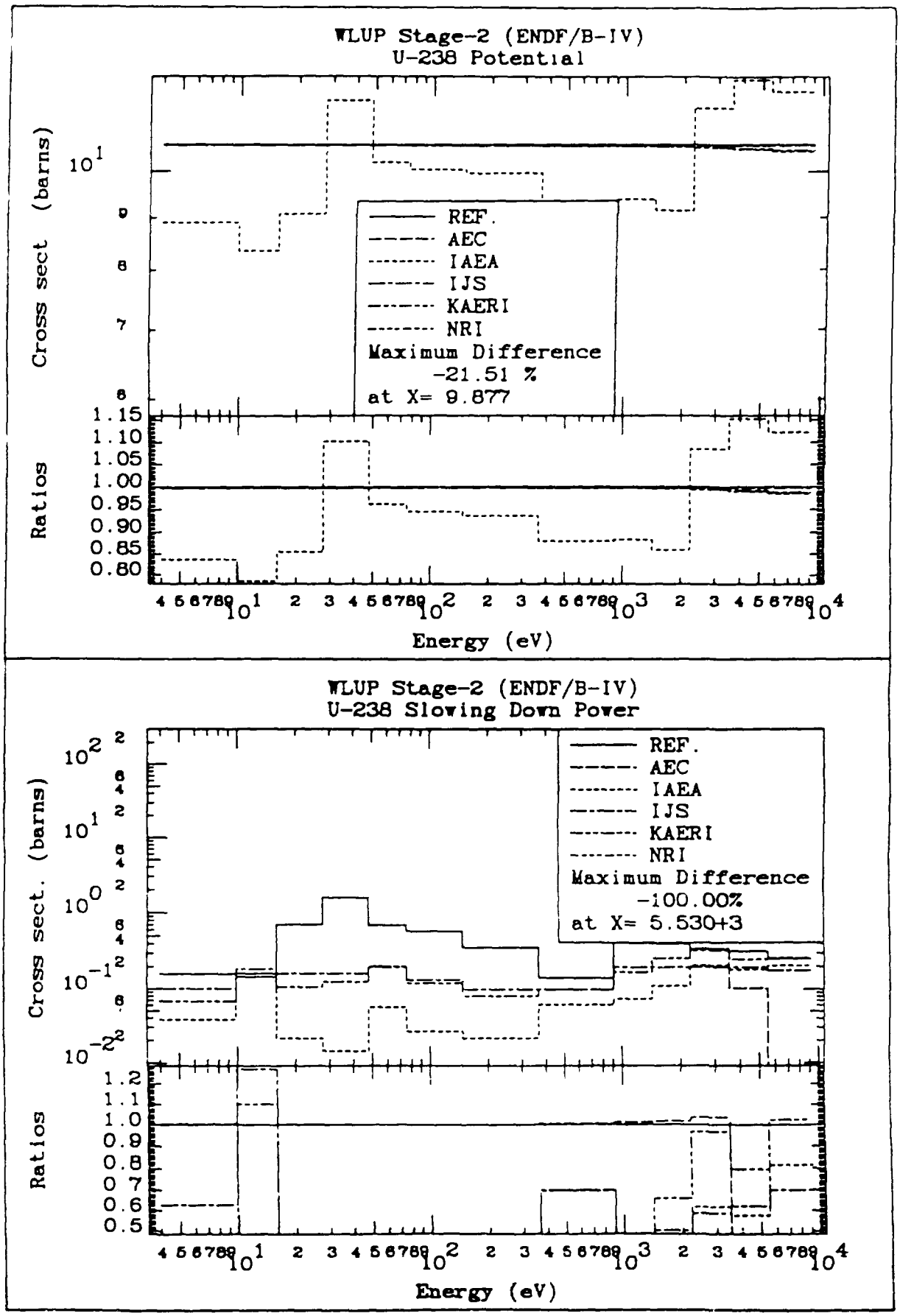


Figure 7: Comparison of the Uranium-238 ENDF/B-IV potential cross section and slowing down power contributed to WLUP by different laboratories.

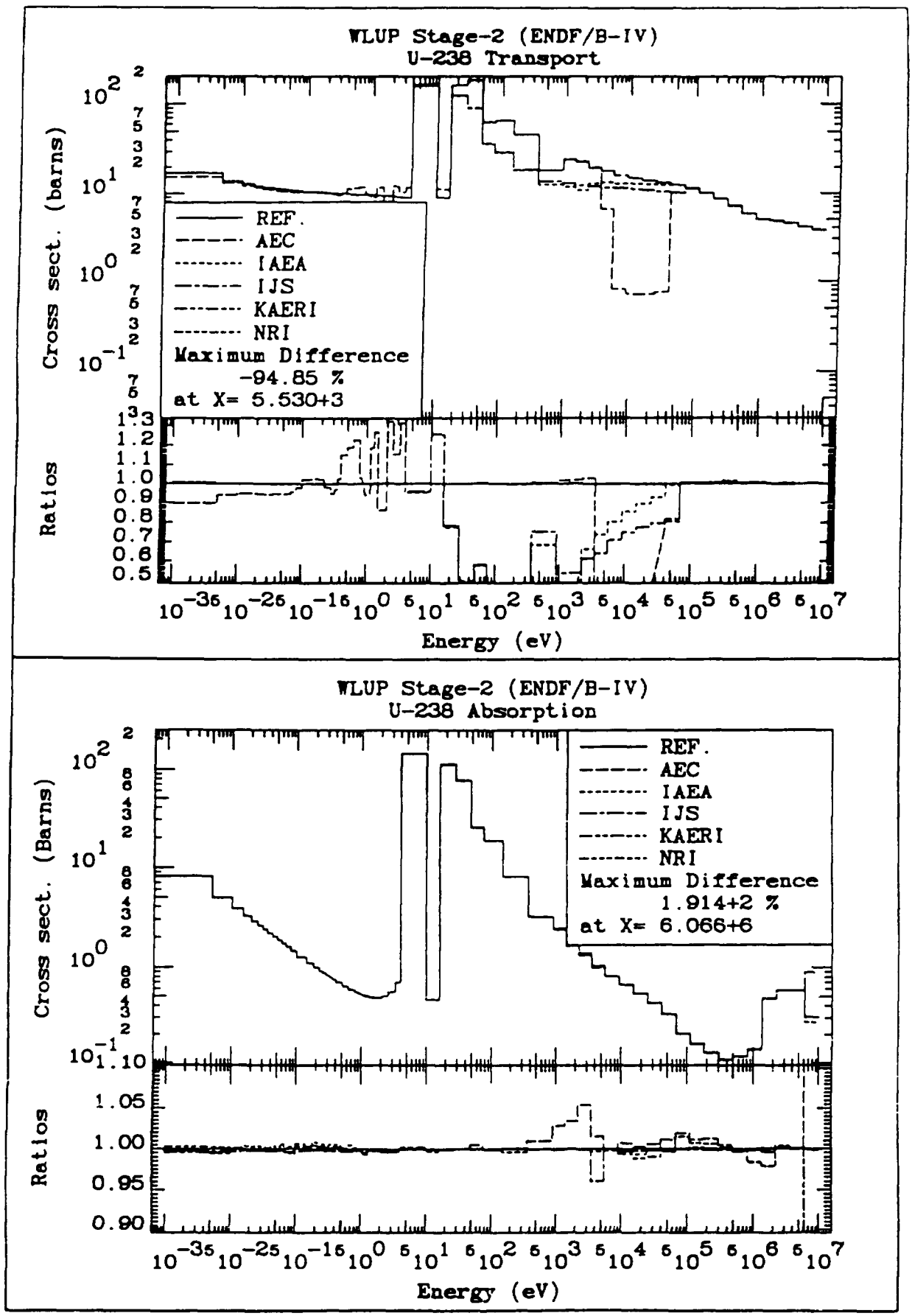


Figure 8: Comparison of the Uranium-238 ENDF/B-IV transport and absorption cross section contributed to WLUP by different laboratories.

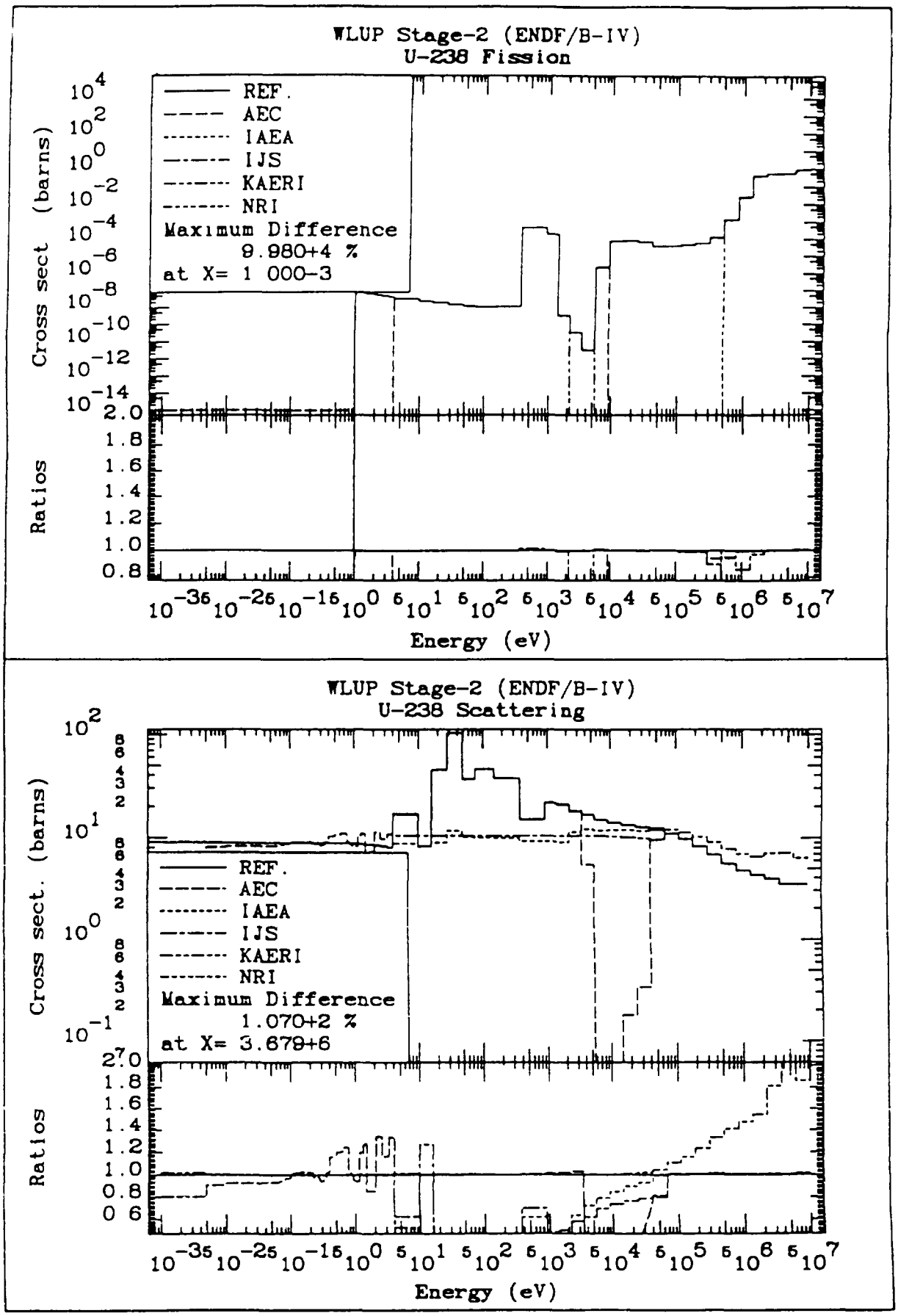


Figure 9: Comparison of the Uranium-238 ENDF/B-IV fission and scattering cross section contributed to WLUP by different laboratories.

Resonance integrals: Comparison of the resonance integrals is limited to a few resonance groups which exhibit a typical behaviour in a certain energy range. From the results received for the WLUP Stage-2, the following data sets have been selected for comparison:

REF Reference calculaltion with a modified GROUPIE code to simulate the Intermediate Resonance approximation but with a constant value of the potential cross section and the Goldstein-Cohen λ.

LRSG Standard GROUPIE/89-1 calculation with the Narrow Resonance approximation.

AEC Resonance integrals calculated by explicitly modelling the mixture of uranium with hydrogen usimg AMPX-II to calculate the averageing spectrum.

IJS Resonance integrals calculated directly by the Intermediate Resonance approximation, with the Goldstein- Cohen λ values based on the Forti approximation [8].

NJOY Calculation at IAEA using NJOY91.38 with the flux calculator option applied up to $347.9\,eV$.

To define a common basis for the comparison of the resonance integrals (i.e. to eliminate the effect of the potential cross section of the absorber which may be treated differently by different code systems), the WIMS background cross sections against which the resonance integrals are tabulated, were converted to the Bondarenko σ_0 cross sections. The dependence of the ^{238}U absorption resonance integrals on σ_0 for groups 15, 17, 20, 22, 24 and 27 is presented in Figures 10-12.

Note that in group 15 the REF and LRSG data sets are not self-shielded. A dependence on σ_0 is apparent due to the definition of the resonance integrals and corresponds to a constant self-shielded cross section. Also, the AEC data in this group should be ignored because they contain a trivial error. The self-shielding effects in the IJS data are stronger in this group compared to the IAEA calculation. This is due to different methods applied in FEDGROUP-C and NJOY. Sinc a suitable benchmark for verifying the self-shielding effects does not exist, it is not possible to say which data set is correct.

In group 20 the IJS and IAEA data sets agree very well and lie somewhat below the AEC data. On the contrary, in all groups at lower energies the AEC and IAEA data agree very well except for very small systematic errors. The flux calculator was applied in NJOY up to $347.9\,eV$ which falls into group 21. The difference between AEC and IAEA data in group 20 can be explained by the use of the Narrow Resonance approximation in NJOY. Good agreement at lower energies is very encouraging since the AEC methodology of calculating the resonance integrals with AMPX-II is the most rigorous and is expected to be the most accurate of all the contributions to the WLUP project received so far. The discrepancy in group 20 is an indication that the flux calculator in NJOY should be applied to higher energies.

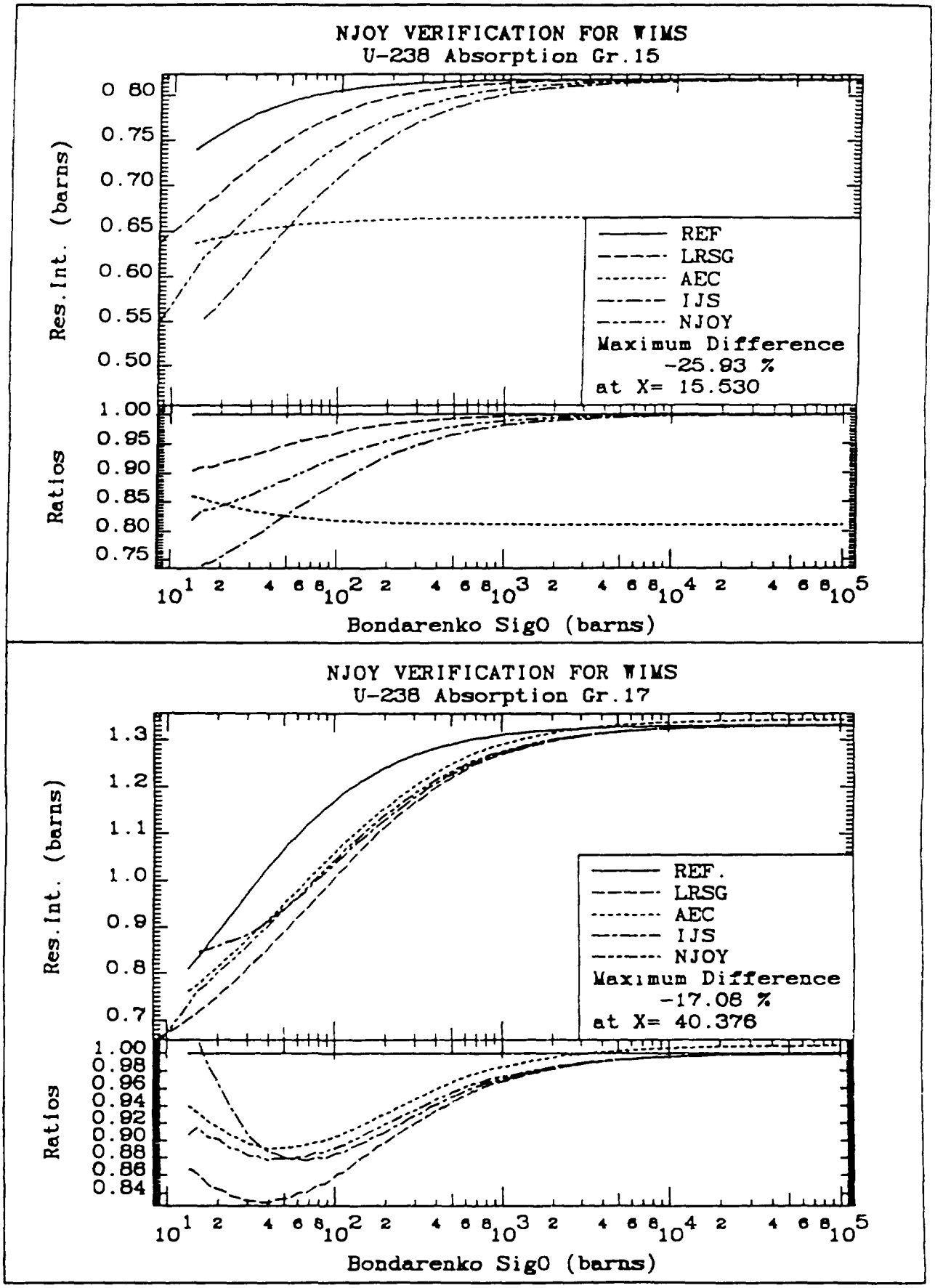


Figure 10: Comparison of the Uranium-238 ENDF/B-IV absorption resonance integrals for groups 15 and 17 contributed to WLUP by different laboratories.

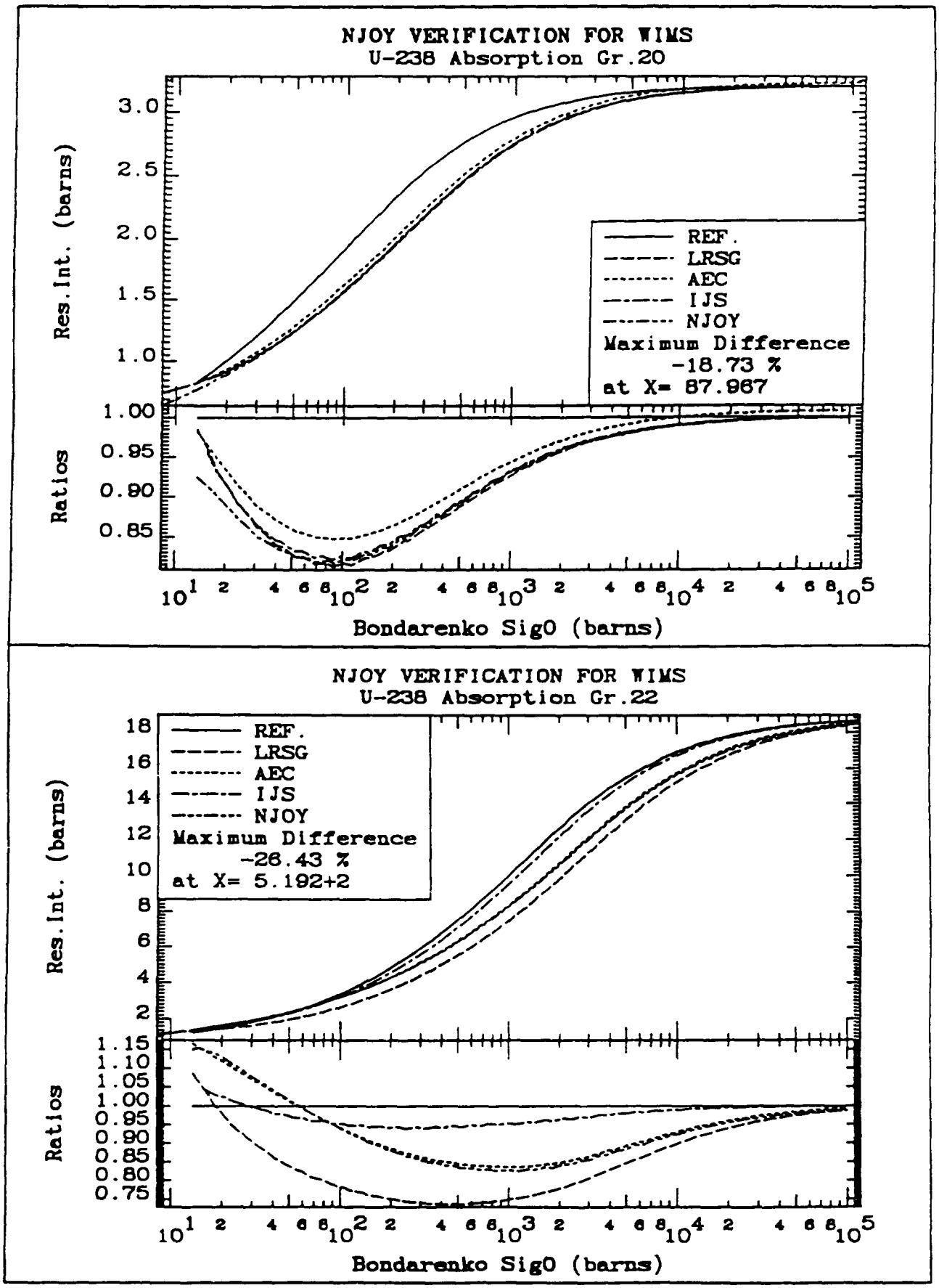


Figure 11: Comparison of the Uranium-238 ENDF/B-IV absorption resonance integrals for groups 20 and 22 contributed to WLUP by different laboratories.

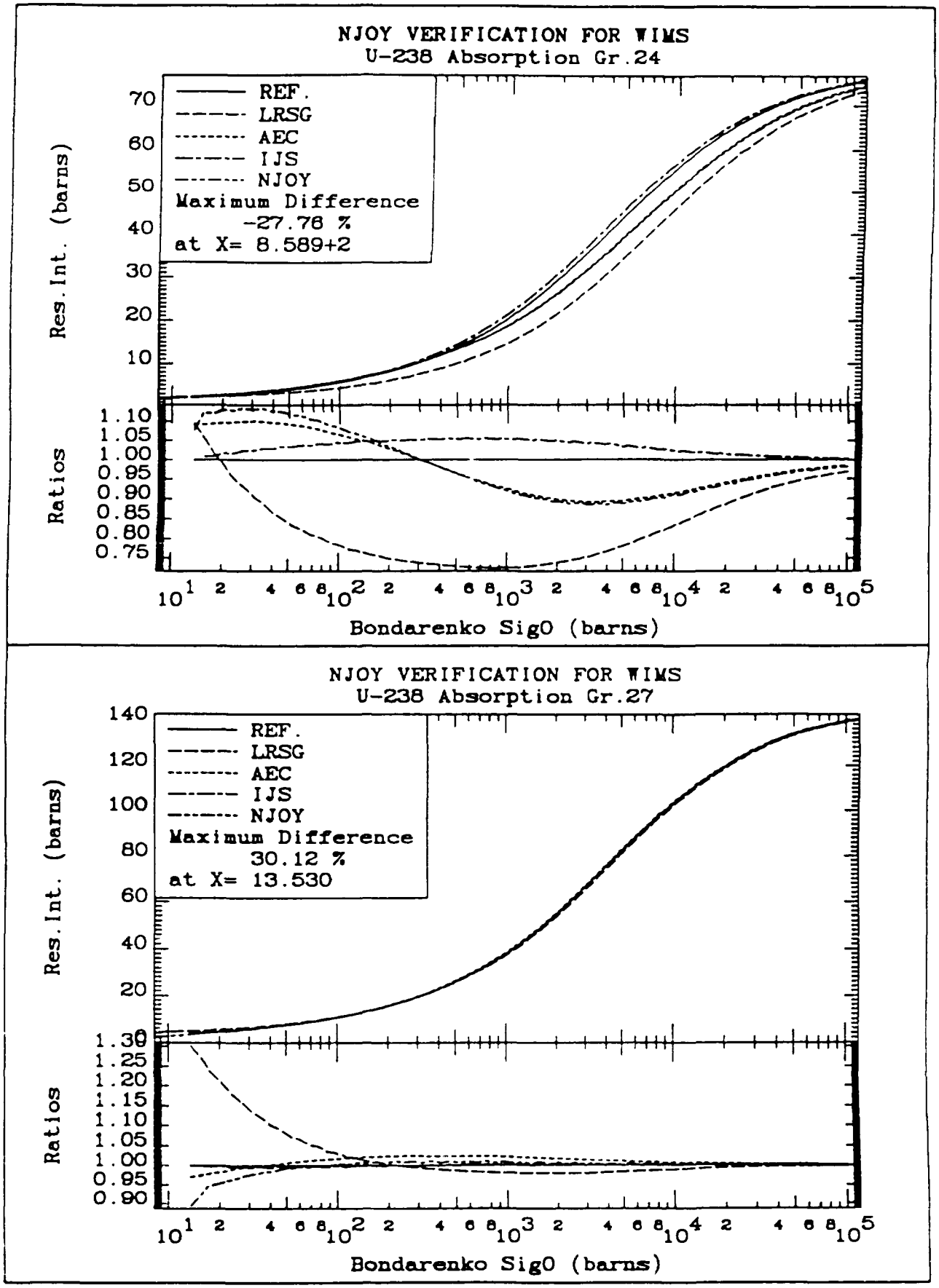


Figure 12: Comparison of the Uranium-238 ENDF/B-IV absorption resonance integrals for groups 24 and 27 contributed to WLUP by different laboratories.

2.7 Integral effects

In order to test the integral effects of the new data, a small WIMS library was generated, which included the following materials:

- hydrogen bound in water,
- oxygen,
- aluminium,
- uranium-235,
- uranium-238.

Such a library is adequate to perform calculations on the benchmark lattices such as TRX-1,2 and BAPL-1,2,3, which were defined in WLUP Stage-1.

At present the library merely serves the purpose to demonstrate that it is formatted correctly to enable calculations with the WIMS code. The input options for cross section generation require some fine tuning, based on a detailed sensitivity study. Preliminary results and comparison with the parameters calculated using libraries produced by other code systems is presented in Table 1.

Table 1: Results for the TRX-1 benchmark lattice using ENDF/B-IV based WIMS Libraries.

	k-inf	k-eff	Dk/k [*E5]	rho28	dif. [%]	del25	dif. [%]	del28	dif. [%]	C*	dif. [%]
Experim.	--	1.00000		1.320	ref.	0.0987	ref.	0.0946	ref.	0.797	ref.
Unc.(+/-)					1.59		1.01		4.33		1.00
IJS(1)	1.16760	0.98499	-1524	1.370	3.79	0.0999	1.22	0.0956	1.06	0.800	0.38
KAERI(2)	1.16591	0.99142	- 865	1.372	3.94	0.0985	-.20	0.0958	1.27	0.802	0.63
AEC	1.16302	0.98562	-1459	1.395	5.68	0.0983	-.41	0.0956	1.06	0.809	1.51
IAEA	1.16525	0.98334	-1694	1.387	5.08	0.1014	2.73	0.0932	-1.48	0.806	1.13
E4(3)	--	0.9876	-1248	1.382	4.70	0.0994	0.71	0.0955	0.95	0.806	1.13
Unc.(+/-)			324		0.43		0.50		0.63		0.25

(1) In the resonance region the scattering cross section is approximated by the potential cross section.
(2) Original KAERI contribution.
(3) Published data, {\em Benchmark Testing of ENDF/B data for Thermal Reactors}, BNL-NCS-29891, (ENDF-313), July 1981.

3 NJOY input optimisation

So far no effort has been made to optimize the NJOY input. Generally, the parameters were selected to approximate those used in the Standard WIMS library which is supplied with the code. NJOY input data used in the WIMS library preparation are listed in Appendix B.

Table 2: Results for the BAPL-1 benchmark lattice using ENDF/B-IV based WIMS Libraries.

	k-inf	k-eff	Dk/k [*E5]	rho28	dif [\%]	del25	dif. [\%]	del28	dif. [\%]	C*	dif. [\%]
Experim.	--	1.00000		1.390	ref.	0.0840	ref.	0.0780	ref.	--	--
Unc.(+/-)					0.72		2.38		5.1		--
IJS(1)	1.13198	0.99203	-803	1.427	2.66	0.0841	0.12	0.0745	-4.5	0.812	--
KAERI(2)	1.13804	1.00311	310	1.381	-.65	0.0836	-.48	0.0739	-5.3	0.798	--
AEC	1.12655	0.99147	-860	1.458	4.89	0.0833	-.83	0.0744	-4.6	0 823	--
IAEA	1.12705	0.98794	-1221	1.439	3.53	0.0854	1.67	0.0719	-7.8	0.817	--
E4(3)	--	0.9914	-867	1.433	3.09	0.0835	-.60	0.0735	-5.8	0.817	--
Unc.(+/-)			151		1.05		0.84		0.5		0.73

(1) In the resonance region the scattering cross section is approximated by the potential cross section.
(2) Original KAERI contribution.
(3) Published data, {\em Benchmark Testing of ENDF/B data for Thermal Reactors}, BNL-NCS-29891, (ENDF-313), July 1981. The quoted uncertainties are simply half the difference between two calculated results.

4 Conclusions

The data calculated at IAEA are preliminary and merely demonstrate the feasibility of WIMS calculations with the libraries generated by NJOY91.38 with the corrected WIMSR module and the WILIT2 library maintenance code (to be documented). A sensitivity analysis to NJOY input parmeters should now be performed to define the optimal input data set. After this step is completed, the generation of an updated WIMS library based on any of the more recent evaluated data libraries in ENDF format is a straightforward technicality.

APPENDIX A

A.1 Corrections applied to the WIMSR moduel of NJOY

Corrections applied to the WIMSR module are limited to the purpose of making WIMSR a useful calculational tool. In addition, the following inconsistencies have been noted but remain in the code:

- burnup data are not correctly copied to output. Since no processing is involved with these data, they can be generated externally and brought directly to the input of the WIMS library maintenance code, so this item was not given any further attention.

- The option of printing the spectrum was not given any attention. No checking for consistency was done.

- The conversion of the self-shielded cross sections to resonance integrals requires the background cross section. Since the resonance integrals are processed before the cross sections, it is not possible to print the WIMS background cross section σ_b values and the resonance integrals. In the printed output from WIMSR the self-shielded cross sections are printed as a function of the Bondarenko σ_0. Conversion to σ_b and to resonance integrals is done just before printout, so the numbers appearing on printed output are not the same as those in the WIMS library.

An extension to the input options which is backwards compatible has been introduced:

- if zero is specified for the potential cross section, this cross section is replaced by the elastic cross section.

- If the reference Bondarenko σ_0 is not found on the list of values processed by the GROUPR module, a message is printed and the first value on the list is taken by default.

- If the reference σ_0 for infinite dilution is selected, the cross sections at infinite dilution are processed except for the scattering cross section (and the scattering matrices) which are fully shielded (i.e.: corresponding to the last σ_0 value on the list when self-shielded cross sections are available).

- Originally in the WIMSR module, the Bondarenko σ_0 of precisely $10^{10}\,barns$ was interpreted as infinite dilution. The input has been modified such that entering any large number ($\sigma_0 \geq 10^{10}$) always defaults to the first σ_0 value which is assumed as infinite dilution (even if a different number is specified in GROUPR input).

  To force the scattering data to be taken at infinite dilution, a reference σ_0 can be selected which is not on the list (usually a large number but smaller than $10^{10}\,barns$).

The corrections to the WIMSR module are listed below.

```
*IDENT UPIAEA1
*/     =======
*/     MODIFICATIONS COLLECTED UNDER THIS IDENT WERE MADE IN ORDER
*/     TO FIX BUGS IN THE WIMSR MODULE  A FEW MINOR EXTENSIONS ARE
*/     INCLUDED TO OFFER GREATER FLEXIBILITY IN CHOOSING THE
*/     REFERENCE SIGO AND THE POTENTIAL CROSS SECTION
*/     ( A.TRKOV, IAEA, DEC.1992 )
*/
*/ DOCUMENT EXTENSIONS IN THE INPUT INSTRUCTIONS
*I WIMSR.31
C     *               (OPTIONS 1 AND 2 HAVE NOT BEEN VERIFIED)         *
*I WIMSR 47
C     *               ( GE  1 E10 TO SELECT ALL CROSS SECT  AT INF DIL *
C     *                           BUT FULLY SHIELDED ELASTIC X-SECT,   *
C     *                .LT  1 E10 TO SELECT ALL X-SECT AT INF.DIL       *
C     *               SIGO        FROM THE LIST ON GROUPR INPUT TO      *
C     *                           SELECT X-SECT  AT THAT SIGO)         *
*I WIMSR.49
C     *               (IF ZERO, REPLACE BY THE ELASTIC CROSS SECTION)  *
*/
*/ DELETE UNUSED SCRATCH ARRAY INDICES (WHICH OVERFLOW THE RESERVED STORAGE AREA)
*D WIMSR.1286,1288
*D WIMSR.1291,1292
*/
*/ TO AVOID CONFUSING NOMENCLATURE, STORE ATOMIC WEIGHT RATIO AT IAWR
*D WIMSR.525
      A(IAWR+NMAT-1)=C2H
*D WIMSR.2639
      AWT=A(IAWR)*1 0086652
      WRITE(NOUT,40) IDENT,AWT,IANUM,IFIS,NTEMP,NRESTB,ISOF
*/
*/ ASSUME ISOTROPIC SCATTERING WHEN AVERAGE LETHARGY DECREMENT PER
*/ COLLISION IS NOT GIVEN (MT252).
*/ THIS OPTION SHOULD BE USED (IE.: NOT REQUESTING MF3 MT252 ON GROUPR INPUT)
*/ AT LEAST FOR HYDROGEN BECAUSE THE VALUE CALCULATED BY GROUPR IS
*/ CURRENTLY INCORRECT BY MORE THAN A FACTOR OF 3
*I WIMSR.1314
      AWR=A(IAWR+NMAT-1)
      ALF=(AWR-1 )/(AWR+1 )
      ALF=ALF*ALF
      XXI=1 + ALOG(ALF)*ALF/(1 -ALF)
*I WIMSR.1316
      A(I-1+IXI)=XXI
*/
*/ FOR SOME COMBINATIONS OF DATA, NEUTRON FISSION YIELD COULD BE INCORRECT
*/ DEFINE. JFISD FOR DELAYED NU-BAR (MT455),
*/         JFIST FOR TOTAL NU-BAR (MT452),
*/         JFISS =1 WHEN USING TOTAL NU-BAR,
*/         JFISS =2 WHEN RECONSTRUCTING FROM FISSION MATRIX
*/ RECONSTRUCTION FROM FISSION MATRIX IS USED PREFERENTIALLY, PROVIDED
*/ THE DELAYED NU-BAR DATA ARE PRESENT. A MESSAGE IS PRINTED IF NU-BAR
*/ RECONSTRUCTION REMAINS INCOMPLETE.
*/
*/ ACCUMULATE NU-BAR FROM FISSION MATRIX LOCNUS LOCNUS, OTHERWISE PUT AT INU  THIS SOLVES
*/ PROBLEM OF INITIALIZATIN AND WHEN MULTIPLE TEMPARATURES ARE REQUESTED
*I WIMSR.1330
```

```
      JFISD=0
      JFIST=0
*D WIMSR 1521
  245 CONTINUE
*D WIMSR 1523
      IF (JFISS.EQ 0) JFISS=1
*D WIMSR.1526
      JFIST=1
      LOC=INU+JG-1
*D WIMSR.1545
      JFISD=1
      LOCN=LOCNUS+JG-1
*D WIMSR.1673
      JFISS=2
*D WIMSR 1675
      LOCN=LOCNUS+JG-1
*D WIMSR.1709
      IF (JFISS.NE.2) GO TO 380
*I WIMSR.1724
      IF (JFISS.EQ.1) GO TO 386
      IF (JFISD.EQ.0 .AND  JFIST.EQ.1) GO TO 386
      IF (JFISD.EQ.1) GO TO 386
      WRITE(STRNG,'(''NU-BAR CALCULATED FROM FISSION MATRIX'')')
      CALL MESS('XSECS',STRNG,'ONLY PROMPT CONTRIBUTION AVAILABLE')
  386 CONTINUE
*D WIMSR.1726
  390 A(I-1+LOCNUS)=A(I-1+INU)*A(I-1+LOCSFO)
*/
*/ SAVE FISSION CROSS SECTION AT INF.DIL  NEEDED WHEN CALCULATIONG
*/ NUE-BAR FROM FISSION MATRIX
*D WIMSR.1233
      NWLOC=NGND*7+NGNDSQ
*D WIMSR.1279
      LOCSFI=LOCABO+NGND
      LOCSFO=LOCSFI+NGND
*D WIMSR.1447
  216 LOC=LOCSFI+JG-1
*I WIMSR.1450
      A(LOC)=A(LOC)+A(LOCA)*A(LOCF)*CFLUX(JGC)
      LOC=LOCSFO+JG-1
*D WIMSR.1712
      IF (A(LOCSFI+I-1).NE.0.) A(INU+I-1)=A(LOCNUS+I-1)/A(LOCSFI+I-1)
*/
*/ FIX PRINTOUT WHEN ONLY ABSORPTION RESONANCE INTEGRALS ARE REQUESTED
*I WIMSR.378
      A(I-1+INDF)=0
*D WIMSR 724
*I WIMSR.1257
      CALL FINDEX('INDF',INDF,A)
*D WIMSR.1749,1754
      JFIS=A(INDF+NMAT-1)
      IF (JFIS.EQ.1 .AND. JFISS.GT.0) JFIS=2
      IF (JFIS.EQ.0 .AND. JFISS.GT.0) JFIS=4
*D WIMSR.2595
      IF (IFIS.NE.3) GO TO 179
*/
```

```
*/ RESET SCRATCH ARRAYS WHEN MULTIPLE TEMPERATURES ARE REQUESTED
*D WIMSR 1777
      CNORM=0
      DNORM=0
      JFISS=0
      JFISD=0
      JFIST=0
  520 DO 530 I=1,NWLOC
*I WIMSR.1779
      A(I-1+IN2N)=0
      A(I-1+L1E)=NGND
      A(I-1+L2E)=1
      A(I-1+L1)=NGND
      A(I-1+L2)=1
      A(I-1+IABS1)=0
      A(I-1+IABS2)=0
      A(I-1+ICSPC)=0
*/
*/ LET ENTERING A LARGE REF SIGO (>=1 E10) ALWAYS IMPLY INF.DILUTION
*D WIMSR.1308
      IF (SGREF.LT.DILINF) ISG=1
*/
*/ IN CASE A REFERENCE SIGO VALUE IS ENTERED WHICH IS NOT ON THE LIST,
*/ THE USER IS WARNED BY A MESSAGE. IN COMBINATION WITH WITH CORRECTION
*/ ABOVE, ENTERING A VALUE NOT ON THE LIST BUT LESS THAN 1E10 WILL
*/ DEFAULT TO THE FIRST SIGO ON THE LIST (I.E  INF.DILUTION) BUT THE
*/ SCATTERING CROSS SECTION (AND MATRIX) AT INF.DILUTION WILL BE USED
*/ (RATHER THAN THE FULLY SHIELDED ONE)
*D WIMSR.1362,1364
      IF (ABS(SGREF-A(L+6+NTW+I)) GT.SGREF* 01) GO TO 147
      IZ=I
      GO TO 148
  147 CONTINUE
      WRITE(STRNG,
     1  '(''REF  SIGO'',1P,E10.3,'' NOT ON THE LIST'')') SGREF
      CALL MESS('XSECS ',STRNG,'FIRST ENTRY USED AS DEFAULT')
      IZ=1
      SGREF=A(L+6+NTW+IZ)
*/
*/ DELETE DEAD CODE WHICH DOES NOTHING - LEAST OF ALL WHAT THE COMMENT SAYS
*/
*/ RESONANCE INTEGRAL DEFINITIONS WERE INCORRECT  DEFER CONVERSION TO
*/ RESONANCE INTEGRALS TO WIMOUT ROUTINE WHEN SIGP VALUES ARE DEFINED
*D WIMSR.948,967
*D UP34 11
*D WIMSR.969,970
*D WIMSR.1031
     1  (A(ISIGZ-1+J),J=1,NSIGZ),
*D WIMSR.1038
     1  (A(ISIGZ-1+J),J=1,NSIGZ),
*D WIMSR.1045
     1  (A(ISIGZ-1+J),J=1,NSIGZ),
*D WIMSR.1059
      WRITE(NSYSO,60) (A(I-1+ISIGZ),I=1,NSIGZ)
*/
*/ RESERVE STORAGE TO ALLOW POTENTIAL CROSS SECTION TO BE ENERGY DEPENDENT
```

```
*/ IF ZERO IS ENTERED ON INPUT, POTENTIAL CROSS SECTION IS REPLACED BY
*/ ELASTIC (SEE UPDATES WHICH DESCRIBE THE OPTIONS TO SELECT THE FULLY
*/ SHIELDED SCATTERING CROSS SECTIONS).
*I WIMSR.1239
      CALL RESERV('SPOT',NGND,ISPOT,A)
*I WIMSR.1270
      CALL FINDEX('SPOT',ISPOT,A)
*I WIMSR.1743
C     REDEFINE POTENTIAL CROSS SECTION IF REQUESTED
      DO 447 I=1,NGND
      LOC=ISPOT+I-1
      A(LOC)=SIGP
      IF(SIGP.EQ.0) A(LOC)=A(ISCAT+I-1)
  447 CONTINUE
*D WIMSR.1836
      CALL FINDEX('SPOT',ISPOT,A)
*D WIMSR.1846
      IF (IVERW.EQ.5) WRITE(NOUT) (A(ISPOT-1+I),I=NGRO,NGR1),
*D WIMSR.1850
      IF (IVERW.EQ.4) WRITE(NOUT) (A(ISPOT-1+I),I=NGRO,NGR1),
*D WIMSR.1868
      WRITE(NSYSO,30) (A(ISPOT-1+I),I=NGRO,NGR1)
*/
*/ USE GOLDSTEIN-COHEN LAMBDA AND SIGPOT TO CONVERT BONDARINKO SIGO TO WIMS SIGB
*/ CONVERT SELF-SHIELDED CROSS SECTIONS TO RESONANCE INTEGRALS
*I WIMSR.2483
      CALL RESERV('SGOL',NRG,ISGOL,A)
*I WIMSR.2498
      CALL FINDEX('SGOL',ISGOL,A)
*I WIMSR.2544
C
C     SAVE SIGO*LAMBDA TO ADJUST BACKGROUNX X-SECT FOR WIMS
      IGL=ISCR+3*NRG+2*NNT
      DO 122 I=1,NRG
      A(ISGOL+I-1)=A(ISCR+I-1)*A(IGL+I-1)
  122 CONTINUE
*D WIMSR.2593,2594
C     *** GOLDSTEIN-COHEN-LAMBDA*SIGP AND CONVERSION FACTORS TO RES.INT.
      SGOL=A(ISGOL+IRG-1)
      DO 465 IT=1,NTEMP
      DO 465 IZ=1,NSIGZ
      LOC=(IT-1)*NSIGZ+IZ
      SIGA=A(ISCR-1+LOC)
      SIGB=SIGOL+A(ISIGZ-1+IZ)
      A(ISCR-1+NTNP+LOC)=SIGB/(SIGA+SIGB)
  465 CONTINUE
C     CONVERT TO WIMS SIGB AND RESONANCE INTEGRALS WHILE WRITING
      WRITE(NOUT,20) (A(ITEMP+J-1)                  ,J=1,NTEMP),
     1               (A(ISIGZ-1+J)+SGOL             ,J=1,NSIGZ),
     1               (A(ISCR-1+J)*A(ISCR-1+NTNP+J) ,J=1,NTNP)
*D WIMSR.2601,2602
      WRITE(NOUT,20) (A(ITEMP+J-1)                  ,J=1,NTEMP),
     1               (A(ISIGZ-1+J)+SGOL             ,J=1,NSIGZ),
     1               (A(ISCR-1+J)*A(ISCR-1+NTNP+J) ,J=1,NTNP)
*D WIMSR.2612,2613
      WRITE(NOUT,20) (A(ITEMP+J-1)                  ,J=1,NTEMP),
     1               (A(ISIGZ-1+J)+SGOL             ,J=1,NSIGZ),
     1               (A(ISCR-1+J)*A(ISCR-1+NTNP+J) ,J=1,NTNP)
*D WIMSR.2642
  200 CALL RELEAS('SGOL',0,A)
      RETURN
```

```
*/
*/ APPLY THE SAME AVERAGEING METHOD FOR SCATTERING MATRIX AS FOR OTHER
*/ CROSS SECTIONS EVEN WHEN FULLY SHIELDED SCATTERING IS REQUESTED.
*/ FIX INCONSISTENT USAGE OF INDICES WHICH RESULT IN PICKING THE WRONG
*/ SELF-SHIELDED CROSS SECTION OR WRONG NORMALIZING FLUX.
*/ SOME OF THE CORRECTIONS FIX BUGS IN PROCESSING THERMAL SCATT MATRIX
*/ AND THE ASSOCIATED SELF-SCATTERING TERM TRANSPORT CORRECTION
*D WIMSR.1477,1478
C     FOR REFERENCE (OR FULLY SHIELDED) SIGMA ZERO
      JZ=NZ
      IF (ISG GT.0 AND.IZ LE NZ) JZ=IZ
*D WIMSR 1480
      LOCA=L+LZ+NL*(JZ-1)
*D WIMSR.1489,1491
C     FOR REFERENCE (OR FULLY SHIELDED) SIGMA ZERO
      JZ=NZ
      IF (ISG GT 0.AND.IZ.LE.NZ) JZ=IZ
      CFLUX(JG+NGND)=CFLUX(JG+NGND)+A(L+LZ+NL*(JZ-1))
*D WIMSR.1507,1511
      LOCA=L+LZ+NL*(NZ-1+NZ)
      LOCF=L+LZ+NL*(NZ-1)
      JGC=JG+NGND
      IF (ISG.GT.0.AND.NZ GE.IZ) THEN
         LOCA=L+LZ+NL*(IZ-1+NZ)
         LOCF=L+LZ+NL*(IZ-1)
      ENDIF
      A(LOC)=A(LOCA)*A(LOCF)*CFLUX(JGC)
*D WIMSR 1583
      A(LOC)=A(LOC)+A(LOCA)*A(LOCF)*CFLUX(JGC)
*D WIMSR.1586
      A(LOC)=A(LOC)+A(LOCA)*A(LOCF)*CFLUX(JGC)
*/ WHY IS THE FIRST THERMAL GROUP NOT TO BE TRANSPORT CORRECTED?!!!
*/ ALSO, REPLACE CONST.(VALID FOR 69 GR LIB ) BY AN APPROPRIATE VARIABLE
*D WIMSR.1591
C     IF (.NOT.(JG.EQ.NFTG.AND.I.GE.NGND+1-NNT)) THEN
*D WIMSR.1593
C     ENDIF
*D WIMSR.1597
C     IF (JG2C LT.NTH) GO TO 290
*D WIMSR.1600,1601
      LOC=LOCXS+JG  -1+NGND*(JG  -1)
      A(LOC)=A(LOC)-A(LOCA+1)
*I WIMSR.1639
      IF (ISG.GT.0.AND.NZ.GE IZ) LOCA=L+LZ+(IL-1)+NL*NZ*(I-1)+(IZ-1)*NL
*I WIMSR.1641
         LOCF=L+LZ+NL*(NZ-1)
         JGC=JG+NGND
*I WIMSR 1643
            LOCF=L+LZ+NL*(IZ-1)
*D WIMSR.1647
      A(LOC)=A(LOC)+(A(LOCA)*MULT)*A(LOCF)*CFLUX(JGC)
*I WIMSR.1660
      IF (JG2C.GE.NTH) GO TO 310
*D WIMSR.1662
      A(LOC)=A(LOC)-A(LOCA+1)*A(LOCF+1)/WTF(JG2C)
*I WIMSR 1804
      IF (CFLUX(I+NGND) NE.0.) CFLUX(I+NGND)=1./CFLUX(I+NGND)
*/
*/ FIX BUG TO PRINT P1 MATRICES IN CONDENSED FORMAT
```

```
*I WIMSR.2509
      IP1OPT=NINT(A(IP1O))
*D WIMSR 2621
C     ***WRITE P1 SCATTERING MATRICES
  195 IF (IP1OPT.NE 0) GO TO 200
*/
*IDENT IAEA2
*/     =======
*/     MODIFICATIONS UNDER THIS IDENT WERE USEFUL OR NECESSARY TO
*/     PROCESS DATA FOR UPDATING THE WIMS LIBRARY  THEY ARE NOT
*/     DIRECTLY RELATED TO THE WIMSR MODULE
*/
*/ FIX FORMAT BUG IN MESSAGE PRINTOUT IN MODER
*D MODER.224
         WRITE(STRNG,'('' MAT,MF,MT,NB,NW'',5I6)') MAT,MF,MT,NB,NW
*/
*/ PREVENT TERPA IN THERMR TO SET TEFF TO ZERO WHEN EXTRAPOLATING
*/ TEMPERATURE SLIGHTLY BELOW TABULATED RANGE FOR S(ALPHA,BETA)
*I THERMR.1329
      IF(A(ISCR+8).GT.TEMP) A(ISCR+8)=TEMP
*I THERMR.1338
      IF(A(ISCR+8).GT.TEMP) A(ISCR+8)=TEMP
*/
*/ INCREASE ARRAY B SIZE IN GENFLX TO ALLOW MORE POINTS FOR FLUX CALC
*/ ISSUE A WARNING IF ARRAY CAPACITY IS EXCEEDED
*D GROUPR.2073
      COMMON/ECS/B(150000)
*D GROUPR.2090
      DATA MAXECS/150000/
*D GROUPR.2128
      IF (NEMAX*NX.LE.MAXECS) GO TO 111
      NEMAX=MAXECS/NX
      CALL MESS('GENFLX','ARRAY B CAPACITY EXCEEDED'
     1          ,'NUMBER OF ENERGY MESH POINTS FOR FLUX IS REDUCED')
  111 CONTINUE
*/
*/ ACCEPT THE CORRECTION PROPOSED IN UP24
*D GROUPR.2166
*D UP24.15
  120 B(IZ+3+LI)=(SIGZ(IZ)-SAM)*WTF*(1.-BETA)
*/
*/ FIX BUG TO OPEN THE AVERAGEING FLUX FILE FOR READING AS BINARY
*I GROUPR.1888
      CALL OPENZ(NINWT,0)
*D GROUPR.1891
*/
*/ FIX THE CALCULATION OF "TERM" IN HNAB WHICH WAS NUMERICALLY ILL-POSED,
*/ CAUSING OVERFLOW ON SHORT-EXPONENT MACHINES
*D GROUPR.7370
      FACT=H
*D GROUPR.7372
      FACT=FACT*H/M
*D GROUPR.7398
  290 TERM=FACT*XK*QMN
*/
*/ CHECK FOR CONVERGENCE OF TAYLOR SERIES EXPANSION IN HNAB, PRINT
*/ WARNING AND USE THE DIRECT DIFFERENCE EXPRESSION IF CONVERGENCE
*/ CRITERIA ARE NOT SATISFIED
*I GROUPR.7276
      CHARACTER STRNG*60
```

```
*I GROUPR 7416
      WRITE(STRNG,'(''NO CONVERGENCE IN TAYLOR EXPANSION OVER ''
     1             ,1P,2E10 3)') AA,BB
      CALL MESS('HNAB  ',STRNG,'DIRECT DIFFERENCE EXPRESSION USED')
      IF(N EQ 0) GO TO 110
      GO TO 320
*/
*/ FIX COMPILATION ERROR IN MATXSR ON VAX
*D UP27 37
*IF SW
      DATA BLANK/4H        /
*ELSE
      DATA BLANK/8H        /
*ENDIF
*/
*IDENT VERS
*/ UPDATE VERSION NUMBER AND DATE TO CORRESPOND TO LAST IDENT
*D NJOY 8
C     *       VERSION 91.38 -- 15 MAY 92 WITH CORRECTIONS    11 DEC 92 *
*D NJOY 326
      DATA VERS/'91.38A'/
```

APPENDIX B

B.1 NJOY input for Uranium-238 from ENDF/B-IV

```
$ '
$ ' WLUP-2 test. Process U-238 from ENDF/B-IV
$ '
$ ' Source data. ENDF/B-IV for U-238 assigned to Unit-20
$      ASS/USER      [TRKOV.DATA]U8E4 DAT   TAPE20
$      ASS/USER                   U8W.XSW   TAPE27
$      ASS/USER                   0         FOR006
$ ' Begin calculations
$      RUN           [TRKOV NJOY91]NJOY
0 /         Batch mode input
4 /         ENDF-4 formatted library processed
*MODER*  / Convert data to binary on Unit-21
20 -21
*RECONR* / Reconstruct x-sect from resonance parameters on Unit-22
-21 -22
*PENDF TAPE FOR U-238 FROM ENDF/B-IV  */
1262 2 /
0.002 / 0. 7 0.002 / 0.001 / PROBLEMS ?-->BROADR
*92-U-238 FROM ENDF/B-IV */
* PROCESSED BY NJOY91.38 */
0 /
*BROADR* / Doppler broaden to Unit-23
-22  -23
1262 3  0  1  0 /
0.005 / 0.001 1.E6 0.002 0.001 / PROBLEMS?
300. 600. 900.
0 /
*UNRESR* / Doppler broaden & self-shield URP data to Unit-24
-21 -23 -24
1262 3 10 1
300. 600. 900.
1.E10 1.E4 3.6E3 1.E3 2.613E2 1.462E2 65.34 31.49 15.53 1.0
0 /
*THERMR* / Add thermal scattering data to Unit-26
0 -24 -26
0 1262 8 3 1 0 1 201 1
300. 600. 900.
0.01  4.0
*GROUPR* / Generate group averaged data on Unit-25
-21  -26  0  -25
1262 9 0 -5  1  3  10  1
*92-U-238 FROM ENDF/B-IV */
300. 600  900.
1.E10 1.E4 3.6E3 1.E3 2.613E2 1 462E2 65 34 31.49 15.53 1.0
347.87 11.17 9000/
3 /          Temperature 300.K
3 201 /
3 252 /
3 452 /
3 455 /
6 /
6 201 /
0 /
```

```
3 /          Temperature 600 K
3 201 /
3 252 /
3 452 /
3 455 /
6 /
6 201 /
0 /
3 /          Temperature 900 K
3 201 /
3 252 /
3 452 /
3 455 /
6 /
6 201 /
0 /
0 /
*WIMSR* / Process data for WIMS
-26 27
2 4
1 0 0 1
1262
92
0 0 1.E10 1 0      201 0 1 1 0 0  / STANDARD [Sige(Sigb=inf) --> Sigp]
.188  188  188 .188  188  188  188  188  188  188  188  188  188
*STOP*
```

B.2 NJOY input for Uranium-235 from ENDF/B-IV

```
$ !
$ ! WLUP-2 test  Process U-235 from ENDF/B-IV
$ !
$ ! Source data  ENDF/B-IV for U-235 assigned to Unit-20
$      ASS/USER      [TRKOV DATA]VARE4 DAT  TAPE20
$      ASS/USER                  U5E4.XSW   TAPE27
$      ASS/USER                  0          FOR006
$ ! Begin calculations
$      RUN           [TRKOV NJOY91]NJOY
0        / Batch mode input
4        / ENDF-4 formatted library processed
*MODER*  / Convert data to binary on Unit-21
20 -21
*RECONR* / Reconstruct x-sect from resonance parameters on Unit-22
-21 -22
*PENDF TAPE FOR U-235 FROM ENDF/B-IV  */
1261 2 /
0 002 / 0  7 0.002 / 0 001 /
*92-U-235 FROM ENDF/B-IV */
* PROCESSED BY NJOY91 38 */
0 /
*BROADR* / Doppler broaden to Unit-23
-22  -23
1261 1  0  1  0 /
0 005 / 0 001 1 E6 0 002 0 001 /
300
0 /
*UNRESR* / Doppler broaden /self-shield URP data to Unit-24
-21 -23 -24
1261 1 9 1
300
```

```
1.E10 1.E4 3.6E3 1.E3 2 613E2 1.462E2 65 34 31.49 15.53
0 /
*THERMR* / Add thermal scattering data to Unit-26
0 -24 -26
0 1261 8 1 1 0 1 201 1
300.
0 01  4.0
*GROUPR* / Generate group averaged data on Unit-25
-21  -26  0  -25
1261 9 0 -5  1  1  9  1
*92-U-235 FROM ENDF/B-IV */
300
1.E10 1.E4 3.6E3 1.E3 2.613E2 1.462E2 65.34 31.49 15.53
347.87 11.17 9000/ Check spectrum above upper end of RR range
3 /          Temperature 300.K
3 201 /
3 252 /
3 452 /
3 455 /
6 /
6 201 /
0 /
0 /
*WIMSR* / Process data for WIMS
-25 27
2 4
1 0 0 1
1261
92
0 7 1.E10 1 0.    201 0 1 0 0 0  / STANDARD: Sige(Sigb=inf) --> Sigp
.1965 .1965 .1965  1965 .1965  1965 .1965 .1965 .1965 .1965 .1965 .1965 .1965
*STOP*
$ EXIT
```

B.3 NJOY input for Aluminium from ENDF/B-IV

```
$ !
$ ! WLUP-2 test  Process Al from ENDF/B-IV
$ !
$ ! Source data  ENDF/B-IV for Al assigned to Unit-20
$      ASS/USER      [TRKOV DATA]VARE4.DAT  TAPE20
$      ASS/USER                  ALW.XSW    TAPE27
$      ASS/USER                  0          FOR006
$ ! Begin calculations
$      RUN           [TRKOV.NJOY91]NJOY
0        / Batch mode input
4        / ENDF-4 formatted library processed
*MODER*  / Convert data to binary on Unit-21
20 -21
*RECONR* / Reconstruct x-sect from resonance parameters on Unit-22
-21 -22
*PENDF TAPE FOR AL-27 FROM ENDF/B-IV  */
1193 2 /
0.002 / 0  7 0.002 / 0 001 /
*13-AL-27 FROM ENDF/B-IV */
* PROCESSED BY NJOY91.38 */
0 /
```

```
*BROADR* / Doppler broaden to Unit-23
-22  -23
1193 1   0   1   0 /
0 005 / 0 001 1 E6 0 002 0 001 /
300
0 /
*UNRESR* / Should not do any harm
-21 -23 -24
1193 1 9 1
300
1 E10 1 E4 3 6E3 1 E3 2 613E2 1 462E2 65 34 31 49 15 53
0 /
*THERMR* / Add thermal scattering data to Unit-26
0 -24 -26
0 1193 8 1 1 0 1 201 1
300
0.01  4 0
*GROUPR* / Generate group averaged data on Unit-25
-21  -26  0  -25
1193 9 0 -5  1  1  9  1
*13-AL-27 FROM ENDF/B-IV */
300
1.E10 1.E4 3 6E3 1.E3 2.613E2 1.462E2 65 34 31.49 15.53
347.87 11.17 9000/ Check the averageing spectrum
3 /          Temperature 300.K
3 201 /
3 252 /
6 /
6 201 /
0 /
0 /
*WIMSR* / Process data for WIMS
-25 27
2 4
1 0 0 1
1193
13
1 0 1 E10 0 0      201 0 1 1 0 0  / STANDARD  Sige(Sigb=inf) --> Sigp
1  1  1  1  1  1  1  1  1  1  1  1  1
*STOP*
$ EXIT
```

B.4 NJOY input for Oxygen from ENDF/B-IV

```
$ !
$ ! WLUP-2 test  Process O-16 from ENDF/B-IV
$ !
$ ! Source data  ENDF/B-IV for O-16 assigned to Unit-20
$      ASS/USER      [TRKOV.DATA]VARE4.DAT  TAPE20
$      ASS/USER                   06W XSW    TAPE27
$      ASS/USER                   0          FOR006
$ ! Begin calculations
$      RUN           [TRKOV NJOY91]NJOY
0        / Batch mode input
4        / ENDF-4 formatted library processed
*MODER*  / Convert data to binary on Unit-21
20 -21
*RECONR* / Reconstruct x-sect from resonance parameters on Unit-22
-21 -22
```

```
*PENDF TAPE FOR O-16 FROM ENDF/B-IV  */
1276 2 /
0 002 / 0. 7 0 002 / 0 001 /
*8-O-16 FROM ENDF/B-IV */
* PROCESSED BY NJOY91.38 */
0 /
*BROADR* / Doppler broaden to Unit-23
-22  -23
1276 1  0  1  0 /
0.005 / 0.001 1 E6 0 002 0 001 /
300
0 /
*UNRESR* / Does not do any harm
-21 -23 -24
1276 1 9 1 / Self shielding specified to see what happens
300.
1.E10 1 E4 3 6E3 1.E3 2.613E2 1 462E2 65.34 31.49 15.53
0 /
*THERMR* / Add thermal scattering data to Unit-26
0 -24 -26
0 1276 8 1 1 0 1 201 1
300.
0.01  4.0
*GROUPR* / Generate group averaged data on Unit-25
-21  -26  0  -25
1276 9 0 -5  1  1  9  1
*8-O-16 FROM ENDF/B-IV */
300.
1.E10 1.E4 3.6E3 1.E3 2.613E2 1.462E2 65.34 31.49 15.53
347.87 11.17 9000/  Check averageing spectrum
3 /          Temperature 300.K
3 201 /
3 252 /
6 /
6 201 /
0 /
0 /
*WIMSR* / Process data for WIMS
-25 27
2 4
1 0 0 1
1276
8
1 0 1.E10 0 0     201 0 0 1 0 0  / STANDARD  Sige(Sigb=inf) --> Sigp
1  1  1  1  1  1  1  1  1  1  1  1  1
*STOP*
$ EXIT
```

B.5 NJOY input for Hydrogen bound in water from ENDF/B-IV

```
$ !
$ ! WLUP-2 test  Process H-1(H2O) from ENDF/B-IV
$ !
$ ! Source data: ENDF/B-IV for H-1(H2O) assigned to Unit-20
$      ASS/USER     [TRKOV.DATA]VARE4.DAT  TAPE20
$      ASS/USER     [TRKOV.DATA]H2OE3.DAT  TAPE30
$      ASS/USER                 H1W.XSW    TAPE27
$      ASS/USER                 0          FOR006
```

```
$ ! Begin calculations
$      RUN          [TRKOV.NJOY91]NJOY
0        / Batch mode input
4        / ENDF-4 formatted library processed
*MODER*  / Convert cross section data to binary on Unit-21
20 -21
*MODER*  / Convert scattering law data to binary on Unit-31
30 -31
*RECONR* / Reconstruct x-sect from resonance parameters on Unit-22
-21 -22
*PENDF TAPE FOR H-1(H2O) FROM ENDF/B-IV  */
1269 2 /
0 002 / 0  7 0 002 / 0.001 /
*1-H-1(H2O) FROM ENDF/B-IV */
* PROCESSED BY NJOY91.38 */
0 /
*BROADR* / Doppler broaden to Unit-23
-22  -23
1269 1  0  1  0 /
0.005 / 0 001 1.E6 0 002 0 001 /
300.
0 /
*UNRESR* / Does not do any harm
-21 -23 -24
1269 1 5 1
300.
1.E10 1.E4 1.E3 1.E2 1.E1  / Checking to see what happens
0 /
*THERMR* / Add thermal scattering data to Unit-26
-31 -24 -26
1002 1269 8 1 4 0 2 201 1
300
0.01  4.0
*GROUPR* / Generate group averaged data on Unit-25
-21  -26  0  -25
1269 9 0 -5  1  1  5  1
*1-H-1(H2O) FROM ENDF/B-IV */
300.
1.E10 1.E4 1.E3 1.E2 1.E1  / SHOULD NOT DO ANY HARM!
347 87 11 17 9000/
3 /          Temperature 300 K
3 201 /
3 252 /
6 /
6 201 /
0 /
0 /
*WIMSR* / Process data for WIMS
-25 27
2 4
1 0 0 1
1269
1
1 0 1 E9 0 0     201 0 0 1 0 0  / STANDARD  Sige(Sigb=inf) --> Sigp
1  1  1  1  1  1  1. 1  1  1  1  1  1
*STOP*
$ EXIT
```

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WIMS Library Update Project
Final Report on Stage 2

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1 Introduction

The WIMS package is a very versatile code system for reactor analysis. Its version WIMS/D4 is freely available from the NEA-Data Bank and is used at several laboratories throughout the world. One of its disadvantages is the group constants library which is deficient for some materials of interest. Also, it is based on very old cross section data. Good agreement with experimentally measured quantities in reactor lattices has been achieved through several sequences of data adjustment. These adjustments were usually empirical and do not reflect consistently the improvements in the nuclear data. Since a number of new evaluated nuclear data libraries have become available recently, it is felt that a new WIMS library could be constructed which would further improve the performance of the WIMS package.

At the end of 1990 the WIMS Library Update Project (WLUP) has been initiated [1] at the International Atomic Energy Agency (IAEA). Phase 1 of the project [2], which included WIMS input optimisation for five experimental benchmark lattices [3], has been completed. The work presented in this report describes the results of Phase 2, in which the cross sections based on ENDF/B-IV evaluated nuclear data library have been processed. The data entered into the WIMS library after processing with different codes have been compared. Subsequent phases of the project will involve processing of the more recent evaluated nuclear data libraries and a new WIMS library construction.

2 Objectives

Through Phase 1 of the project the current capability of the WIMS package to reproduce measured quantities in experimental lattices has been established. These results serve as reference to quantify the relative merits of an updated library.

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The calculated parameters of Phase 1 results contain errors due to errors in the nuclear data as well as errors due to inadequate physical models in representing the actual experimental configurations. To some extent these two sources of error can be decoupled by repeating the calculations using a cross section library (such as ENDF/B-IV), the performance of which is well known from the literature [4]. By comparing the calculated results to the published data, the error contributions from the physical models and the multigroup constants library format limitations can be distinguished from the errors in the data (assuming that the data processing errors are small).

The main objectives of Stage 2 of the project are the following:

- to process ENDF/B-IV evaluated nuclear data library and insert the calculated group constants into the WIMS library using several, entirely different and independent sets of processing codes,
- by comparing the data calculated by different processing codes, check for data processing errors, and errors in the group constants definitions (if possible),
- since the WIMS library format restrictions prohibit exact data representation for general cases, optimize the assumptions and processing routes in preparing the WIMS library by investigating their effect on global lattice parameters,
- by comparing the WIMS results (using ENDF/B-IV based library) to published results for the same benchmark lattices (particularly the results of more sophisticated calculational models), establish the WIMS modelling capability for the selected benchmarks.

3 Scope of the project

The project was organised as an international research project, coordinated at the Institute *"Jožef Stefan"* on behalf of the International Atomic Energy Agency. Participants were asked to process hydrogen bound in water, oxygen, aluminium, uranium-235 and uraniun-238 from the ENDF/B-IV evaluated nuclear data library, under the same conditions as in the original WIMS library (particularly witn regards to temperatures and background cross section values in the cross sections and resonance integrals tabulations). Seven sets of results were received from different laboratories, each using a different set of processing codes. Abbreviations of the participating laboratories and their adresses and the code system used are given in the following table:

Lab.	Address	Author	Code
AEC	Atomic Energy Corporation of South Africa Ltd., Pretoria, South Africa	C.Stoker, G.Ball	AMPEX-II
CAB	Centro Atómico Bariloche, S.C.de Bariloche, RN, Argentina	F.Leszczynski	NJOY89 / REMET21

processes the evaluated data for the purpose of the WIMS library preparation. Furthermore, the selected data processing options reflect the experience from the previous work on WLUP, therefore this data set has been chosen as a new reference against which the other data sets were compared.

Figures containing graphical intercomparison of the data were produced using PLOTTAB/92.2 code [11]. and are presented in the Appendix.

4.1 General remarks on data processing

In the WIMS library, self-shielding of the absorption and the fission reaction in resonance materials can be taken into account explicitly by tabulating the resonance integrals. For other materials any self-shielding must be incorporated in the cross sections. This approach is followed in the reference IAEA data set where the cross sections correspond to the Bondarenko background cross sections values σ_0 in the table below:

Material	σ_0 [*barns*]
hydrogen	∞
oxygen	40
aluminium	∞
uranium-235	1000
uranium-238	28

A more detailed discussion on data processing assumptions is given in reports [12,13].

A similar but less rigorous approach was applied to ^{238}U in the IJS data set where in the resonance range in the definition of the slowing-down power, the transport cross section and the scattering matrix, the scattering cross section was replaced by the potential cross section. It was argued that at very high levels of self shielding the potential cross section may be a better approximation to the scattering cross section while in highly diluted cases the scattering contribution of the absorber is negligible anyway.

4.2 Averageing spectra

To simplify data comparison, practically all laboratoties used the Maxwellian-$1/E$-Fission spectrum for cross section averaging except that AEC and NRI used a somewhat higher energy threshold at which the $1/E$ weighting spectrum changes into the fission neutron spectrum. This energy is referred to as the fission spectrum threshold energy in this report. In Figure 1 the averaging spectra with $67KeV$ and $670KeV$ fission spectrum threshold energy are compared to a typical PWR lattice cell coolant spectrum as calculated by WIMS. The curves represent the neutron flux per unit lethargy. Using a $67KeV$ threshold produces a spectrum which has an excessively high fast-to-thermal spectral ratio. In the case of the $670KeV$ threshold the spectral ratio is only slightly too low but the gradient of the averaging spectrum below the fission spectrum threshold is incorrect. Figure 1 shows quite clearly that the Maxwellian-$1/E$-Fission spectrum is oversimplified, particularly near the

Lab.	Address	Author	Code
IAEA	International Atomic Energy Agency, Vienna, Austria	A.Trkov, T.Zidi, S.Ganesan	NJOY91.38+
IAP	Institute of Atomic Physics, Bucharest, Roumania	S.N.Rapeanu	various
IJS	Institute *"Jožef Stefan"*, Ljubljana, Slovenia	A.Trkov	FEDGROUP-C86 (Rev.3)
KAERI	Korean Atomic Energy Research Institute, Choong-Nam, Republic of Korea	J.D.Kim	NJOY-87 / NJOY91
NRI	Nuclear Research Institute, Řež, Czechoslovakia	A.Holubar	FEDGROUP-R

Intercomparison of the Roumanian data (IAP) could only be performed to a limited extent since the results were submitted on paper printout only. A discussion on these data has been given in the Phase report on Stage-2 [5] and will not be repeated here.

Some participants re-submitted their data (NRI and KAERI). The new KAERI data were given for uranium isotopes only and were generated with NJOY91 on a long-word machine. This contribution was invaluable in the verification process of NJOY91 [6], but for the purpose of this exercise it seemed more illustrative to present the original KAERI results which form a complete and self-consistent set.

Two new contributions (BAC and IAEA) had been added.

In the Phase report a fairly detailed intercomparison of the submitted data has been performed. Problem areas in data processing had been identified, therefore only a brief discussion and comparison of the data is given in the next sections.

4 Library Data Intercomparison

Cross sections and resonance integrals (for uranium isotopes) were compared. Burnup chains and other data were not checked at this stage. Scattering matrices were analysed to a limited extent. Since a more detailed data intercomparison can be found in the Phase report, only general comments and summary plots of the data are given in this work. It may not always be possible to identify the individual data sets on the plots, but they show the reaction types and energy regions where significant differences exist. A brief discussion of the data processing details which cause these differences is given.

In the Phase report a reference data set for intercomparison purposes was used which has been constructed using codes [7] LINEAR, RECENT, SIGMA1, GROUPIE. Some fundamental data processing errors in the submitted data were identified, particularly in the codes (or their versions) which did not participate in the Code Verification Project [8,9,10]. It has been shown by a separate analysis [6] that the NJOY91 code with additional updates, particularly in the WIMSR module, correctly

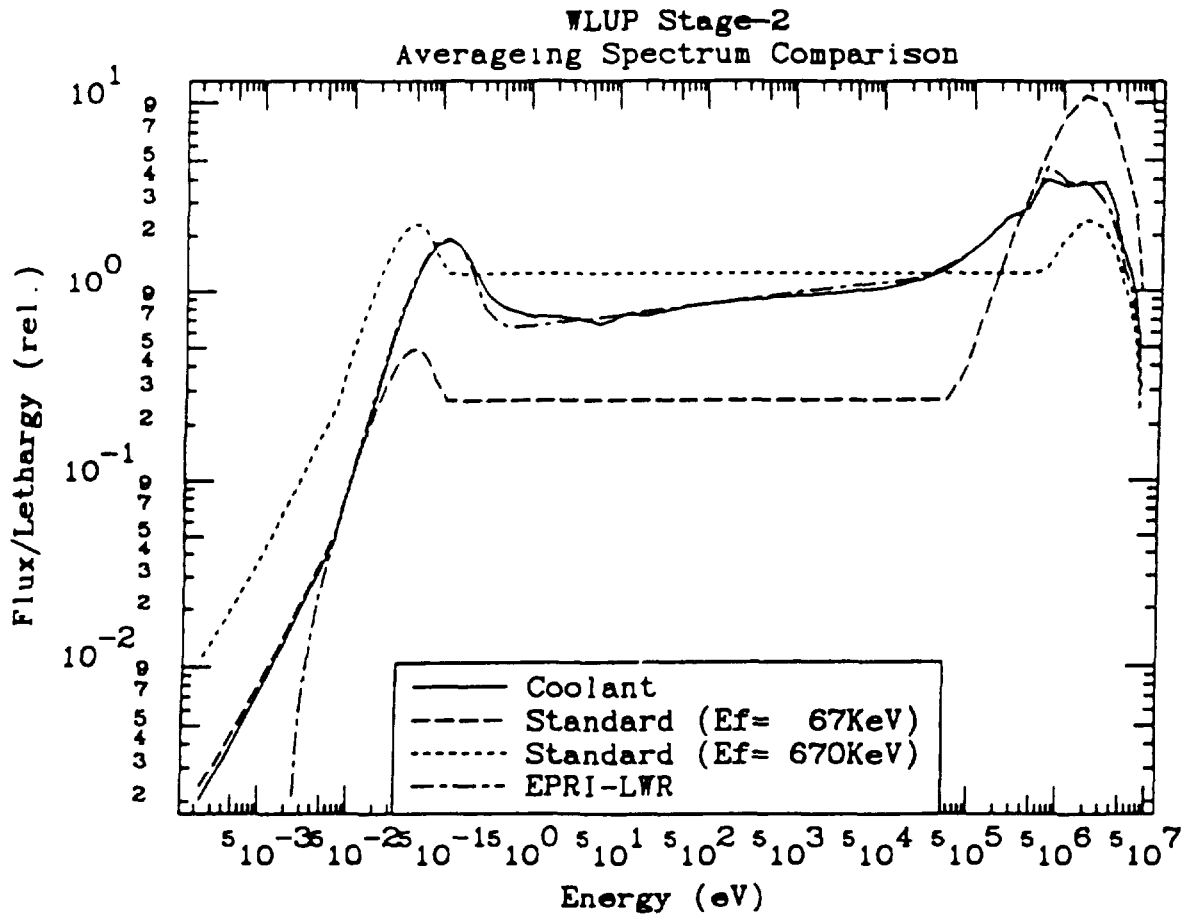

Figure 1: Averageing spectra compared to a typical PWR lattice cell coolant spectrum.

regions where different spectrum representations join one another. Based on this experience, a more realistic spectrum was used in preparing the IAEA data set. The spectrum is labelled EPRI-LWR in the diagram and is also available in NJOY91 as one of the options. It can be observed that the spectrum matches very well the coolant spectrum of a typical PWR lattice cell.

4.3 Potential cross section

Usually the participants entered a constant value, taken from the comment section in the evaluated data file, or a weakly energy-dependent value calculated from the atomic radius (NRI and IJS). Some participant adopted the original WIMS values (KAERI) which may be energy-dependent, as in the case of ^{235}U. The integral results are not very sensitive to the precise value of the potential cross section, provided it is consistent with the definition of the resonance integrals. It is the opinion of the author, that the potential cross section should be defined as the self-shielded scattering cross section. The values in the IAEA data set were entered accordingly.

4.4 Slowing down power

The slowing-down power is defined by the product of the average lethargy decrement per collision ξ and the scattering cross section σ_s, normalized by the group lethargy width τ. The values calculated by most of the participants agree quite well with each other but differ from the reference IAEA data set, in which the self-shielded scattering cross section was used. Data from IAP were not supplied. The reference values for ^{238}U lie quite close to the IJS data in which the potential scattering cross section was applied instead of the scattering cross section.

4.5 Transport cross section

The definition of the group g transport cross section $\sigma_{tr(g)}$ in the thermal range is the following:

$$\sigma_{tr(g)} = \sigma_{a(g)} + \sigma_{s(g)} - \sum_h \sigma_{s1(g \to h)} \tag{1}$$

where $\sigma_{a(g)}$ is the absorption cross section, $\sigma_{s(g)}$ is the scattering cross section and $\sigma_{s1(g \to h)}$ is the first moment of the scattering cross section for transfer from group g to h. In the resonance and fast energy ranges a different definition is used:

$$\sigma_{tr(g)} = \sigma_{a(g)} + \sigma_{s(g)} - \sum_h \sigma_{s1(h \to g)} \frac{J_{(h)}}{J_{(g)}} \tag{2}$$

where $J_{(g)}$ is the neutron current spectrum. Due to different assumptions in calculating the transport cross section, large differences are observed between the data submitted by different participants.

In the reference IAEA results the B_1 flux approximation for large systems as calculated by NJOY91 was applied to define $J_{(g)}$. Other participants used the simple $1/E$ approximation for $J_{(g)}$ except CAB which specified the spectrum explicitly from input, but the details are not known. Differences in the current spectrum affect only the transport cross section for hydrogen in the *keV* range: σ_{tr} values lie above the reference IAEA results, except for the CAB data which are lower.

Other differences in the fast energy range can be attributed to the differences in the cross section averaging spectra and are less significant.

In the resonance range the reference IAEA results use the self-shielded cross sections. This has a particularly strong influence on the data for ^{238}U. The IJS data approach the reference at the upper end of the resonance range due to the use of the potential cross section instead of the scattering cross section. All other contributions use the cross sections at infinite dilution and differ significantly from the reference. The anomaly in the AEC data in the unresolved energy range is due to a trivial error.

In the thermal range a few percent differences were observed between different data sets, which originate from the scattering cross section. Note also the comments on the outscattering cross section

4.6 Absorption cross section

In the WIMS definition of the absorption cross section σ_a, the values are reduced by the value of the $(n, 2n)$ cross section to preserve the neutron balance, since the scattering cross section is also defined accordingly. Some participants omitted the $(n, 2n)$ correction. Above the resonance range the differences between different data sets can be attributed to the averaging spectra. In the reference data set the absorption cross sections for all isotopes (including uranium) are self-shielded and hence lower than those calculated by other participants. Also, the reference values for oxygen may be less accurate than some other contributions, due to the less rigorous treatment of very small cross sections in NJOY. The errors are not physically significant. In the thermal range most of the data agree quite well. The few percent differences in the CAB data may require some attention.

4.7 Fission cross section and fission neutron yield

The fission neutron yield is the product of the fission cross section and the number of neutrons per fission. At higher energies some differences are observed due to the averaging spectra. In the resolved resonance range the reference IAEA data set for ^{235}U is self-shielded and hence lower than the others. Other data sets agree well with each other, except AEC which is a few percent too high in the unresolved range. The CAB data set is too high in the thermal range and may require some attention. The differences in the subthreshold fission of ^{238}U data may be attributed to different approximations in treating very small cross sections.

4.8 Scattering cross section

The scattering cross section $\sigma_{s(g\to h)}$ for transfer from group g to h is the sum of the elastic component σ_e, the inelastic component σ_i and the multiple neutron scattering component σ_{mn} (with group index omitted for clarity):

$$\sigma_s = \sigma_e + \sigma_i + m\sigma_{mn} \tag{3}$$

where m is the multiplicity of the outcomming neutrons. The self-scattering term is corrected such that the total group scattering cross section and the absorption cross section add up to the transport cross section, and not to the total cross section. This correction is omitted for moderators which have the P_1 scattering matrices tabulated explicitly. In our case these exceptions are oxygen and hydrogen.

In the diagrams in the Appendix the outscattering cross sections have been compared (i.e. the scattering cross sections without the self-scattering term). At higher energies for light isotopes the differences can be attributed to the averaging spectra.

The most significant differences between different data sets are observed in the thermal range. Some data sets are clearly in error. When summing the elements of the scattering matrix, some data sets do not reproduce the total scattering cross section. This is reflected also in the differences in the transport cross section in the

thermal range, discussed earlier. Some problems were also encountered in the course of the verification of the reference IAEA data set [6]. The integral scattering cross section is consistent but there remains some doubt in the differential scattering cross section. The influence of the error on global parameters is difficult to estimate.

4.9 Goldstein-Cohen parameter

Most of the participants adopted the original WIMS values for the Goldstein-Cohen parameters λ. IJS and NRI assume the Intermediate Resonance approximation, where λ is a measure of the resonance widths. It is calculated explicitly in the resolved resonance range and set to one elsewhere. For aluminium and oxygen, CAB used the method of Aldous [14] which was developed for the original WIMS library but not implemented in all versions of the library.

A more detailed and rigorous approach to define λ is described in the report on the validation of the EPRI-CELL lattice code [15], which uses resonance treatment very similar to WIMS. The quoted λ values from this report were condensed to the WIMS group structure and used in the IAEA data set.

The Goldstein-Cohen parameters for ^{238}U and ^{235}U form IAEA, IJS and NRI are compared in Tables I. The values for oxygen from IAEA and CAB are compared in Table II. The IAEA values for hydrogen are also given in Table II. All other data sets adopt the original WIMS values.

4.10 Resonance integrals comparison

In the WIMS library the resonance integrals are tabulated as a function of the background cross section. The WIMS definition of the background cross section σ_b includes the contribution of the absorber nuclei to the potential cross section. The relation between the more commonly applied Bondarenko background cross section σ_0 and the WIMS definition is given by:

$$\sigma_0 = \sigma_b - \lambda\sigma_p \tag{4}$$

where λ is the Goldstein-Cohen parameter and σ_p is the potential cross section of the absorber nucleus.

To calculate the self shielded cross sections from the resonance integrals, the following formula is used in WIMS:

$$\sigma_x(\sigma_b) = \frac{I_x(\sigma_b)}{1 - \frac{I_a(\sigma_b)}{\sigma_b}} \tag{5}$$

where σ_x is the self shielded cross section for reaction x (subscript a stands for absorption) and I_x is the corresponding resonance integral.

According to the intermediate resonance approximation the resonance integrals are defined:

Table I: Comparison of the Goldstein-Cohen parameters of Uranium-238 and Uranium-235 from IAEA, IJS and NRI.

	Uranium-238			Uranium-235		
Group	IAEA	IJS	NRI	IAEA	IJS	NRI
15	0.990	0.1000	1.0000	0.990	1.0000	1.0000
16	0.980	0.1000	1.0000	0.980	1.0000	1.0000
17	0.971	0.9624	0.9683	0.971	1.0000	1.0000
18	0.963	0.9230	0.9260	0.963	1.0000	1.0000
19	0.954	0.8973	0.9045	0.954	1.0000	1.0000
20	0.939	0.8899	0.9329	0.939	1.0000	1.0000
21	0.733	0.4697	0.5024	0.733	1.0000	1.0000
22	0.320	0.3067	0.3188	0.320	1.0000	1.0000
23	0.320	0.2820	0.2587	0.320	0.5930	0.6209
24	0.076	0.1032	0.0895	0.075	0.4536	0.4814
25	0.165	0.1159	0.0913	0.164	0.2951	0.2759
26	0.800	0.3379	0.9466	0.800	0.2209	0.1961
27	0.396	0.1420	0.0456	0.396	0.1673	0.1059

Table II: Comparison of the Goldstein-Cohen parameters of Uranium-235 from IAEA, CAB, IJS and NRI.

	Aluminium	Oxygen		Hydrogen
Group	CAB	IAEA	CAB	IAEA
15	0.995	1.000	1.000	1.000
16	0.975	1.000	1.030	1.000
17	0.990	1.000	0.993	1.000
18	0.991	1.000	0.996	1.000
19	0.987	1.000	0.992	1.000
20	0.985	0.992	0.993	1.000
21	0.920	0.976	0.956	0.995
22	0.950	0.911	0.978	0.987
23	0.985	0.909	1.040	0.987
24	0.970	0.712	1.113	0.963
25	0.920	0.734	1.092	0.965
26	0.990	0.984	1.266	1.000
27	0.590	0.643	0.918	0.969

$$I_x = \frac{1}{\int_g \phi(E)\,dE} \int_g \sigma_x(E)\phi(E) \left[\frac{\sigma_0 + \lambda\sigma_p}{\sigma_0 + \lambda\sigma_p + \lambda\sigma_{er}(E) + \sigma_a(E)} \right] dE \qquad (6)$$

where $\phi(E)$ is the "smooth" neutron spectrum (i.e.: without local perturbations due to resonances, normally approximated by $1/E$ shape) and σ_{er} is the resonance

contribution to elastic scattering. Using this definition, the relation between the self shielded cross sections and the resonance integrals is:

$$\sigma_x(\sigma_b) = \frac{I_x(\sigma_b)}{1 - \frac{I_a(\sigma_b)}{\sigma_b} - \frac{\lambda I_{er}(\sigma_b)}{\sigma_b}} \tag{7}$$

Definitions given by Equations (5) and (7) are equivalent if the resonance contribution to elastic scattering is negligible. Although this is not always true, a consistent data set can be defined if the resonance integrals for the WIMS library are calculated from the self shielded cross section by equation:

$$I_x = \frac{\sigma_x \sigma_b}{\sigma_a + \sigma_b} \tag{8}$$

which is the inverse form of Equation (5). Consistency is achieved because the resonance integrals in WIMS are not used directly, except to calculate the cross sections.

In the AEC, CAB and the revised NRI contributions the the self shielded cross sections were calculating by explicitly mixing the absorber with hydrogen. Conversion to resonance integrals was performed using Equation (8). In the original KAERI contribution (presented in this work) the simple Narrow Resonance approximation (NR) was used to calculate the self shielded cross sections. Conversion to resonance integrals was done in the same way. IJS applied the Intermediate Resonance approximation (IR) and $\psi - \chi$ doppler broadening to calculate the resonance integrals directly. This data set is susceptible to the errors in converting resonance integrals to cross sections in WIMS due to the differences between Equations (5) and (7). To calculate the resonance integrals of ^{238}U in the IAEA data set the flux calculator of NJOY91 was applied below $906\,eV$ and the NR approximation was used above this energy. The input parameters for the flux calculator correspond to a $1\,cm$ diameter fuel pin in a water moderated lattice with a 1:2 fuel to moderator ratio. Oxygen in the case of oxide fuel was not considered explicitly because slowing down on oxygen nuclei is already accounted for through the appropriate selection of the Goldstein-Cohen parameters for oxygen. For ^{235}U the flux calculator was applied below $82\,eV$ since this is the upper limit of the resolved resonance range. The NR approximation was used above this energy. The simplest flux calculator option was selected which corresponds to homogeneous mixtures of the absorber with a hydrogeneous moderator.

In the Appendix the resonance integrals submitted by different participants are compared with reference to the IAEA data set. The resonance integrals are plotted as a function of the Bondarenko σ_0, to eliminate the effects of different potential cross sections and Goldstein-Cohen parameters used by different participants (note that two resonance integrals at the same background cross section σ_b do not correspond to the same absorber environment if λ and σ_p of the absorber are not the same). The comparison has been limited to 6 typical resonance groups (out of 13) to simplify the presentation of results.

Uranium-238 : Only the absorption resonance integrals are given. In the unresolved resonance range (group-15) the agreement between different groups of data sets is very good. A distinct difference is observed between IJS and NRI results compared to the others. This can be explained by the use of a different methodology for calculating the self shielded cross sections in these two data sets. The CAB data do not seem to be self shielded at all.

At the upper end of the resolved resonance range (group-17) the NRI data exhibit slightly stronger self shielding than the rest. At high levels of self shielding the CAD data differ by almost an order of magnitude. At lower energies the agreement is better.

In the range where the resonance widths becomes important (see plots for groups 22 and 24), the differences are rather interesting. The agreement between data sets, which explicitly solve for the slowing-down spectrum, is very good. The old KAERI data which use the NR approximation underpredict the self shielded resonance integrals. On the other hand, IJS which use an intermediate resonance approximation, overpredict the resonance integrals at relatively high dilutions, but tend to agree better with the rest of the results at lower dilutions.

Uranium-235 : Absorption and fission neutron yield resonance integrals are given. Most of the resonance range is described by the unresolved resonance parameters. The resonance integrals tables start at much higher levels of dilution, so the corresponding differences in the resonance integrals are also smaller. For absorption as well as for fission neutron yield they remain below 1 % over most of the energy range for all σ_0 values of interest.

5 Global effects

The WIMS libraries submitted by the participating laboratories have been tested on calculations of the TRX and BAPL lattices using Model input described in the report for Stage-1 of the project. Calculated parameters defined in Table III were compared to measured values. The assumed thermal cutoff energy in the definition of the reaction rate ratio is $0.625\,eV$.

Table III: Definitions of some of the parameters

k_∞	infinite medium multiplication factor,
k_{eff}	finite medium effective multiplication factor,
ρ^{28}	ratio of epithermal to thermal ^{238}U capture reaction rate,
δ^{25}	ratio of epithermal to thermal ^{235}U fission reaction rate,
δ^{28}	ratio of ^{238}U fission to ^{235}U fission reaction rate,
C^*	ratio of ^{238}U capture to ^{235}U fission reaction rate.

Table IV: Summary of WIMS results based on ENDF/B-IV data for selected benchmark lattices and comparison with reference results.

LATTICE	k_{eff}	ρ^{28}	δ^{25}	δ^{28}	C^*
TRX-1	0.98760(.32)	1.382(43)	0.0994(.50)	0 0955(.63)	0.806(.25)
AEC	0.98562(-.20)	1.410(+2.0)	0.0983(-1.1)	0.0956(+.15)	0.814(+.99)
CAB	0 99201(+ 45)	1 347(-2.5)	0.0990(-.40)	0 0964(+.96)	0.787(-2.3)
IAEA	0.98706(-.05)	1.380(-.14)	0.1002(+.80)	0.0928(-2.8)	0.804(-.25)
IJS	0.98499(-.27)	1 387(+.36)	0.0999(+.46)	0.0956(+.13)	0.805(-.11)
KAERI	0.99142(+.39)	1 388(+.43)	0.0985(-.92)	0 0958(+.29)	0.807(+.16)
NRI	0.98670(- 09)	1 409(+2.0)	0.0986(-.82)	0 0964(+.96)	0.813(+.89)
TRX-2	0.99350(.31)	0.863(.58)	0.0609(.49)	0.0676(.44)	0.647(.31)
AEC	0.98825(-.54)	0.887(+2.8)	0.0604(-.89)	0.0680(+.58)	0.654(+1.1)
CAB	0.99088(-.27)	0.845(-2.1)	0.0607(-.28)	0.0685(+1 3)	0.636(-1.7)
IAEA	0.98916(-.44)	0.868(+.58)	0.0615(+1.0)	0 0660(-2.4)	0.649(+.25)
IJS	0.98757(-.61)	0 869(+.70)	0.0613(+.71)	0.0681(+.72)	0.648(+.12)
KAERI	0.99202(- 15)	0 867(+.46)	0.0605(-.62)	0.0681(+.77)	0.648(+.20)
NRI	0.98799(-.56)	0.884(+2.4)	0.0605(-.66)	0.0685(+1.3)	0.653(+.96)
BAPL-1	0.99140(.30)	1.433(2.0)	0.0835(1.6)	0.0735(.95)	0.817(1.3)
AEC	0.99147(+.01)	1.470(+2.6)	0.0833(-.20)	0.0744(+1.3)	0.827(+1.2)
CAB	0.99379(+.24)	1.426(-.49)	0 0839(+.51)	0.0749(+1.9)	0.807(-1.2)
IAEA	0.99321(+.18)	1.429(- 28)	0 0843(+.98)	0 0717(-2.5)	0.814(-.31)
IJS	0.99203(+.06)	1.439(+.42)	0.0841(+.75)	0.0745(+1.4)	0.816(-.07)
KAERI	1.00311(+1.2)	1.393(-2.8)	0.0836(+.17)	0.0739(+.59)	0.802(-1.8)
NRI	0.99118(-.02)	1.478(+3.1)	0.0837(+.20)	0.0750(+2.0)	0.828(+1.4)
BAPL-2	0.99320(.09)	1.188(1.3)	0.0678(1.8)	0.0631(.79)	0.742(.81)
AEC	0.99206(-.11)	1.224(+3.0)	0.0680(+.27)	0.0640(+1.4)	0.753(+1.4)
CAB	0.99360(+.04)	1.187(-.08)	0.0684(+.91)	0.0644(+2.0)	0.735(-.92)
IAEA	0.99325(+.01)	1.191(+.25)	0.0688(+1.4)	0.0617(-2.3)	0.743(+.08)
IJS	0.99213(-.11)	1.198(+.84)	0.0687(+1.3)	0.0641(+1.6)	0.743(+.20)
KAERI	1.00233(+.91)	1.157(-2.6)	0.0683(+.71)	0 0636(+.82)	0.730(-1.5)
NRI	0.99161(-.16)	1.229(+3.5)	0.0683(+.66)	0 0644(+2.1)	0.753(+1.5)
BAPL-3	0.99395(.21)	0.936(1.7)	0.0522(.38)	0.0516(.78)	0.664(1.1)
AEC	0.99282(-.11)	0.963(+2.9)	0.0523(+.11)	0.0525(+1.6)	0.671(+1.1)
CAB	0.99377(-.02)	0.933(-.32)	0.0526(+ 69)	0.0527(+2.2)	0.657(-1.1)
IAEA	0.99373(-.02)	0.938(+.21)	0.0529(+1.3)	0.0506(-2.0)	0.664(0.00)
IJS	0.99289(-.11)	0.942(+.64)	0.0528(+1.2)	0.0526(+2.0)	0.664(0.00)
KAERI	1.00106(+.71)	0.908(-3.0)	0.0525(+.67)	0.0522(+1.2)	0.653(-1.7)
NRI	0.99253(-.14)	0.965(+3.1)	0.0525(+.48)	0.0527(+2.2)	0.671(+1.1)

NOTE: For each lattice the reference solution and the % uncertainty is given in the first row. The results using the updated ENDF/B-IV based library and the % difference from reference for each participant are given in subsequent rows.

The results of calculations are presented in Tables IV. The reference solution (first row of the results for every benchmark lattice) were taken from [4] and represent an average over a number of very detailed Monte Carlo calculations. Statistical errors for each parameters are given. Then follow the results of each participant which have been recalculated from the library they submitted with WIMS using optimized inputs for the relevant benchmarks from Stage-1. The corrections due to the $(n, 2n)$ reaction are included In Table V the averages over the benchmark

Table V: Differences from reference results based on ENDF/B-IV data averaged over selected benchmark lattices.

	k_{eff}	ρ^{28}	δ^{25}	δ^{28}	C^*
Ref.	0.26	1.35	1.11	0.74	0.86
AEC	-0.19(0.18)	2.66(0.35)	-0.37(0.55)	1.00(0.55)	1.18(0.15)
CAB	0.09(0.24)	-1.10(1.00)	0.29(0.53)	1.69(0.46)	-1.44(0.50)
IAEA	-0.07(0.21)	0.12(0.31)	1.10(0.23)	-2.40(0.28)	-0.05(0.21)
IJS	-0.20(0.23)	0.59(0.18)	0.88(0.31)	1.17(0.67)	0.03(0.12)
KAERI	0.61(0.46)	-1.50(1.59)	0.00(0.66)	0.74(0.31)	-0.93(0.91)
NRI	-0.20(0.19)	2.82(0.54)	-0.03(0.60)	1.72(0.50)	1.17(0.24)

NOTE: For the reference results the root-mean-square % uncertainties are given. For each participant the simple average of the % differences and the standard deviation from the mean are tabulated.

lattices for each participant are given. Similarly like in the previous table, the first row represents the average uncertainty for a particular parameter in the reference results, then follow the average differences for the data of the participants. The averages uncertainty of the reference results is the root-mean-square average over all benchmarks. For each participant the simple average of the differences from reference and the standard deviation (as a measure of the scattering of results) are given.

From Table V it can be seen that on average the predicted k_{eff} is within the uncertainty interval of the reference results and the spread in the results is not very large for most of the participants. Parameter ρ^{28} is overpredicted using AEC and NRI data, but not the IAEA and IJS data. The cause of the differences can be traced to the use of the unshielded ^{238}U scattering cross section. Underprediction of ρ^{28} with the original KAERI data is due to the use of the NR approximation, while the reason for the discrepancy with the CAB data can not be identified so easily. For parameter C^* a similar conclusion as for ρ^{28} can be drawn. Parameter δ^{25} is predicted quite well with all data. On the contrary, all participants overpredict the δ^{28} parameter, except IAEA where a considerable underprediction is observed. It has been shown in a separate analysis [12] that this parameter is sensitive to the fission spectrum and the averaging spectrum. The fission spectrum in ENDF/B-IV does not differ significantly from the original WIMS fission spectrum, so its influence on the results in not so large. On the other hand the sensitivity of the results on the averaging spectrum shows that the energy group structure in the fast energy range is not adequate to describe the processes in sufficient detail. This may be considered an inherent deficiency of the 69-group WIMS library which can not be overcome within the present scope of work.

Some more understanding of the differences in the calculated parameters can be obtained by considering the reaction rates. The source for the reference results was the same as for the integral parameters considered before [4]. The group boundaries for the 4-group reaction rates are given in Table VI. The reaction rates without the leakage corrections were considered. The results of the participants include the correction in the fast capture reaction rate due to the $(n,2n)$ reaction. For easier

Table VI: Coarse group energy mesh for reaction rate edit.

Group	Upper	Lower
1	$10\,MeV$	$67.379\,KeV$
2	$67.379\,KeV$	$3.355\,KeV$
3	$3.355\,KeV$	$0.625\,eV$
4	$0.625\,eV$	$0\,eV$

presentation of the results only the IAEA and IJS result are reported, which showed least discrepancies in the integral parameters compared to the reference results. They are presented in Table VII.

The reaction rate comparison in Table VII shows that at thermal energies the reaction rates are predicted quite well. Small differences in excess of the uncertainties of the reference results can be attributed to the differences in the averaging spectrum. In the fast energy range the differences arise from the coarseness of the energy mesh. In the resonance range the reaction rates for ^{238}U are predicted very well, but the results are much less satisfactory for ^{235}U. The cross sections over most of the resonance range for this isotope are described by the unresolved resonance parameters. Two possible explanations for the observed differences could be found:

- there are differences in the treatment of the cross sections represented by the unresolved resonance parameters in the Monte Carlo codes and the methodology for calculating the resonance integrals,
- in the WIMS code a first order approximation is applied to account for the resonance interference effect.

In the first case the problem would disappear with the use of a more recent evaluated data file, since new evaluations rely much more on representing the cross sections by resolved resonance parameters. In the second case the problem is more difficult to tackle and would require either to introduce a better resonance interference treatment into the WIMS code, or to adjust the calculated cross sections to give a correct response, consistent with the resonance interference assumptions in WIMS.

6 Conclusions

6.1 Processing codes

The results indicate that differences which could be attributed to data processing errors are quite small, particularly for the codes which participated in the Code Verification Project. Most of the differences could be traced to some differences in the definitions, or to data processing assumptions due to format limitations of the WIMS library.

Although good results can be obtained with relatively simple codes (such as used at IJS, for example), one should not ignore the merits of a versatile and very general evaluated data processing code such as NJOY, which is the *state of the art* on the

Table VII: Calculated reaction rates with WIMS using ENDF/B-IV based library for the TRX lattices and comparison with published reference results.

TRX-1 Reaction rates (ENDF/B-IV)					
U-235 Capture					
Group	1	2	3	4	1+2+3
Ref.	.000405(.30)	.000594(.33)	.01620(.62)	.06907(.18)	.01720(.58)
IAEA	.000401(-.99)	.000606(+2.0)	.01711(+5.6)	.06908(+.01)	.01812(+5.3)
IJS	.000408(+.74)	.000605(+1.8)	.01698(+4.8)	.06899(-.12)	.01799(+4.6)
U-235 Fission					
Group	1	2	3	4	1+2+3
Ref.	.00335 (.31)	.00161 (.60)	.03357(.47)	.3996 (.11)	.03853(.41)
IAEA	.00329 (-1.8)	.001602(-.50)	.03399(+1.3)	.4000 (+.10)	.03888(+.91)
IJS	.00336 (+.33)	.001603(-.43)	.03374(+.51)	.3997 (+.02)	.03870(+.44)
U-238 Capture					
Group	1	2	3	4	1+2+3
Ref.	.01900 (.27)	.02375 (.48)	.1554 (.29)	.1486 (.17)	.1982 (.24)
IAEA	.01879 (-1.1)	.02365 (-.42)	.1555 (+.06)	.1487 (+.05)	.1980 (-.10)
IJS	.01922 (+1.2)	.02345 (-1.2)	.1558 (+.24)	.1482 (-.24)	.1985 (+.13)
U-238 Fission					
Group	1	2	3	4	1+2+3
Ref.	-	-	-	0	.03905(.55)
IAEA	-	-	-	0	.03787(-3.0)
IJS	-	-	-	0	.03889(-.41)

TRX-2 Reaction rates (ENDF/B-IV)					
U-235 Capture					
Group	1	2	3	4	1+2+3
Ref.	.000259(.18)	.000359(.30)	.01066(.27)	.07211(.09)	.01118(.26)
IAEA	.000257(-.77)	.000366(+1.9)	.01103(+3.5)	.07205(-.08)	.01165(+4.2)
IJS	.000262(+1.2)	.000365(+1.7)	.01095(+2.7)	.07201(-.14)	.01158(+3.6)
U-235 Fission					
Group	1	2	3	4	1+2+3
Ref.	.002250(.25)	.000972(.52)	.02166(.52)	.4204 (.08)	.02488(.45)
IAEA	.002212(-1.7)	.000968(-.41)	.02193(+1.2)	.4199 (-.13)	.02511(+.92)
IJS	.002267(+.75)	.000967(-.51)	.02179(+.60)	.4198 (-.14)	.02503(+.60)
U-238 Capture					
Group	1	2	3	4	1+2+3
Ref.	.01235 (.19)	.01441 (.44)	.1029 (.60)	.1550 (.14)	.1296 (.48)
IAEA	.01224 (-.89)	.01434 (-.49)	.1035 (+.58)	.1547 (-.17)	.1301 (+.39)
IJS	.01255 (+1.7)	.01423 (-1.3)	.1032 (+.28)	.1544 (-.38)	.1300 (+.29)
U-238 Fission					
Group	1	2	3	4	1+2+3
Ref.	-	-	-	0	.02852(.40)
IAEA	-	-	-	0	.02773(-2.8)
IJS	-	-	-	0	.02857(-.18)

NOTE: In brackets the statistical % uncertainty is quoted for the reference solution and % deviation from reference for the WIMS solution using ENDF/B-IV based libraries.

subject at the moment. It is recommended to continue the effort with NJOY maintenance for thermal reactor applications and to use it (if possible) for all multigroup library preparation.

Verification of NJOY91 with corrections for WIMS library preparation has been performed. Some minor open questions remain in the preparation of the thermal scattering matrices and in the documentation describing the use of the flux calculator, so that presently selected input options could be confirmed.

6.2 WIMS library data

6.2.1 Fission spectrum

In the WIMS library for the WIMS/D-4 code a single fission spectrum is specified for all fissile nuclei. This does not seem to have an excessively strong effect on the multiplication factor of well thermalized systems, but the reaction rates were found to differ considerably with changes in the fission spectrum, particularly in the fast energy range. For the WIMS library a fission spectrum should be constructed, which would represent a spectrum due to fission in a mixture of isotopes, most typically encountered in reactor cores. When applying WIMS to a class of problems, the limitations due to the fission spectrum should be considered.

6.2.2 Cross sections

Differences in the averaging spectrum cause a few percent differences in the cross sections. From a practical point of view, these differences are probably unimportant. However, the use of a simple, smooth and realistic averaging spectrum is desirable in the multigroup library preparation to improve data consistency.

The cross sections entered into the WIMS library should be Doppler-broadened to the most typical temperature at which the cross sections are likely to be used (or several temperatures in the thermal range, if temperature effects are important). Also, the self shielding correction should be applied. The level of self shielding should correspond to the most typical dimensions and composition at which a material is likely to be used, and under conditions when the contribution of the material in question is significant. For example, for resonance absorbers the selected level of self shielding should be biased towards low dilutions, since a high dilutions the contribution of the absorber is smaller. This recommendation applies also to materials with explicitly tabulated resonance integrals, since the self shielding in the scattering reaction can not be treated otherwise. With the selection of the reference temperature and Bondarenko background cross section to define the level of self shielding, all cross sections in the library are uniquely defined with equations, given in the previous sections of this report.

6.2.3 Resonance integrals

The resonance integrals should be calculated from the cross sections by the inverse formula used in WIMS to calculate the cross sections. Care should be taken to note the difference between the Bondarenko and the WIMS definition of the background cross section against which the self shielded cross sections are tabulated.

Although an Intermediate Resonance approximation for calculating the resonance integrals gives acceptable results, one should preferentially apply an explicit calculation of the slowing down spectrum, corresponding to a configuration most typically encountered for the material in question.

6.3 Global effects

The overall agreement of the integral lattice parameters with the published data is quite good. The results presented in this work provide a firm foundation for generating a WIMS library from other evaluated nuclear data files.

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APPENDIX

Diagrams are presented to compare the following data types from different participants:

- cross sections for each reaction type, for all participants, with reference to the IAEA data set,
- resonance integrals as a function of the background cross section for all participants, with reference to the IAEA data set.

The definition of the background cross section is the usual definition used in a variety of the processing codes and does not include the potential scattering of the absorber atom. In this respect the definition differs from the WIMS definition.

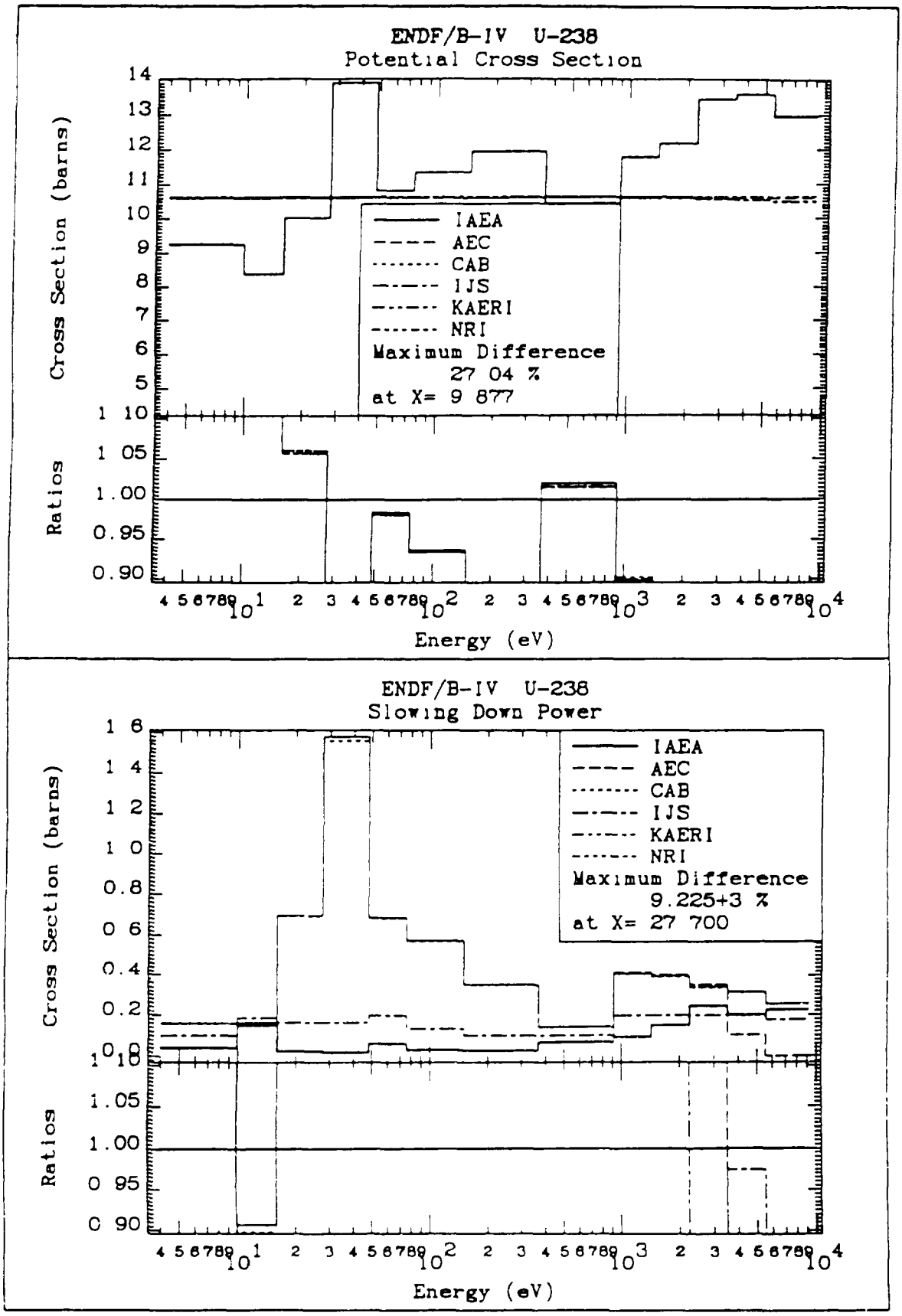

Figure 2: Comparison of potential cross section and slowing-down power for Uranium-238.

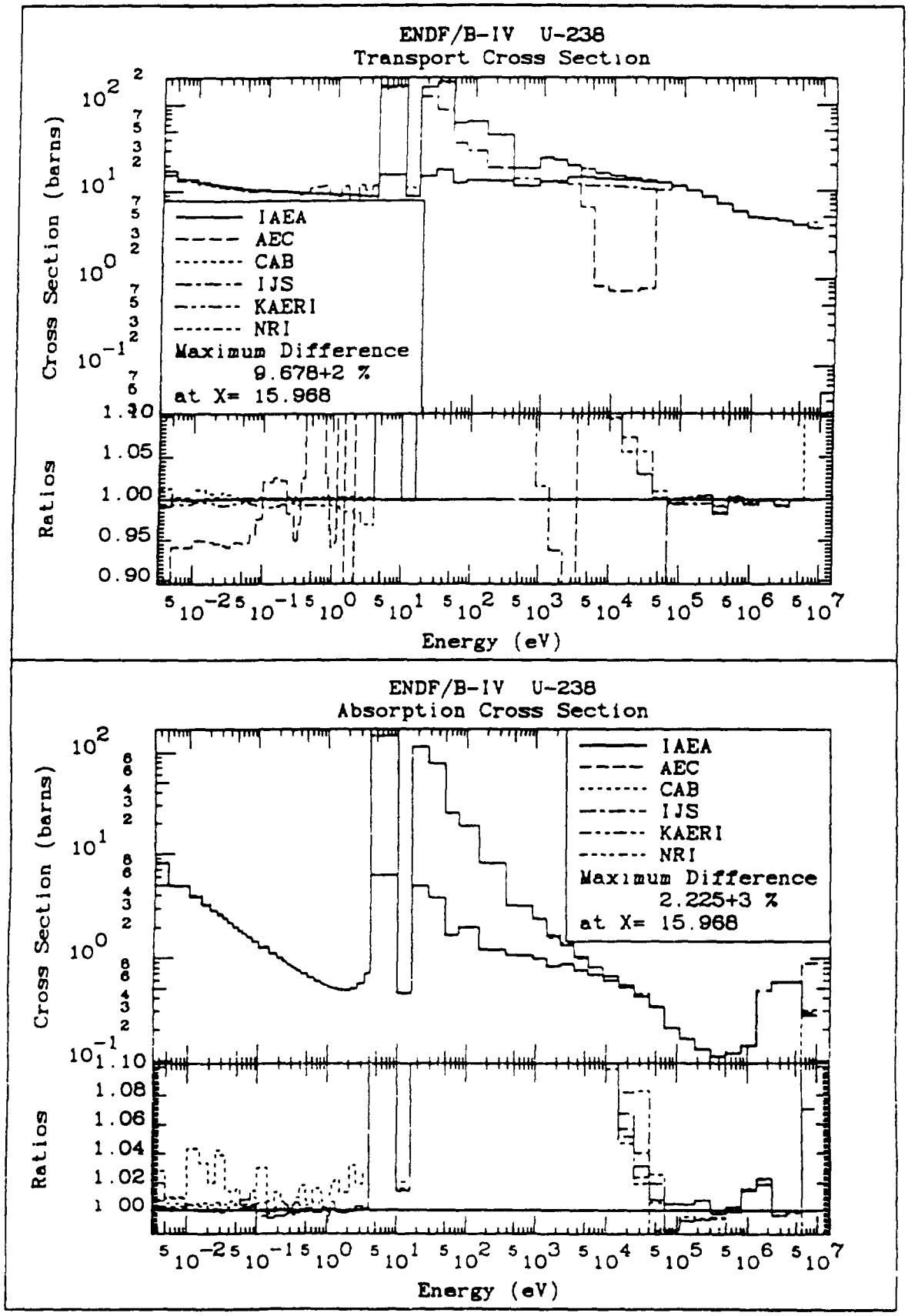

Figure 3: Comparison of transport and absorption cross sections for Uranium-238.

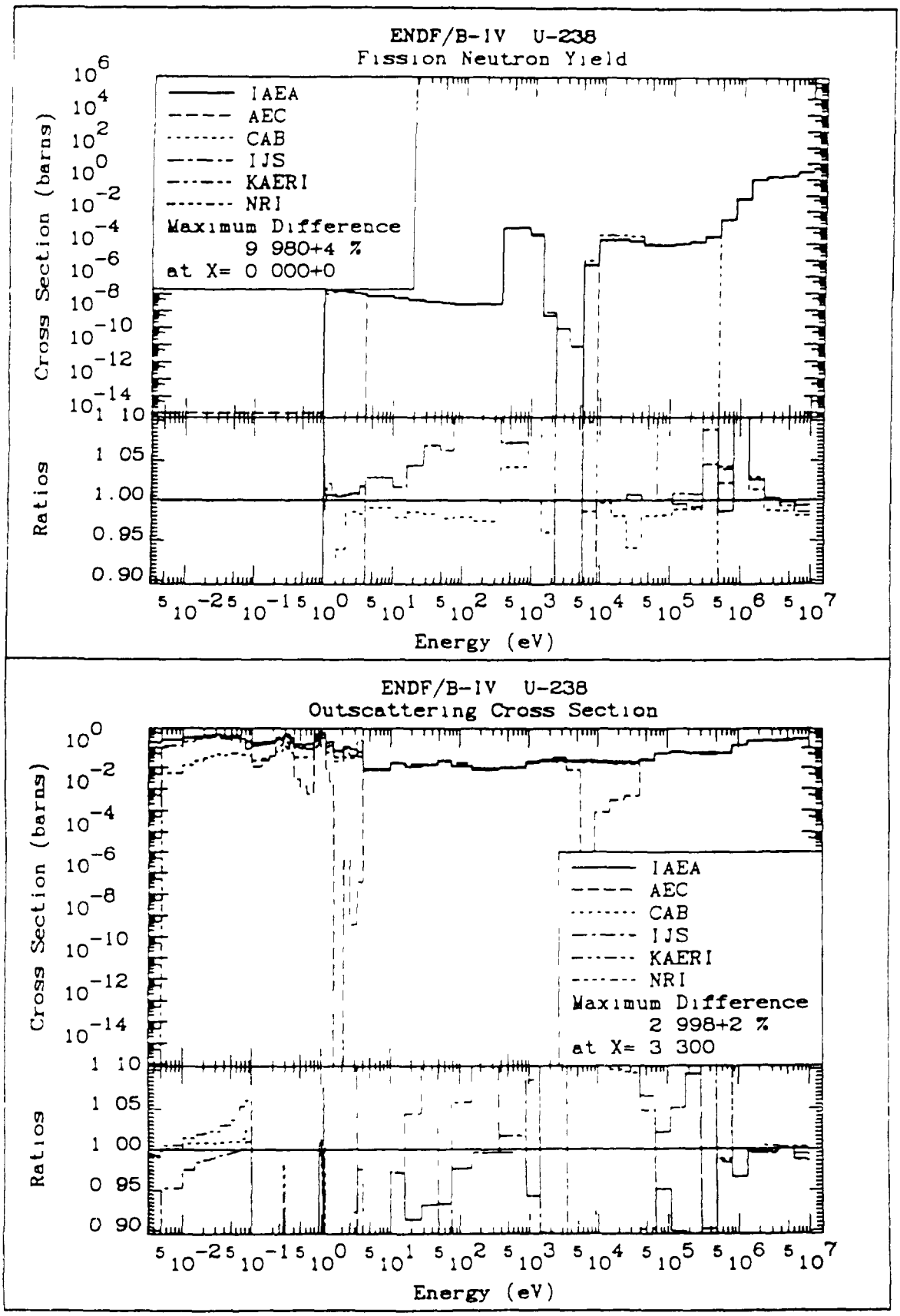

Figure 4: Comparison of fission neutron yield and outscattering cross section for Uranium-238

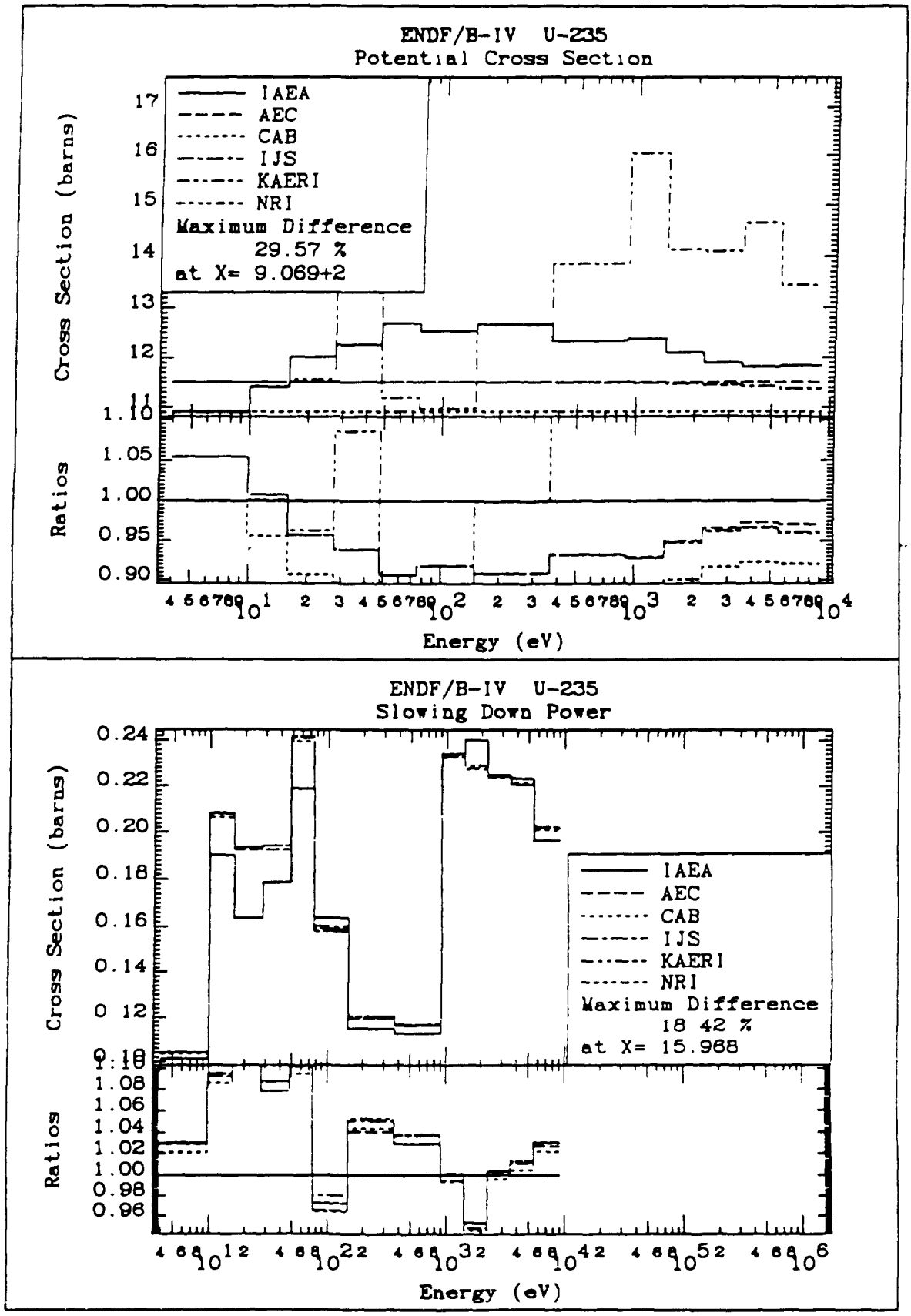

Figure 5: Comparison of potential cross section and slowing-down power for Uranium-235.

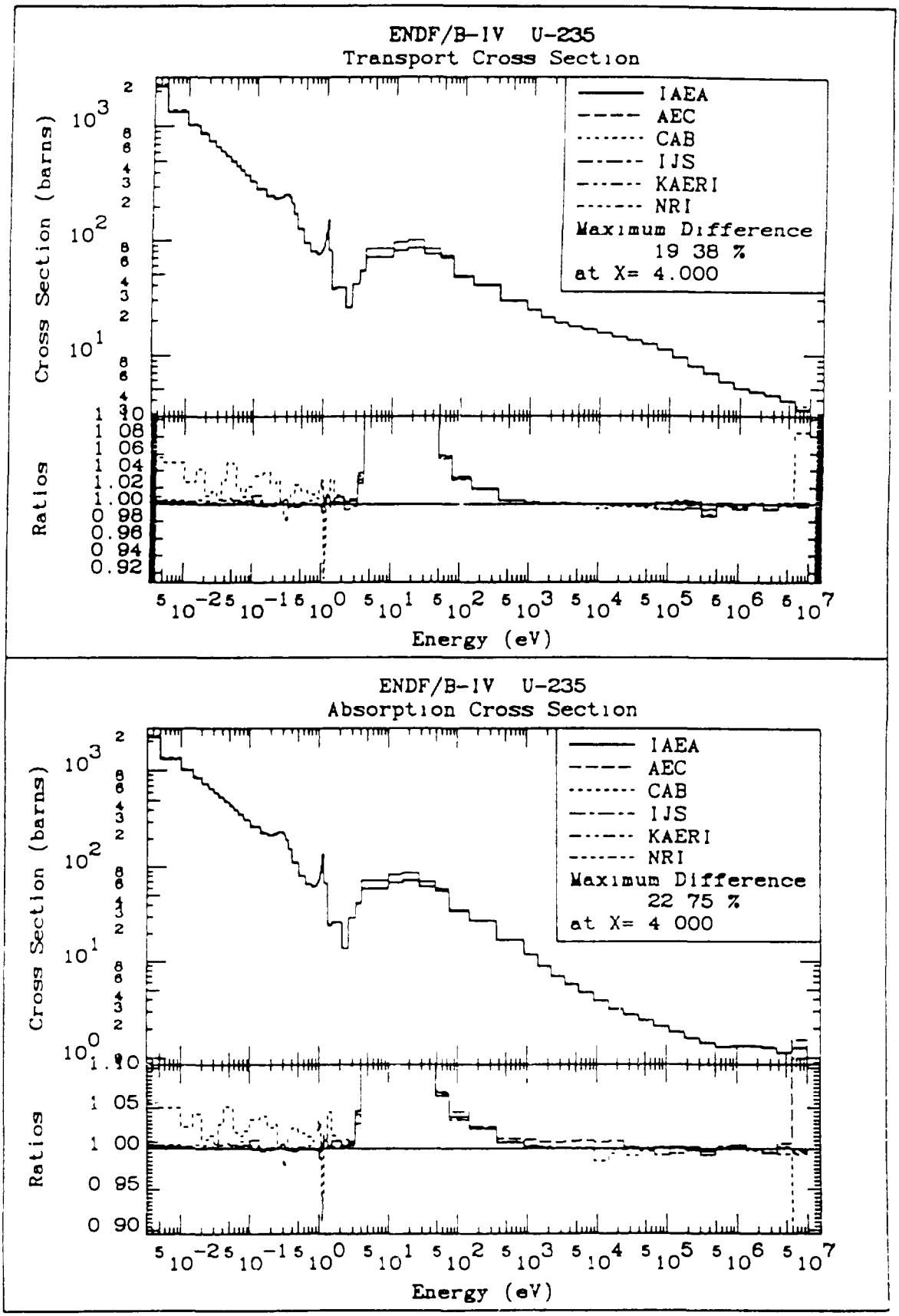

Figure 6: Comparison of transport and absorption cross sections for Uranium-235.

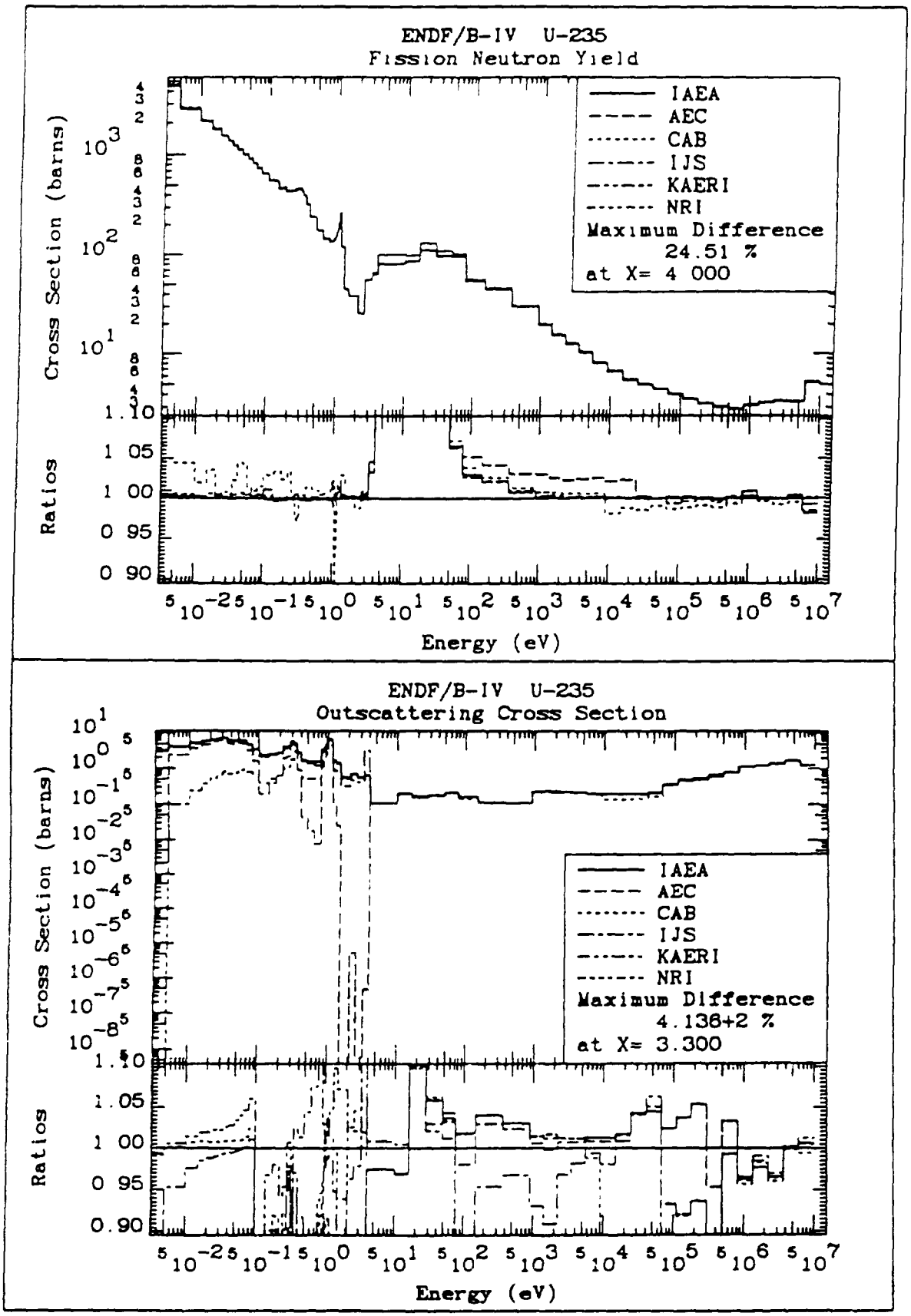

Figure 7: Comparison of fission neutron yield and outscattering cross section for Uranium-235.

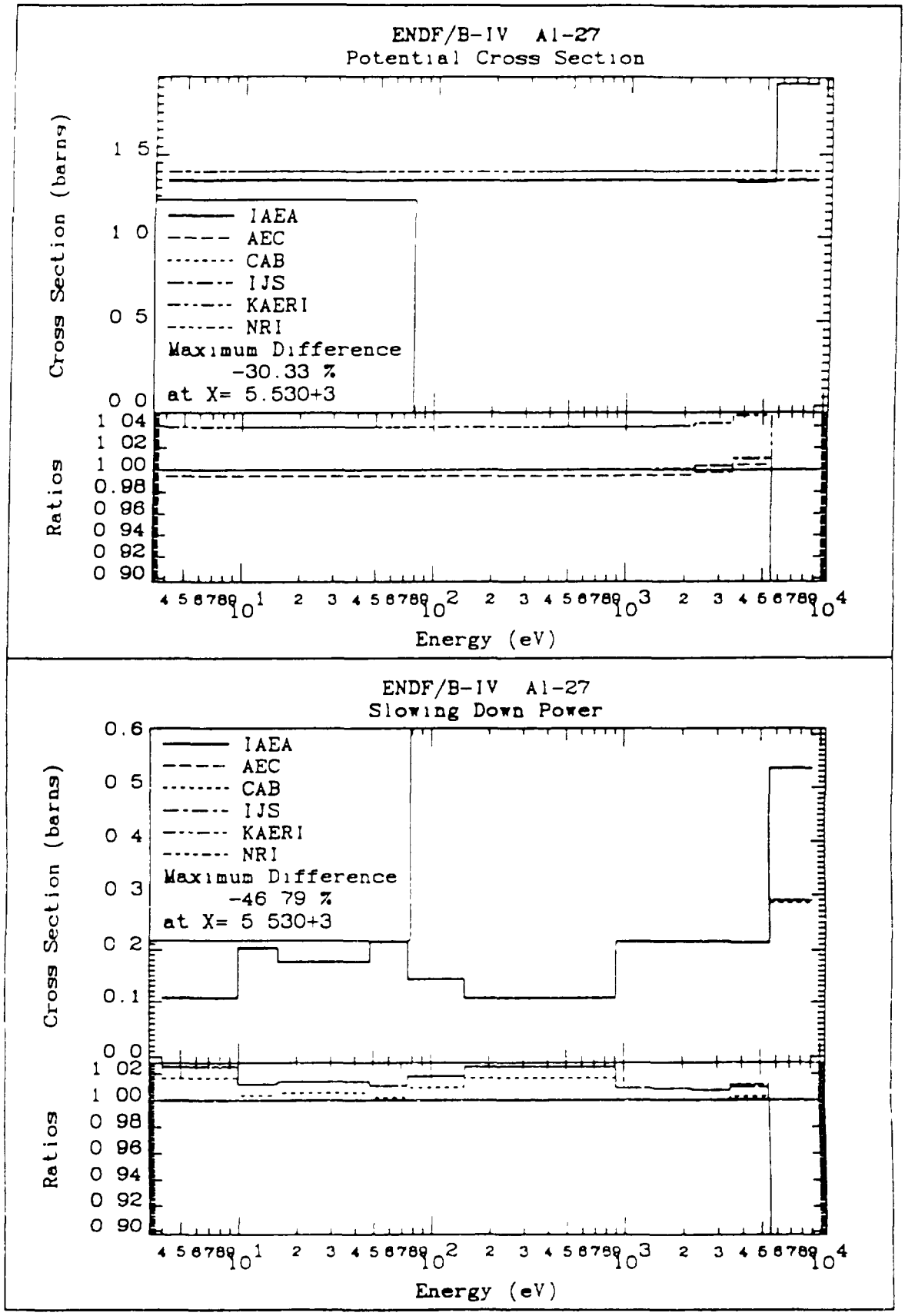

Figure 8· Comparison of potential cross section and slowing-down power for aluminium

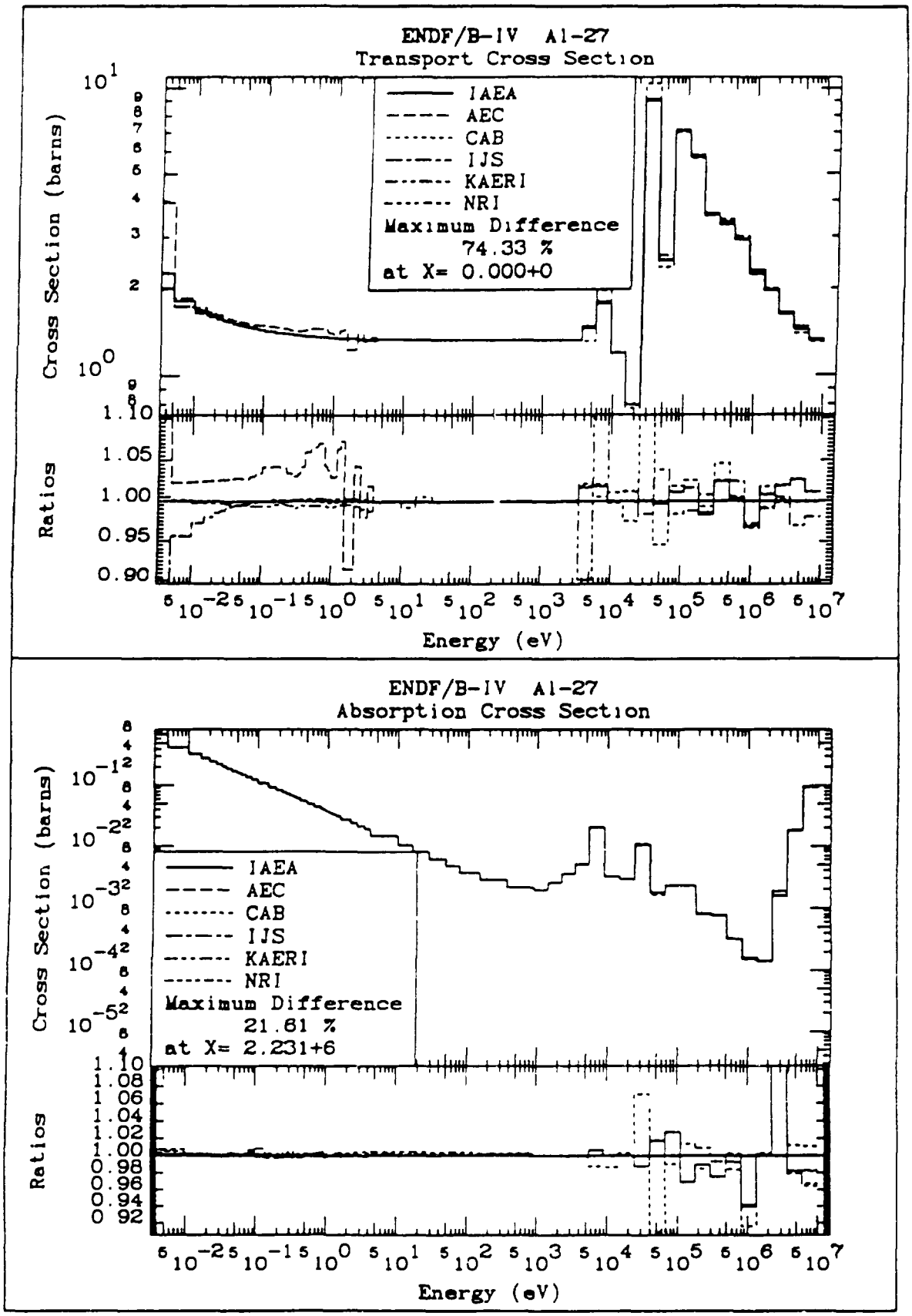

Figure 9: Comparison of transport and absorption cross sections for aluminium.

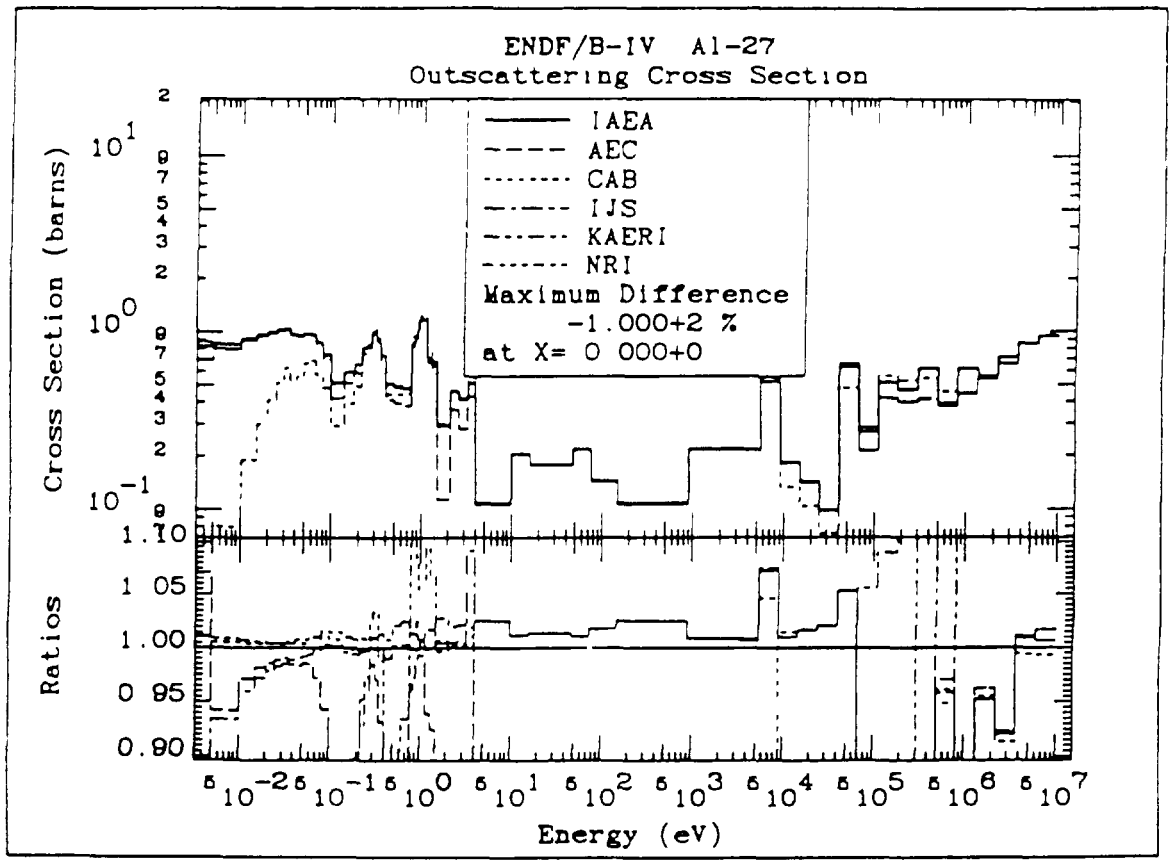

Figure 10: Comparison of outscattering cross section for aluminium.

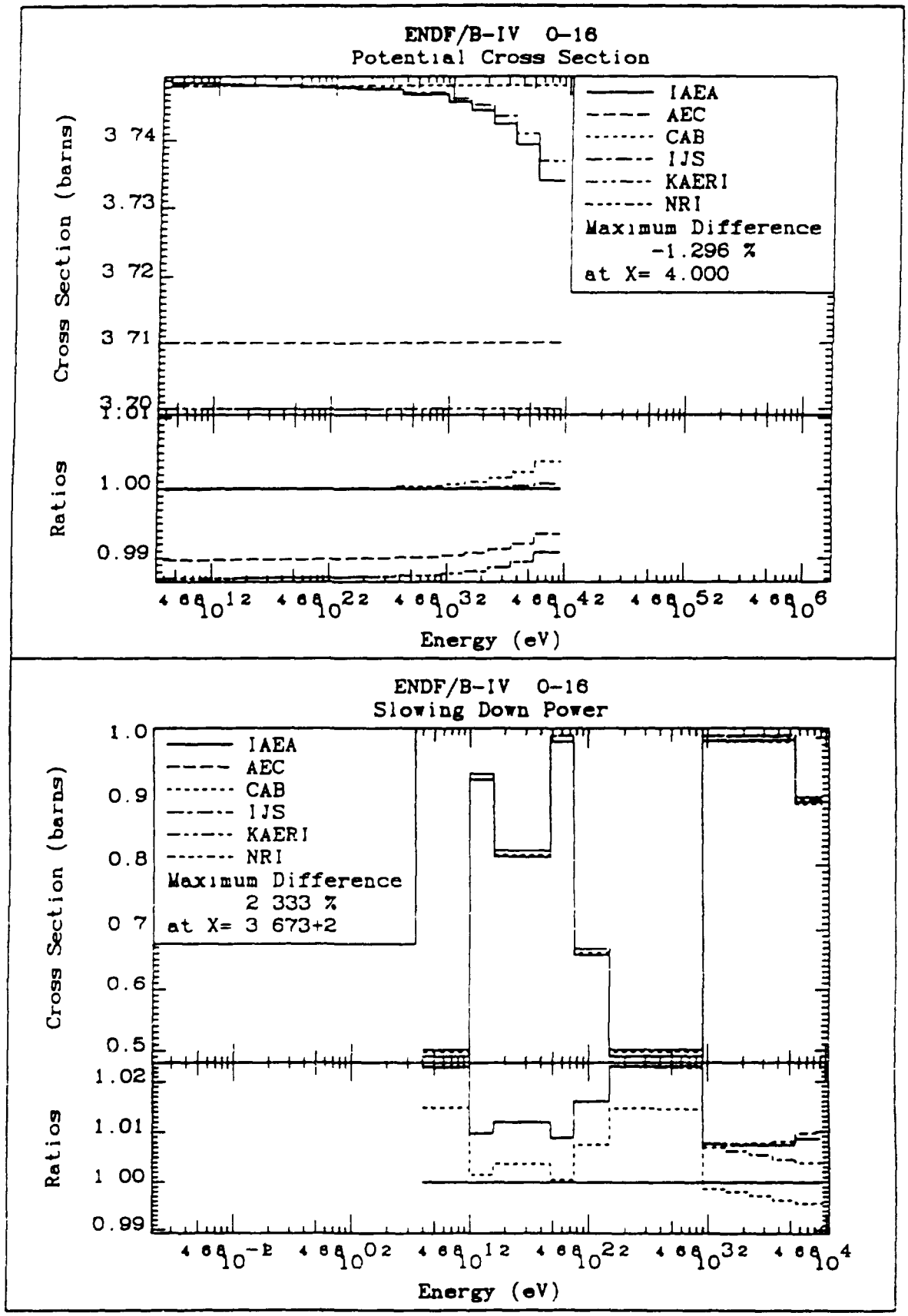

Figure 11: Comparison of potential cross section and slowing-down power for oxygen.

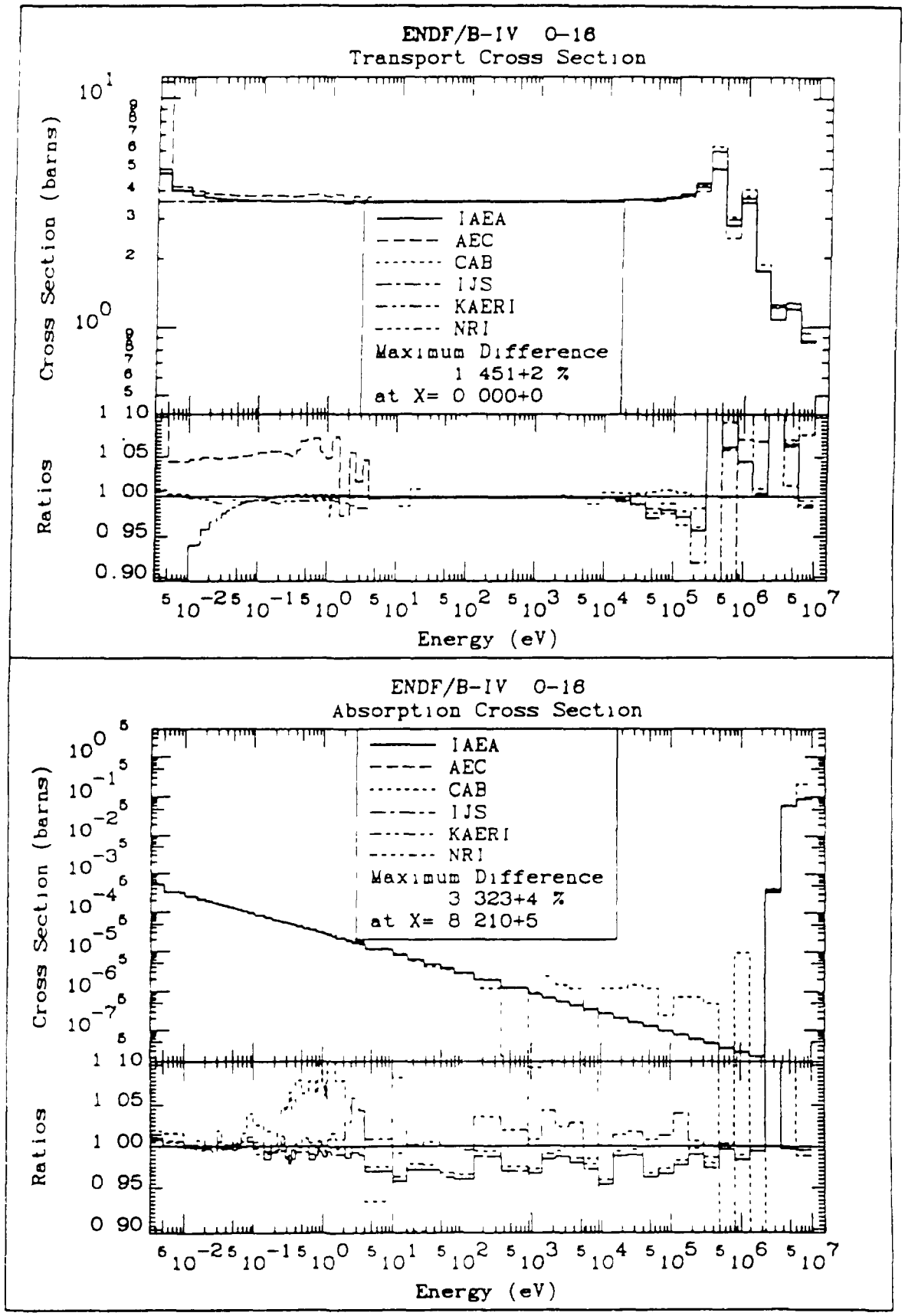

Figure 12: Comparison of transport and absorption cross sections for oxygen

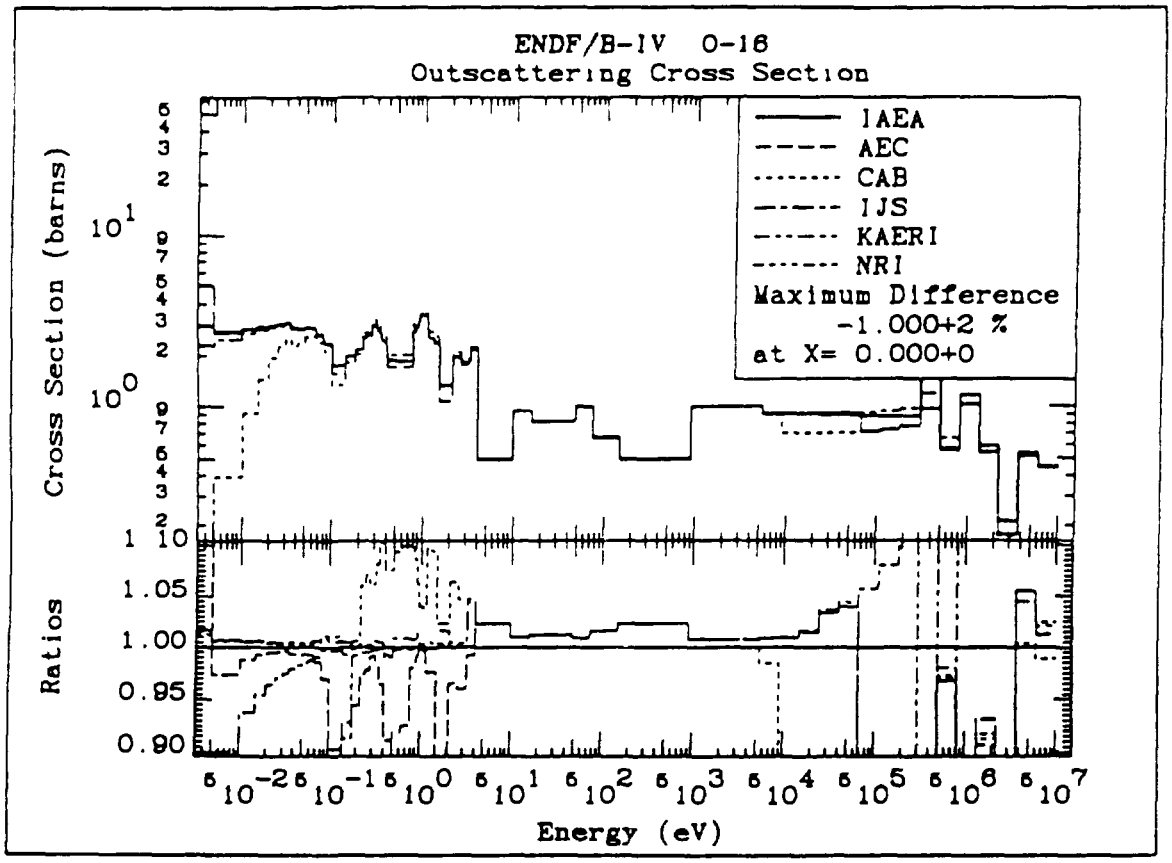

Figure 13: Comparison of outscattering cross section for oxygen.

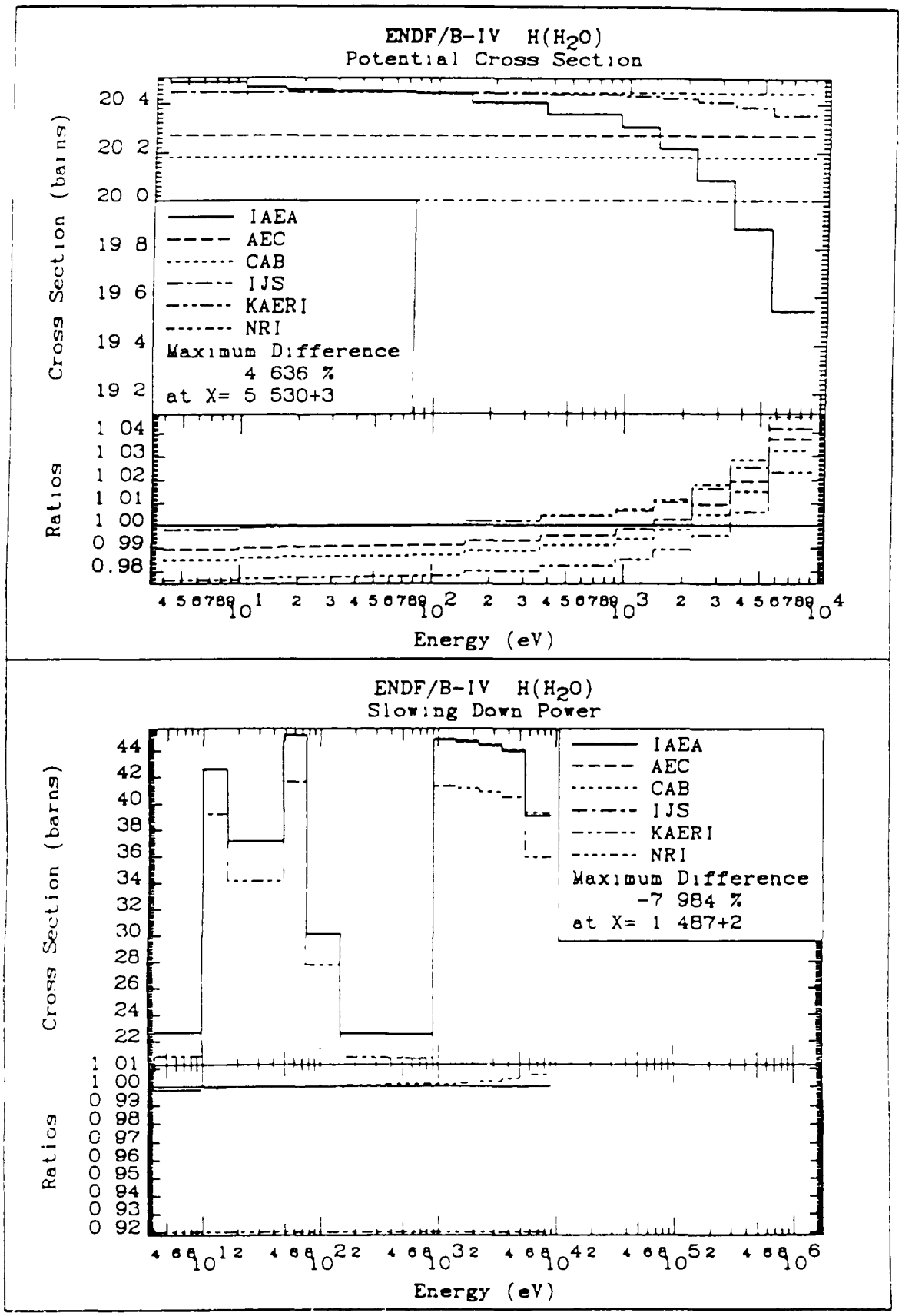

Figure 14: Comparison of potential cross section and slowing-down power for hydrogen

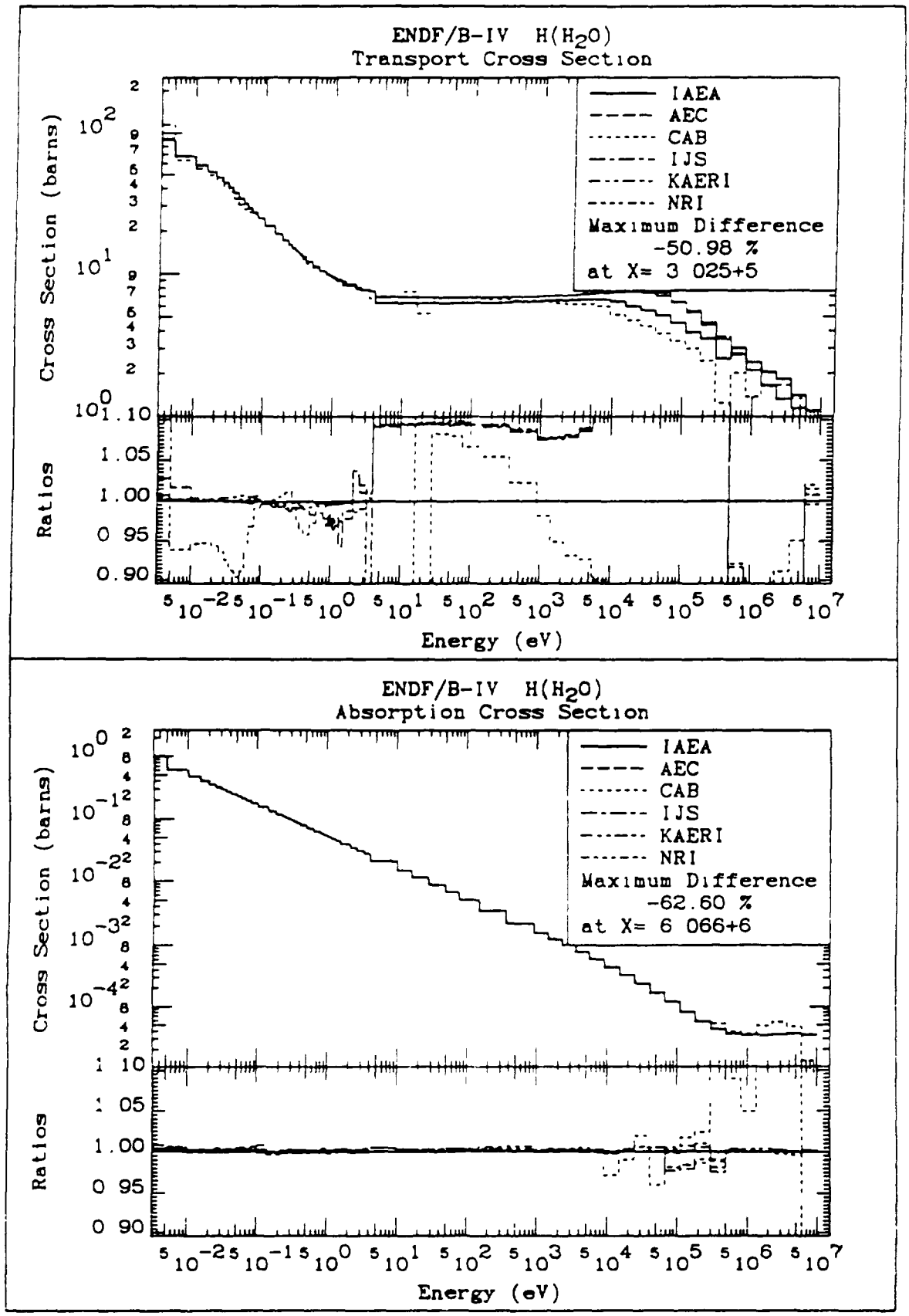

Figure 15· Comparison of transport and absorption cross sections for hydrogen.

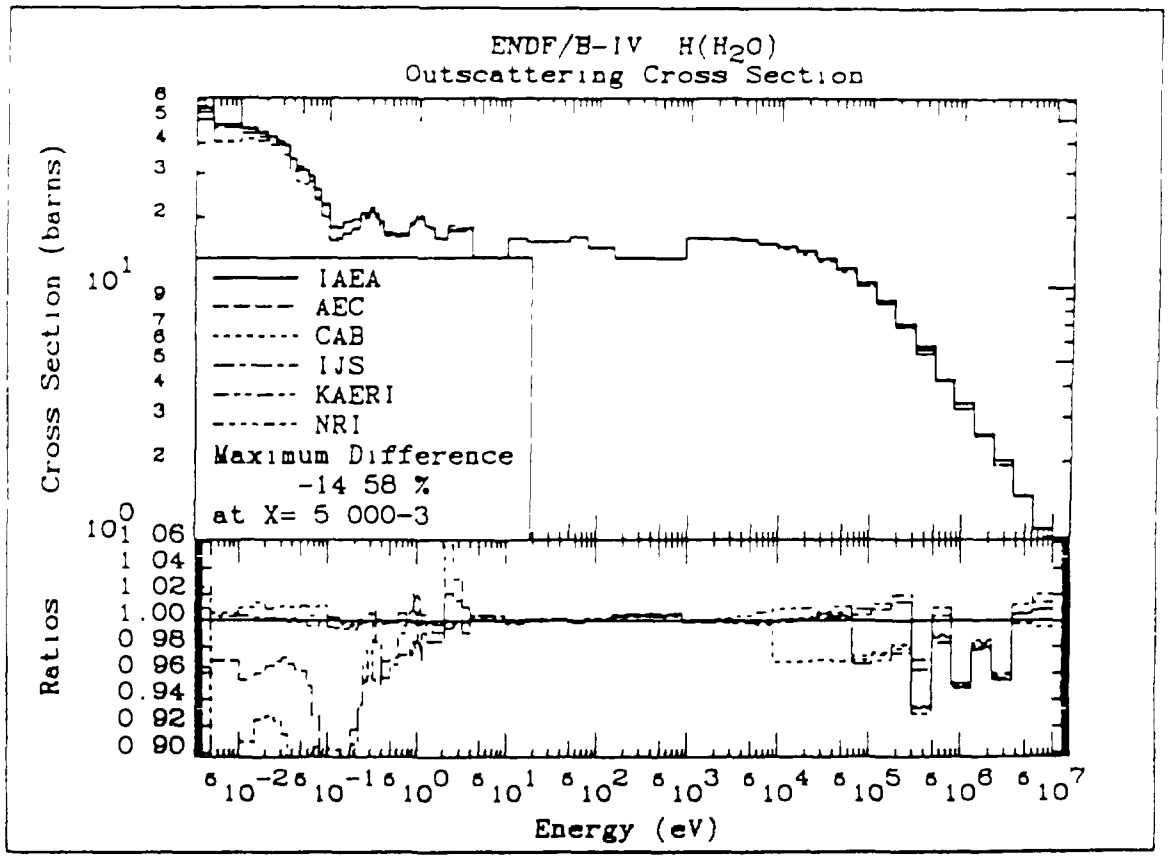

Figure 16: Comparison of outscattering cross section for hydrogen.

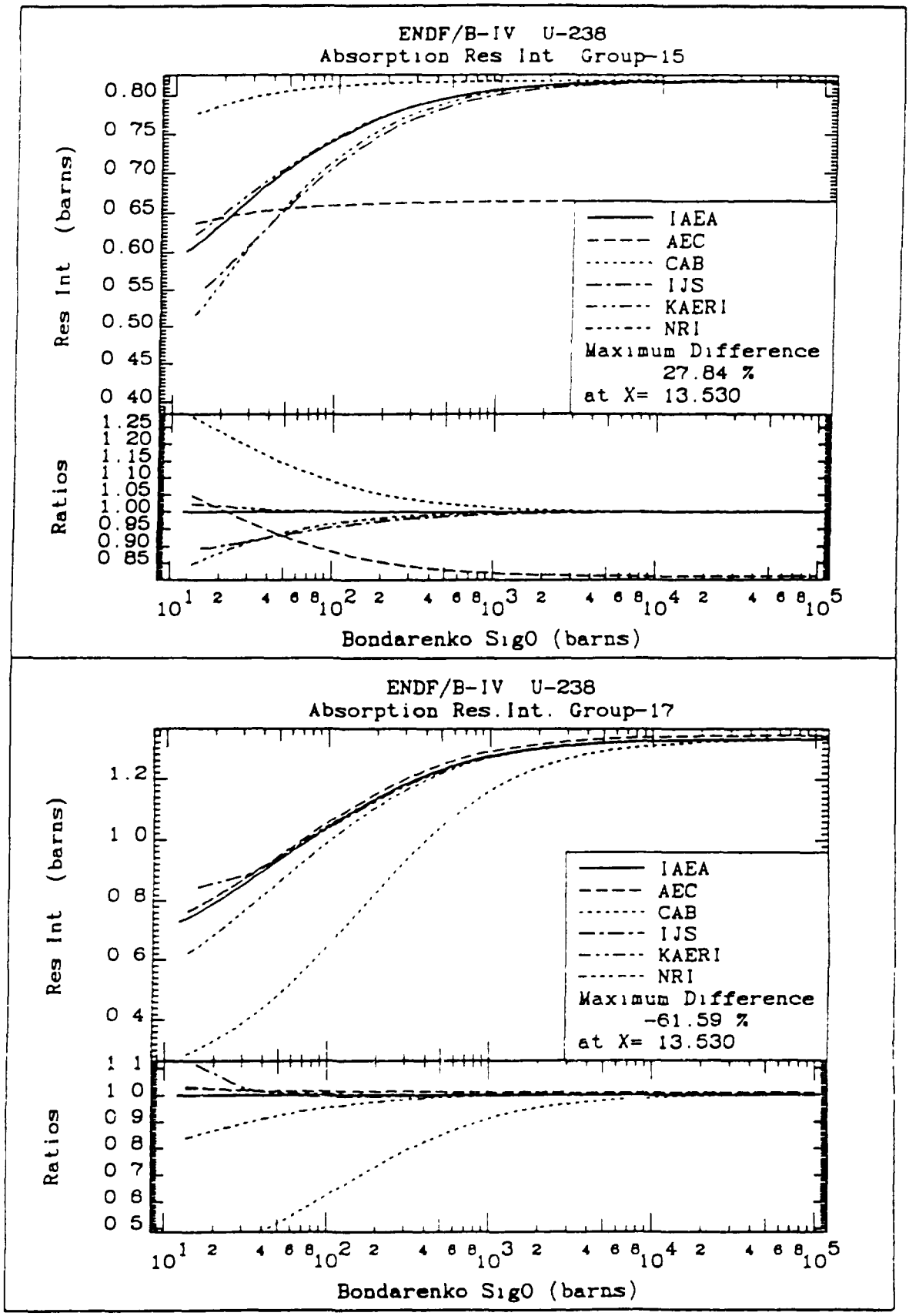

Figure 17: Absorption resonance integrals of Uranium-238 in Groups 15 and 17.

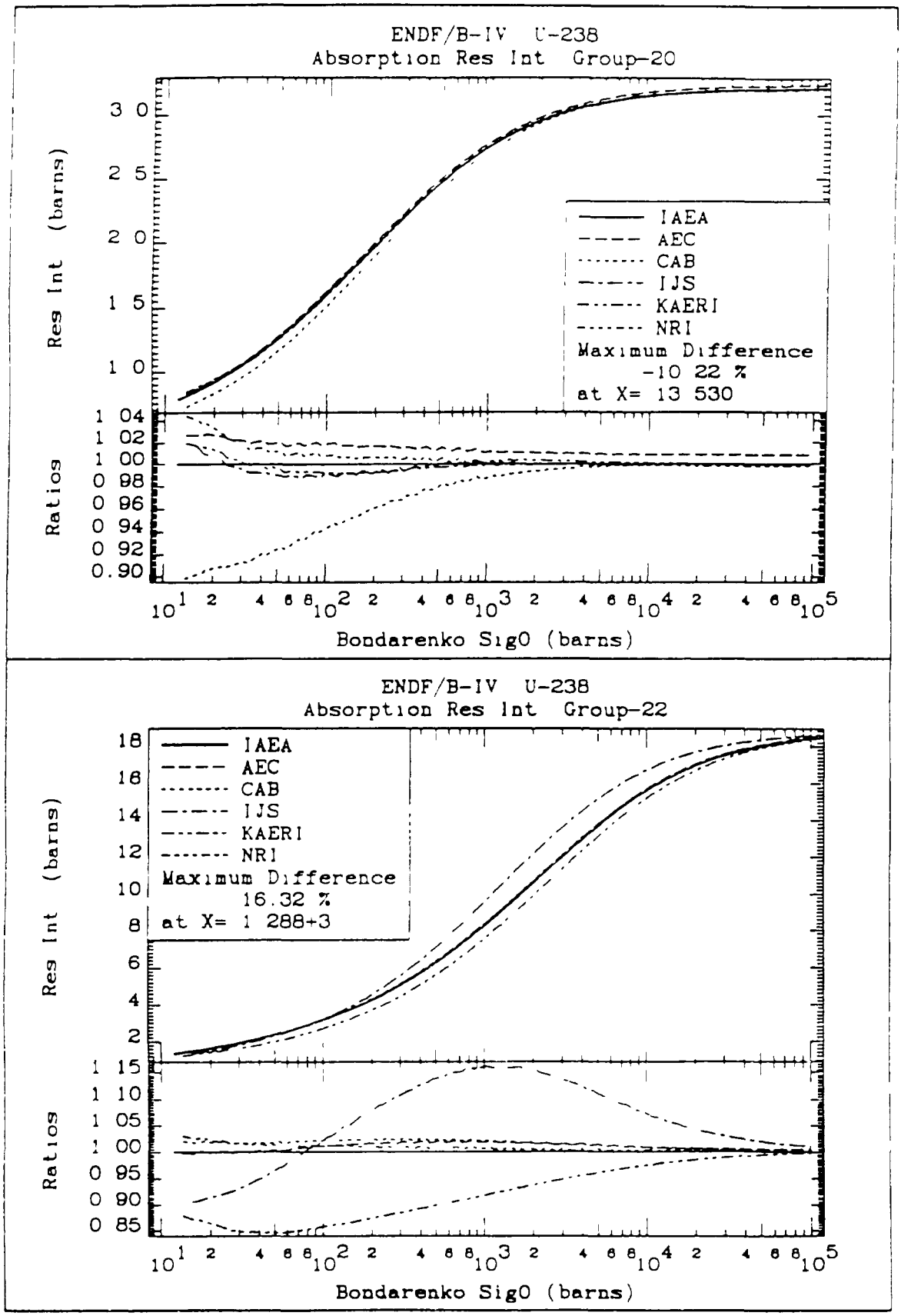

Figure 18: Absorption resonance integrals of Uranium-238 in Groups 20 and 22

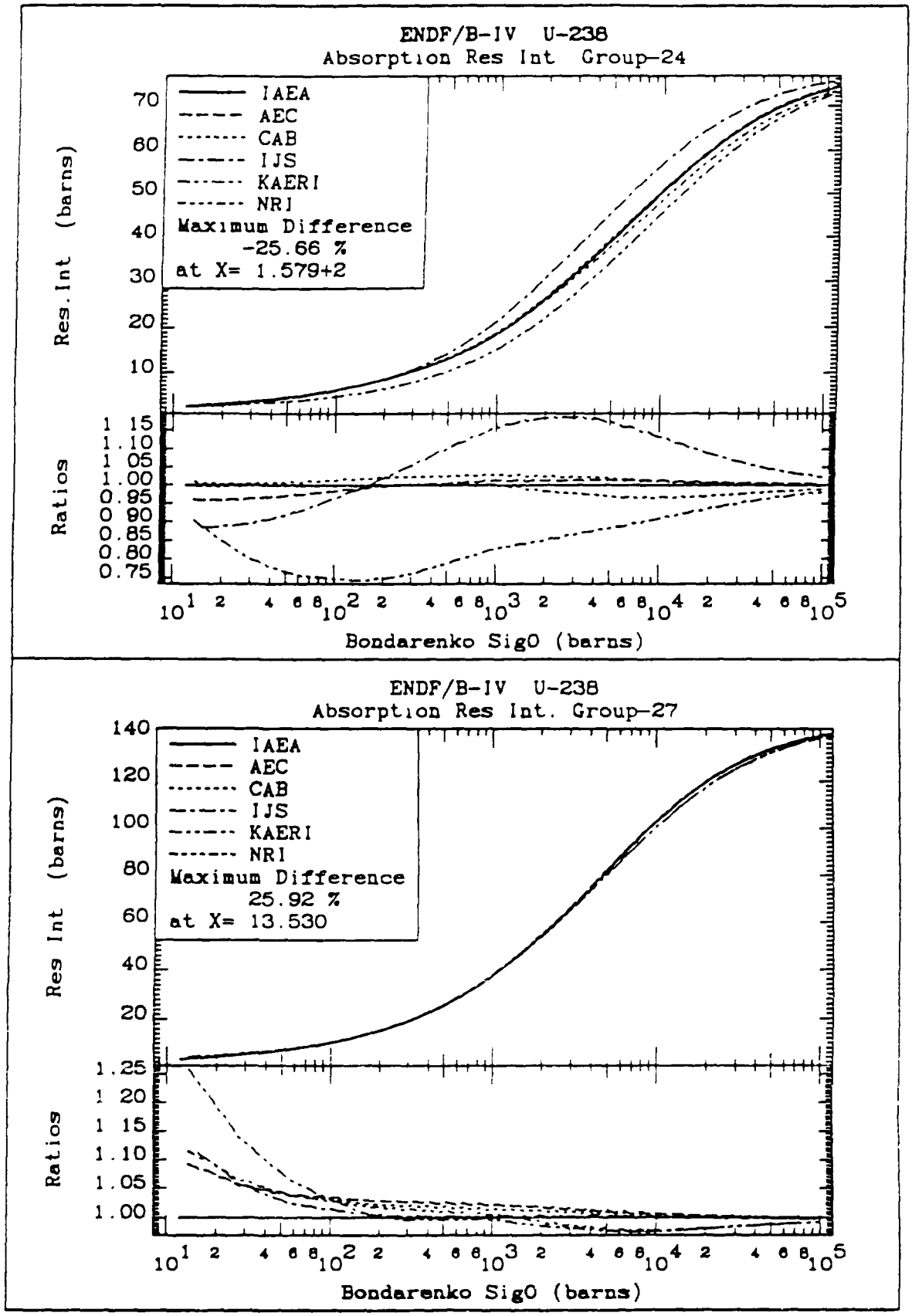

Figure 19: Absorption resonance integrals of Uranium-238 in Groups 24 and 27.

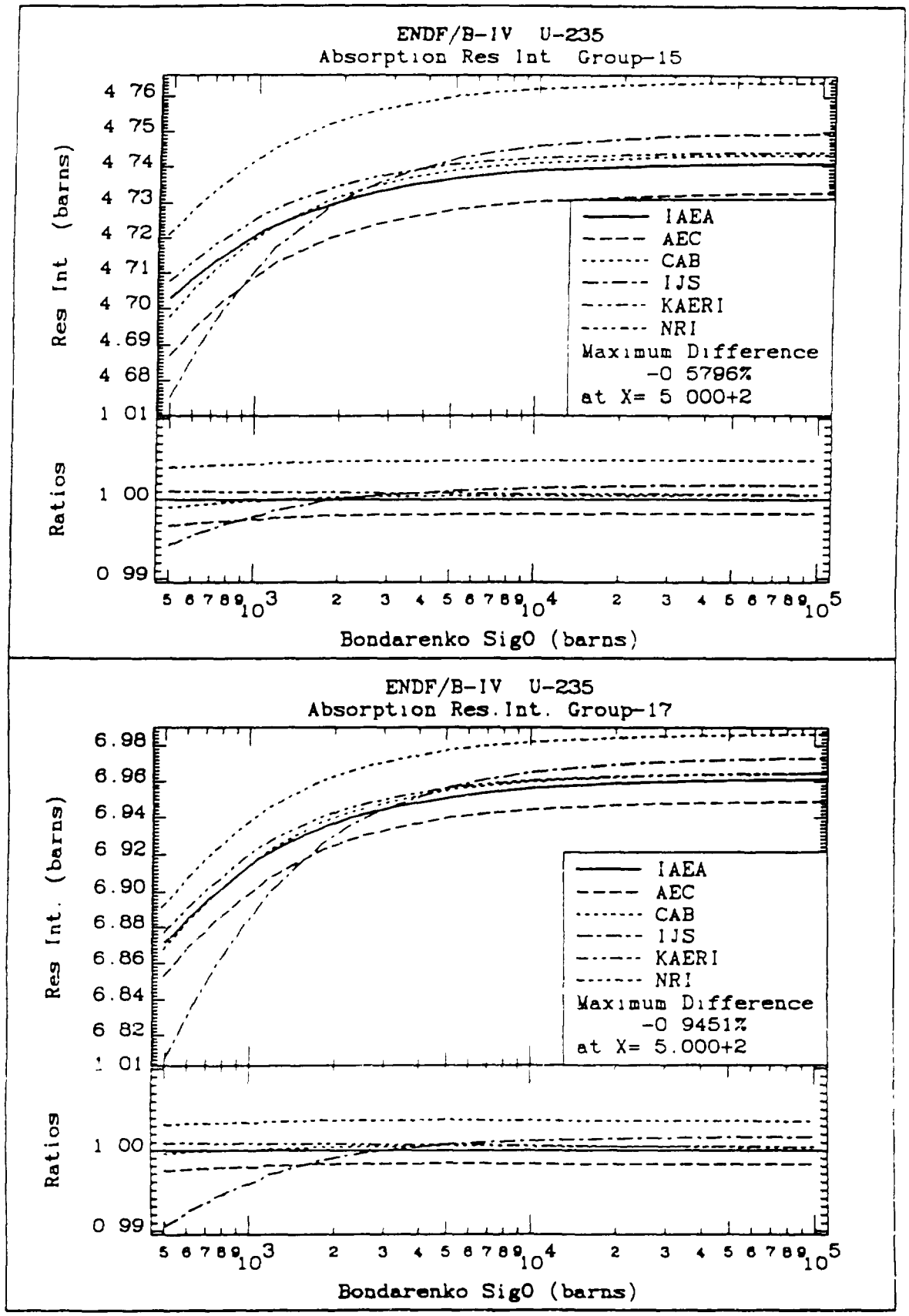

Figure 20: Absorption resonance integrals of Uranium-235 in Groups 15 and 17.

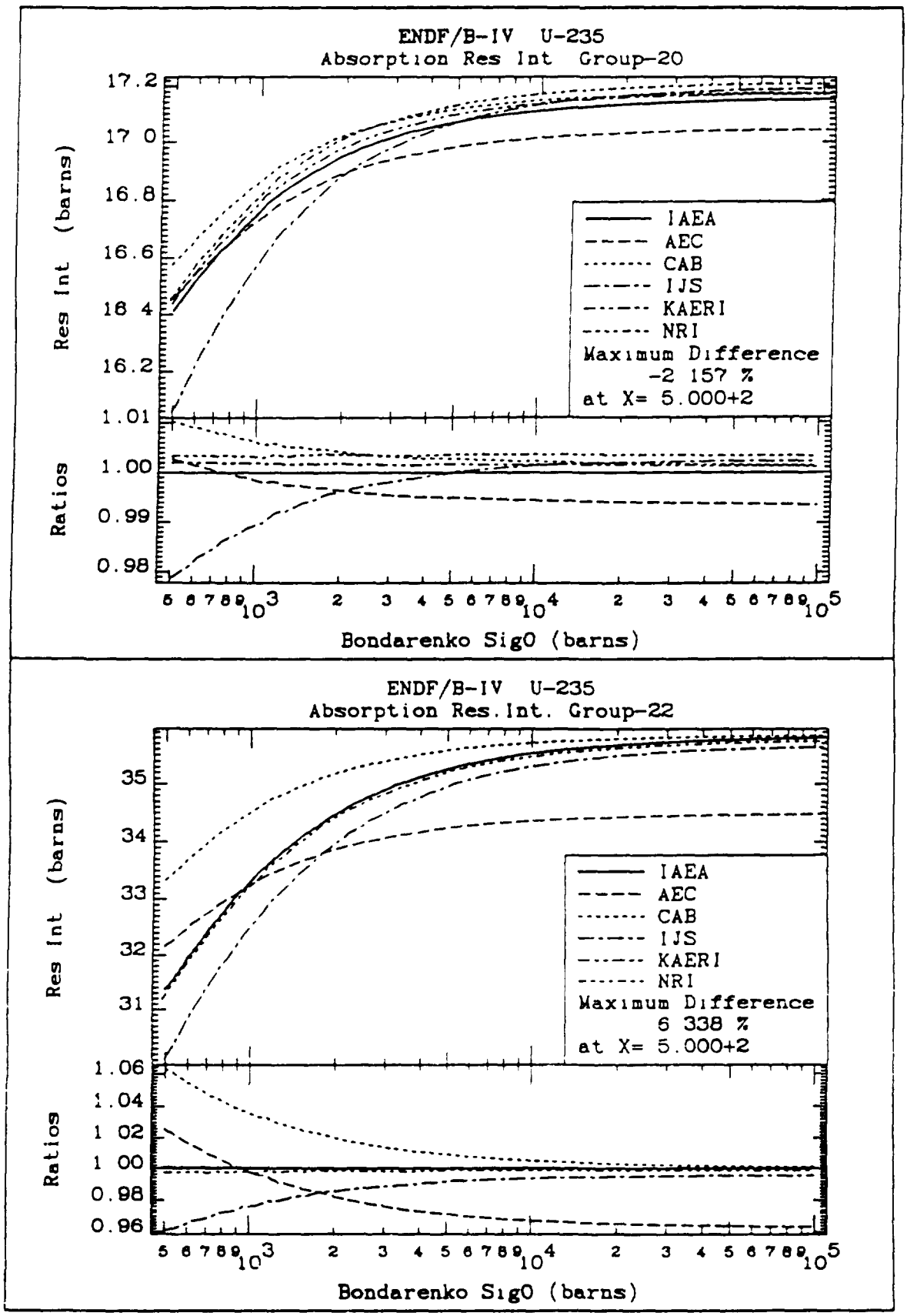

Figure 21: Absorption resonance integrals of Uranium-235 in Groups 20 and 22.

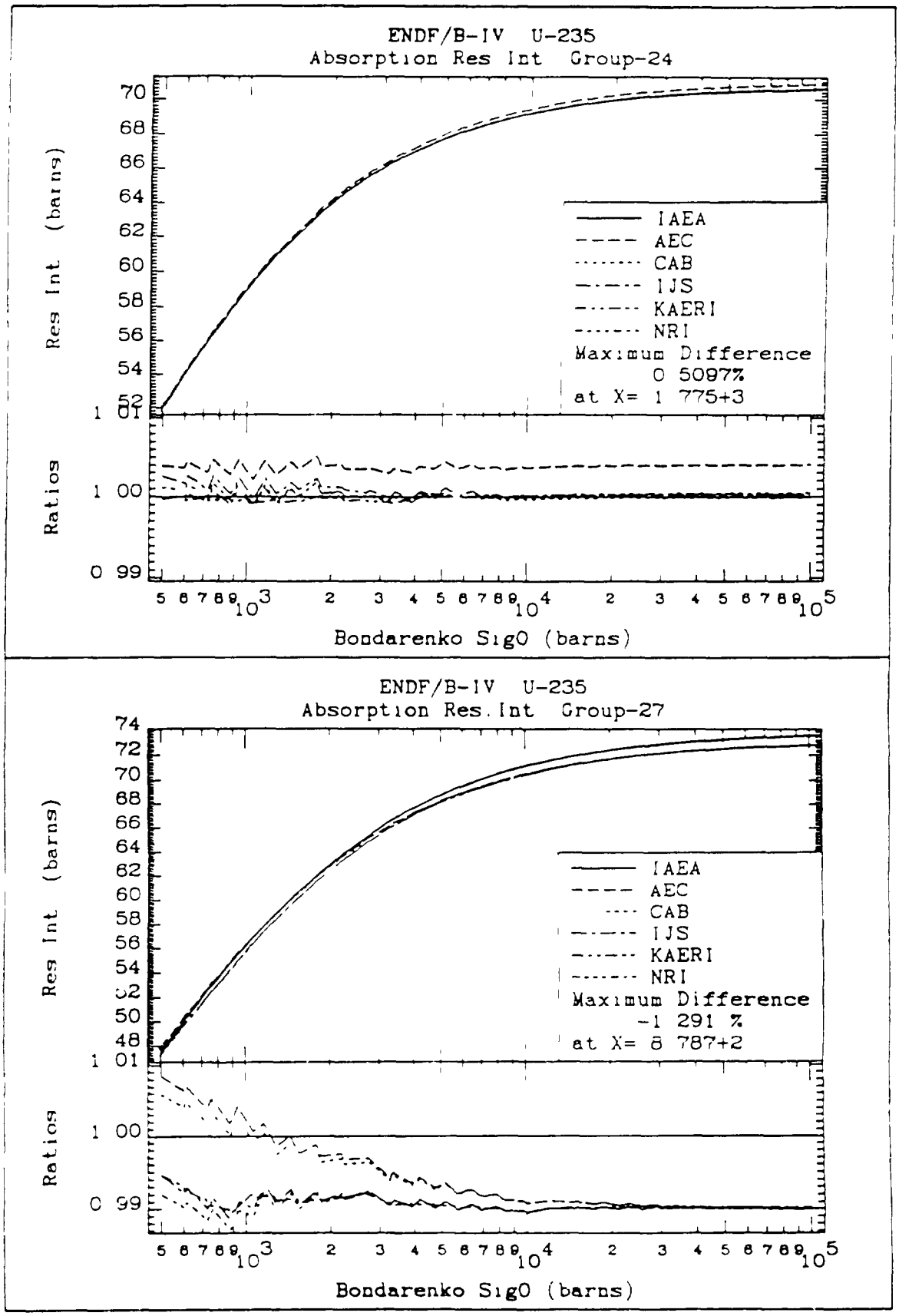

Figure 22: Absorption resonance integrals of Uranium-235 in Groups 24 and 27

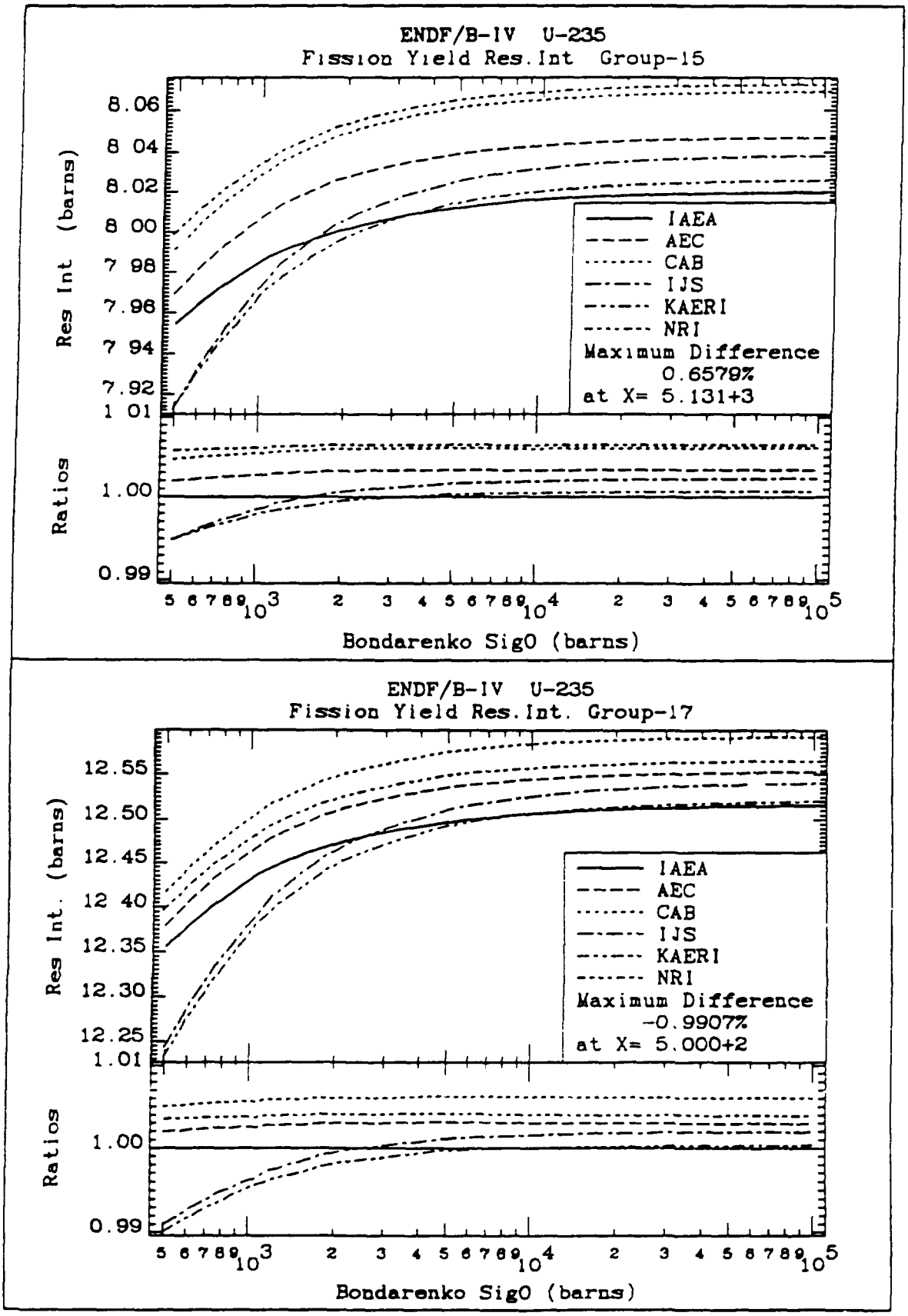

Figure 23: Fission neutron yield resonance integrals of Uranium-235 in Groups 15 and 17.

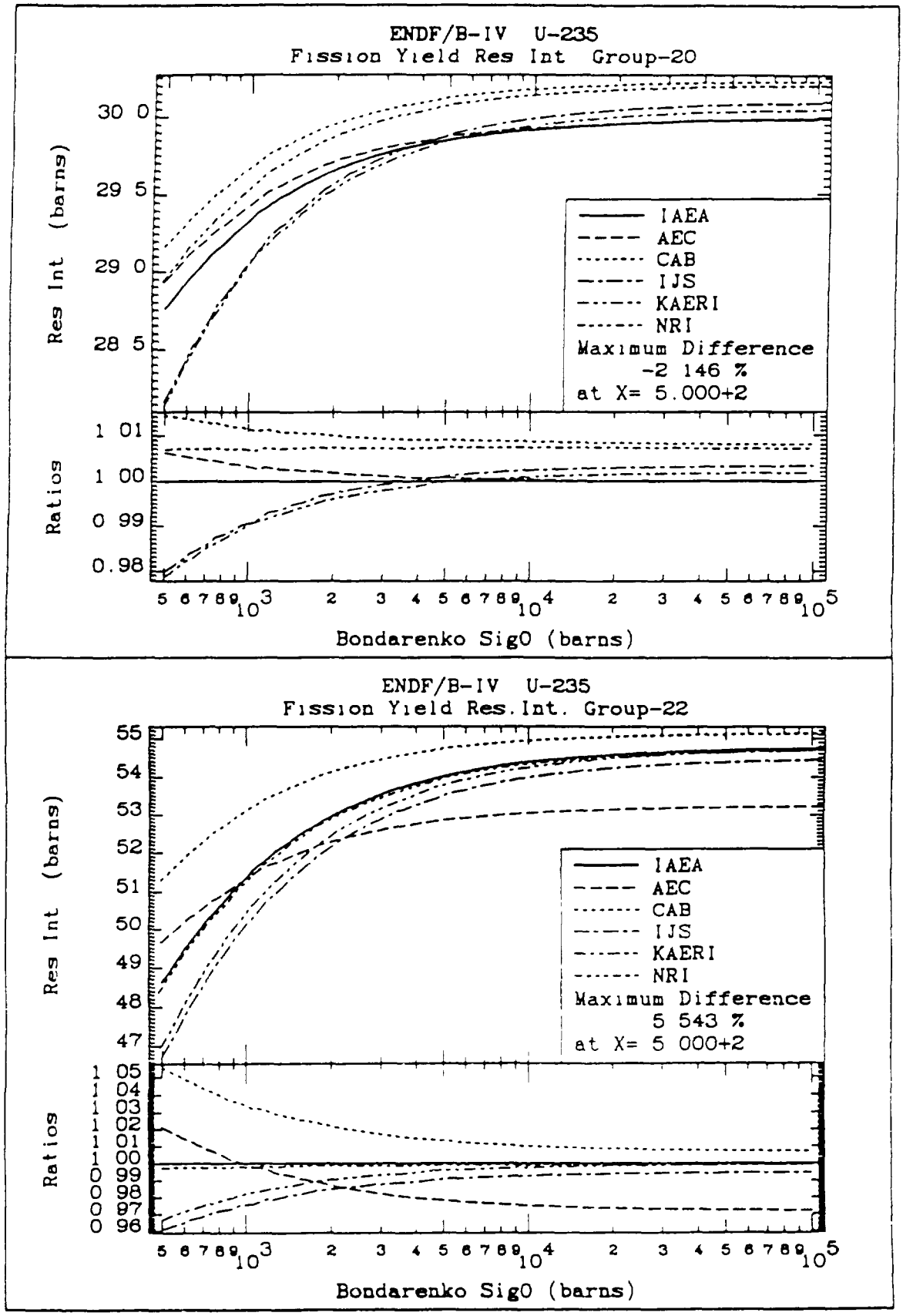

Figure 24: Fission neutron yield resonance integrals of Uranium-235 in Groups 20 and 22.

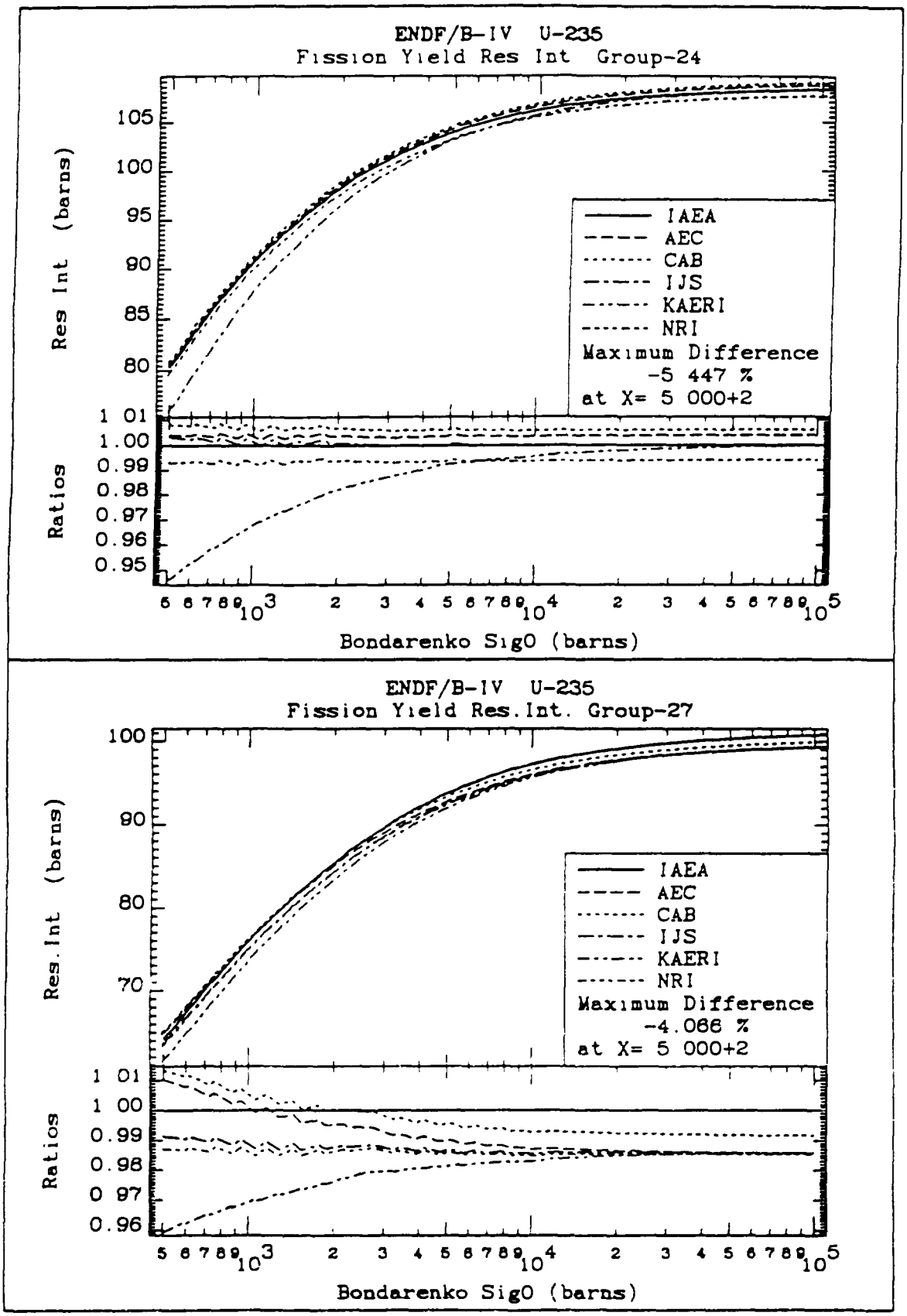

Figure 25: Fission neutron yield resonance integrals of Uranium-235 in Groups 24 and 27.

WIMS Library Update Project
Final Report on Stage 1

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1 Introduction

The results on Stage 1 of the Wims Library Update Project are presented in this report. They mainly include results and conclusions important for continuing the project. However, results are also presented in a more general form, being interesting to participants on the project as well as to other WIMS users.

The steps of Stage 1 defined in [1] were carried out without major modifications. The main goals of the project at this stage were:

- identification of the differences between different versions of the WIMS-D4 code and of the library stemming from computer adaptations or modifications by the users,
- optimal modeling of the selected benchmark problems and
- evaluation of benchmark results obtained with the original WIMS library.

The purpose of Stage 1 was also to offer the possibility to the participants to check their version of the code, as well as their ability of using it by intercomparing the results.

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Principal investigator: Dr. Andrej Trkov

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Supported by the Ministry of Science and Technology of the Republic of Slovenia

Note on revisions

1. The late contribution from Iran was included in the analysis.
2. Minor corrections to the text referring to Table 1 were made.

List of participants:

Argentina	CNEA (Comision Nacional de Energia Atomica)	Ana Maria Lerner
Bangladesh	AERE (Atomic Energy Research Establishment)	Shafiqul I. Bhuiyan, Anisur Rashid Khan
Brasil	CNEN (Comissao Nacional de Energia Nuclear)	Clotilde M. Pina dos Santos, Antonio Carlos Fonseca de Santo
Brasil	IEA (Instituto de Estudos Avancados)	Airton Prati
Cuba	CEADN (Centro de Estudios Aplicados al Desarrollo Nuclear)	Caridad M. Alvarez Cardona et.al.
Czech and Slovak Federal Republic	ŠKODA, Nuclear Engineering Plant	Jiři Vacek
Czech and Slovak Federal Republic	NRI (Nuclear Resea-ch Institute)	Aleš Holubar
Germany	ZFK (Zentralinstitut fur Kernforschung)	Hartmut Wand
India	BARC (Bhabha Atomic Research Centre)	Kamala Balakrishnan, Umashankari P.
India	IGCAR (Indira Gandhi Centre for Atomic Research)	P. Mohanakrishnan
Indonesia	NAEA (National Atomic Energy Agency)	Riyanto Raharjo, Ahmad Syaukat
Iran	TU (Tehran University)	A. Pazirandeh, M.Ghods Mahmoudzadeh
Korea	KAERI (Korea Atomic Energy Research Institute)	Jung-Do Kim
Mexico	IIE (Instituto de Investigaciones Electricas)	Juan Luis Francois
Pakistan	PINST (Pakistan Institute of Nuclear Science and Technology)	Asif Salahuddin et.al.
Peru	IPEN (Instituto Peruano de Energia Nuclear)	Juan Avila Lopez, Javier Guarnizo Olivera
Slovenia	IJS (Institute Jožef Stefan)	Matjaž Ravnik, Andrej Trkov
South Africa	AEC (Atomic Energy Corporation)	Gavin Ball, Coenie Stoker
Thailand	OAEP (Office of Atomic Energy for Peace)	Sunanta Patrashakorn
Turkey	CNAEM	Mehmet H. Turgut
Turkey	HU (Hacettepe University)	Sedat Goluoglu
Vietnam		Ngo Dang Nhan

Chronologically, Stage 1 may be divided into two parts:

- benchmark calculations without prescriptions on the input models (November 1990 - May 1991)
- benchmark calculations with the prescribed input (May 1991 - October 1991).

Originally it was expected that the differences between different instalations of the code could be derived from the original contributions on benchmark problems. However, first compilation of the results [4] showed significant differences in the input models used by different participants, resulting in large differences in the final results and obscuring the installation effects. It was decided to ask the participants to repeat selected benchmark calculations using prescribed input data.

2 Benchmark Calculations

Benchmark calculations started in August 1990 when an invitation letter was sent to several potential participants [2]. Five benchmark test cases [3] were specified in the letter (TRX-1 and 2, BAPL-1, 2 and 3). It was explicitly stated that computations should be limited to the lattice codes which use the WIMS library (the WIMS code in particular). Participants were invited to provide the main benchmark results which were given in the benchmark specifications together with basic software and hardware specifications: the code and the library version, the type of computer. Appropriate inputs were required as well, since the purpose of this stage was to detect differences due to the use of different versions, installations and modifications of the original WIMS code and its library.

First contributions arrived in November 1990, most of them arrived by February 1991, while several late participants sent their contributions as late as October 1991. Alltogether, 22 contributions have been received. The list of participants is given in alphabetical order.

Five participants (from Czechoslovakia, Korea, Roumania, Slovenia and South Africa) provided also results for the second stage of the project. Data for the WIMS library from Roumania were presented in printed form only, so they could not be fully processed.

The results of the benchmarks were filed and tabulated. The definition of the integral parameters which are compared to the measured values are given in Table 1. The ratios refer to reaction rates which were deduced from experimental measurements and correspond to a thermal cutoff of $0.625\,eV$.

Preliminary evaluation was performed by the authors of this report. Some trivial errors were removed either by repeating calculations or by contacting the participants. Preliminary results of the evaluation were also discussed with S. Ganesan and J.J. Schmidt at IAEA. The results are presented in Tables 2-6. They contain only the results of calculations with the WIMS code and the original WIMS library. Some participants contributed also results obtained with other codes and libraries (e.g. IGCAR India). Such contributions are presented in Tables A-1 to A-5 in Appendix A.

Table 1. Definitions of some of the integral parameters

k_∞	infinite medium multiplication factor,
k_{eff}	finite medium effective multiplication factor (approximating the leakage by experimentally measured buckling),
ρ^{28}	ratio of epithermal to thermal ^{238}U capture,
δ^{25}	ratio of epithermal to thermal ^{235}U fission,
δ^{28}	ratio of ^{238}U fission to ^{235}U fission,
C^*	ratio of ^{238}U capture to ^{235}U fission.

The tables are arranged according to the date of arrival of the contributions.

Each table contains the main input parameters and results of the calculations. In case of several contributions by the same participant (e.g. some participants performed sensitivity analysis, some participants sent corrections and modifications to their first results), the results of the most sophisticated input model is considered. The relative differences between measured and calculated values are presented. The error in the measured k_{eff} value is estimated from the critical buckling error which is provided in the benchmark descriptions [3].

The following conclusions may be drawn about the results:

- The multiplication factor k_{eff} is the most important benchmark integral parameter. It comprises all reactor physics parameters of the problem: geometry, isotopic composition, cross sections of all isotopes, spectrum etc. For this reason it is very sensitive to the WIMS input modelling.

  Significant differences can be observed between the results of different participants. The distribution of k_{eff} is presented in graphical form in Figs. 1. Each bar in a diagram corresponds to the number of participants with k_{eff} results in the j^{th} interval $[k_{eff}^{(j-1)}, k_{eff}^{(j)}]$ of width Δk which is arbitrarily chosen as 0.1% of the average k_{eff}. The spread of the results is mainly due to different input models as can be observed from Tables 2-6. It is bigger than the differences due to the modifications of the code, which are negligible, as presented in the next section. The spread of the results shows properties of the normal distribution, what indicates that the differences arise more due to uncorrelated effects than to biases or systematic discrepancies.

- Average results from Tables 2-6 are summarized in Table 7. The peaks of the distributions of k_{eff} in Figs. 1 correspond closely with the most sophisticated (but still practical) input models which may be used in WIMS, such as presented in Appendix B.2 (using a large number of groups, S_n order greater than default, B_1 approximation). These results may be defined as *reference* when making conclusions about the agreement of the calculations and the measurements. They are given in Table 8 and they are marked with an arrow in Figs. 1. They agree well with the average results in Table 7.

- It may be observed that the reference results lie at the limit (or just outside) of the error interval (dotted line in Figs. 1) for k_{eff}. A systematic shift of the reference k_{eff} results may be observed if all benchmark cases are compared. WIMS k_{eff} is overestimated for TRX-1 and BAPL-1 which are both rather tight lattices compared to TRX-2 and BAPL-3, where k_{eff} is underestimated. The dependence of the error in k_{eff} on lattice pitch or fuel/water ratio either stems from the resonance calculation method in WIMS (Dancoff corrections), methods for the effective diffusion constant and leakage calculations or from the cross sections which are used in this calculations. The effect is relatively strong (total shift of 0.6% δk between TRX-1 and TRX-2 or 0.55% δk between BAPL-1 and BAPL-3). According to the sensitivity analysis calculations the effect is too strong to be attributed to the WIMS calculational models alone. The sensitivity analysis and references [3,5] suggest that the error in k_{eff} can be better explained by the error in the resonance integrals of U-238. This is also in agreement with the observed errors in the calculated spectral indicators (particularly ρ^{28}) which are discussed below.

- The influence of different input options is not so strong in the case of other benchmark parameters ($\rho^{28}, \delta^{28}, \delta^{25}, C^*$), as they depend only on the spectrum and on the particular isotope microscopic cross-sections. The spread of the results presented in Tables 2-6 is relatively small. The average values are presented in Table 7 and the reference results in Table 8. It may be observed that the calculated results systematically lie within the experimental error interval for δ^{25} and δ^{28} while for ρ^{28} and C^* they are mainly out of it.

  ρ^{28} is underestimated by approximately 4% in the case of TRX-1 and 2 and by approximately 2% in the case of BAPL-1 and 3. In the case of BAPL-2 the overestimation of ρ^{28} is small. Experimental value for C^* is provided only for TRX-1 and 2, in both cases the calculated C^* being approximately 2% underestimated. Both results indicate that the epithermal capture of U-238 is underestimated by about 4%. Independently, from the good agreement for δ^{25} and δ^{28} it can be concluded, that the U-235 fission reaction rate in the denominator of C^* being correct, the U-238 capture is responsible for the discrepancies. Since $\rho^{28} \approx 1$, the thermal and the epithermal capture are approximately equal. Assuming that the thermal capture is correct, the error in C^* should be two times smaller than that of ρ^{28}, as it is indeed observed.

- The WIMS ρ^{28} is on average underestimated, indicating that the resonance cross-sections are probably underestimated, yielding overestimated k_{eff} in tight lattices, where the spectrum is harder and ρ^{28} is large. Going to lattices with a bigger lattice pitch (such as TRX-2 or BAPL-3), ρ^{28} becomes smaller and the error in the resonance integral becomes less important. The k_{eff} is less overestimated, i.e., it is shifted in the negative directions with respect to the experimental value.

The conclusion that the epithermal and the resonance capture cross sections in WIMS U-238 data are incorrect can not be definitely confirmed but it is consistent with the observed indications, although there are also many other unaccounted effects which may influence the results. Among them it is important to note that the epithermal capture of U-238 is underestimated also due to the definition of the U-238 absorption cross section in the WIMS library. Per definition, the $(n, 2n)$ cross section is subtracted from the absorption cross section. The neutron balance and the total cross section are preserved by taking the extra neutron into account in the transfer matrix. However the definition affects the calculated reaction rates, where the complete absorption cross section should be used and is not available in the WIMS library. This effect on the calculated reaction rates was pointed out by Jung-Do Kim of Korea. In his contribution he analysed this effect, estimating that it amounts to approximately 1% in the total of 4% error in ρ^{28}.

Table 2: TRX-1 benchmark, main input parameters and results.

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NM	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	11	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	13	24	2	-1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235.4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235.4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238.4	2001	2			9	18	2	0
HU	TURKEY 9)	235 4	2238.4	2001	1	4	1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	10	69	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		12	20	2	0
SKODA	CSFR 1)	235.4	2238.4	2001	2		1 6	11	28	1	1
BARC	INDIA	235.4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
NRI	CSFR 1)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		11	36	2	1
CNEA	ARGENTINA 8)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
CNAEM	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

Table 2: Continued.

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	R028	R.D.R028 (%)
EXPERIMENT			1.0000	+-0.30	1.3200	+-1.59
IIE	MEXICO	1.18603	1.00803	0.80	1.2620	-4.39*
OAEP	THAILAND	1.18259	1.00372	0.37	1.2592	-4.60*
IEA	BRASIL	1.18130	1.00023	0.02	1.2690	-3.86*
CNEN	BRASIL	1.18416	1.00410	0.41	1.2620	-4.39*
KAERI	KOREA	1.18179	1.00301	0.30	1.2621	-4.39*
ZFK	GERMANY	1.18360	1.00290	0.29	1.2685	-3.90*
IPEN	PERU	1.17899	1.00487	0.49		
AEC	SOUTH AFRICA	1.18263	1.00221	0.22	1.2626	-4.35*
	VIETNAM	1.18590	0.99990	-0.01	1.2510	-5.23*
CNEA	ARGENTINA		1.00253	0.25	1.2811	-2.95*
HU	TURKEY 9)	1.17958	0.99908	-0.09	1.2819	-2.89*
IJS	SLOVENIA	1.18270	1.00227	0.23	1.2630	-4.32*
AERE	BANGLADESH	1.18387	1.00309	0.31		
PINST	PAKISTAN	1.18181	1.00241	0.24	1.2757	-3.36*
SKODA	CSFR 1)	1.18330	1.00110	0.11	1.2719	-3.64*
BARC	INDIA		1.00254	0.25	1.2834	-2.77*
NRI	CSFR 3)	1.18498	1.00236	0.24	1.2630	-4.32*
NRI	CSFR 1)	1.18270	1.00228	0.23	1.2630	-4.32*
CEADN	CUBA	1.18248	1.00156	0.16	1.2754	-3.38*
CNEA	ARGENTINA 8)		0.99908	-0.09	1.2818	-2.89*
CNAEM	TURKEY	1.17940	1.00090	0.09	1.2810	-2.95*
TU	IRAN	1.18192	1.00079	0.08	1.2749	-3.42*

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R.D.D28 (%)	C*	R.D.C* (%)
EXPERIMENT		0.0987	+-1.01	0.0946	+-4.33	0.7970	+-1.00
IIE	MEXICO	0.0992	0.51	0.0973	2.85	0.7740	-2.89*
OAEP	THAILAND	0.0989	0.25	0.0959	1.38	0.7733	-2.97*
IEA	BRASIL	0.0996	0.91	0.0966	2.11	0.7770	-2.51*
CNEN	BRASIL	0.0992	0.51	0.0962	1.69	0.7750	-2.76*
KAERI	KOREA	0.0990	0.27	0.0960	1.48	0.7743	-2.84*
ZFK	GERMANY	0.0987	0.00	0.0973	2.85	0.7767	-2.55*
IPEN	PERU						
AEC	SOUTH AFRICA	0.0990	0.30	0.0964	1.90	0.7744	-2.84*
	VIETNAM	0.0989	0.20	0.0960	1.48	0.7734	-2.96*
CNEA	ARGENTINA	0.0990	0.30	0.0967	2.26	0.7810	-2.01*
HU	TURKEY 9)	0.0997	1.00	0.0965	1.99	0.7803	-2.10*
IJS	SLOVENIA	0.0990	0.30	0.0965	2.01	0.7745	-2.82*
AERE	BANGLADESH						
PINST	PAKISTAN	0.0991	0.43	0.0953	0.77	0.7787	-2.30*
SKODA	CSFR 1)	0.0996	0.91	0.0962	1.69	0.7769	-2.52*
BARC	INDIA	0.0990	0.33	0.0978	3.34	0.7808	-2.03*
NRI	CSFR 3)	0.0990	0.30	0.0965	2.01	0.7745	-2.82*
NRI	CSFR 1)	0.0990	0.30	0.0965	2.01	0.7745	-2.82*
CEADN	CUBA	0.0991	0.41	0.0967	2.22	0.7789	-2.27*
CNEA	ARGENTINA 8)	0.0997	1.01	0.0965	2.01	0.7803	-2.10*
CNAEM	TURKEY	0.0996	0.91	0.0964	1.90	0.7802	-2.11*
TU	IRAN	0.0992	0.51	0.0967	2.22	0.7780	-2.38*

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table 3: TRX-2 benchmark, main input parameters and results.

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REC	NM	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	13	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	13	24	2	-1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235.4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235.4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238.4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	14	69	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		13	20	2	0
SKODA	CSFR 1)	235.4	2238.4	2001	2		1 6	15	28	1	1
BARC	INDIA	235.4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	14	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		11	36	2	1
CNEA	ARGENTINA 8)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNAEM	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	RO28	R.D.RO28 (%)
EXPERIMENT			1.0000	+-0.10	0.8370	+-1.91
IIE	MEXICO	1.16643	1.00442	0.44	0.7960	-4.90*
OAEP	THAILAND	1.16268	0.99789	-0.21	0.7948	-5.04*
IEA	BRASIL	1.16257	0.99515	-0.49	0.8000	-4.42*
CNEN	BRASIL	1.16395	0.99900	-0.10	0.7950	-5.02*
KAERI	KOREA	1.16173	0.99702	-0.30	0.7957	-4.93*
ZFK	GERMANY	1.16460	0.99860	-0.14	0.7988	-4.56*
IPEN	PERU	1.15864	0.99923	-0.08		
AEC	SOUTH AFRICA	1.16330	0.99650	-0.35	0.7965	-4.84*
	VIETNAM	1.16800	1.00000	0.00	0.7941	-5.13*
CNEA	ARGENTINA		1.00137	0.14	0.8051	-3.81*
HU	TURKEY 9)	1.16471	0.99757	-0.24	0.8057	-3.74*
IJS	SLOVENIA	1.16334	0.99654	-0.35	0.7967	-4.81*
AERE	BANGLADESH	1.16317	0.99715	-0.29		
PINST	PAKISTAN	1.16300	0.99879	-0.12	0.8022	-4.16*
SKODA	CSFR 1)	1.16430	0.99650	-0.35	0.8000	-4.42*
BARC	INDIA		1.00227	0.23	0.8063	-3.67*
NRI	CSFR 3)	1.16492	0.99668	-0.33	0.7967	-4.81*
CEADN	CUBA	1.16396	0.99897	-0.10	0.8023	-4.15*
CNEA	ARGENTINA 8)		0.99758	-0.24	0.8058	-3.73*
CNAEM	TURKEY	1.16120	0.99730	-0.27	0.8055	-3.76*
TU	IRAN	1.16555	0.99914	-0.09	0.8012	-4.28*

Table 3: Continued.

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R.D.D28 (%)	C*	R.D.C* (%)
EXPERIMENT		0.0614	+-1.30	0.0693	+-5.05	0.6470	+-0.93
IIE	MEXICO	0.0610	-0.65	0.0699	0.87	0.6310	-2.47*
OAEP	THAILAND	0.0610	-0.72	0.0688	-0.69	0.6315	-2.39*
IEA	BRASIL	0.0613	-0.16	0.0694	0.14	0.6340	-2.01*
CNEN	BRASIL	0.0610	-0.65	0.0691	-0.29	0.6320	-2.32*
KAERI	KOREA	0.0610	-0.72	0.0690	-0.49	0.6319	-2.34*
ZFK	GERMANY	0.0608	-0.98	0.0701	1.15	0.6329	-2.18*
IPEN	PERU						
AEC	SOUTH AFRICA	0.0611	-0.49	0.0694	0.14	0.6320	-2.32*
	VIETNAM	0.0608	-0.98	0.0689	-0.58		
CNEA	ARGENTINA	0.0608	-0.90	0.0695	0.33	0.6352	-1.82*
HU	TURKEY 9)	0.0612	-0.39	0.0700	1.07	0.6347	-1.90*
IJS	SLOVENIA	0.0610	-0.64	0.0695	0.30	0.6321	-2.30*
AERE	BANGLADESH						
PINST	PAKISTAN	0.0610	-0.70	0.0685	-1.21	0.6339	-2.02*
SKODA	CSFR 1)	0.0612	-0.33	0.0688	-0.72	0.6329	-2.18*
BARC	INDIA	0.0608	-0.94	0.0702	1.27	0.6346	-1.92*
NRI	CSFR 3)	0.0610	-0.64	0.0695	0.30	0.6321	-2.30*
CEADN	CUBA	0.0610	-0.65	0.0695	0.29	0.6342	-1.98*
CNEA	ARGENTINA 8)	0.0612	-0.33	0.0700	1.01	0.6348	-1.89*
CNAEM	TURKEY	0.0613	-0.16	0.0692	-0.14	0.6349	-1.87*
TU	IRAN	0.0609	-0.81	0.0696	0.43	0.6349	-2.18*

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table 4: BAPL-UO2-1 benchmark, main input parameters and results.

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NM	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	10	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	15	24	4	-1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235.4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235.4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238.4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	10	69	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		12	20	2	0
SKODA	CSFR 1)	235.4	2238.4	2001	2		1	15	18	1	1
BARC	INDIA	235.4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		10	36	2	1
CNEA	ARGENTINA 8)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNAEM	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

Table 4: Continued.

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	R028	R.D.R028 (%)
EXPERIMENT			1.0000	+-0.10	1.3900	+-0.72
IIE	MEXICO	1.14639	1.00666	0.67	1.3400	-3.60*
OAEP	THAILAND	1.14212	1.00333	0.33	1.3412	-3.51*
IEA	BRASIL	1.14162	1.00128	0.13	1.3500	-2.88*
CNEN	BRASIL	1.13419	0.99459	-0.54	1.4100	1.44*
KAERI	KOREA	1.14120	1.00253	0.25	1.3462	-3.15*
ZFK	GERMANY	1.14300	0.99980	-0.02	1.3586	-2.26*
IPEN	PERU	1.13900	1.00329	0.33		
AEC	SOUTH AFRICA	1.14167	1.00284	0.28	1.3456	-3.19*
	VIETNAM	1.14580	1.00090	0.09	1.4302	2.89*
CNEA	ARGENTINA		1.00070	0.07	1.3688	-1.53*
HU	TURKEY 9)	1.14044	1.00123	0.12	1.3601	-2.15*
IJS	SLOVENIA	1.14175	1.00292	0.29	1.3454	-3.21*
AERE	BANGLADESH	1.14423	1.00261	0.26		
PINST	PAKISTAN	1.14227	1.00168	0.17	1.3608	-2.10*
SKODA	CSFR 1)	1.14610	1.00390	0.39	1.3395	-3.63*
BARC	INDIA		0.99264	-0.74	1.3091	-5.82*
NRI	CSFR 3)	1.14492	1.00301	0.30	1.3454	-3.21*
CEADN	CUBA	1.14206	0.99897	-0.10	1.3625	-1.98*
CNEA	ARGENTINA 8)		1.00294	0.29	1.3451	-3.23*
CNAEM	TURKEY	1.14000	1.00110	0.11	1.3614	-2.06*
TU	IRAN	1.14208	1.00111	0.11	1.3550	-2.52*

LAB.	COUNTRY	DEL25 (%)	R.D.D25	DEL28 (%)	R.D.D28	C*
EXPERIMENT		0.0840	+-2.38	0.0780	+-5.13	
IIE	MEXICO	0.0840	0.00	0.0770	-1.28	
OAEP	THAILAND	0.0840	0.02	0.0752	-3.63	0.7947
IEA	BRASIL	0.0840	0.00	0.0770	-1.28	
CNEN	BRASIL	0.0840	0.00	0.0770	-1.28	
KAERI	KOREA	0.0841	0.08	0.0752	-3.62	0.7963
ZFK	GERMANY	0.0841	0.12	0.0768	-1.54	0.8004
IPEN	PERU					
AEC	SOUTH AFRICA	0.0843	0.36	0.0754	-3.33	
	VIETNAM	0.0838	-0.24	0.0766	-1.79	
CNEA	ARGENTINA	0.0840	0.06	0.0768	-1.53	0.8043
HU	TURKEY 9)	0.0843	0.39	0.0762	-2.27	0.8007
IJS	SLOVENIA	0.0840	0.05	0.0755	-3.23	0.7960
AERE	BANGLADESH					
PINST	PAKISTAN	0.0842	0.20	0.0759	-2.72	0.8011
SKODA	CSFR 1)	0.0840	0.00	0.0758	-2.82	0.7939
BARC	INDIA	0.0787	-6.29*	0.0742	-4.87	0.7861
NRI	CSFR 3)	0.0840	0.05	0 0755	-3.24	0.7960
CEADN	CUBA	0.0843	0.36	0.0764	-2.05	0.8021
CNEA	ARGENTINA 8)	0.0840	0.00	0.0761	-2.44	0.7958
CNAEM	TURKEY	0.0843	0.36	0.0768	-1.54	0.8013
TU	IRAN	0.0840	0.00	0.0779	-0.13	0.7991

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3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table 5: BAPL-UO2-2 benchmark, main input parameters and results.

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NM	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	10	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	15	24	4	-1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235.4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235.4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238.4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	10	69	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		13	20	2	0
SKODA	CSFR 1)	235.4	2238.4	2001	2		1	15	18	1	1
BARC	INDIA	235.4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		10	36	2	1
CNEA	ARGENTINA 8)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNAEM	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	RO28	R.D.RO28 (%)
EXPERIMENT			1.0000	+-0.10	1.1200	+-0.89
IIE	MEXICO	1.14846	1.00522	0.52	1.1200	0.00
OAEP	THAILAND	1.14444	1.00127	0.13	1.1194	-0.05
IEA	BRASIL	1.14397	0.99881	-0.12	1.1300	0.89
CNEN	BRASIL	1.14064	0.99671	-0.33	1.1600	3.57*
KAERI	KOREA	1.14368	1.00059	0.06	1.1227	0.24
ZFK	GERMANY	1.14550	0.99860	-0.14	1.1335	1.21*
IPEN	PERU	1.14110	1.00144	0.14		
AEC	SOUTH AFRICA	1.14419	1.00047	0.05	1.1228	0.25
	VIETNAM	1.14820	1.00000	0.00	1.1177	-0.21
CNEA	ARGENTINA		0.99963	-0.04	1.1422	1.98*
HU	TURKEY 9)	1.14335	0.99923	-0.08	1.1351	1.35*
IJS	SLOVENIA	1.14428	1.00049	0.05	1.1227	0.24
AERE	BANGLADESH	1.14642	1.00071	0.07		
PINST	PAKISTAN	1.14488	1.00036	0.04	1.1347	1.31*
SKODA	CSFR 1)	1.14840	1.00170	0.17	1.1187	-0.12
BARC	INDIA		0.98923	-1.08	1.0959	-2.15*
NRI	CSFR 3)	1.14720	1.00061	0.06	1.1226	0.23
CEADN	CUBA	1.14477	0.99793	-0.21	1.1362	1.45*
CNEA	ARGENTINA 8)		0.99923	-0.08	1.1351	1.35*
CNAEM	TURKEY	1.14270	0.99960	-0.04	1.1354	1.38*
TU	IRAN	1.14479	0.99959	-0.04	1.1325	1.12*

Table 5: Continued.

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R.D.D28 (%)	C*
EXPERIMENT		0.0680	+-1.47	0.0700	+-5.71	
IIE	MEXICO	0.0690	1.47	0.0670	-4.29	
OAEP	THAILAND	0.0686	0.94	0.0649	-7.34*	0.7272
IEA	BRASIL	0.0690	1.47	0.0660	-5.71*	
CNEN	BRASIL	0.0690	1.47	0.0670	-4.29	
KAERI	KOREA	0.0687	0.97	0.0649	-7.27*	0.7283
ZFK	GERMANY	0.0687	1.03	0.0663	-5.29	0.7319
IPEN	PERU					
AEC	SOUTH AFRICA	0.0688	1.18	0.0652	-6.86*	
	VIETNAM	0.0685	0.74	0.0660	-5.71*	
CNEA	ARGENTINA	0.0686	0.96	0.0663	-5.33	0.7353
HU	TURKEY 9)	0.0689	1.26	0.0659	-5.87*	0.7322
IJS	SLOVENIA	0.0687	1.00	0.0652	-6.80*	0.7282
AERE	BANGLADESH					
PINST	PAKISTAN	0.0687	1.07	0.0654	-6.57*	0.7323
SKODA	CSFR 1)	0.0686	0.88	0.0656	-6.29*	0.7267
BARC	INDIA	0.0645	-5.21*	0.0641	-8.49*	0.7207
NRI	CSFR 3)	0.0687	0.99	0.0652	-6.81*	0.7282
CEADN	CUBA	0.0688	1.18	0.0659	-5.86*	0.7332
CNEA	ARGENTINA 8)	0.0689	1.32	0.0659	-5.86*	0.7322
CNAEM	TURKEY	0.0688	1.18	0.0662	-5.43	0.7325
TU	IRAN	0.0687	1.03	0.0672	-4.00	0.7310

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table 6: BAPL-UO2-3 benchmark, main input parameters and results.

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NM	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	11	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	15	24	4	-1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235.4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235.4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238.4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	10	69	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		14	20	2	0
SKODA	CSFR 1)	235.4	2238.4	2001	2		1	15	18	1	1
BARC	INDIA	235.4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		10	36	2	1
CNEA	ARGENTINA 8)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNAEM	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

Table 6: Continued.

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	RO28	R.D.RO28 (%)
EXPERIMENT			1.0000	+-0.10	0.9060	+-1.10
IIE	MEXICO	1.13234	1.00365	0.36	0.8800	-2.87*
OAEP	THAILAND	1.12886	0.99892	-0.11	0.8824	-2.60*
IEA	BRASIL	1.12868	0.99676	-0.32	0.8870	-2.10*
CNEN	BRASIL	1.12937	0.99922	-0.08	0.9040	-0.22
KAERI	KOREA	1.12817	0.99835	-0.16	0.8847	-2.36*
ZFK	GERMANY	1.13000	0.99770	-0.23	0.8928	-1.46*
IPEN	PERU	1.12518	0.99915	-0.09		
AEC	SOUTH AFRICA	1.12885	0.99809	-0.19	0.8848	-2.34*
	VIETNAM	1.13270	0.99990	-0.01	0.8808	-2.78*
CNEA	ARGENTINA		0.99911	-0.09	0.8998	-0.68
HU	TURKEY 9)	1.12892	0.99775	-0.22	0.8940	-1.32*
IJS	SLOVENIA	1.12899	0.99807	-0.19	0.8849	-2.33*
AERE	BANGLADESH	1.13018	0.99849	-0.15		
PINST	PAKISTAN	1.12937	0.99912	-0.09	0.8934	-1.39*
SKODA	CSFR 1)	1.13280	0.99990	-0.01	0.8821	-2.64*
BARC	INDIA		0.98618	-1.38	0.8670	-4.30*
NRI	CSFR 3)	1.13115	0.99821	-0.18	0.8849	-2.33*
CEADN	CUBA	1.12942	0.99715	-0.28	0.8941	-1.31*
CNEA	ARGENTINA 8)		0.99900	-0.10	0.8847	-2.35*
CNAEM	TURKEY	1.12770	0.99830	-0.17	0.8939	-1.34*
TU	IRAN	1.13006	0.99895	-0.10	0.8910	-1.65*

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R.D.D28 (%)	C*
EXPERIMENT		0.0520	+-1.92	0.0570	+-5.26	
IIE	MEXICO	0.0530	1.92	0.0550	-3.51	
OAEP	THAILAND	0.0527	1.44	0.0534	-6.25*	0.6531
IEA	BRASIL	0.0530	1.92	0.0540	-5.26	
CNEN	BRASIL	0.0530	1.92	0.0550	-3.51	
KAERI	KOREA	0.0529	1.69	0.0535	-6.16*	0.6539
ZFK	GERMANY	0.0529	1.73	0.0546	-4.21	0.6566
IPEN	PERU					
AEC	SOUTH AFRICA	0.0530	1.92	0.0538	-5.61*	
	VIETNAM	0.0527	1.35	0.0542	-4.91	
CNEA	ARGENTINA	0.0529	1.63	0.0546	-4.26	0.6594
HU	TURKEY 9)	0.0529	1.83	0.0543	-4.65	0.6568
IJS	SLOVENIA	0.0529	1.73	0.0538	-5.56*	0.6539
AERE	BANGLADESH					
PINST	PAKISTAN	0.0529	1.75	0.0538	-5.65*	0.6568
SKODA	CSFR 1)	0.0529	1.73	0.0541	-5.09	0.6528
BARC	INDIA	0.0498	-4.29*	0.0528	-7.39*	0.6456
NRI	CSFR 3)	0.0529	1.73	0.0538	-5.56*	0.6539
CEADN	CUBA	0.0530	1.92	0.0542	-4.91	0.6574
CNEA	ARGENTINA 8)	0.0530	1.92	0.0540	-5.26	0.6537
CNAEM	TURKEY	0.0530	1.92	0.0544	-4.56	0.6569
TU	IRAN	0.0528	1.54	0.0551	-3.33	0.6557

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table 7: Averages of calculated values from Tables 2-6

TRX1

	EXPERIMENT		CALCULATION				
		ERROR [%]	AVERAGE	DEV	RELDEV [%]	DIF	RELDIF [%]
K-EFF	1.00000	+-.30	1.00222	0.00195	0.19	0.00222	0.23
K-INF			1.18262	0.00192	0.16	-0.00008	-0.00
RO 28	1.32000	1.59	1.26963	0.00912	0.73	-0.05037	-3.84
DEL25	0.09870	1.01	0.09918	0.00029	0.29	0.00048	0.48
DEL28	0.09460	4.33	0.09650	0.00053	0.55	0.00190	2.00
C*	0.79700	1.00	0.77684	0.00266	0.34	-0.02016	-2.54

TRX2

	EXPERIMENT		CALCULATION				
		ERROR [%]	AVERAGE	DEV	RELDEV [%]	DIF	RELDIF [%]
K-EFF	1.00000	+-.10	0.99843	0.00218	0.22	-0.00157	-0.16
K-INF			1.16356	0.00201	0.17	0.00022	0.02
RO 28	0.83700	1.91	0.79985	0.00427	0.53	-0.03715	-4.44
DEL25	0.06140	1.30	0.06102	0.00015	0.25	-0.00038	-0.61
DEL28	0.06930	5.05	0.06941	0.00049	0.71	0.00011	0.15
C*	0.64700	0.92	0.63322	0.00134	0.21	-0.01378	-2.13

BAPL1

	EXPERIMENT		CALCULATION				
		ERROR [%]	AVERAGE	DEV	RELDEV [%]	DIF	RELDIF [%]
K-EFF	1.00000	+-.10	1.00135	0.00305	0.30	0.00135	0.13
K-INF			1.14216	0.00289	0.25	0.00041	0.04
RO 28	1.39000	0.71	1.35666	0.02606	1.92	-0.03334	-2.40
DEL25	0.08400	2.38	0.08379	0.00124	1.48	-0.00021	-0.25
DEL28	0.07800	5.12	0.07607	0.00078	1.03	-0.00193	-2.47

BAPL2

	EXPERIMENT		CALCULATION				
		ERROR [%]	AVERAGE	DEV	RELDEV [%]	DIF	RELDIF [%]
K-EFF	1.00000	+-.10	0.99959	0.00290	0.29	-0.00041	-0.04
K-INF			1.14483	0.00226	0.20	0.00055	0.05
RO 28	1.12000	0.89	1.12804	0.01291	1.14	0.00804	0.72
DEL25	0.06800	1.47	0.06852	0.00100	1 45	0.00052	0.77
DEL28	0.07000	5.71	0.06572	0 00072	1.10	-0.00428	-6.11

BAPL3

	EXPERIMENT		CALCULATION				
		ERROR [%]	AVERAGE	DEV	RELDEV [%]	DIF	RELDIF [%]
K-EFF	1.00000	+-.10	0.99815	0.00307	0.31	-0.00185	-0.18
K-INF			1.12957	0.00185	0.16	0.00058	0.05
RO 28	0.90600	1.10	0.88752	0.00825	0.93	-0.01848	-2.04
DEL25	0.05200	1.92	0.05274	0.00073	1.38	0.00074	1.43
DEL28	0.05700	5.26	0.05408	0.00053	0.99	-0.00292	-5.13

Table 8: Reference results for the benchmark lattices using input from Appendix B.2

TRX1

	EXPERIMENT	ERROR [%]	CALCULATION	DIF	RELDIF [%]
K-EFF	1.00000	0.30	1.00227	0.00227	0.23
RO 28	1.32000	1.59	1.26300	-0.05700	-4.32
DEL25	0.09870	1.01	0.09900	0.00030	0.30
DEL28	0.09460	4.33	0.09650	0.00190	2.01
C*	0.79700	1.00	0.77450	-0.02250	-2.82

TRX2

	EXPERIMENT	ERROR [%]	CALCULATION	DIF	RELDIF [%]
K-EFF	1.00000	0.10	0.99654	-0.00346	-0.35
RO 28	0.83700	1.91	0.79670	-0.04030	-4.81
DEL25	0.06140	1.30	0.0610.	-0.00039	-0.64
DEL28	0.06930	5.05	0.06951	0.00021	0.30
C*	0.64700	0.93	0.63210	-0.01490	-2.30

BAPL1

	EXPERIMENT	ERROR [%]	CALCULATION	DIF	RELDIF [%]
K-EFF	1.00000	0.10	1.00292	0.00292	0.29
RO 28	1.39000	0.72	1.34540	-0.04460	-3.21
DEL25	0.08400	2.38	0.08404	0.00004	0.05
DEL28	0.07800	5.13	0.07548	-0.00252	-3.23

BAPL2

	EXPERIMENT	ERROR [%]	CALCULATION	DIF	RELDIF [%]
K-EFF	1.00000	0.10	1.00049	0.00049	0.05
RO 28	1.12000	0.89	1.12270	0.00270	0.24
DEL25	0.06800	1.47	0.06868	0.00068	1.00
DEL28	0.07000	5.71	0.06524	-0.00476	-6.80

BAPL3

	EXPERIMENT	ERROR [%]	CALCULATION	DIF	RELDIF [%]
K-EFF	1.00000	0.10	0.99807	-0.00193	-0.19
RO 28	0.90600	1.10	0.88490	-0.02110	-2.33
DEL25	0.05200	1.92	0.05290	0.00090	1.73
DEL28	0.05700	5.26	0.05383	-0.00317	-5.56

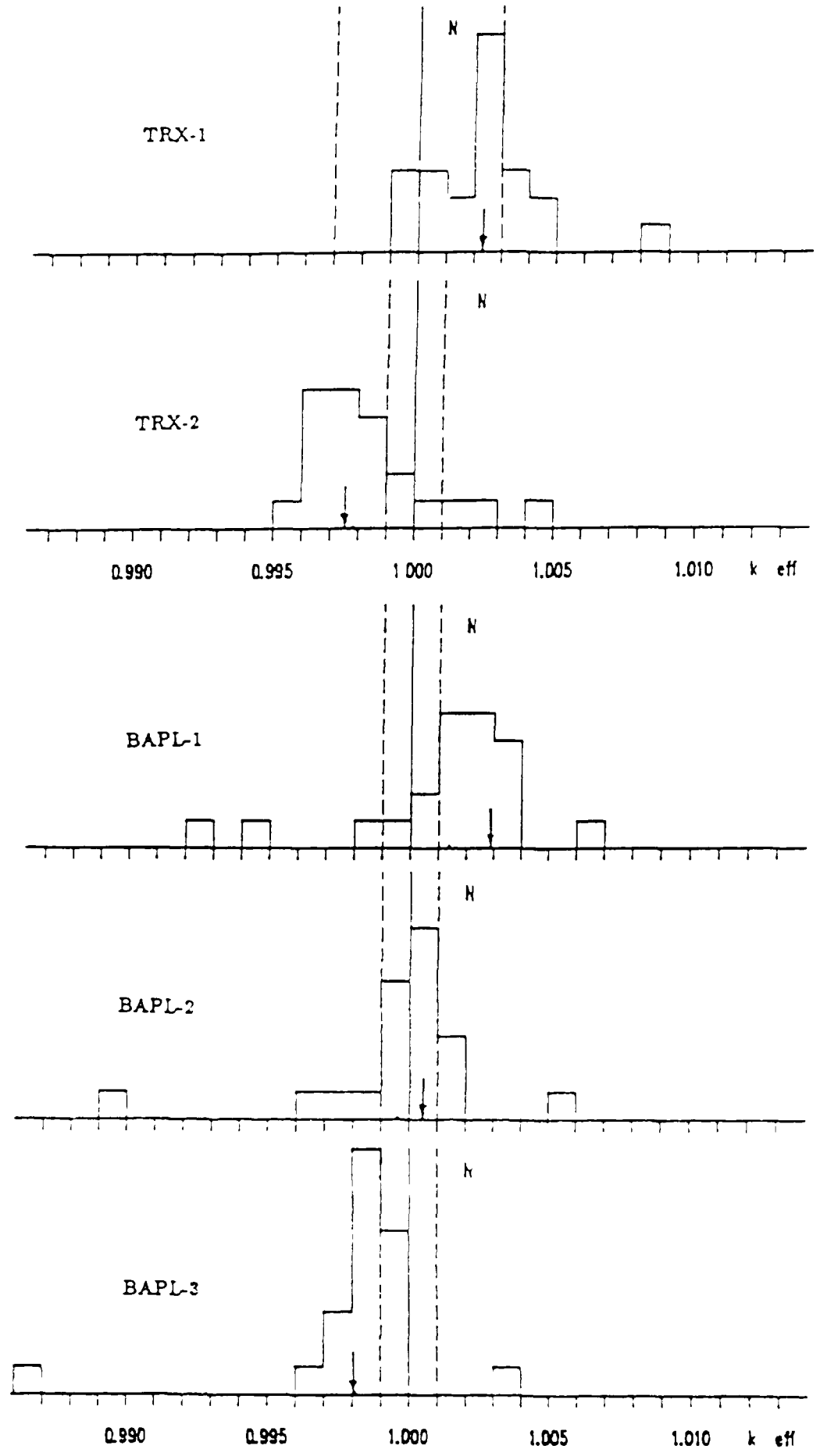

Figure 1: Distribution of calculated k_{eff} values for the benchmark lattices

3 Sensitivity Analysis on the WIMS Code Version

In order to separate the effects of different input models from the effects due to different versions or modifications of the code, the participants were asked to repeat the TRX-1 calculation using prescribed (model) input, which was defined by the coordinator of the project (see Appendix B.1). The input is close to the optimal except for some parameters which were deliberately relaxed in order to make the calculation feasible also to the participants with smaller computers.

In Table 9 the calculated parameters of TRX-1 benchmark, using the distributed model input data (Appendix B.1) are presented. As the input data for this calculation were prescribed, most of participants sent only the results, without the input data really used in the calculation. However, it seems that in some cases not completely identical input data were used.

The sequence of contributions in Table 9 was rearranged according to the values of k_∞ as it shows correlation with the particular version of the WIMS code used in the calculation. The versions and origin of the codes used by participants is presented in Table 10. The list of WIMS-D/4 code versions distributed by the NEA CPL from 1982 till now is presented in Table 11.

In the first group there are identical results produced with versions NEA 0329/13 and NEA 0329/06. Only a slightly different value of k_∞ is given by the version NEA 0329/10 prepared and used by the AEC of South Africa.

Table 9: Results contributed for the model input data (void as material 0).

BENCHMARK : TRX1

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NM	NG	DI	BE
IJS	SLOVENIA	235.4	2238.4	2001	1	4	1 6	10	18	1	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1 6	10	18	1	1
IIE	MEXICO	235.4	2238.4	2001	1	4	1 6	10	18	1	1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	18	1	1
NRI	CSFR 1)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1 6	10	18	1	1
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	4	1 6	10	18	1	1
ZFK	GERMANY	235.4	2238.4	2001	1	4	1 6	10	18	1	1
NRI	CSFR 3)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
PINST	PAKISTAN	235.4	2238.4	2001	1	4	1 6	10	18	1	1
AERE	BANGLADESH	235.4	2238.4	2001	1	4	1 6	10	18	1	1
CEADN	CUBA	235.4	2238.4	2001	1	4	1 6	10	18	1	1
CNEA	ARGENTINA	235.4	2238.4	2001	1	4	1 6	10	18	1	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1 6	10	18	1	1
HU	TURKEY	235.4	2238.4	2001	1	4	1 6	10	18	1	1
***)		235.4	2238.4	2001	1	4	1 6	10	18	1	1
IPEN	PERU	235.4	2238.4	2001	1	4	1 6	10	18	1	1

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
*) K-INF VALUE FROM CHAIN 6
**) K-INF VALUE FROM 2-GROUP CALCULATION (?)
***) NEA 0329/13 PROGRAM AND LIBRARY, "DNB 3 0. 0. 0. 0." CARD USED

Table 9: Continued.

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	RO28	R.D.RO28 (%)
EXPERIMENT					1.3200	+-1.59
IJS	SLOVENIA	1.18106	1.00030	0.03	1.2726	-3.59*
IEA	BRASIL	1.18106	1.00030	0.03	1.2726	-3.59*
IIE	MEXICO	1.18106	1.00030	0.03	1.2726	-3.59*
KAERI	KOREA	1.18106	1.00030	0.03	1.2726	-3.59*
NRI	CSFR 1)	1.18106	1.00030	0.03	1.2726	-3.59*
TU	IRAN	1.18106	1.00029	0.03	1.2726	-3.59*
CNEN	BRASIL	1.18398**)	1.00030	0.03	1.2720	-3.64*
AEC	SOUTH AFRICA	1.18116	1.00038	0.04	1.2720	-3.64*
ZFK	GERMANY	1.18310 *)	1.00032	0.03	1.2726	-3.59*
NRI	CSFR 3)	1.18299	1.00032	0.03	1.2726	-3.59*
PINST	PAKISTAN	1.18297	1.00030	0.03	1.2726	-3.59*
AERE	BANGLADESH	1.18297	1.00792	0.79		
CEADN	CUBA	1.18298	1.00032	0.03	1.2726	-3.59*
CNEA	ARGENTINA		1.00032	0.03	1.2726	-3.59*
OAEP	THAILAND	1.18049	1.00793	0.79		
HU	TURKEY	1.18049	1.00792	0.79	1.2703	-3.77*
***)		1.18049	1.00793	0.79	1.2702	-3.77*
IPEN	PERU	1.17647	0.93300	-6.70		

BENCHMARK : TRX1

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R.D.D28 (%)	C*	R.D.C* (%)
EXPERIMENT		0.0987	+-1.01	0.0946	+-4.33	0.7970	+-1.00
IJS	SLOVENIA	0.0996	0.90	0.0963	1.85	0.7772	-2.48*
IEA	BRASIL	0.0996	0.90	0.0963	1.85	0.7772	-2.48*
IIE	MEXICO	0.0996	0.90	0.0963	1.85	0.7772	-2.48*
KAERI	KOREA	0.0996	0.90	0.0963	1.85	0.7772	-2.48*
NRI	CSFR 1)	0.0996	0.90	0.0963	1.84	0.7772	-2.48*
TU	IRAN	0.0996	0.90	0.0963	1.84	0.7772	-2.48*
CNEN	BRASIL	0.0995	0.81	0.0963	1.80	0.7710	-3.26*
AEC	SOUTH AFRICA	0.0996	0.91	0.0963	1.80	0.7770	-2.51*
ZFK	GERMANY	0.0996	0.90	0.0963	1.84	0.7772	-2.48*
NRI	CSFR 3)	0.0996	0.90	0.0963	1.84	0.7772	-2.48*
PINST	PAKISTAN	0.0996	0.90	0.0963	1.85	0.7772	-2.48*
AERE	BANGLADESH						
CEADN	CUBA	0.0996	0.91	0.0963	1.80	0.7772	-2.48*
CNEA	ARGENTINA	0.0996	0.91	0.0963	1.80	0.7772	-2.48*
OAEP	THAILAND						
HU	TURKEY	0.0994	0.73	0.0950	0.44	0.7766	-2.56*
***)		0.0994	0.72	0.0950	0.44	0.7766	-2.56*
IPEN	PERU						

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
*) K-INF VALUE FROM CHAIN 6
**) K-INF VALUE FROM 2-GROUP CALCULATION (?)
***) NEA 0329/13 PROGRAM AND LIBRARY, "DNB 3 0. 0. 0. 0." CARD USED

Table 10: Applied versions of program and library.

	Program	Library
CNEA Argentina		
AERE Bangladesh	IBM version 101 (NEA 0329/05)	
CNEN Brasil	WIMS-TRACA (NEA 0926/02)	
IEA Brasil	NEA 0329/06	
CEADN Cuba	version 101 (Nov1981) (NEA 0329/05)	
SKODA CSFR	NEA 0329/13	NEA 0329/13
	WIMSD2A	version 1986
NRI CSFR	version 101 (Nov.1981) (NEA 0329/05)	NEA 0329/13
	NEA 0329/13	NEA 0329/13
ZFK Germany	version 101 (Nov.1981) (NEA 0329/05)	
BARC India	version adapted to NORSK DATA computer	
IGCAR India	MURLI code	version 1971 + changes recommended in AEEW-R-2133 (1986)
NAEA Indonesia	NEA 0329/08	
TU Iran	PC version (?)	
KAERI Korea	NEA 0329/06 (?)	
IIE Mexico	NEA 0329/06	
PINST Pakistan	version 100 (created 1980)	
IPEN Peru	NEA 0329/08	
IJS Slovenia	NEA 0329/13	NEA 0329/13
AEC South Africa	version 4.1 (NEA 0329/10)	NEA 0329/10
OAEP Thailand	NEA 0329/08	
CNAEM Turkey	NEA 0329/08	
HU Turkey		
Vietnam	PC version (?)	

Table 11: List of WIMS-D/4 versions reported by NEA DB.

Package ID	Original computer	Test computer	Date
NEA 0329/05	IBM 3081	IBM 3081	Dec 1982
NEA 0329/06	CDC CYBER 740	CDC CYBER 740	Aug 1983
NEA 0329/08	DEC VAX series		Nov 1986
NEA 0329/10 (WIMSD 4.1)	IBM 370 series		Nov 1990
NEA 0329/13	DEC VAX 11/780	all computers	
NEA 0329/14	IBM PC	IBM PC	Feb 1990
NEA 0329/15	IBM PC		Nov 1990

There is the second group of similar values of k_∞ produced with the "version 101 of WIMS (Nov. 1981)", which probably corresponds to NEA 0329/05 (received at NEA Data Bank in December 1982). A slightly different value reported from ZFK is said to be taken from Chain 6, while the others are from Chain 14.

CNEN Brasil supplied the 2-group value of k_∞ from Chain 14, which, as it will be shown later, is consistent with other contributions, giving the 18-groups value.

Results reported by OAEP Thailand and HU Turkey and probably also the value of k_{eff} reported by Bangladesh are affected by an error in the input data. The contribution from HU contained also the input data used, so that this error could be detected undoubtedly by repeating the calculation with the NEA 0329/13 version of the code at IJS (denoted * * * in Table 9). The error occured because originally (in the letter of 12 April) input data with 4 materials (and 4 DNB cards) were distributed. Later-on (in the letter of 7 May) the input was revised, with only 3 materials (and therefore 3 DNB cards, see Appendix B.1). In the contributions mentioned above probably the corresponding change in the DNB cards was not performed.

In the contribution from IPEN Peru a mistake in input data is most probably involved. Unfortunately the actual input data were not supplied with the results for this calculation.

It can be seen that in fact all versions of the WIMS code give almost the same value of k-eff (when we exclude the values received with obvious errors in input). It was further noticed that the 18-groups value of k_∞ from Chain 14 obtained with version 101 of WIMS agrees well with the NEA 0329/13 version computed values in Chains 6 and 13 (see Table 12). Even the 2-groups values of k_∞ from Chain 14 produced by both versions agree well. It seems that the two versions differ only in the 18-groups value (or better, in the few-group calculation value) of k_∞ from Chain 14. The results are summarized in Table 12.

This difference, as it can be seen from Tables 9 and 11 starts probably with the version NEA 0329/06 when the source code was converted from IBM to CDC. At the same time some additional changes were introduced to incorporate WIMS into the

Table 12: Values of k_∞ (TRX-1, input data Appendix B.1).

Chain	NEA 0329/13	Vers.101 (Nov.1981)	Halsall [5]
4	1.188084	1.187989	-
6	1.182986	-	1.18256
13	1.182984	-	1.18255
14 18-groups	1.181065	1.182986	1.18254
14 2-groups	1.183976	1.183972	-

so called MARIA system. Furthermore, it has been pointed out by Halsall [5] that there should be no significant differences between k_∞ values given by the main and the edit chains of the code. The results in Table 12 provided by Halsall have been obtained with the recent Winfrith version of the code on the SUN workstation, using a library very similar to the one used in this project. By looking into the WIMS-D/4 source code used at IJS in Slovenia and deactivating the corrections introduced for the MARIA system, a consistent value of $k_\infty = 1.18298$ was indeed obtained. It remains for the authors of the changes to either justify or correct the modifications they have introduced. From a practical point of view these differences are not very important since they do not affect any other part of the code.

When the results affected by mistakes in input data are excluded from comparison we can conclude that the computed values of spectral characteristics agree almost exactly. Only very slightly different values are produced by the versions NEA 0329/10 and NEA 0926/02. A slightly more noticeable difference occurs in C* produced with NEA 0926/02.

In conclusions of this comparison it can be said that except for a small difference in the few-group value of k_∞ in Chain 14 (about 0.16%) all versions of the WIMS program and the library distributed by NEA CPL and implemented on different computers give practically the same results.

4 Sensitivity Analysis of TRX-1, TRX-2, BAPL-1 and BAPL-2 Benchmark Calculations

4.1 General results

Dependence of the calculated parameters on various options in WIMS input data is described on the TRX-1 benchmark problem. In some cases also comments on TRX-2, BAPL-1, BAPL-3 are added, but mainly they are presented in Appendix C.

Input options which are not presented in the head of the tables have the following "standard" values :

```
SEQUENCE 1
S 12
NMESH 10 (NMESH 14 for TRX-2)
NGROUPS 69
REGULAR 1 6
DIFFUSION 1 3 1
BEEONE 1
```

Relative differences of calculated and experimental values (in per cent) are given in the tables except for k_∞, where the result of presumably the most sophisticated calculation (of those performed) is taken as the reference value.

The influence of the NMESH parameter is shown in Table 13. There are no significant differences in the results obtained with 10 and 20 mesh points.

Table 13: Influence of NMESH on TRX-1

BENCHMARK :	TRX1				
SEQUENCE		1	1	1	1
S		8	8	8	8
NMESH		10	20	10	20
BEEONE		0	0	1	1
K-INFIN.		1.18336	1.18326	1.18336	1.18326
ERR. [%]		-0.02	-0.03	-0.02	-0.03
K-EFF.	1.00000	1.00373	1.00365	1.00092	1.00085
ERR. [%]		0.37	0.36	0.09	0.08
RHO28	1.3200	1.2694	1.2695	1.2715	1.2716
ERR. [%]	+-1.59	-3.83	-3.83	-3.67	-3.67
DEL25	0.09870	0.09890	0.09890	0.09908	0.09909
ERR. [%]	+-1.01	0.20	0.20	0.38	0.40
DEL28	0.09460	0.09491	0.09491	0.09649	0.09649
ERR. [%]	+-4.33	0.33	0.33	2.00	2.00
C*	0.7970	0.7768	0.7768	0.7774	0.7774
ERR. [%]	+-1.00	-2.53	-2.53	-2.46	-2.46

Tables 14 and 15 compare the results of DSN and PERSEUS options for transport calculation (transport calculation being followed by either B_1 (Table 14) or Diagonal transport corrected (Table 15) leakage calculation). The results of S_n method with the increasing value of n are changing towards the results by the collision probability method (last column in Tables 14 and 15). A change from S_4 to S_8 is more significant than the change from S_8 to S_{12}. Probably there would be no further significant change in the results with a further increase in the value of n.

Differences in the results of both transport methods (S_n and collision probability) are significantly smaller than the range of the experimental uncertainties.

The same results for other three benchmarks are presented in Appendix C. The influence of the method used for Dancoff factor calculation is shown in Table 16. The difference between the default option and option REGULAR 1 is noticeable, while the difference between REGULAR 1 and REGULAR 1 6 (triangular mesh taken into account) is only slight. The most sensitive parameters are ρ^{28} and k_{eff}. This effect was studied also for the other benchmarks and is documented in Appendix C. It can be seen that BAPL-UO2 lattices are even more sensitive to this input option.

Table 14: Influence of SEQUENCE on TRX-1 (BEEONE 1)

BENCHMARK : TRX1

SEQUENCE		1	1	1	2
S		4	8	12	
BEEONE		1	1	1	1
K-INFIN.		1.18250	1.18336	1.18360	1.18431
ERR. [%]		-0.09	-0.02	0.00	0.06
K-EFF.	1.00000	1.00018	1.00092	1.00112	1.00170
ERR. [%]		0.02	0.09	0.11	0.17
RHO28	1.3200	1.2725	1.2715	1.2716	1.2691
ERR. [%]	+-1.59	-3.60	-3.67	-3.67	-3.86
DEL25	0.09870	0.09917	0.09908	0.09907	0.09893
ERR. [%]	+-1.01	0.48	0.38	0.37	0.23
DEL28	0.09460	0.09616	0.09649	0.09663	0.09716
ERR. [%]	+-4.33	1.65	2.00	2.15	2.71
C*	0.7970	0.7778	0.7774	0.7774	0.7766
ERR. [%]	+-1.00	-2.41	-2.46	-2.46	-2.56

Table 15: Influence of SEQUENCE on TRX-1 (BEEONE 0)

BENCHMARK : TRX1

SEQUENCE		1	1	1	2
S		4	8	12	
BEEONE		0	0	0	0
K-INFIN.		1.18250	1.18336	1.18360	1.18431
ERR. [%]		-0.09	-0.02	0.00	0.06
K-EFF.	1.00000	1.00300	1.00373	1.00391	1.00448
ERR. [%]		0.30	0.37	0.39	0.45
RHO28	1.3200	1.2703	1.2694	1.2694	1.2670
ERR. [%]	+-1.59	-3.77	-3.83	-3.83	-4.02
DEL25	0.09870	0.09899	0.09890	0.09889	0.09875
ERR. [%]	+-1.01	0.29	0.20	0.19	0.05
DEL28	0.09460	0.09459	0.09491	0.09505	0.09558
ERR. [%]	+-4.33	-0.01	0.33	0.48	1.04
C*	0.7970	0.7772	0.7768	0.7768	0.7760
ERR. [%]	+-1.00	-2.48	-2.53	-2.53	-2.63

Table 16: Influence of REGULAR on TRX-1

BENCHMARK : TRX1

REGULAR			1	1 6
K-INFIN.		1.18150	1.18407	1.18360
ERR. [%]		-0.18	0.04	0.00
K-EFF.	1.00000	0.99939	1.00152	1.00112
ERR. [%]		-0.06	0.15	0.11
RH028	1.3200	1.2844	1.2686	1.2716
ERR. [%]	+-1.59	-2.70	-3.89	-3.67
DEL25	0.09870	0.09918	0.09905	0.09907
ERR. [%]	+-1.01	0.49	0.35	0.37
DEL28	0.09460	0.09682	0.09658	0.09663
ERR. [%]	+-4.33	2.35	2.09	2.15
C*	0.7970	0.7817	0.7764	0.7774
ERR. [%]	+-1.00	-1.92	-2.58	-2.46

Table 17 presents the influence of various methods for leakage calculation, including various methods for diffusion coefficient calculation. The effects are not negligible and are listed below:

k_{eff}	0.5%
ρ^{28}	0.3%
δ^{25}	0.3%
δ^{28}	1.7%
C*	0.15%

The largest value of k_{eff} (smallest value of ρ^{28}, δ^{25}, δ^{28}, C*) is obtained with options DIFFUSION 2, BEEONE 0 (implying sigma transport diffusion coefficients and "Diagonal-transport corrected flux solution" leakage calculation), while the smallest value of k_{eff} (largest value of ρ^{28}, δ^{25}, δ^{28}, C*) is obtained with the options DIFFUSION 1, BEEONE 1 (implying Benoist diffusion coefficients and B_1 leakage calculation). The second alternative is considered to be more appropriate according to the WIMS manual and the benchmark description.

Change from DIFFUSION 1 to DIFFUSION 2 gives approximately:

0.15%	higher	k_{eff}
0.15%	lower	ρ^{28}
0.10%	"	δ^{25}
0.10%	"	δ^{28}
0.07%	"	C*

Table 17: Influence of DIFFUSION and BEEONE on TRX-1

BENCHMARK :	TRX1				
DIFFUS.		1	1	2	2
BEEONE		1	0	1	0
K-INFIN.		1.18360	1.18360	1.18360	1.18360
ERR. [%]		0.00	0.00	0.00	0.00
K-EFF.	1.00000	1.00112	1.00391	1.00283	1.00564
ERR. [%]		0.11	0.39	0.28	0.56
RHO28	1.3200	1.2716	1.2694	1.2699	1.2678
ERR. [%]	+-1.59	-3.67	-3.83	-3.80	-3.95
DEL25	0.09870	0.09907	0.09889	0.09895	0.09878
ERR. [%]	+-1.01	0.37	0.19	0.25	0.08
DEL28	0.09460	0.09663	0.09505	0.09655	0.09500
ERR. [%]	+-4.33	2.15	0.48	2.06	0.42
C*	0.7970	0.7774	0.7768	0.7769	0.7763
ERR. [%]	+-1.00	-2.46	-2.53	-2.52	-2.60

Table 18: Influence of NGROUPS on TRX-1 (BEEONE 1)

BENCHMARK :	TRX1			
S		4	4	4
NGROUPS		20	48	69
REGULAR				
BEEONE		1	1	1
K-INFIN.		1.17970	1.18056	1.18043
ERR. [%]		-0.33	-0.26	-0.27
K-EFF.	1.00000	0.99761	0.99861	0.99846
ERR. [%]		-0.24	-0.14	-0.15
RHO28	1.3200	1.2934	1.2852	1.2853
ERR. [%]	+-1.59	-2.02	-2.64	-2.63
DEL25	0.09870	0.09971	0.09926	0.09927
ERR. [%]	+-1.01	1.02	0.57	0.58
DEL28	0.09460	0.09664	0.09634	0.09635
ERR. [%]	+-4.33	2.16	1.84	1.85
C*	0.7970	0.7843	0.7820	0.7821
ERR. [%]	+-1.00	-1.59	-1.88	-1.87

Table 19· Influence of NGROUPS on TRX-1 (BEEONE 0)

BENCHMARK :		TRX1		
S		4	4	4
NGROUPS		20	48	69
REGULAR				
BEEONE		0	0	0
K-INFIN.		1.17970	1.18056	1.18043
ERR. [%]		-0.33	-0.26	-0.27
K-EFF.	1.00000	1.00036	1.00139	1.00126
ERR. [%]		0.04	0.14	0.13
RHO28	1.3200	1.2912	1.2831	1.2831
ERR. [%]	+-1.59	-2.18	-2.80	-2.80
DEL25	0.09870	0.09953	0.09908	0.09909
ERR. [%]	+-1.01	0.84	0.38	0.40
DEL28	0.09460	0.09502	0.09477	0.09477
ERR. [%]	+-4.33	0.44	0.18	0.18
C*	0.7970	0.7837	0.7814	0.7815
ERR. [%]	+-1.00	-1.67	-1.96	-1.94

Change from BEEONE 1 to BEEONE 0 gives approximately:

0.30%	higher	k_{eff}
0.15%	lower	ρ^{28}
0.18%	"	δ^{25}
1.6%	"	δ^{28}
0.07%	"	C*

Although these uncertainties are not negligible, they are smaller (except for k_{eff}) than experimental uncertainties and usually also smaller than differences between experimental and calculated results.

Calculational uncertainties can be reduced by qualified selection of one leakage calculation method (if possible).

Comparison of different leakage calculation methods in case of the other benchmarks are given in Appendix C. Essentially, the same effects are observed. Quantitative comparisons are given in the summary tables.

Table 18 and Table 19 show the influence of the number of groups in the main transport (and then leakage) calculation. While a change from 20 to 48 groups is noticeable, further refinement to 69 groups brings only negligible changes.

4.2 Summary of calculational uncertainties

Brief review of calculational uncertainties is given in tables 20 to 26. In these tables the maximum relative change (in per cent) in the parameter in question due to

Table 20: Changes of TRX-1 calculated parameters resulting from the change from 20 groups (6 thermal) to 48 groups (21 thermal).

	relative change in calculated value [%]	uncertainty of experimental value [%]
k-inf	+0.07	
k-eff	+0.10	
rho28	-0.62	1.59
delta25	-0.45	1.01
delta28	-0.32	4.33
C*	-0.29	1.00

a possible change in a WIMS input option is presented. The values of the input options (except for the input option under investigation) are as follows :

```
CELL       6
SEQUENCE   1
NGROUP    69 2
NMESH     10     (14 FOR TRX2)

REGULAR    1 6
S         12

BEEONE     1
DIFFUSION COEFFICIENTS 1 3 1
LEAKAGE    5
PARTITION 45 69
```

The range of changes in WIMS input options is mentioned in the preceding text and in the related tables (Tables 14 to 19) and is briefly summarized here:

Option	Parameter values
REGULAR	1 / 1 6 / no input card
SEQUENCE	1 / 2
Sn	n= 4 / 8 / 12 (for SEQUENCE 1 only)
BEEONE	1 / 0
DIFFUSION	1 3 1 / 2
NGROUP	20 / 48 /69

In the summary tables 21 to 26 only the maximum changes in the relative differences between the claculated and the measured values due to parameter variations

Table 21: Range of relative changes (in %) in k_∞.

benchmark	input option: REGULAR	input option: SEQUENCE, Sn
TRX-1	0.22	0.15
TRX-2	0.09	0.31
BAPL-1	0.22	0.10
BAPL-3	0.14	0.14

Table 22: Range of relative changes (in %) in k_{eff}

benchmark	input option: REGULAR	input option: SEQUENCE, Sn	input option: BEEONE, DIFFUSION
TRX-1	0.21	0.15	0.45
TRX-2	0.11	0.32	0.54
BAPL-1	0.30	0.11	0.21
BAPL-3	0.16	0.15	0.36

are given. For changes in the relative differences due to a particular variation of a selected parameter refer to Tables 14 to 19 and to Appendix C.

Naturally, this sensitivity analysis is not complete. Moreover, the influence of a selected parameter was investigated for only one set of fixed values of the other parameters, but this is not expected to invalidate the recommendations stated below.

To reduce possible sources of imprecision of calculated results the following options should be used :

NMESH 10	is sufficient (or maybe less)
NGROUPS	approx. 50 or greater
REGULAR 1	(or better REGULAR 1 6)
SEQUENCE 1	together with Sn, where n is greater or equal to 8 or SEQUENCE 2

Table 23: Range of relative changes (in %) in ρ^{28}

benchmark	input option: REGULAR	input option: SEQUENCE, Sn	input option: BEEONE, DIFFUSION	experimental uncertainty
TRX-1	1.20	0.26	0.28	1.59
TRX-2	0.86	0.23	0.27	1.91
BAPL-1	1.60	0.26	0.20	0.72
BAPL-3	1.31	0.14	0.23	1.10

Table 24: Range of relative changes (in %) in δ^{25}

benchmark	input option: REGULAR	input option: SEQUENCE, Sn	input option: BEEONE, DIFFUSION	experimental uncertainty
TRX-1	0.14	0.29	0.29	1.01
TRX-2	0.05	0.22	0.30	1.30
BAPL-1	0.21	0.18	0.23	2.38
BAPL-3	0.13	0.09	0.25	1.92

Although SEQUENCE 1, S12 and SEQUENCE 2 do not give identical results, the differences are not significant (in comparison with experimental uncertainties). Calculation with SEQUENCE 2 method is faster by a factor of 2.

Using these options, there remains only the method of leakage calculation (including diffusion coefficient calculation) as the only significant source of uncertainties of the calculated results.

It is recommended that options DIFFUSION 1, BEEONE 1 are normally used, however, in some cases it should be checked whether the application of some other method would affect the agreement of experimental and calculated results. We

Table 25: Range of relative changes (in %) in δ^{28}

benchmark	input option: REGULAR	input option: SEQUENCE, Sn	input option: BEEONE, DIFFUSION	experimental uncertainty
TRX-1	0.26	1.06	1.73	4.33
TRX-2	0.10	1.18	1.78	5.06
BAPL-1	0.31	0.86	1.18	5.13
BAPL-3	0.17	1.14	1.33	5.26

Table 26: Range of relative changes (in %) in C*

benchmark	input option: REGULAR	input option: SEQUENCE, Sn	input option: BEEONE, DIFFUSION	experimental uncertainty
TRX-1	0.66	0.15	0.14	1.00
TRX-2	0.39	0.12	0.11	0.93
BAPL-1	0.68	0.16	0.10	
BAPL-3	0.67	0.08	0.11	

should have in mind, that using DIFFUSION 2, BEEONE 0 gives approximately 0.5% higher k_{eff} in case of TRX lattices and about 0.3% higher k_{eff} in case of BAPL lattices.

4.3 Sensitivity of the TRX-1 and BAPL-2 calculated parameters to various uranium data in the WIMS-D/4 library

Comparison of the results using various U-238 data sets is presented in Tables 27 and 28. Using the same resonance tabulation (decimal index .4 in the material number), the comparison of materials 238, 1238, 2238 does not show any significant differences except for δ^{28}, where materials 238 and 1238 lead to approximately 5% lower value than material 2238.

Table 27: Influence of U-238 cross section data on TRX-1

BENCHMARK :	TRX1			
MATERIAL		235.4	235.4	235.4
MATERIAL		2238.4	1238.4	238.4
K-INFIN.		1.18360	1.18139	1.18080
ERR. [%]		0.00	-0.19	-0.24
K-EFF.	1.00000	1.00112	1.00280	1.00264
ERR. [%]		0.11	0.28	0.26
RHO28	1.3200	1.2716	1.2655	1.2708
ERR. [%]	+-1.59	-3.67	-4.13	-3.73
DEL25	0.09870	0.09907	0.09885	0.09884
ERR. [%]	+-1.01	0.37	0.15	0.14
DEL28	0.09460	0.09663	0.09091	0.09147
ERR. [%]	+-4.33	2.15	-3.90	-3.31
C*	0.7970	0.7774	0.7754	0.7773
ERR. [%]	+-1.00	-2.46	-2.71	-2.47

Table 28: Influence of U-238 cross section data on BAPL-2

BENCHMARK :	BAPL2			
MATERIAL		235.4	235.4	235.4
MATERIAL		2238.4	1238.4	238.4
K-INFIN.		1.14546	1.14424	1.14371
ERR. [%]		0.00	-0.11	-0.15
K-EFF.	1.00000	0.99900	0.99971	0.99927
ERR. [%]		-0.10	-0.03	-0.07
RHO28	1.1200	1.1334	1.1298	1.1336
ERR. [%]	+-0.89	1.20	0.87	1.21
DEL25	0.06800	0.06876	0.06866	0.06866
ERR. [%]	+-1.47	1.12	0.97	0.97
DEL28	0.07000	0.06534	0.06222	0.06245
ERR. [%]	+-5.71	-6.66	-11.11	-10.79
C*	0.0000	0.7319	0.7307	0.7320
ERR. [%]	+-0.00	0.00	0.00	0.00

Table 29: Influence of U-238 resonance integral data on TRX-1

BENCHMARK : TRX1

MATERIAL		235.4	235.4	235.4	235.4
MATERIAL		2238.4	238.4	238.3	238.2
K-INFIN.		1.18360	1.18080	1.17931	1.15998
ERR. [%]		0.00	-0.24	-0.36	-1.99
K-EFF.	1.00000	1.00112	1.00264	1.00142	0.98526
ERR. [%]		0.11	0.26	0.14	-1.47
RH028	1.3200	1.2716	1.2708	1.2803	1.4008
ERR. [%]	+-1.59	-3.67	-3.73	-3.01	6.12
DEL25	0.09870	0.09907	0.09884	0.09881	0.09899
ERR. [%]	+-1.01	0.37	0.14	0.11	0.29
DEL28	0.09460	0.09663	0.09147	0.09160	0.09326
ERR. [%]	+-4.33	2.15	-3.31	-3.17	-1.42
C*	0.7970	0.7774	0.7773	0.7805	0.8216
ERR. [%]	+-1.00	-2.46	-2.47	-2.07	3.09

Table 30: Influence of U-238 resonance integral data on TRX-1

BENCHMARK : TRX1

MATERIAL		235.4	235.4	235.4
MATERIAL		2238.4	2238.3	2238.2
K-INFIN.		1.18360	1.18211	1.16281
ERR. [%]		0.00	-0.13	-1.76
K-EFF.	1.00000	1.00112	0.99990	0.98385
ERR. [%]		0.11	-0.01	-1.61
RH028	1.3200	1.2716	1.2810	1.4016
ERR. [%]	+-1.59	-3.67	-2.95	6.18
DEL25	0.09870	0.09907	0.09905	0.09923
ERR. [%]	+-1.01	0.37	0.35	0.54
ERR. [%]	+-4.33	2.15	2.28	4.14
C*	0.7970	0.7774	0.7806	0.8217
ERR. [%]	+-1.00	-2.46	-2.06	3.10

Table 31: Influence of U-238 resonance integral data on TRX-1

BENCHMARK : TRX1

MATERIAL		235.4	235.4	235.4	235.4
MATERIAL		2238.4	1238.4	1238.3	1238.2
K-INFIN.		1.18360	1.18139	1.17995	1.16058
ERR. [%]		0.00	-0.19	-0.31	-1.94
K-EFF.	1.00000	1.00112	1.00280	1.00161	0.98543
ERR. [%]		0.11	0.28	0.16	-1.46
RHO28	1.3200	1.2716	1.2655	1.2748	1.3953
ERR. [%]	+-1.59	-3.67	-4.13	-3.42	5.70
DEL25	0.09870	0.09907	0.09885	0.09882	0.09899
ERR. [%]	+-1.01	0.37	0.15	0.12	0.29
DEL28	0.09460	0.09663	0.09091	0.09103	0.09268
ERR. [%]	+-4.33	2.15	-3.90	-3.77	-2.03
C*	0.7970	0.7774	0.7754	0.7786	0.8197
ERR. [%]	+-1.00	-2.46	-2.71	-2.31	2.85

Table 32: Influence of U-238 resonance integral data on BAPL-2

BENCHMARK : BAPL2

MATERIAL		235.4	235.4	235.4	235.4
MATERIAL		2238.4	238.4	238.3	238.2
K-INFIN.		1.14546	1.14371	1.14739	1.12966
ERR. [%]		0.00	-0.15	0.17	-1.38
K-EFF.	1.00000	0.99900	0.99927	1.00245	0.98714
ERR. [%]		-0.10	-0.07	0.25	-1.29
RHO28	1.1200	1.1334	1.1336	1.1112	1.2217
ERR. [%]	+-0.89	1.20	1.21	-0.79	9.08
DEL25	0.06800	0.06876	0.06866	0.06857	0.06877
ERR. [%]	+-1.47	1.12	0.97	0.84	1.13
DEL28	0.07000	0.06534	0.06245	0.06224	0.06328
ERR. [%]	+-5.71	-6.66	-10.79	-11.09	-9.60
C*	0.0000	0.7319	0.7320	0.7244	0.7621
ERR. [%]	+-0.00	0.00	0.00	0.00	0.00

Table 33: Influence of U-238 resonance integral data on BAPL-2

BENCHMARK : BAPL2

MATERIAL		235.4	235.4	235.4
MATERIAL		2238.4	2238.3	2238.2
K-INFIN.		1.14546	1.14914	1.13143
ERR. [%]		0.00	0.32	-1.23
K-EFF.	1.00000	0.99900	1.00218	0.98691
ERR. [%]		-0.10	0.22	-1.31
RHO28	1.1200	1.1334	1.1110	1.2215
ERR. [%]	+-0.89	1.20	-0.80	9.06
DEL25	0.06800	0.06876	0.06867	0.06887
ERR. [%]	+-1.47	1.12	0.99	1.28
DEL28	0.07000	0.06534	0.06512	0.06620
ERR. [%]	+-5.71	-6.66	-6.97	-5.43
C*	0.0000	0.7319	0.7242	0.7620
ERR. [%]	+-0.00	0.00	0.00	0.00

Table 34: Influence of U-238 resonance integral data on BAPL-2

BENCHMARK : BAPL2

MATERIAL		235.4	235.4	235.4	235.4
MATERIAL		2238.4	1238.4	1238.3	1238.2
K-INFIN.		1.14546	1.14424	1.14792	1.13018
ERR. [%]		0.00	-0.11	0.22	-1.33
K-EFF.	1.00000	0.99900	0.99971	1.00291	0.98758
ERR. [%]		-0.10	-0.03	0.29	-1.24
RHO28	1.1200	1.1334	1.1298	1.1073	1.2179
ERR. [%]	+-0.89	1.20	0.87	-1.13	8.74
DEL25	0.06800	0.06876	0.06866	0.06857	0.06877
ERR. [%]	+-1.47	1.12	0.97	0.84	1.13
DEL28	0.07000	0.06534	0.06222	0.06200	0.06304
ERR. [%]	+-5.71	-6.66	-11.11	-11.43	-9.94
C*	0.0000	0.7319	0.7307	0.7230	0.7608
ERR. [%]	+-0.00	0.00	0.00	0.00	0.00

In case of BAPL-2 the value of δ^{28} calculated with 238 or 1238 is far out of the range of experimental uncertainty.

The results using various resonance integral tabulations for U238 are compared in Tables 29, 30, 31 (TRX-1) and 32, 33, 34 (BAPL-2). They are in good agreement with the information in the WIMS manual, stating that .4 and .3 tabulations have reduced resonance integrals compared to .2 tabulation.

Tabulation .2 leads to an excessively low values of k_{eff} and too high values of ρ^{28}.

There are no significant differences between tabulations .4 and .3. We can only notice that .4 gives a somewhat lower value of ρ^{28} and a higher value of k_{eff}. The difference in ρ^{28} is 0.7% for TRX-1 and 2% for BAPL-2. In the case of BAPL-2 both values of ρ^{28} calculated with .4 and .3 tabulations have approximately the same departure from experimental value, but opposite signs.

Comparison of results using various resonance integral tabulations for U-235 is given in Tables 35 and 36. Tabulations .3 and .2 give too low values of δ^{25}, k_∞ and k_{eff} in the case of TRX-1 and BAPL-2.

4.4 Sensitivity of calculated benchmark parameters to various fission spectra

Calculations with three different fission spectra were performed. One is the fission spectrum used in WIMS-D/4 library, second set of values was prepared on the basis of data for U-235 in ENDF/B-IV and the third set was taken from the KAERI WIMS library and should correspond to U-235 ENDF/B-V fission spectrum. Graphical representation of the above spectra is shown in Fig. 2 and their tabular representation is given below.

```
  WIMSD4 LIBRARY (1975) FISSION SPECTRUM

2.821999-02 1.092999-01 2.034998-01 2.249999-01 1.791998-01
1.159999-01 6.759965-02 3.585999-02 1.807999-02 8.918993-03
4.327997-03 2.077999-03 9.916995-04 4.710995-04 2.234999-04
9.871000-05 5.016998-05 2.548996-05 1.294999-05 9.911999-06
2.554989-06 5.662999-07 1.579999-07 9.161988-08 4.009999-08
1.602999-08 1.126999-08


  ENDF/B-IV U235 FISSION SPECTRUM

2.712248-02 1.078777-01 2.026600-01 2.253874-01 1.801128-01
1.168332-01 6.817495-02 3.619114-02 1.825238-02 9.008716-03
4.372667-03 2.099851-03 1.002071-03 4.760655-04 2.258407-04
9.974102-05 5.069459-05 2.575515-05 1.307973-05 1.001334-05
2.580029-06 5.712204-07 1.591106-07 9.208895-08 4.014412-08
1.594147-08 1.104673-08
```

Table 35: Influence of U-235 resonance integral data on TRX-1

BENCHMARK : TRX1

MATERIAL		235.4	235.3	235.2
MATERIAL		2238.4	2238.4	2238.4
K-INFIN.		1.18360	1.17232	1.17451
ERR. [%]		0.00	-0.95	-0.77
K-EFF.	1.00000	1.00112	0.99133	0.99331
ERR. [%]		0.11	-0.87	-0.67
RHO28	1.3200	1.2716	1.2702	1.2716
ERR. [%]	+-1.59	-3.67	-3.77	-3.67
DEL25	0.09870	0.09907	0.08380	0.08957
ERR. [%]	+-1.01	0.37	-15.10	-9.25
DEL26	0.09460	0.09663	0.09769	0.09747
ERR. [%]	+-4.33	2.15	3.27	3.03
C*	0.7970	0.7774	0.7878	0.7842
ERR. [%]	+-1.00	-2.46	-1.15	-1.61

Table 36: Influence of U-235 resonance integral data on BAPL-2

BENCHMARK : BAPL2

MATERIAL		235.4	235.3	235.2
MATERIAL		2238.4	2238.4	2238.4
K-INFIN.		1.14546	1.13725	1.13884
ERR. [%]		0.00	-0.72	-0.58
K-EFF.	1.00000	0.99900	0.99164	0.99311
ERR. [%]		-0.10	-0.84	-0.69
RHO28	1.1200	1.1334	1.1325	1.1334
ERR. [%]	+-0.89	1.20	1.12	1.20
DEL25	0.06800	0.06876	0 05803	0.06199
ERR. [%]	+-1.47	1.12	-14.66	-8.84
DEL28	0.07000	0.06534	0.06586	0.06576
ERR. [%]	+-5.71	-6.66	-5.91	-6.06
C*	0.0000	0.7319	0.7390	0.7365
ERR. [%]	+-0.00	0.00	0.00	0.00

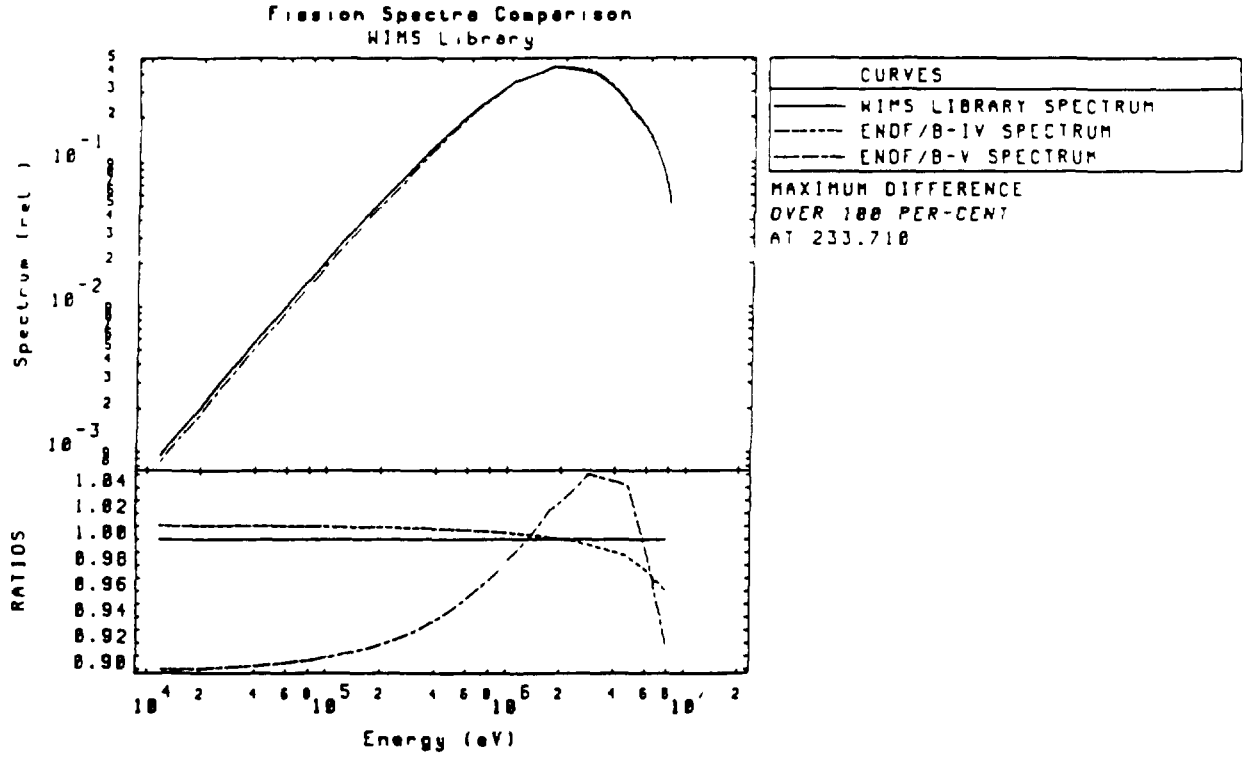

Figure 2: Fission spectra comparison

ENDF/B-V U235 FISSION SPECTRUM (KAERI WIMS LIBRARY)

2.595000-02 1.139000-01 2.138000-01 2.300000-01 1.768000-01
1.111000-01 6.330000-02 3.307000-02 1.651000-02 8.094000-03
3.913000-03 1.874000-03 8.931000-04 4.239000-04 2.010000-04
8.872000-05 4.508000-05 2.290000-05 1.163000-05 2.670000-06

Approximate range of changes in the values of k and spectral characteristics due to different fission spectra used is presented in Table 37.

It can be seen that the differences due to different fission spectra used are not significant except for δ^{28} where the difference is comparable to experimental uncertainty.

ENDF/B-IV spectrum gives a slightly lower k_∞ and ENDF/B-V spectrum a slightly higher k_∞ compared to the WIMS library spectrum. Differences in k_{eff} are even smaller, becoming almost negligible.

ENDF/B-V spectrum, although leading to the highest value of k_∞, gives the lowest value of k_{eff}. ENDF/B-V spectrum gives also the highest values of ρ^{28}, δ^{25}, δ^{28} and C^*.

ENDF/B-IV spectrum gives the lowest value of δ^{28}. While in the case of TRX lattices, ENDF/B-IV spectrum values are in good agreement with experiment, they are too low for BAPL-UO2 lattices. The ENDF/B-V spectrum results are nearest to the experiment in this case.

Table 37: Range of relative changes (in %) in calculated benchmark parameters due to different fission spectra

	k-inf	k-eff	rho28	del25	del28	C*
TRX-1	0.17	0.05	0.15	0.15	4.1	0.05
TRX-2	0.1	0.1	0.1	0.1	4.0	0.05
BAPL-1	0.14	0.04	0.1	0.1	3.9	0.05
BAPL-2	0.13	0.07	0.1	0.1	3.7	0.05
BAPL-3	0.1	0.1	0.1	0.1	3.7	0.05

As it can be seen from the table, ENDF/B-V spectrum is the hardest of the ones compared. (Reasons for the change of ENDF/B-IV U235 fission spectrum are discussed in the report EPRI-NP-1098.)

Results of calculations which are summarized in Table 37 are presented in Appendix C.

5 Conclusions

From the aspect of the following stages of the project it may be concluded, that all versions and installations of the WIMS code which are used by the participants give almost identical results, provided that the same input model is used. However, large discrepancies may emerge if the participants are free to use the input options. For this reason it is essential that comparison of integral parameters for different libraries is performed with a prescribed WIMS input.

The main results of Stage 1 of the project presented in this report are:

- confirmation that different versions of the code used at various laboratories produce practically the same results,
- *model* inputs representative of the TRX-1, TRX-2, BAPL-1, BAPL-2 and BAPL-3 lattices which are useful for comparative studies and require modest computer resources are given in Appendix B.1,
- *optimized* inputs for the same benchmark lattices which produce as accurate results as the mathematical models in WIMS allow are given in Appendix B.2,
- results for the benchmark lattices based on the original WIMS library, which will serve as reference in the assessment of the relative merits of new libraries which

will be produced in the subsequent stages of the project have been established and are given in Table 8.

The primary objectives of this stage of the project have been successfully completed. The results presented herein are open for constructive discussions and improvements.

References

[1] A. Trkov, M. Ravnik, *WIMS Library Update Project*, Report on the project preparation meeting at the IAEA, 4-6 June 1990, IJS-DP-5852, July 1990.

[2] Letter from Dr.S.Ganesan, IAEA, to participants of WIMS Library Update Project, 334-F4.01, dated 27. August 1990.

[3] BNL, *Cross Sections Working Group Benchmark Specifications*, BNL 19 302 (ENDF-202) with Supplements (1986).

[4] M. Ravnik, A. Trkov, A. Holubar, *WIMS Library Update Project, Phase Report on Stage 1*, IAEA Research Contract No. 6291/RB, IJS-DP-6164, April 1991.

[5] M.J. Halsall, AEA Reactor Services, Winfrith, A letter to S. Ganesan, IAEA, Feb. 10^{th} 1992.

APPENDIX A

A Benchmark Calculations - Complete Contributions

Table A-1 TRX-1 results contributed for the first stage of WLUP
BENCHMARK : TRX1

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NN	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	11	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	13	24	2	-1
NAEA	INDONESIA	235.4	238.4	2001	1	4	1	3	6	2	1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235.4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235.4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238.4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	10	69	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		12	20	2	0
SKODA	CSFR 1)	235.4	2238.4	2001	2		1 6	11	28	1	1
SKODA	CSFR 2)	2235.0	8238.0	3001	2		1 6	11	28	1	1
BARC	INDIA	235.4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
NRI	CSFR 1)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		11	36	2	1
IGCAR	INDIA 4)	235.4	3238.4	2001							
IGCAR	INDIA 5)	235.4	3238.4	2001							
CNEA	ARGENTINA 6)	1235.4	3238.5	6001	2	4		9	18	2	0
CNEA	ARGENTINA 8)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
CNAEN	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

1) NEA 0329/13 PROGRAM AND LIBRARY
2) WINSD2A PROGRAM, 1986 WIMS LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
4) MURLI PROGRAM, WIMS 1971 LIBRARY
5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
6) CRNL LIBRARY
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-1: Continued
BENCHMARK : TRX1

LAB.	COUNTRY	K-INF	K-EFF	R D EFF (%)	RO28	R.D RO28 (%)
EXPERIMENT					1.3200	+-1.59
IIE	MEXICO	1.18603	1.00803	0.80	1.2620	-4.39*
OAEP	THAILAND	1.18259	1.00372	0.37	1.2592	-4.60*
IEA	BRASIL	1.18130	1.00023	0.02	1.2690	-3.86*
CNEN	BRASIL	1.18416	1.00410	0.41	1.2620	-4.39*
NAEA	INDONESIA	1.18221	1.01269	1.27	1.2621	-4.39*
KAERI	KOREA	1.18179	1.00301	0.30	1.2621	-4.39*
ZFK	GERMANY	1.18360	1.00290	0.29	1.2685	-3.90*
IPEN	PERU	1.17899	1.00487	0.49		
AEC	SOUTH AFRICA	1.18263	1.00221	0.22	1.2626	-4.35*
	VIETNAM	1.18590	0.99990	-0.01	1.2510	-5.23*
CNEA	ARGENTINA		1.00253	0.25	1.2811	-2.95*
HU	TURKEY 9)	1.17958	0.99908	-0.09	1.2819	-2.89*
IJS	SLOVENIA	1.18270	1.00227	0.23	1.2630	-4.32*
AERE	BANGLADESH	1.18387	1.00309	0.31		
PINST	PAKISTAN	1.18181	1.00241	0.24	1.2757	-3.36*
SKODA	CSFR 1)	1.18330	1.00110	0.11	1.2719	-3.64*
SKODA	CSFR 2)	1.18800	0.99590	-0.41	1.3369	1.28
BARC	INDIA		1.00254	0.25	1.2834	-2.77*
NRI	CSFR 3)	1.18498	1.00236	0.24	1.2630	-4.32*
NRI	CSFR 1)	1.18270	1.00228	0.23	1.2630	-4.32*
CEADN	CUBA	1.18248	1.00156	0.16	1.2754	-3.38*
IGCAR	INDIA 4)	1.17547	1.00282	0.28	1.3000	-1.52
IGCAR	INDIA 5)	1.17749	0.99256	-0.74	1.3000	-1.52
CNEA	ARGENTINA 6)		0.99888	-0.11	1.3227	0.20
CNEA	ARGENTINA 8)		0.99908	-0.09	1.2818	-2.89*
CNAEN	TURKEY	1.17940	1.00090	0.09	1.2810	-2.95*
TU	IRAN	1.18192	1.00079	0.08	1.2749	-3.42*

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
2) WINSD2A PROGRAM, 1986 WIMS LIBRARY
3) WIMS VERSION 101 (NOV 1981), NEA 0329/13 LIBRARY
4) MURLI PROGRAM, WIMS 1971 LIBRARY
5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
6) CRNL LIBRARY
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-1: Continued

BENCHMARK : TRX1

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R.D.D28 (%)	C*	R.D.C* (%)
EXPERIMENT		0.0987	+-1.01	0.0946	+-4.33	0.7970	+-1.00
IIE	MEXICO	0.0992	0.51	0 0973	2.85	0.7740	-2.89*
OAEP	THAILAND	0.0989	0.25	0.0959	1.38	0.7733	-2.97*
IEA	BRASIL	0.0996	0.91	0.0966	2.11	0.7770	-2.51*
CNEN	BRASIL	0.0992	0.51	0.0962	1.69	0.7750	-2.76*
NAEA	INDONESIA	0.0990	0.27	0.0934	-1.31	0.7747	-2.79*
KAERI	KOREA	0.0990	0.27	0.0960	1.48	0.7743	-2.84*
ZFK	GERMANY	0.0987	0.00	0.0973	2.85	0.7767	-2.55*
IPEN	PERU						
AEC	SOUTH AFRICA	0.0990	0.30	0.0964	1.90	0.7744	-2.84*
	VIETNAM	0.0989	0.20	0.0960	1.48	0.7734	-2.96*
CNEA	ARGENTINA	0.0990	0.30	0.0967	2.26	0.7810	-2.01*
HU	TURKEY 9)	0.0997	1.00	0.0965	1.99	0.7803	-2.10*
IJS	SLOVENIA	0.0990	0.30	0.0965	2.01	0.7745	-2.82*
AERE	BANGLADESH						
PINST	PAKISTAN	0.0991	0.43	0.0953	0.77	0.7787	-2.30*
SKODA	CSFR 1)	0.0996	0.91	0 0962	1.69	0.7769	-2.52*
SKODA	CSFR 2)	0.0977	-1 01*	0.1017	7.51*	0.7876	-1.18*
BARC	INDIA	0.0990	0.33	0.0978	3.34	0.7808	-2.03*
NRI	CSFR 3)	0.0990	0.30	0.0965	2.01	0.7745	-2.82*
NRI	CSFR 1)	0.0990	0.30	0 0965	2.01	0.7745	-2.82*
CEADN	CUBA	0.0991	0.41	0.0967	2.22	0.7789	-2.27*
IGCAR	INDIA 4)	0.0989	0.20	0.0897	-5.18*	0.7890	-1.00*
IGCAR	INDIA 5)	0.0989	0.20	0.0945	-0.11	0.7890	-1.00*
CNEA	ARGENTINA 6)	0.0971	-1.62*	0.1008	6.55*	0.7897	-0.92
CNEA	ARGENTINA 8)	0.0997	1.01	0.0965	2.01	0.7803	-2.10*
CNAEN	TURKEY	0.0996	0.91	0.0964	1.90	0.7802	-2.11*
TU	IRAN	0.0992	0.51	0.0967	2.22	0.7780	-2.38*

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
2) WIMSD2A PROGRAM, 1986 WIMS LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
4) MURLI PROGRAM, WIMS 1971 LIBRARY
5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
6) CRNL LIBRARY
8) MODEL INPUT DATA (MATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (MATERIAL 4)

Table A-2: TRX-2 results contributed for the first stage of WLUP

BENCHMARK : TRX2

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NM	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	13	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	13	24	2	-1
NAEA	INDONESIA	235.4	238.4	2001	1	4	1	3	6	2	1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235.4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235.4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238.4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
IEA	BRASIL 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	14	69	1	1
AERE	BANGLAD. 9)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		13	20	2	0
PINST	PAKISTAN 9)	235.4	2238 4	2001	2		1 6	10	18	1	1
CNEN	BRASIL 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
SKODA	CSFR 1)	235.4	2238.4	2001	2		1 6	15	28	1	1
SKODA	CSFR 2)	2235.0	8238.0	3001	2		1 6	15	28	1	1
BARC	INDIA	235.4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	14	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		11	36	2	1
CEADN	CUBA 7)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
IGCAR	INDIA 4)	235.4	3238.4	2001							
IGCAR	INDIA 5)	235.4	3238.4	2001							
CNEA	ARGENTINA 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNEA	ARGENTINA 8)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNAEN	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

1) NEA 0329/13 PROGRAM AND LIBRARY
2) WIMSD2A PROGRAM, 1986 WIMS LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
4) MURLI PROGRAM, WIMS 1971 LIBRARY
5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
7) MODEL INPUT DATA (MATERIAL 3)
8) MODEL INPUT DATA (MATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (MATERIAL 4)

Table A-2 Continued

BENCHMARK : TRX2

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	RO28	R D.RO28 (%)
EXPERIMENT					0.8370	+-1.91
IIE	MEXICO	1 16643	1.00442	0.44	0.7960	-4.90*
OAEP	THAILAND	1.16268	0.99789	-0.21	0.7948	-5.04*
IEA	BRASIL	1.16257	0.99515	-0.49	0.8000	-4.42*
CNEN	BRASIL	1.16396	0.99900	-0.10	0.7950	-5.02*
NAEA	INDONESIA	1.16676	1.00968	0 97	0 7947	-5.06*
KAERI	KOREA	1 16173	0 99702	-0.30	0.7957	-4.93*
ZFK	GERMANY	1.16460	0.99860	-0.14	0.7988	-4.56*
IPEN	PERU	1 15864	0.99923	-0.08		
AEC	SOUTH AFRICA	1 16330	0.99650	-0.35	0 7965	-4.84*
	VIETNAM	1.16800	1.00000	0.00	0.7941	-5.13*
CNEA	ARGENTINA		1.00137	0.14	0.8051	-3.81*
HU	TURKEY 9)	1 16471	0.99757	-0.24	0.8057	-3.74*
IEA	BRASIL 7)	1.16572	0.99841	-0.16	0.7997	-4.46*
IJS	SLOVENIA	1.16334	0.99654	-0.35	0 7967	-4.81*
AERE	BANGLAD 9)	1.16603	0.99762	-0.24		
AERE	BANGLADESH	1.16317	0 99715	-0.29		
PINST	PAKISTAN	1.16300	0 99879	-0.12	0 8022	-4.16*
PINST	PAKISTAN 9)	1 16602	1 00069	0 07	0.8045	-3.88*
CNEN	BRASIL 7)	1 16744	0 99844	-0.16	0 7990	-4.54*
SKODA	CSFR 1)	1 16430	0 99650	-0 35	0 8000	-4.42*
SKODA	CSFR 2)	1.17270	0.99800	-0.20	0.8377	0.08
BARC	INDIA		1.00227	0.23	0 8063	-3.67*
NRI	CSFR 3)	1.16492	0.99668	-0.33	0.7967	-4.81*
CEADN	CUBA	1.16396	0.99897	-0.10	0.8023	-4.15*
CEADN	CUBA 7)	1 16376	0.99555	-0 46	0 8017	-4.22*
IGCAR	INDIA 4)	1 15890	0.99921	-0.08	0.8150	-2.63*
IGCAR	INDIA 5)	1 16041	0.98897	-1.10	0.8150	-2.63*
CNEA	ARGENTINA 7)		0.99845	-0.16	0 7997	-4.46*
CNEA	ARGENTINA 8)		0.99758	-0.24	0.8058	-3.73*
CNAEN	TURKEY	1.16120	0.99730	-0.27	0.8055	-3.76*
TU	IRAN	1 16555	0.99914	-0.09	0.8012	4.28*

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
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4) MURLI PROGRAM, WINS 1971 LIBRARY
5) MURLI PROGRAM, WINS 1971 LIBRARY WITH CHANGES
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-2: Continued

BENCHMARK : TRX2

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R D D28 (%)	C*	R.D.C* (%)
EXPERIMENT		0.0614	+-1 30	0.0693	+-5.05	0 6470	+-0 93
IIE	MEXICO	0.0610	-0.65	0.0699	0.87	0.6310	-2 47*
OAEP	THAILAND	0 0610	-0.72	0.0688	-0 69	0.6315	-2.39*
IEA	BRASIL	0.0613	-0 16	0.0694	0 14	0.6340	-2 01*
CNEN	BRASIL	0.0610	-0.65	0.0691	-0.29	0.6320	-2 32*
NAEA	INDONESIA	0 0608	-0.99	0.0670	-3.30	0.6316	-2.37*
KAERI	KOREA	0.0610	-0.72	0.0690	-0.49	0.6319	-2.34*
ZFK	GERMANY	0.0608	-0.98	0.0701	1.15	0.6329	-2 18*
IPEN	PERU						
AEC	SOUTH AFRICA	0.0611	-0.49	0.0694	0 14	0.6320	-2 32*
	VIETNAM	0.0608	-0.98	0 0689	-0.58		
CNEA	ARGENTINA	0 0608	-0 90	0.0695	0.33	0.6352	-1.82*
HU	TURKEY 9)	0.0612	-0.39	0.0700	1.07	0 6347	-1.90*
IEA	BRASIL 7)	0.0611	-0.44	0.0700	0 98	0.6326	-2 23*
IJS	SLOVENIA	0 0610	-0 64	0.0695	0.30	0.6321	-2 30*
AERE	BANGLAD. 9)						
AERE	BANGLADESH						
PINST	PAKISTAN	0 0610	-0.70	0 0685	-1.21	0.6339	-2 02*
PINST	PAKISTAN 9)	0.0611	-0.57	0.0688	-0 76	0.6344	-1.95*
CNEN	BRASIL 7)	0 0611	-0.49	0 0699	0 87	0 6320	-2 32*
SKODA	CSFR 1)	0 0612	-0 33	0.0688	-0.72	0 6329	-2 18*
SKODA	CSFR 2)	0 0601	-2.12*	0.0728	5 05	0.6369	-1.56*
BARC	INDIA	0 0608	-0.94	0 0702	1.27	0 6346	-1.92*
NRI	CSFR 3)	0.0610	-0 64	0 0695	0.30	0.6321	-2.30*
CEADN	CUBA	0.0610	-0.65	0.0695	0.29	0.6342	-1 98*
CEADN	CUBA 7)	0 0613	-0.16	0 0691	-0 29	0.6334	-2.10*
IGCAR	INDIA 4)	0.0608	-0.98	0.0642	-7.36*	0.6400	-1 08*
IGCAR	INDIA 5)	0.0609	-0.81	0.0677	-2.31	0.6400	-1 08*
CNEA	ARGENTINA 7)	0.0611	-0.49	0 0700	1.01	0.6326	-2 23*
CNEA	ARGENTINA 8)	0.0612	-0.33	0.0700	1 01	0.6348	-1.89*
CNAEN	TURKEY	0.0613	-0.16	0.0692	-0.14	0 6349	-1.87*
TU	IRAN	0.0609	-0 81	0.0696	0.43	0.6349	-2.18*

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
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4) MURLI PROGRAM, WINS 1971 LIBRARY
5) MURLI PROGRAM, WINS 1971 LIBRARY WITH CHANGES
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-3. BAPL-1 Results contributed for the first stage of WLUP

BENCHMARK : BAPL1

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NN	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	10	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	15	24	4	-1
NAEA	INDONESIA	235.4	238.4	2001	1	4	1	3	6	2	1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235.4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235.4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238 4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
IEA	BRASIL 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	10	69	1	1
AERE	BANGLAD. 9)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		12	20	2	0
PINST	PAKISTAN 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNEN	BRASIL 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
SKODA	CSFR 1)	235.4	2238.4	2001	2		1	15	18	1	1
SKODA	CSFR 2)	2235.0	8238.0	3001	2		1	15	18	1	1
BARC	INDIA	235 4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
NRI	CSFR 1)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		10	36	2	1
CEADN	CUBA 7)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
IGCAR	INDIA 4)	235.4	3238.4	2001							
IGCAR	INDIA 5)	235.4	3238.4	2001							
CNEA	ARGENTINA 6)	1235.4	3238.5	6001	2			9	18	2	0
CNEA	ARGENTINA 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNEA	ARGENTINA 8)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNAEN	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

1) NEA 0329/13 PROGRAM AND LIBRARY
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5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
6) CRNL LIBRARY
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-3: Continued

BENCHMARK : BAPL1

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	RO28	R.D.RO28 (%)
EXPERIMENT					1.3900	+-0.72
IIE	MEXICO	1.14639	1.00666	0.67	1.3400	-3.60*
OAEP	THAILAND	1.14212	1.00333	0.33	1.3412	-3.51*
IEA	BRASIL	1.14162	1.00128	0.13	1.3500	-2.88*
CNEN	BRASIL	1.13419	0.99459	-0.54	1.4100	1.44*
NAEA	INDONESIA	1.14281	0.98968	-1.03	1.3660	-1.73*
KAERI	KOREA	1.14120	1.00253	0.25	1.3462	-3.15*
ZFK	GERMANY	1.14300	0.99980	-0 02	1.3586	-2.26*
IPEN	PERU	1.13900	1.00329	0.33		
AEC	SOUTH AFRICA	1.14167	1.00284	0.28	1.3456	-3.19*
	VIETNAM	1.14580	1.00090	0.09	1 4302	2.89*
CNEA	ARGENTINA		1.00070	0 07	1.3688	-1.53*
HU	TURKEY 9)	1.14044	1.00123	0.12	1 3601	-2.15*
IEA	BRASIL 7)	1.14245	1.00294	0.29	1.3453	-3.22*
IJS	SLOVENIA	1.14175	1.00292	0.29	1.3454	-3.21*
AERE	BANGLAD. 9)	1.14330	1.00124	0.12		
AERE	BANGLADESH	1.14423	1.00261	0.26		
PINST	PAKISTAN	1.14227	1.00168	0 17	1.3608	-2.10*
PINST	PAKISTAN 9)	1.14329	1.00123	0.12	1 3601	-2.15*
CNEN	BRASIL 7)	1.14543	1.00295	0.29	1 3400	-3.60*
SKODA	CSFR 1)	1.14610	1.00390	0 39	1 3395	-3.63*
SKODA	CSFR 2)	1.14760	0.99750	-0.25	1.4290	2.81*
BARC	INDIA		0.99264	-0.74	1.3091	-5.82*
NRI	CSFR 3)	1.14492	1 00301	0 30	1.3454	-3.21*
NRI	CSFR 1)	1.14174	1.00292	0 29	1 3454	-3.21*
CEADN	CUBA	1.14206	0.99897	-0 10	1 3625	-1.98*
CEADN	CUBA 7)	1.14409	1.00196	0.20	1 3494	-2.92*
IGCAR	INDIA 4)	1.13352	0.99753	-0.25	1.4090	1.37*
IGCAR	INDIA 5)	1.13515	0.99157	-0.84	1.4090	1.37*
CNEA	ARGENTINA 6)		0.99984	-0.02	1.3680	-1.58*
CNEA	ARGENTINA 7)		1.00297	0.30	1.3457	-3.19*
CNEA	ARGENTINA 8)		1.00294	0.29	1.3451	-3.23*
CNAEN	TURKEY	1.14000	1.00110	0.11	1 3614	-2.06*
TU	IRAN	1.14208	1.00111	0 11	1 3550	-2.52*

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
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5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
6) CRNL LIBRARY
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-3: Continued

BENCHMARK : BAPL1

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R D.D28 (%)	C*
EXPERIMENT		0.0840	+-2.38	0 0780	+-5.13	
IIE	MEXICO	0.0840	0.00	0 0770	-1 28	
OAEP	THAILAND	0.0840	0.02	0 0762	-3 63	0 7947
IEA	BRASIL	0 0840	0.00	0 0770	-1 28	
CNEN	BRASIL	0.0840	0.00	0.0770	-1 28	
NAEA	INDONESIA	0.0858	2.18	0 0769	-1 40	0.8029
KAERI	KOREA	0.0841	0.08	0.0762	-3 62	0 7963
ZFK	GERMANY	0.0841	0 12	0 0768	-1 54	0 8004
IPEN	PERU					
AEC	SOUTH AFRICA	0.0843	0 36	0.0764	-3.33	
	VIETNAM	0.0838	-0.24	0 0766	-1 79	
CNEA	ARGENTINA	0.0840	0.06	0.0768	-1 53	0 8043
HU	TURKEY 9)	0.0843	0.39	0.0762	-2 27	0.8007
IEA	BRASIL 7)	0.0840	0 04	0 0761	-2 47	0 7958
IJS	SLOVENIA	0.0840	0.05	0 0755	-3 23	0 7960
AERE	BANGLAD. 9)					
AERE	BANGLADESH					
PINST	PAKISTAN	0.0842	0 20	0 0759	-2.72	0 8011
PINST	PAKISTAN 9)	0.0843	0.39	0.0762	-2.27	0 8007
CNEN	BRASIL 7)	0.0840	0.00	0 0760	-2.56	
SKODA	CSFR 1)	0.0840	0 00	0 0758	-2 82	0.7939
SKODA	CSFR 2)	0.0826	-1 79	0.0791	1 41	0.8078
BARC	INDIA	0.0787	-6.29*	0.0742	-4 87	0.7861
NRI	CSFR 3)	0.0840	0.05	0.0755	-3 24	0 7960
NRI	CSFR 1)	0.0840	0 05	0.0755	-3.24	0 7960
CEADN	CUBA	0.0843	0.36	0.0764	-2.05	0.8021
CEADN	CUBA 7)	0.0842	0 24	0 0754	-3.33	0.7972
IGCAR	INDIA 4)	0.0844	0 48	0.0714	-8 46*	
IGCAR	INDIA 5)	0.0845	0.60	0 0750	-3 85	
CNEA	ARGENTINA 6)	0.0807	-3 93*	0 0759	-2 68	0.7992
CNEA	ARGENTINA 7)	0.0841	0.12	0.0761	-2 44	0.7979
CNEA	ARGENTINA 8)	0.0840	0 00	0 0761	-2 44	0.7958
CNAEM	TURKEY	0 0843	0.36	0 0768	-1.54	0 8013
TU	IRAN	0.0840	0 00	0 0779	-0.13	0.7991

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
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4) NURLI PROGRAM, WINS 1971 LIBRARY
5) NURLI PROGRAM, WINS 1971 LIBRARY WITH CHANGES
6) CRNL LIBRARY
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-4: BAPL-2 results contributed for the first stage of WLUP

BENCHMARK : BAPL2

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NM	NG	DI	BE
IIE	MEXICO	235.4	2238.4	2001	1	4	1	10	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235.4	2238.4	2001	1	4	1	15	24	4	-1
NAEA	INDONESIA	235.4	238.4	2001	1	4	1	3	6	2	1
KAERI	KOREA	235.4	2238.4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235 4	2238.4	2001	2			20	69	2	1
IPEN	PERU	235 4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235.4	2238.4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238 4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
IEA	BRASIL 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
IJS	SLOVENIA	235.4	2238.4	2001	1	12	1 6	10	69	1	1
AERE	BANGLAD 9)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
AERE	BANGLADESH	235.4	2238.4	2001					69		
PINST	PAKISTAN	235.4	2238.4	2001	1	4		13	20	2	0
PINST	PAKISTAN 9)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNEN	BRASIL 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
SKODA	CSFR 1)	235.4	2238.4	2001	2		1	15	18	1	1
SKODA	CSFR 2)	2235.0	8238.0	3001	2		1	15	18	1	1
BARC	INDIA	235.4	2238.4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238.4	2001	1	12	1 6	10	69	1	1
CEADN	CUBA	235.4	2238.4	2001	1	8		10	36	2	1
CEADN	CUBA 7)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
IGCAR	INDIA 4)	235.4	3238.4	2001							
IGCAR	INDIA 5)	235.4	3238.4	2001							
CNEA	ARGENTINA 7)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNEA	ARGENTINA 8)	235.4	2238.4	2001	2		1 6	10	18	1	1
CNAEM	TURKEY	235.4	2238.4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

1) NEA 0329/13 PROGRAM AND LIBRARY
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3) WINS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
4) NURLI PROGRAM, WINS 1971 LIBRARY
5) NURLI PROGRAM, WINS 1971 LIBRARY WITH CHANGES
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-4: Continued

BENCHMARK : BAPL2

LAB.	COUNTRY	K-INF	K-EFF	R.D.EFF (%)	RO28	R.D.RO28 (%)
EXPERIMENT					1.1200	+-0.89
IIE	MEXICO	1.14846	1.00522	0.52	1.1200	0.00
OAEP	THAILAND	1.14444	1 00127	0.13	1.1194	-0.05
IEA	BRASIL	1.14397	0.99881	-0.12	1.1300	0.89
CNEN	BRASIL	1.14064	0.99671	-0.33	1.1600	3.57*
NAEA	INDONESIA	1.14665	0.99235	-0.77	1.1381	1.62*
KAERI	KOREA	1.14368	1.00059	0.06	1.1227	0.24
ZFK	GERMANY	1.14550	0.99860	-0.14	1.1335	1.21*
IPEN	PERU	1.14110	1.00144	0.14		
AEC	SOUTH AFRICA	1.14419	1.00047	0.05	1.1228	0.25
	VIETNAM	1.14820	1.00000	0.00	1.1177	-0.21
CNEA	ARGENTINA		0 99963	-0.04	1.1422	1.98*
HU	TURKEY 9)	1.14335	0 99923	-0.08	1.1351	1.35*
IEA	BRASIL 7)	1.14519	1.00078	0.08	1.1226	0.23
IJS	SLOVENIA	1.14428	1 00049	0.05	1.1227	0.24
AERE	BANGLAD. 9)	1.14599	0.99925	-0.07		
AERE	BANGLADESH	1.14642	1.00071	0.07		
PINST	PAKISTAN	1.14488	1.00036	0.04	1.1347	1.31*
PINST	PAKISTAN 9)	1.14596	0.99916	-0.08	1.1351	1.35*
CNEN	BRASIL 7)	1 14785	1 00080	0.08	1.1200	0.00
SKODA	CSFR 1)	1.14840	1 00170	0.17	1.1187	-0.12
SKODA	CSFR 2)	1.15160	0 99740	-0.26	1.1767	5.06*
BARC	INDIA		0.98923	-1.08	1.0959	-2.15*
NRI	CSFR 3)	1.14720	1.00061	0.06	1.1226	0.23
CEADN	CUBA	1.14477	0.99793	-0.21	1.1362	1.45*
CEADN	CUBA 7)	1.14652	0.99974	-0.03	1.1256	0.50
IGCAR	INDIA 4)	1.13806	0.99745	-0.26	1.1700	4.46*
IGCAR	INDIA 5)	1.13947	0.99091	-0.91	1.1720	4.64*
CNEA	ARGENTINA 7)		1 00081	0.08	1.1226	0.23
CNEA	ARGENTINA 8)		0.99923	-0.08	1.1351	1.35*
CNAEN	TURKEY	1.14270	0.99960	-0.04	1.1354	1.38*
TU	IRAN	1.14479	0.99959	-0.04	1.1325	1.12*

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
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2) WIMSD2A PROGRAM, 1986 WIMS LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
4) MURLI PROGRAM, WIMS 1971 LIBRARY
5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-4: Continued

BENCHMARK : BAPL2

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R.D.D28 (%)	C*
EXPERIMENT		0.0680	+-1.47	0 0700	+-5.71	
IIE	MEXICO	0.0690	1.47	0.0670	-4.29	
OAEP	THAILAND	0.0686	0.94	0.0649	-7.34*	0.7272
IEA	BRASIL	0.0690	1.47	0.0660	-5.71*	
CNEN	BRASIL	0.0690	1.47	0.0670	-4.29	
NAEA	INDONESIA	0.0700	2.90*	0.0662	-5.46	0 7337
KAERI	KOREA	0.0687	0.97	0.0649	-7.27*	0.7283
ZFK	GERMANY	0.0687	1.03	0.0663	-5.29	0.7319
IPEN	PERU					
AEC	SOUTH AFRICA	0.0688	1.18	0.0652	-6.86*	
	VIETNAM	0.0685	0.74	0.0660	-5.71*	
CNEA	ARGENTINA	0.0686	0.96	0.0663	-5.33	0.7363
HU	TURKEY 9)	0.0689	1.26	0.0659	-5.87*	0.7322
IEA	BRASIL 7)	0.0687	0.99	0.0658	-6.03*	0.7280
IJS	SLOVENIA	0.0687	1.00	0.0652	-6.80*	0.7282
AERE	BANGLAD. 9)					
AERE	BANGLADESH					
PINST	PAKISTAN	0.0687	1.07	0.0654	-6.57*	0.7323
PINST	PAKISTAN 9)	0.0689	1.26	0.0659	-5.86*	0.7322
CNEN	BRASIL 7)	0.0680	0.00	0.0650	-7.14*	
SKODA	CSFR 1)	0.0686	0.88	0 0656	-6.29*	0 7267
SKODA	CSFR 2)	0.0674	-0.88	0.0682	-2.57	0.7367
BARC	INDIA	0.0645	-5.21*	0.0641	-8.49*	0.7207
NRI	CSFR 3)	0.0687	0.99	0.0652	-6.81*	0.7282
CEADN	CUBA	0.0688	1.18	0.0659	-5.86*	0.7332
CEADN	CUBA 7)	0.0688	1.18	0.0651	-7 00*	0.7291
IGCAR	INDIA 4)	0.0689	1.32	0.0616	-12.00*	
IGCAR	INDIA 5)	0.0689	1.32	0.0646	-7.71*	
CNEA	ARGENTINA 7)	0.0687	1.03	0.0658	-6.00*	0.7281
CNEA	ARGENTINA 8)	0.0689	1.32	0.0659	-5.86*	0.7322
CNAEN	TURKEY	0.0688	1.18	0.0662	-5.43	0.7325
TU	IRAN	0.0687	1.03	0.0672	-4.00	0.7310

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
2) WIMSD2A PROGRAM, 1986 WIMS LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
4) MURLI PROGRAM, WIMS 1971 LIBRARY
5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-5: BAPL-3 Results contributed for the first stage of WLUP

BENCHMARK : BAPL3

LAB.	COUNTRY	U235	U238	H1	SEQ	SN	REG	NM	NG	DI	BE
IIE	MEXICO	235 4	2238 4	2001	1	4	1	11	11	2	1
OAEP	THAILAND	235.4	2238.4	2001	1	4	1	7	56	2	1
IEA	BRASIL	235.4	2238.4	2001	1	4	1	16	18	1	1
CNEN	BRASIL	235 4	2238 4	2001	1	4	1	15	24	4	-1
NAEA	INDONESIA	235.4	238.4	2001	1	4	1	3	6	2	1
KAERI	KOREA	235.4	2238 4	2001	1	4	1 6	10	69	2	1
ZFK	GERMANY	235 4	2238 4	2001	2			20	69	2	1
IPEN	PERU	235 4	2238.4	2001	1	4		12	18	2	0
AEC	SOUTH AFRICA	235.4	2238.4	2001	1	10	1 6	17	69	1	1
	VIETNAM	235 4	2238 4	2001	1	4	1 6	8	6	2	0
CNEA	ARGENTINA	235.4	2238.4	2001	2			9	18	2	0
HU	TURKEY 9)	235.4	2238 4	2001	2		1 6	10	18	1	1
IEA	BRASIL 7)	235 4	2238 4	2001	2		1 6	10	18	1	1
IJS	SLOVENIA	235 4	2238 4	2001	1	12	1 6	10	69	1	1
AERE	BANGLAD 9)	235.4	2238 4	2001	1	4	1 6	10	18	1	1
AERE	BANGLADESH	235.4	2238 4	2001					69		
PINST	PAKISTAN	235 4	2238 4	2001	1	4		14	20	2	0
PINST	PAKISTAN 9)	235.4	2238 4	2001	2		1 6	10	18	1	1
CNEN	BRASIL 7)	235.4	2238 4	2001	2		1 6	10	18	1	1
SKODA	CSFR 1)	235.4	2238 4	2001	2		1	15	18	1	1
SKODA	CSFR 2)	2235.0	8238 0	3001	2		1	15	18	1	1
BARC	INDIA	235.4	2238 4	2001	2			12	6	2	0
NRI	CSFR 3)	235.4	2238 4	2001	1	12	1 6	10	69	1	1
CEADN	CUBA	235 4	2238 4	2001	1	8		10	36	2	1
CEADN	CUBA 7)	235.4	2238.4	2001	1	4	1 6	10	18	1	1
IGCAR	INDIA 4)	235.4	3238 4	2001							
IGCAR	INDIA 5)	235 4	3238 4	2001							
CNEA	ARGENTINA 7)	235 4	2238 4	2001	2		1 6	10	18	1	1
CNEA	ARGENTINA 8)	235.4	2238 4	2001	2		1 6	10	18	1	1
CNAEM	TURKEY	235.4	2238 4	2001	1	4		20	20	2	0
TU	IRAN	235.4	2238.4	2001	1	4	1 6	10	6	2	0

1) NEA 0329/13 PROGRAM AND LIBRARY
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5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-5· Continued

BENCHMARK : BAPL3

LAB.	COUNTRY	K-INF	K-EFF	R D EFF (%)	RO28	R D RO28 (%)
EXPERIMENT					0 9060	+-1 10
IIE	MEXICO	1.13234	1.00365	0 36	0 8800	-2 87*
OAEP	THAILAND	1.12886	0.99892	-0.11	0 8824	-2 60*
IEA	BRASIL	1 12868	0.99676	-0.32	0 8870	-2.10*
CNEN	BRASIL	1.12937	0.99922	-0.08	0.9040	-0 22
NAEA	INDONESIA	1.13353	0.99672	-0 33	0.8948	-1 24*
KAERI	KOREA	1.12817	0.99835	-0 16	0.8847	-2 36*
ZFK	GERMANY	1 13000	0.99770	-0.23	0.8928	-1 46*
IPEN	PERU	1.12518	0.99915	-0 09		
AEC	SOUTH AFRICA	1.12885	0.99809	-0 19	0.8848	-2 34*
	VIETNAM	1 13270	0.99990	-0 01	0.8808	-2 78*
CNEA	ARGENTINA		0.99911	-0 09	0 8998	-0 68
HU	TURKEY 9)	1.12892	0.99775	-0 22	0 8940	-1 32*
IEA	BRASIL 7)	1.13038	0.99901	-0 10	0 8847	-2 35*
IJS	SLOVENIA	1.12899	0.99807	-0 19	0 8849	-2.33*
AERE	BANGLAD 9)	1.13090	0.99781	-0 22		
AERE	BANGLADESH	1.13018	0.99849	-0 15		
PINST	PAKISTAN	1 12937	0.99912	-0 09	0 8934	-1 39*
PINST	PAKISTAN 9)	1 13090	1 00005	0 00	0 8931	-1 42*
CNEN	BRASIL 7)	1 13230	0.99905	-0 10	0 8840	-2 43*
SKODA	CSFR 1)	1 13280	0.99990	-0 01	0 8821	-2 64*
SKODA	CSFR 2)	1 13780	0.99880	-0.12	0 9249	2 09*
BARC	INDIA		0.98618	-1 38	0 8670	-4.30*
NRI	CSFR 3)	1 13115	0.99821	-0 18	0.8849	-2 33*
CEADN	CUBA	1 12942	0.99715	-0.28	0 8941	-1 31*
CEADN	CUBA 7)	1.13070	0 99768	-0.23	0 8869	-2 11*
IGCAR	INDIA 4)	1.12461	0 99745	-0 26	0 9200	1 55*
IGCAR	INDIA 5)	1.12578	0.99091	-0 91	0 9200	1.55*
CNEA	ARGENTINA 7)		0.99910	-0 09	0 8847	-2.35*
CNEA	ARGENTINA 8)		0.99900	-0.10	0 8847	-2.35*
CNAEM	TURKEY	1.12770	0.99830	-0.17	0.8939	-1 34*
TU	IRAN	1.13006	0.99895	-0.10	0 8910	-1 65*

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7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

Table A-5: Continued

BENCHMARK : BAPL3

LAB.	COUNTRY	DEL25	R.D.D25 (%)	DEL28	R.D.D28 (%)	C*
EXPERIMENT		0.0520	+-1.92	0.0570	+-5.26	
IIE	MEXICO	0.0530	1.92	0.0550	-3.51	
OAEP	THAILAND	0.0527	1.44	0.0534	-6.25*	0.6531
IEA	BRASIL	0.0530	1.92	0.0540	-5.26	
CNEN	BRASIL	0.0530	1.92	0.0550	-3.51	
NAEA	INDONESIA	0.0537	3.33*	0.0541	-5.11	0.6577
KAERI	KOREA	0.0529	1.69	0.0535	-6.16*	0.6539
ZFK	GERMANY	0.0529	1.73	0.0546	-4.21	0.6566
IPEN	PERU					
AEC	SOUTH AFRICA	0.0530	1.92	0.0538	-5.61*	
	VIETNAM	0.0527	1.35	0.0542	-4.91	
CNEA	ARGENTINA	0.0529	1.63	0.0546	-4.26	0.6594
HU	TURKEY 9)	0.0529	1.83	0.0543	-4 65	0.6568
IEA	BRASIL 7)	0.0529	1.71	0.0543	-4.77	0.6537
IJS	SLOVENIA	0.0529	1.73	0.0538	-5.56*	0.6539
AERE	BANGLAD. 9)					
AERE	BANGLADESH					
PINST	PAKISTAN	0.0529	1.75	0.0538	-5 65*	0.6568
PINST	PAKISTAN 9)	0.0529	1.71	0.0536	-5.91*	0.6566
CNEN	BRASIL 7)	0.0520	0 00	0 0540	-5 26	
SKODA	CSFR 1)	0 0529	1 73	0.0541	-5 09	0 6528
SKODA	CSFR 2)	0 0519	-0.19	0.0561	-1.58	0.6588
BARC	INDIA	0.0498	-4.29*	0.0528	-7.39*	0.6456
NRI	CSFR 3)	0 0529	1.73	0.0538	-5 56*	0.6539
CEADN	CUBA	0.0530	1.92	0.0542	-4.91	0.6574
CEADN	CUBA 7)	0.0530	1.92	0 0536	-5 96*	0.6544
IGCAR	INDIA 4)	0.0529	1.73	0.0507	-11.05*	
IGCAR	INDIA 5)	0 0530	1.92	0.0532	-6.67*	
CNEA	ARGENTINA 7)	0.0530	1.92	0.0540	-5.26	0.6536
CNEA	ARGENTINA 8)	0.0530	1.92	0.0540	-5.26	0.6537
CNAEM	TURKEY	0.0530	1.92	0.0544	-4.56	0.6569
TU	IRAN	0.0528	1.54	0.0551	-3.33	0.6557

* OUT OF RANGE OF EXPERIMENTAL UNCERTAINTY
1) NEA 0329/13 PROGRAM AND LIBRARY
2) WIMSD2A PROGRAM, 1986 WIMS LIBRARY
3) WIMS VERSION 101 (NOV. 1981), NEA 0329/13 LIBRARY
4) MURLI PROGRAM, WIMS 1971 LIBRARY
5) MURLI PROGRAM, WIMS 1971 LIBRARY WITH CHANGES
7) MODEL INPUT DATA (NMATERIAL 3)
8) MODEL INPUT DATA (NMATERIAL 4), NEA 0329/14
9) MODEL INPUT DATA (NMATERIAL 4)

APPENDIX B

B Prescribed WIMS Input

B.1 Model input specifications for the benchmark lattices

```
*************************************************************
* WIMS
* TRX-1
*************************************************************
CELL       6
SEQUENCE   1
NGROUP    18   2
NMESH     10
NREGION    4   0   4
NMATERIAL  3
NREACT     2
PREOUT
INITIATE
ANNULUS    1   0 4915    1
ANNULUS    2   0 5042    0
ANNULUS    3   0 5753    2
ANNULUS    4   0.94822   3
FEWGROUP   2   3   4   5   6   7   9 12 16 20 23 27 45 54 57 60 63 69
MESH       4   1   1   4
MATERIAL   1  -1   293.0 1 235 4 .0006253 2238.4   047205
MATERIAL   2  -1   293 0 2     27   06025
MATERIAL   3  -1   293 0 3   2001   06676        16   03338
REGULAR    1   6
S          4
BEGINC
THERMAL    6
BEEONE     1
DNB        1 0        0  0        0
DNB        2 0        0. 0.       0
DNB        3 0 06676 0   0.03338 0
BUCKLINGS 0.005174   0.000526
DIFFUSION  1   3   1
LEAKAGE    5
REACTION (235,293 0) (2238,293 0)
PARTITION 45 69
BEGINC
```

```
*************************************************************
* WIMS
* TRX-2
*************************************************************
CELL       6
SEQUENCE   1
NGROUP    18   2
NMESH     14
NREGION    4   0   4
NMATERIAL  3
NREACT     2
PREOUT
INITIATE
ANNULUS    1   0 4915    1
ANNULUS    2   0.5042    0
ANNULUS    3   0 5753    2
ANNULUS    4   1 1414    3
NGROUP    18   2
FEWGROUP   2   3   4   5   6   7   9 12 16 20 23 27 45 54 57 60 63 69
MESH       4   1   1   8
MATERIAL   1  -1   293.0 1 235 4   0006253 2238 4   047205
MATERIAL   2  -1   293.0 2     27   06025
MATERIAL   3  -1   293 0 3   2001   06676        16   03338
REGULAR    1   6
S          4
BEGINC
THERMAL    6
BEEONE     1
DNB        1 0        0  0        0
DNB        2 0.       0  0        0
DNB        3 0.06676  0   0 03338 0
BUCKLINGS 0.004943   0 000526
DIFFUSION  1   3   1
LEAKAGE    5
REACTION (235,293 0) (2238,293 0)
PARTITION 45 69
BEGINC
```

```
*************************************************************
* WIMS
* BAPL-U02-1
*************************************************************
CELL      6
SEQUENCE  1
NGROUP    18  2
NMESH     10
NREGION   4  0  4
NMATERIAL 3
NREACT    2
PREOUT
INITIATE
ANNULUS   1  0.4864   1
ANNULUS   2  0.5042   0
ANNULUS   3  0.5753   2
ANNULUS   4  0.81790  3
NGROUP    18  2
FEWGROUP  2  3  4  5  6  7  9 12 16 20 23 27 45 54 57 60 63 69
MESH      4  1  1  4
MATERIAL  1 -1  293.0 1 235.4 .0003112 2238.4 .023127 16 .046946
MATERIAL  2 -1  293.0 2    27 .06025
MATERIAL  3 -1  293.0 3  2001  06676        16 .03338
REGULAR   1  6
S         4
BEGINC
THERMAL   6
BEEONE    1
DNB       1 0.       0  0.       0
DNB       2 0.       0. 0.       0
DNB       3 0.06676  0. 0.03338  0
BUCKLINGS 0.002734  0.000525
DIFFUSION 1  3  1
LEAKAGE   5
REACTION (235,293.0) (2238,293 0)
PARTITION 45 69
BEGINC
```

```
*************************************************************
* WIMS
* BAPL-U02-2
*************************************************************
CELL      6
SEQUENCE  1
NGROUP    18  2
NMESH     10
NREGION   4  0  4
NMATERIAL 3
NREACT    2
PREOUT
INITIATE
ANNULUS   1  0.4864   1
ANNULUS   2  0.5042   0
ANNULUS   3  0.5753   2
ANNULUS   4  0.86752  3
NGROUP    18  2
FEWGROUP  2  3  4  5  6  7  9 12 16 20 23 27 45 54 57 60 63 69
MESH      4  1  1  4
MATERIAL  1 -1  293.0 1 235.4 .0003112 2238 4 .023127 16 .046946
MATERIAL  2 -1  293.0 2    27 .06025
MATERIAL  3 -1  293.0 3  2001 .06676        16  03338
REGULAR   1  6
S         4
BEGINC
THERMAL   6
BEEONE    1
DNB       1 0        0. 0.       0
DNB       2 0.       0. 0.       0.
DNB       3 0.06676  0  0.03338  0.
BUCKLINGS 0.003018  0.000529
DIFFUSION 1  3  1
LEAKAGE   5
REACTION (235,293 0) (2238,293 0)
PARTITION 45 69
BEGINC
```

```
*************************************************************
* WIMS
* BAPL-U02-3
*************************************************************
CELL       6
SEQUENCE   1
NGROUP    18   2
NMESH     10
NREGION    4   0   4
NMATERIAL  3
NREACT     2
PREOUT
INITIATE
ANNULUS    1   0 4864    1
ANNULUS    2   0 5042    0
ANNULUS    3   0 5753    2
ANNULUS    4   0 94806   3
NGROUP    18   2
FEWGROUP   2   3   4   5   6   7   9 12 16 20 23 27 45 54 57 60 63 69
MESH       4   1   1   4
MATERIAL   1  -1   293 0 1 235 4   0003112 2238 4   023127 16  .046946
MATERIAL   2  -1   293 0 2     27   06025
MATERIAL   3  -1   293 0 3   2001   06676         16   03338
REGULAR    1   6
S          4
BEGINC
THERMAL    6
BEEONE     1
DNB        1 0         0   0         0
DNB        2 0         0   0         0
DNB        3 0 06676 0   0 03338 0
BUCKLINGS 0 002892   0 000530
DIFFUSION 1   3   1
LEAKAGE    5
REACTION (235,293 0) (2238,293 0)
PARTITION 45 69
BEGINC
```

B.2 Optimized input specifications for the benchmark lattices

```
*************************************************************
* WIMS
* TRX-1   SEQUENCE 1    S12   REGULAR 1 6
* 7.11.91               STAND  INPUT    NMATERIAL 3
*************************************************************
CELL       6
SEQUENCE   1
NGROUP    69   2
NMESH     10
NREGION    4   0   4
NMATERIAL  3
NREACT     2
PREOUT
INITIATE
ANNULUS    1 0 4915     1
ANNULUS    2 0 5042     0
ANNULUS    3 0 5753     2
ANNULUS    4 0.94822    3
FEWGROUP   1   2   3   4   5   6   7   8   9 10 11 12 13 14 15 $
          16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 $
          31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 $
          46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 $
          61 62 63 64 65 66 67 68 69
MESH       4   1   1   4
MATERIAL   1  -1   293.0 1 235.4   0006253 2238 4   047205
MATERIAL   2  -1   293 0 2     27  .06025
MATERIAL   3  -1   293 0 3   2001  .06676         16   03338
REGULAR    1   6
S         12
BEGINC
THERMAL   24
BEEONE     1
DNB        1 0         0   0         0
DNB        2 0         0   0         0
DNB        3 0.06676 0   0.03338 0
BUCKLINGS 0.005174   0.000526
DIFFUSION 1   3   1
LEAKAGE    5
REACTION (235,293 0) (2238,293 0)
PARTITION 45 69
BEGINC
```

```
**********************************************************
* WIMS
* TRX-2   SEQUENCE 1    S 12   REGULAR 1 6
* 17.5.91                STAND. INPUT   NMATERIAL 3
**********************************************************
CELL       6
SEQUENCE   1
NGROUP    69  2
NMESH     14
NREGION    4  0  4
NMATERIAL  3
NREACT     2
PREOUT
INITIATE
ANNULUS    1  0.4915    1
ANNULUS    2  0.5042    0
ANNULUS    3  0.5753    2
ANNULUS    4  1.1414    3
FEWGROUP   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 $
          16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 $
          31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 $
          46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 $
          61 62 63 64 65 66 67 68 69
MESH       4  1  1  8
MATERIAL   1 -1  293.0 1 235.4  0006253 2238.4  047205
MATERIAL   2 -1  293.0 2    27  .06025
MATERIAL   3 -1  293.0 3  2001  06676       16  .03338
REGULAR    1  6
S         12
BEGINC
THERMAL   24
BEEONE     1
DNB        1 0.      0. 0       0
DNB        2 0.      0  0       0.
DNB        3 0.06676 0  0 03338 0
BUCKLINGS 0 004943  0 000526
DIFFUSION 1  3  1
LEAKAGE    5
REACTION (235,293.0) (2238,293.0)
PARTITION 45 69
BEGINC
```

```
**********************************************************
* WIMS
* BAPL-U02-1   SEQUENCE 1    S 12   REGULAR 1 6
* 17.5.91                    STAND. INPUT   NMATERIAL 3
**********************************************************
CELL       6
SEQUENCE   1
NGROUP    69  2
NMESH     10
NREGION    4  0  4
NMATERIAL  3
NREACT     2
PREOUT
INITIATE
ANNULUS    1  0.4864    1
ANNULUS    2  0.5042    0
ANNULUS    3  0.5753    2
ANNULUS    4  0.81790   3
FEWGROUP   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 $
          16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 $
          31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 $
          46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 $
          61 62 63 64 65 66 67 68 69
MESH       4  1  1  4
MATERIAL   1 -1  293.0 1 235.4 .0003112 2238.4 .023127 16 .046946
MATERIAL   2 -1  293.0 2    27  .06025
MATERIAL   3 -1  293.0 3  2001 .06676       16  03338
REGULAR    1  6
S         12
BEGINC
THERMAL   24
BEEONE     1
DNB        1 0.      0. 0.      0
DNB        2 0.      0. 0.      0.
DNB        3 0 06676 0. 0.03338 0
BUCKLINGS 0.002734  0.000525
DIFFUSION 1  3  1
LEAKAGE    5
REACTION (235,293.0) (2238,293.0)
PARTITION 45 69
BEGINC
```

```
*************************************************************
* WINS
* BAPL-U02-2   SEQUENCE 1   S 12   REGULAR 1 6
* 17.5.91                   STAND  INPUT   NMATERIAL 3
*************************************************************
CELL      6
SEQUENCE  1
NGROUP   69  2
NMESH    10
NREGION   4  0  4
NMATERIAL 3
NREACT    2
PREOUT
INITIATE
ANNULUS   1  0 4864    1
ANNULUS   2  0 5042    0
ANNULUS   3  0 5753    2
ANNULUS   4  0 86752   3
FEWGROUP  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 $
         16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 $
         31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 $
         46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 $
         61 62 63 64 65 66 67 68 69
MESH      4  1  1  4
MATERIAL  1 -1  293.0 1 235 4  0003112 2238 4  023127 16  046946
MATERIAL  2 -1  293 0 2    27  06025
MATERIAL  3 -1  293.0 3  2001  06676       16  03338
REGULAR   1  6
S        12
BEGINC
THERMAL  24
BEEONE    1
DNB       1 0       0  0       0
DNB       2 0       0  0       0
DNB       3 0.06676 0  0 03338 0
BUCKLINGS 0 003018  0 000529
DIFFUSION 1  3  1
LEAKAGE   5
REACTION (235,293 0) (2238,293 0)
PARTITION 45 69
BEGINC
```

```
*************************************************************
* WINS
* BAPL-U02-3   SEQUENCE 1   S 12   REGULAR 1 6
* 17.5.91                   STAND  INPUT   NMATERIAL 3
*************************************************************
CELL      6
SEQUENCE  1
NGROUP   69  2
NMESH    10
NREGION   4  0  4
NMATERIAL 3
NREACT    2
PREOUT
INITIATE
ANNULUS   1  0 4864    1
ANNULUS   2  0.5042    0
ANNULUS   3  0.5753    2
ANNULUS   4  0 94806   3
FEWGROUP  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 $
         16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 $
         31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 $
         46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 $
         61 62 63 64 65 66 67 68 69
MESH      4  1  1  4
MATERIAL  1 -1  293.0 1 235 4 .0003112 2238 4  023127 16  046946
MATERIAL  2 -1  293.0 2    27 .06025
MATERIAL  3 -1  293 0 3  2001 .06676       16  03338
REGULAR   1  6
S        12
BEGINC
THERMAL  24
BEEONE    1
DNB       1 0       0  0       0
DNB       2 0       0  0       0
DNB       3 0.06676 0  0 03338 0
BUCKLINGS 0.002892  0 000530
DIFFUSION 1  3  1
LEAKAGE   5
REACTION (235,293.0) (2238,293 0)
PARTITION 45 69
BEGINC
```

APPENDIX C

C Complete Sensitivity Analysis Results

Table C-6 Influence of SEQUENCE on TRX-2 (BEEONE 1)

BENCHMARK	TRX2				
SEQUENCE		1	1	1	2
S		4	8	12	
NMESH		14	14	14	10
K-INFIN.		1.16218	1.16361	1.16395	1.16580
ERR. [%]		-0.15	-0 03	0.00	0.16
K-EFF.	1 00000	0.99415	0.99542	0.99572	0.99744
ERR. [%]		-0 58	-0.46	-0.43	-0.26
RHO28	0 8370	0 8025	0.8023	0 8024	0.8006
ERR [%]	+-1.91	-4.12	4.15	-4.13	-4.35
DEL25	0.06140	0.06106	0.06103	0.06103	0.06093
ERR. [%]	+-1.30	-0.55	-0.60	-0.60	-0.77
DEL28	0.06930	0.06907	0 06942	0 06957	0.06989
ERR [%]	+-5.05	-0.33	0 17	0.39	0.85
C*	0.6470	0.6342	0.6340	0.6341	0.6334
ERR [%]	+-0.93	-1.98	-2.01	-1.99	-2.10

Table C-7: Influence of SEQUENCE on BAPL-1 (BEEONE 1)

BENCHMARK :	BAPL1				
SEQUENCE		1	1	1	2
S		4	8	12	
K-INFIN.		1.14234	1.14287	1.14304	1.14348
ERR. [%]		-0.06	-0.01	0.00	0.04
K-EFF.	1.00000	1.00072	1.00116	1.00130	1 00183
ERR. [%]		0.07	0.12	0.13	0 18
RHO28	1.3900	1.3596	1.3578	1 3574	1.3560
ERR. [%]	+-0 72	-2.19	-2 32	-2.35	-2 45
DEL25	).08400	0.08425	0.08416	0 08414	0.08410
ERR. [%]	+-2.38	0.30	0.19	0.17	0 12
DEL28	0.07800	0.07535	0.07553	0.07561	0.07602
ERR. [%]	+-5.13	-3.40	-3.17	-3.06	-2 54
C*	0.0000	0.8008	0.8001	0.8000	0.7995
ERR. [%]	+-0 00	0.00	0.00	0.00	0.00

Table C-8 Influence of SEQUENCE on BAPL-3 (BEEONE 1)

BENCHMARK : BAPL3					
SEQUENCE		1	1	1	2
S		4	8	12	
NMESH		10	10	10	10
K-INFIN		1.12882	1.12951	1 12971	1.13048
ERR [%]		0 08	-0 02	0 00	0.07
K-EFF	1 00000	0 99605	0 99665	0 99682	0.99757
ERR [%]		-0 39	-0 33	-0 32	-0.24
RHO28	0 9060	0 8948	0 8939	0 8938	0.8935
ERR [%]	+-1 10	-1 24	-1 34	-1.35	-1 38
DEL25	0 05200	0 05301	0 05297	0 05296	0 05297
ERR [%]	+-1 92	1 94	1 87	1 85	1.87
DEL28	0 05700	0 05360	0 05381	0.05390	0.05425
ERR [%]	+-5 26	-5 96	-5 60	-5 44	-4.82
C*	0 0000	0 6573	0 6570	0 6570	0.6568
ERR. [%]	+-0 00	0 00	0 00	0 00	0.00

Table C-9 Influence of REGULAR on TRX-2

BENCHMARK TRX2				
REGULAR			1	1 6
K-INFIN		1 16290	1 16412	1 16396
ERR. [%]		-0 09	0.01	0.00
K-EFF	1 00000	0 99484	0 99586	0 99572
ERR [%]		-0 52	-0 41	-0 43
RHO28	0 8370	0 8086	0 8014	0.8024
ERR [%]	+-1 91	-3.39	-4.25	-4 13
DEL25	0 06140	0 06106	0 06103	0 06103
ERR. [%]	+-1 30	-0 55	-0 60	-0.60
DEL28	0 06930	0 06963	0 06956	0 06957
ERR. [%]	+-5 05	0 48	0 38	0 39
C*	0 6470	0 6362	0 6337	0 6341
ERR [%]	+-0 93	-1 67	-2 06	-1 99

Table C-10 Influence of REGULAR on BAPL-1

BENCHMARK : BAPL1				
REGULAR			1	1 6
K-INFIN		1.14052	1 14397	1 14304
ERR [%]		-0 22	0 08	0 00
K-EFF	1.00000	0 99913	1 00211	1 00130
ERR [%]		-0.09	0 21	0 13
RHO28	1 3900	1.3736	1.3514	1 3574
ERR [%]	+-0.72	-1.18	-2 78	-2 35
DEL25	0 08400	0 08427	0 08409	0.08414
ERR [%]	+-2 38	0 32	0 11	0 17
DEL28	0.07800	0.07579	0 07555	0.07561
ERR [%]	+-5.13	-2.83	-3 14	-3 06
C*	0 0000	0 8054	0 7980	0 8000
ERR [%]	+-0 00	0 00	0 00	0 00

Table C-11 Influence of REGULAR on BAPL-3

BENCHMARK : BAPL3				
REGULAR			1	1 6
K-INFIN.		1.12815	1 13006	1 12971
ERR [%]		-0.14	0 03	0 00
K-EFF.	1 00000	0.99546	0.99713	0 99682
ERR [%]		-0.45	-0 29	-0 32
RHO28	0 9060	0.9035	0 8916	0 8938
ERR [%]	+-1 10	-0 28	-1 59	-1 35
DEL25	0 05200	0 05302	0 05295	0 05296
ERR [%]	+-1 92	1 96	1 83	1 85
DEL28	0 05700	0 05398	0 05388	0 05390
ERR [%]	+-5 26	-5 30	-5 47	-5 44
C*	0 0000	0 6603	0 6562	0 6570
ERR [%]	+-0.00	0 00	0 00	0 00

Table C-12 Influence of DIFFUSION and BEEONE on TRX-2

BENCHMARK :		TRX2			
DIFFUS		1	1	2	2
BEEONE		1	0	1	0
K-INFIN.		1.16395	1.16395	1.16395	1.16395
ERR. [%]		0.00	0.00	0.00	0 00
K-EFF.	1.00000	0.99572	0.99905	0.99777	1.00113
ERR [%]		-0 43	-0.10	-0.22	0 11
RHO28	0 8370	0.8024	0.8012	0.8014	0.8002
ERR. [%]	+-1 91	-4.13	-4.28	-4 25	-4.40
DEL25	0.06140	0 06103	0.06092	0.06096	0.06085
ERR. [%]	+-1.30	-0 60	-0 78	-0 72	-0.90
DEL28	0.06930	0.06957	0.06833	0.06952	0.06829
ERR. [%]	+-5.05	0.39	-1.40	0.32	-1.46
C*	0.6470	0.6341	0.6337	0 6337	0.6334
ERR. [%]	+-0.93	-1.99	-2.06	-2.06	-2.10

Table C 13 Influence of DIFFUSION and BEEONE on BAPL-1

BENCHMARK :		BAPL1			
DIFFUS.		1	1	2	2
BEEONE		1	0	1	0
K-INFIN.		1.14304	1.14304	1.14304	1 14304
ERR [%]		0.00	0.00	0.00	0.00
K-EFF.	1.00000	1.00130	1.00324	1.00150	1.00344
ERR. [%]		0.13	0.32	0.15	0.34
RHO28	1.3900	1.3574	1.3560	1.3560	1.3546
ERR. [%]	+-0.72	-2.35	-2 45	-2.45	-2 55
DEL25	0.08400	0.08414	0.08403	0.08405	0 08395
ERR. [%]	+-2.38	0.17	0.04	0.06	-0.06
DEL28	0.07800	0.07561	0.07475	0.07555	0.07469
ERR. [%]	+-5 13	-3.06	-4.17	-3.14	-4.24
C*	0.0000	0 8000	0.7996	0.7996	0.7992
ERR. [%]	+-0.00	0.00	0.00	0.00	0.00

Table C-14: Influence of DIFFUSION and BEEONE on BAPL-3

BENCHMARK :		BAPL3			
DIFFUS.		1	1	2	2
BEEONE		1	0	1	0
K-INFIN.		1.12971	1.12971	1.12971	1.12971
ERR [%]		0.00	0 00	0 00	0 00
K-EFF.	1.00000	0.99682	0.99927	0.99793	1.00039
ERR. [%]		-0.32	-0.07	-0.21	0.04
RHO28	0.9060	0.8938	0 8929	0.8926	0.8917
ERR [%]	+-1.10	-1.35	-1.45	-1 48	-1 58
DEL25	0.05200	0.05296	0.05289	0.05289	0 05283
ERR. [%]	+-1.92	1.85	1.71	1.71	1 60
DEL28	0 05700	0.05390	0.05320	0.05383	0.05314
ERR. [%]	+-5.26	-5.44	-6 67	-5.56	-6.77
C*	0.0000	0.6570	0.6567	0 6566	0 6563
ERR. [%]	+-0.00	0.00	0 00	0.00	0 00

Table C-15· Influence of fission spectrum on TRX-1

BENCHMARK :		TRX1		
FIS.SPEC		WIMSD4	E4 FISSP	E5 FISSP
K-INFIN.		1.18360	1.18285	1.18495
ERR. [%]		0.00	-0.06	0.11
K-EFF.	1.00000	1.00112	1.00098	1.00056
ERR. [%]		0.11	0.10	0.06
RHO28	1.3200	1.2716	1.2721	1.2735
ERR [%]	+-1.59	-3 67	-3.63	-3.52
DEL25	0.09870	0 09907	0.09905	0.09920
ERR [%]	+-1.01	0.37	0 35	0.51
DEL28	0.09460	0.09663	0.09573	0.09960
ERR. [%]	+-4.33	2.15	1 19	5.29
C*	0.7970	0.7774	0.7776	0.7779
ERR. [%]	+-1.00	-2.46	-2.43	-2.40

Table C-16: Influence of fission spectrum on TRX-2

BENCHMARK	TRX2			
FIS.SPEC		WINSD4	E4 FISSP	E5 FISSP
K-INFIN		1 16395	1 16341	1 16499
ERR [%]		0 00	-0 05	0 09
K-EFF.	1 00000	0 99572	0 99581	0 99487
ERR [%]		-0 43	-0 42	-0 51
RH028	0 8370	0 8024	0 8029	0 8035
ERR [%]	+-1 91	-4 13	-4 07	-4 00
DEL25	0 06140	0 06103	0 06102	0 06110
ERR [%]	+-1 30	-0 60	-0 62	-0 49
DEL28	0 06930	0 06957	0 06892	0 07166
ERR [%]	+-5 05	0 39	-0 55	3 41
C*	0 6470	0 6341	0 6342	0 6344
ERR [%]	+-0 93	-1 99	-1 98	-1 95

Table C-17 Influence of fission spectrum on BAPL-1

BENCHMARK	BAPL1			
FIS SPEC		WINSD4	E4 FISSP	E5 FISSP
K-INFIN		1 14304	1 14253	1 14423
ERR [%]		0 00	-0 04	0 10
K-EFF	1 00000	1 00130	1 00127	1 00090
ERR [%]		0 13	0 13	0 09
RH028	1 3900	1 3574	1 3578	1 3589
ERR [%]	+-0 72	-2 35	-2 32	-2 24
DEL25	0 08400	0 08414	0 08412	0 08423
ERR [%]	+-2 38	0 17	0 14	0 27
DEL28	0 07800	0 07561	0 07490	0 07791
ERR. [%]	+-5 13	-3 06	-3 97	-0 12
C*	0 0000	0 8000	0 8001	0 8004
ERR [%]	+-0 00	0 00	0 00	0 00

Table C-18 Influence of fission spectrum on BAPL-2

BENCHMARK	BAPL2			
FIS.SPEC		WINSD4	E4 FISSP	E5 FISSP
K-INFIN		1 14546	1 14501	1 14649
ERR [%]		0 00	-0 04	0 09
K-EFF.	1 00000	0.99900	0.99907	0 99836
ERR. [%]		-0 10	-0.09	-0 16
RH028	1.1200	1.1334	1.1337	1.1347
ERR [%]	+-0.89	1.20	1.22	1 31
DEL25	0 06800	0.06876	0.06874	0 06883
ERR [%]	+-1 47	1 12	1.09	1 22
DEL28	0.07000	0 06534	0 06472	0 06732
ERR [%]	+-5 71	-6 66	-7 54	-3 83
C*	0 0000	0 7319	0 7320	0 7322
ERR [%]	+-0 00	0 00	0 00	0 00

Table C-19 Influence of fission spectrum on BAPL-3

BENCHMARK	BAPL3			
FIS SPEC		WINSD4	E4 FISSP	E5 FISSP
K-INFIN.		1 12971	1 12936	1 13059
ERR [%]		0 00	-0 03	0 08
K-EFF.	1 00000	0.99682	0 99697	0 99613
ERR [%]		-0 32	-0.30	-0 39
RH028	0 9060	0 8938	0 8941	0 8948
ERR [%]	+-1 10	-1 35	-1 31	-1 24
DEL25	0.05200	0 05296	0 05295	0 05302
ERR [%]	+-1 92	1 85	1 83	1 96
DEL28	0 05700	0 05390	0 05338	0 05550
ERR [%]	+-5 26	-5 44	-6 35	-2 63
C*	0 0000	0 6570	0 6571	0.6573
ERR [%]	+-0.00	0 00	0 00	0 00

LETTER INVITING SCIENTISTS TO PARTICIPATE IN THE "WIMS LIBRARY UPDATE PROJECT," 27 AUGUST 1990, INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, AUSTRIA

INTERNATIONAL ATOMIC ENERGY AGENCY
AGENCE INTERNATIONALE DE L'ENERGIE ATOMIQUE
МЕЖДУНАРОДНОЕ АГЕНТСТВО ПО АТОМНОЙ ЭНЕРГИИ
ORGANISMO INTERNACIONAL DE ENERGIA ATOMICA

WAGRAMERSTRASSE 5 P O BOX 100, A-1400 VIENNA, AUSTRIA
TELEX 1-12645, CABLE INATOM VIENNA FACSIMILE 43 1 234564 TELEPHONE 43 1 2360

IN REPLY PLEASE REFER TO
PRIERE DE RAPPELER LA REFERENCE

DIAL DIRECTLY TO EXTENSION
COMPOSER DIRECTEMENT LE NUMERO DE POSTE

334-F4.01

27 August 1990

Dear Colleague,

The International Atomic Energy Agency is initiating a project to update the multigroup nuclear data input library of the WIMS reactor physics code (in short: WIMS Library Update Project). The WIMS code is one of the most widely used thermal reactor physics codes and is of interest especially to reactor physics groups in developing countries.

The idea for a project to update the multigroup nuclear data input library of the WIMS code grew out of discussions between the participants, lecturers and directors of the Joint IAEA/ICTP Workshop on Reactor Physics Calculations for Applications in Nuclear Technology held at the ICTP from 12 February to 16 March 1990 and organized in co-operation with the Nuclear Data and Physics Sections of the Department of Research and Isotopes of IAEA. The planned project is in line with the relevant conclusions and recommendations of the Technical Committee Meeting on In-core Fuel Management held by the IAEA in Vienna, 4 - 7 December 1989. The project is thus being organized by the Nuclear Data and Physics Sections of the IAEA, with the co-operation of the IAEA Nuclear Power Technology Development Section.

After a development period of 10 - 15 years, improved evaluated nuclear data libraries such as ENDF/B-VI from the U.S.A. and JENDL-3 from Japan have recently been released to the Agency. There are many reactor physicists around the world who are interested in updating and improving the multigroup nuclear data input to the WIMS code.

The "WIMS Library Update" project (WLU Project) is principally conceived to proceed through a series of thermal reactor benchmark calculations using the evaluated nuclear data libraries, nuclear data processing codes and the WIMS code, with a gradual replacement of old by new nuclear data, and, including at each step, a checking of the reliability of the calculational results. Deviations between calculated and experimental benchmark data will be used to remedy inaccuracies in the calculations and/or nuclear data input and will also be fed back to the originators of the codes and/or evaluated nuclear data for review and improvement.

The final outcome of this project will thus be a reliable up-to-date nuclear data base for the WIMS code. Project participants will simultaneously acquire a detailed knowledge of nuclear data relevant to thermal reactor physics as well as a capability for reliable use of an important reactor physics computer code and associated nuclear data processing codes.

With this letter I would like to invite you and your colleagues to participate in the project. The enclosure gives the proposed plan of the different stages of the project. The project will be carried out primarily through correspondence and at no cost to the Agency.

Dr. M. Ravnik and Dr. A. Trkov from the Jozef Stefan Institute in Ljubljana, Yugoslavia, will be responsible for the co-ordination of the Project. The undersigned will be the contact person in charge of this project at the IAEA.

Please let me know at your early convenience, preferably before 30 September whether you wish to participate in this project. If you need any additional information and/or clarifications, or if you have any suggestions for improving this project, please do not hesitate to contact me.

Yours sincerely,

S. Ganesan

Srinivasan GANESAN
Nuclear Data Section
Division of Physical and
Chemical Sciences

Enclosure

cc: Dr. M. Ravnik, Ljubljana
Dr. A. Trkov, Ljubljana

PROPOSED PLAN OF DIFFERENT STAGES OF "WIMS LIBRARY UPDATE" PROJECT

The "WIMS Library Update" (WLU) Project is planned to be executed in several stages:

FIRST STAGE

The following benchmarks are recommended for inclusion in the analysis for this stage:

1. TRX-1
2. TRX-2
3. BAPL-UO_2-1
4. BAPL-UO_2-2
5. BAPL-UO_2-3

The specifications are to be taken from the ENDF-202 document. For your later use under this project, we enclose extracts of the relevant portions of the ENDF-202 document.

In this stage, all participants are requested to calculate the integral parameters mentioned in the benchmark specifications using the WIMS code and the associated WIMS library available with them. The main aim of this stage of the exercise is to compare the results calculated by different teams for the same physical parameters. These results also expected to throw light on differences caused by different modelling assumptions in the use of the WIMS code. The majority of the participants will probably use the original WIMS code available freely from the NEA Data Bank and its associated multigroup nuclear data library for this stage (called "original WIMS-D/4" herein after).

The participants should provide the following information, when submitting their results:

1) Detailed specifications of the version of the WIMS code and the multigroup cross section library that the participant is using, the source from which the code and the library were obtained and the date of receipt of these.

2) For each of the benchmarks, the card image of the input. Please include your comments on your choice of major input options/parameters. (For example: buckling, mesh, energy groups.)

3) The calculated values of k-infinity and k-eff, and of as many measured parameters as is practical.

4) The participants may be requested later to send us the full output of the WIMS run on a floppy disk or on magnetic tape, in order to help us in the process of evaluation.

Note that the first stage of this project does not involve any processing of the evaluated basic data libraries.

Please mail the results to

M. Ravnik
"J. Stefan" Institute
Jamova 39
P.O. Box 100
YU-61111 Ljubljana
YUGOSLAVIA

Telephone: (061) 371-321
Facsimile: (061) 374919
Telex: 31-296 yu jostin

with a copy to

S. Ganesan
Nuclear Data Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna
AUSTRIA/EUROPE.

Telephone: 43 1 2360 ext. 1713
Facsimile: 43 1 234564
Telex: 1-12645
Cable: INATOM VIENNA
E-Mail: RNQ@IAEA1

Note that the integral results may be sent either as printed matter or on IBM compatible PC-diskette, for the first stage of the project.

SECOND STAGE

The second stage of the project involves updating the original WIMS-D/4 nuclear data library (herein after referred to as WIMS library)

For this stage of the project, the evaluated data library ENDF/B-IV has been selected. (Subsequent stages will use ENDF/B-VI, JENDL-3 and BROND libraries, from which the final updated WIMS library will eventually be created.) This stage of the project is designed to validate and intercompare results of various processing codes such as AMPX, NJOY, FEDGROUP-C, etc , for updating the WIMS library.

The participants are requested to process the ENDF/B-IV file for the following isotopes which occur in the five benchmarks mentioned under the first stage to create a complete multigroup library in WIMS format, for all reactions and for each isotope:

1. U-235
2. U-238
3. Hydrogen bound in water
4. Oxygen
5. Aluminium

Participants are encouraged to submit results isotope by isotope. The participants should use the same temperatures and dilution cross sections (σ_0 values) as in the original WIMS library to facilitate intercomparison. Please mail the generated WIMS library for these isotopes to

Andrej Trkov
"J. Stefan" Institute
Jamova 39
P.O. Box 100
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Telex: 31-296 yu jostin,

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S. Ganesan
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Telephone: 43 1 2360 ext. 1713
Facsimile: 43 1 234564
Telex: 1-12645
Cable: INATOM VIENNA
E-Mail: RNQ@IAEA1

The recommended tape specifications for transmittal of the WIMS library so generated are as follows:

1600 BPI
NO LABEL
9 track

In view of the nature of the tasks to be performed under stages 1 and 2, in order to save time, it has been decided to conduct stages 1 and 2 in parallel. The participants in each of these stages are expected to submit first results as soon as possible. We do expect that additional participants may join the project later, but to make progress within a reasonable period of time, this deadline has been specified. Depending on your interest, you are encouraged to participate in stage 1 or stage 2 or in both.

It is recommended that the processing codes that are usually used in your laboratory be used for this project (examples: NJOY, FEDGROUP-C, AMPX, etc.).

STAGE 3 and beyond

Only after completion of stages 1 and 2, the tasks for stage 3 and beyond will be taken up. Please see the enclosed report by Dr Ravnik and Dr Trkov for further details

Stage 3 involves

- processing of ENDF/B-VI, BROND and JENDL-3 libraries for the same five isotopes mentioned in stage 2.

The participants will be supplied with the selected updated libraries in WIMS format obtained in stage 3 for analysis of same benchmarks mentioned in stage 1.

In stage 5 the project will include updating of data for structural and light elements and fission products using ENDF/B-VI, JENDL-3 and BROND data The validation of these WIMS cross section updates will be made using a series of appropriate benchmarks including benchmarks for burnup. The results are expected to lead to recommendations on the most appropriate choice and use of updated libraries for application calculations. Thus, at the end of the project, the participants will have acquired updated WIMS libraries based on the performance of different multigroup data derived from the different basic data libraries using validated processing codes.

A. Benchmark Name and Type: TRX-1 through TRX-4, H_2O-moderated uranium lattices.

B. System Description

These benchmarks are H_2O moderated lattices of slightly enriched (1.3%) uranium rods with diameters of .4915 cm in a triangular pattern Measured lattice parameters include ρ^{28}, δ^{25}, δ^{28}, and C*; B^2 was measured for TRX-1 and TRX-2, but not for TRX-3 and TRX-4 which are two-region lattices

These lattices directly test the U235 resonance fission integral and thermal fission cross section They also test U238 shielded resonance capture and the thermal capture cross section. They are sensitive to the U238 fast fission cross section, U238 inelastic scattering and the U235 fission spectrum. The scattering and (thermal) absorbtion cross sections of H_2O are very important also.

C. Model Description

There are two principal methods of analysis:

- a heterogeneous infinite lattice cell calculation followed by a homogenized-core leakage calculation.
-- an explicit description of the full core in three dimensions.

1. Infinite Lattice Cell

a. Physical Properties

Region	Outer Radius, cm	Isotope	Concentration 10^{24} Atoms/cm^3
Fuel	0.4915	^{235}U	6.253×10^{-4}
		^{238}U	4.7205×10^{-2}
Void	0.5042	-	
Clad	0.5753	Al	6.025×10^{-2}
Moderator	*	^{1}H	6.676×10^{-2}
		^{16}O	3.338×10^{-2}

*Lattice spacings of 1.8060, 2.1740, 1.4412, and 2.8824 cm, respectively, for TRX-1 through TRX-4. (Triangular arrays)

b. Suggested Method of Calculation

Monte Carlo, multigroup $S_n (n \geq 4)$ or equivalent P_l, or integral transport theory. An accurate treatment of resonance absorption is essential.

2. Leakage Calculation

a. To account for leakage use a homogenized multigroup B_l calculation with a total buckling $B^2 = .0057\ cm^{-2}$ for TRX-1 and $B^2 = .005469\ cm^{-2}$ for TRX-2. This is not suitable for TRX-3 and TRX-4 which are two-region lattices.

b. An alternative treatment of leakage, applicable to all four lattices, is to cylinderize them and calculate radial shapes explicitly using multigroup S_n or P_l theory. In all four lattices the axial buckling is $.000526\ cm^{-2}$; all are fully reflected.

Dimensions of Cylinderized TRX Lattices

Composition	Outer Radius (cm) TRX-1	TRX-2	TRX-3	TRX-4
Homogenized test lattice cells	26.2093	27.4419	11.1467	11.8198
Water gap	-	-	12.3268	12.3268
Homogenized driver lattice cells	-	-	37.9406	42.1717
Reflector	large			

Properties of UO_2 Driver Lattice (TRX-3 and TRX-4)

Region	Outer Radius, cm	Isotope	Concentration 10^{24} Atoms/cm^3
Fuel	.4864	^{235}U	3.112×10^{-4}
		^{238}U	2.3127×10^{-2}
		^{16}O	4.6946×10^{-2}
Void	.5042	-	
Clad	.5753	Al	6.025×10^{-2}
Moderator	*	^{1}H	6.676×10^{-2}
		^{16}O	3.338×10^{-2}

*Triangular pitch lattice with spacing of 1.8060 cm.

3. Full Core Model

The actual full-core configurations and loadings were:

TRX-1: 764 fuel rods

TRX-2: 578 fuel rods

TRX-3: A hexagonal array of 169 UO_2 rods was removed from the center of the driver lattice (pitch 1.806 cm), leaving 1432 rods. A hexagonal array of 217 metal rods (pitch 1.4412 cm) was centered in the opening.

TRX-4: Every other rod of the TRX-3 inner lattice was removed, leaving 61 metal rods (pitch 2.8824 cm). 1809 UO_2 driver rods were now required.

Figures 1 and 2 show 1/3-core representations of these lattices. Slight differences from the actual core loadings are due to symmetrizing the outer boundary (for simplicity). Figure 3 shows the axial model for these lattices. The tank inner diameter is 162.56 cm.

This model neglects the following items, which are considered to be inconsequential. It has omitted the 0.635 cm-thick lucite spacer sheets located at 1/3 and 2/3 of fuel full-height. In some cases, the top lattice plate was of aluminum. In some metal-fueled lattices, the rod handles and tips were actually made of brass.

D. Experimental Data

	TRX-1	TRX-2	TRX-3	TRX-4
Pitch, cm	1.8060	2.1740	1.4412	2.8824
Water/fuel vol. ratio	2.35	4.02	1.00	8.11
Number of rods	764	578	217	61
B^2, 10^{-4} cm^{-2}	57 ± 1	54.69 ± .36	-	-
ρ^{28}	1.320 ± .021	.837 ± .016	3.03 ± .05	.481 ± .011
δ^{25}	.0987 ± .0010	.0614 ± .0008	.231 ± .003	.0358 ± .0005
δ^{28}	.0946 ± .0041	.0693 ± .0035	.167 ± .008	.0482 ± .0020
C*	.797 ± .008	.647 ± .006	1.255 ± .011	.531 ± .004

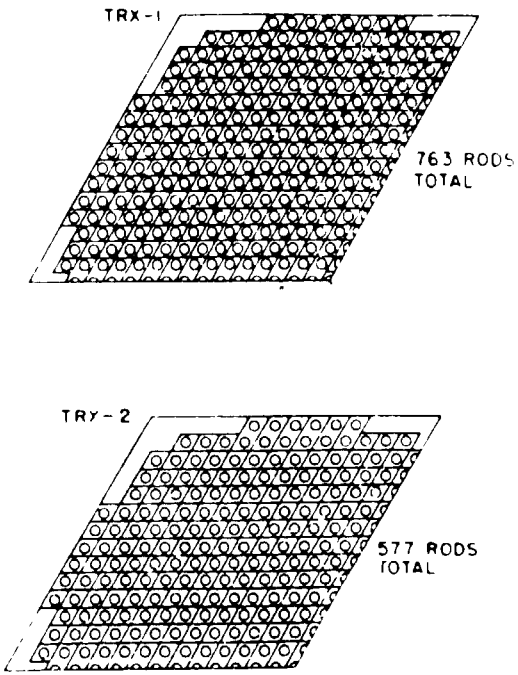

Figure 1.

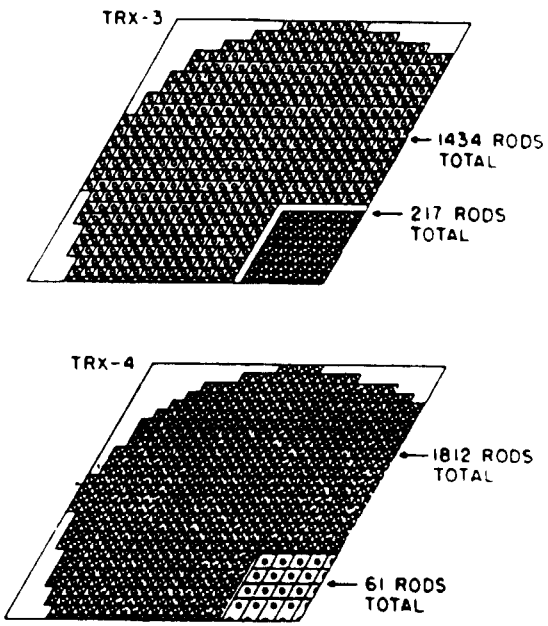

Figure 2.

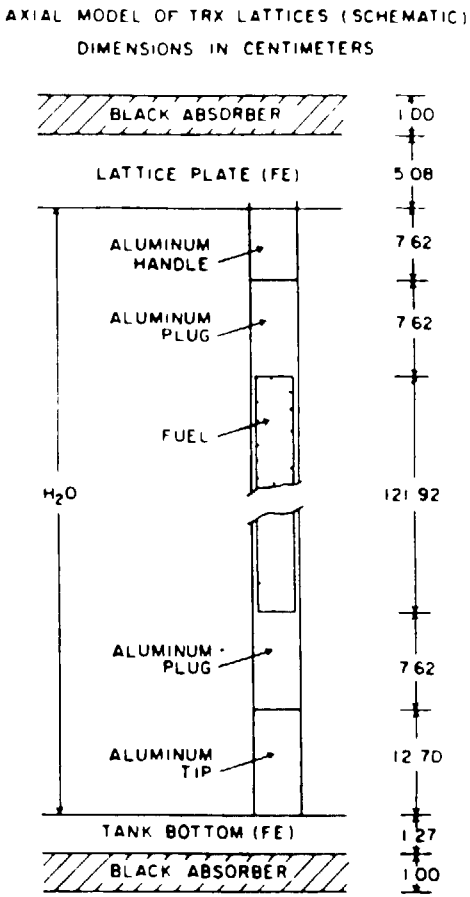

Figure 3.

Note: Parameters correspond to thermal cutoff of 0.625 eV and were measured at core center. They embody corrections obtained in Ref 6.

ρ^{28} = ratio of epithermal-to-thermal ^{238}U captures.

δ^{25} = ratio of epithermal-to-thermal ^{235}U fissions.

δ^{28} = ratio of ^{238}U fissions to ^{235}U fissions.

C* = ratio of ^{238}U captures to ^{235}U fissions.

E. Comments and Documentation

Parameter measurements are described in Ref. 1 and 2. Measurements of thermal disadvantage factors (Ref. 3) and fast advantage factors (Ref. 4) are also available. Reference 5 shows some additional details about the lattices, fuel rods, etc. Cadmium cutoff energies and foil perturbation were given careful attention.

REFERENCES

1. J. Hardy, Jr., D. Klein and J. J. Volpe, "A Study of Physics Parameters in Several Water-Moderated Lattices of Slightly Enriched and Natural Uranium," WAPD-TM-931, March 1970.
2. J. Hardy, Jr., D. Klein and J. J. Volpe, Nucl. Sci. Eng., 40, 101 (1970).
3. J. J. Volpe, J. Hardy, Jr., and D. Klein, Nucl. Sci. Eng. 40, 116 (1970).
4. J. Hardy, Jr., D. Klein and R. Dannels, Nucl. Sci. Eng. 26, 462 (1966).
5. J. R. Brown et al., "Kinetics and Buckling Measurements in Lattices of Slightly Enriched U or UO_2 Rods in H_2O," WAPD-176 (January 1958).
6. R. Sher and S. Fiarman, "Studies of Thermal Reactor Benchmark Data Interpretation: Experimental Corrections," EPRI NP-209, October 1976.

A. Benchmark Name and Type BAPL-UO_2-1 through 3, H_2O moderated uranium oxide critical lattices

B. System Description

These experiments consist of H_2O moderated critical lattices of 1.311 w% enriched uranium oxide rods (O.D. 0.9728 cm) arranged in a triangular pattern. The measured parameters include ρ^{28}, δ^{25}, δ^{28}, and B^2. Three lattices with moderator to fuel volume ratios of 1.43, 1.78 and 2.40 are specified

C. Model Description

1. Infinite lattice calculation

a) Physical properties (cylindrical geometry)

Region	Outer Radius (cm)	Isotope	Concentration (10^{24} atoms/cm^3)
Fuel	.4864	^{235}U	3.112×10^{-4}
		^{238}U	2.3127×10^{-2}
		O	4.6946×10^{-2}
Void	.5042	--	--
Clad	.5753	Al	6.025×10^{-2}
Moderator	*	O	3.338×10^{-2}
		H	6.676×10^{-2}

*Triangular lattices with a pitch of 1.5578, 1.6523 and 1.8057 cm respectively.

b) Suggested Method of Calculation

Integral transport theory, Monte Carlo or Multigroup Sn with special treatment of the resonance region.

2. Leakage Calculation

To account for leakage a homogenized B_ℓ calculation with the following total bucklings should be used.

Lattice	Buckling [m^{-2}]
BAPL-UO_2-1	$32.59 \pm .15$
BAPL-UO_2-2	$35.47 \pm .18$
BAPL-UO_2-3	$34.22 \pm .13$

D. Experimental Data

	BAPL-UO_2-1	BAPL-UO_2-2	BAPL-UO_2-3
Pitch, Cm	1.5578	1.6523	1.8057
Water/fuel vol. ratio	1.43	1.78	2.40
Number of rods	2173 ± 3	1755 ± 3	1575 ± 3
B^2 [m^{-2}]	32.59 ± .15	35.47 ± .15	34.22 ± .13
ϵ^{28}	1.39 ± .01	1.12 ± .01	0.906 ± .01
δ^{25}	.084 ± .002	.068 ± .001	.052 ± .001
δ^{28}	.078 ± .004	.070 ± .004	.057 ± .003

NOTE. Measured parameters correspond to a thermal cutoff of 0.625 eV and were measured at the core center.

E. Comments and Documentation

The specifications for the lattices and the measured values were taken from reference 1 where the following identifications have been used

BAPL-UO_2-1	OA-131-383-143
BAPL-UO_2-2	OA-131-383-178
BAPL-UO_2-3	OA-131-383-240

Reference 2 describes the original experiment. Results of an analysis using ENDF/B-IV data are given in Reference 3

References

1. Heliens R. L., Price, G. A. , "Reactor Physics Data for Water-Moderated Lattices of Slightly Enriched Uranium", Reactor Technology Selected Reviews, 529, 1964.
2. Brown, J. R. and Harris, D. R., et al., "Kinetic and Buckling Measurements on Lattices of Slightly Enriched Uranium and UO_2 Rods in Light Water" WAPD-176 (1958).
3. Rothenstein, W., 'Thermal Reactor Lattice Analysis Using ENDF/B-IV Data with Monte Carlo Resonance Reaction Rates", BNL-20446 (1975), Nucl. Sci. Eng. 59, 337-349, (1976).

LETTER INVITING SCIENTISTS TO PARTICIPATE IN THE EXTENSION OF PHASE I AND IN STAGE 3 OF

THE "WIMS LIBRARY UPDATE PROJECT,"

8 SEPTEMBER 1992,

INTERNATIONAL ATOMIC ENERGY AGENCY,

VIENNA, AUSTRIA

INTERNATIONAL ATOMIC ENERGY AGENCY
AGENCE INTERNATIONALE DE L'ENERGIE ATOMIQUE
МЕЖДУНАРОДНОЕ АГЕНТСТВО ПО АТОМНОЙ ЭНЕРГИИ
ORGANISMO INTERNACIONAL DE ENERGIA ATOMICA

WAGRAMERSTRASSE 5 P O BOX 100, A-1400 VIENNA, AUSTRIA
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IN REPLY PLEASE REFER TO
PRIERE DE RAPPELER LA REFERENCE

DIAL DIRECTLY TO EXTENSION
COMPOSER DIRECTEMENT LE NUMERO DE POSTE

334-F4.01

8 September 1992

Dear Colleague,

Subject: WIMS Library Update Project.

The WIMS library update project (WLU Project) has gone through Phase 1 and Phase 2 with the selected reactor benchmarks. It is planned to extend the WLU project by inclusion of additional benchmark experiments. Enclosed herewith, please find the specifications for these additional benchmarks. You are invited to participate in the extension of WLUP Stage 1.

The participation in Stage 3, involving the processing of ENDF/B-VI, BROND-2, JENDL-3.1, and CENDL-2 basic libraries for the selected isotopes, can also be started in parallel by teams having the data processing capability. JEF-2 will be included subject to its free availability.

You are most welcome to participate in these projects and send your results for inclusion in the comparison studies to Dr. A. Trkov and Dr. M. Ravnik at the following address:

"J. Stefan" Institute
Jamova 39
P.O. Box 100
61111 Ljubljana
SLOVENIA (EUROPE)

Telephone: (061) 371321
Facsimile: (061) 374919
Telex: 31-296 yu jostin,

.. /2

with a copy to

Dr. S. Ganesan
Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
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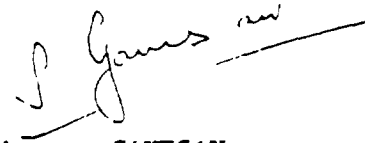
Telephone: +43-1-2360 ext. 1713
E-Mail: (EARN-BITNET) RNQ@IAEA1
Facsimile: +43-1-234564
Telex: 112645 ATOM A
Cable: INATOM VIENNA.

As you are aware, the WIMS Library Update Project is being carried out primarily through correspondence and at no cost to the Agency.

Best wishes and regards,

Yours sincerely,



Srinivasan GANESAN
Nuclear Data Section
Division of Physical and
Chemical Sciences

Enclosures:

1. M. Ravnik, A. Trkov, "WLUP Stage 1 - Extended; Benchmark Specifications", 2 September 1992.

2. A. Trkov, M. Ravnik, "NJOY-91 and Thermal Reactor Applications", presented at the Seminar on NJOY-91 and THEMIS, OECD/NEA Data Bank, Saclay, 7-9 April 1992.

WLUP Stage 1 - Extended

Benchmark specifications

M.Ravnik, A.Trkov

September 2, 1992

1 Introduction

Stage 1 of the WIMS Library Update Project (WLUP) has been completed successfully The results include optimized WIMS inputs for 5 thermal lattices (TRX-1,2 and BAPL-1,2,3) and a set of reference results using WIMS/D-4 with the original library as distributed through the NEA-Data Bank at Saclay) The results are documented in [1]

Due to the success of Project Stage 1 it has been decided to propose an extension which would include additional benchmark experiments Some participants expressed interest in the heavy water and thorium cycle data, so appropriate benchmarks were considered

2 Benchmark selection

The document [2] includes a limited number of suitable benchmarks to be modelled with WIMS. Furthermore, in the literature some authors express doubts about the measured quantities, particularly for the heavy water lattices. By considering several alternatives, the following selection has been made:

1 R/100H benchmarks (3 lattices) as an additional independent test of light water moderated ^{235}U fuelled latices,

2 ZEEP benchmarks (3 lattices), D_2O moderated and fuelled with natural uranium,

3 BNL-ThO_2 benchmarks (3 lattices), light water moderated, thorium oxide exponential lattices

Lattice descriptions are taken from documents [3,2] and are given in the appendix Parts of the specifications (particularly sections related to the calculational methodology) which are not obligatory for the purpose of the project have been crossed out, but they are readable and for the sake of completeness they have been included in the distribution Note that the full documents [3,2] are not required for carrying out the exercise and the Agency has no spare copies to distribute to the participants

3 Calculational methods

The WIMS/D-4 code alone is to be used. No global criticality calculations are required. Measured bucklings are to be applied to account for leakage.

4 Presentation of results

Apart from the k_∞ and k_{eff}, the spectral indices are to be calculated (if possible) so that comparison with the measured values can be made. It is advisable to supply the WIMS inputs with the results in case any ambiguities need to be resolved.

The participants should comment their choice of the WIMS options used in as much detail as possible. If applicable, a summary of a sensitivity analysis should be presented, which proves that the selected options are adequate.

The participants experienced in heavy water calculations are urged to comment and justify their calculational methods since heavy water lattices are less frequently modelled with WIMS.

At present it is not certain that meaningful reference results for the Thorium lattices can be obtained using WIMS/D-4 with the existing library. Participants interested in the thorium data are asked to make an effort to point out any difficulty which they might encounter.

References

[1] M.Ravnik, A.Holubar, A.Trkov, *WIMS Library Update Project - Final Report on Stage 1*, Institute "Jožef Stefan", Ljubljana, IJS-DP-6245, May 1992.

[2] BNL, *Cross Sections Working Group Benchmark Specifications*, BNL 19302 (ENDF-202) with Supplements (1986).

[3] D.S.Craig, *Testing ENDF/B-V Data for Thermal Reactors*, Atomic Energy of Canada Ltd., AECL-7690 (Rev 1), June 1984.

APPENDIX

A.1 R/100H Benchmark Specifications

ADDENDUM 2

LATTICES R1/100H, R2/100H, and R3/100H

Description of Lattices

R1/100H, R2/100H and R3/100H are H_2O-moderated lattices of UO_2 fuel rods enriched to 3.003 wt.% in U-235. The fuel pellets are 10.12 mm in diameter. They are clad with stainless steel, 0.267 mm thick. The rods are arranged in square lattices with pitches of 13.20 mm, 18.66 mm, and 12.506 mm for R1/100H, R2/100H and R3/100H, respectively. The volume ratios of moderator to fuel in these lattices are 1.001, 3.163 and 0.779. Complete details of the lattice and the measurements have been given by Brown et al[1]. We will refer to the series as the R/100H series.

Interest

The thermal-reactor benchmarks for H_2O-moderated lattices containing U-235 and U-238 are the TRX and BAPL-UO_2 series. Both were measured at the Bettis Atomic Power Laboratory. It was thought desirable to use a series of lattices measured at another laboratory. The R/100H series was measured at the United Kingdom Atomic Energy Establishment, Winfrith. These lattices are of particular interest as a number of lattice parameters were measured - namely, B^2, RCR, δ^{28}, the ratio of fissions in Pu-239 to fissions in U-235 in the lattice to that in a Maxwellian, $\bar{\eta}^{5}_{25}$, and the thermal neutron spectrum index captures in a region in the cell.

$$L = \frac{(Lu\text{-}176/Mn\text{-}55)\ \text{captures in a region in the cell}}{(Lu\text{-}176/Mn\text{-}55)\ \text{captures in a Maxwellian spectrum}}$$

These lattices are also of interest because in R1 and R3 the ratio of epithermal to thermal capture in U-238, δ^{28}, is three to four times larger than that in TRX-1. Thus these lattices should provide a better test of the accuracy of the U-238 resonance data.

not applicable

Calculations

The calculations were made using the RAHAB/OZMA code combination as described in the body of the report.

The resonance reaction rate was calculated using OZMA with the S_8P_1 option and the combinatorial scheme for calculating the fluxes. Because of the uncertainty about the temperature to use in Doppler broadening the resonances, calculations were made using both 293 K and 353 K. This uncertainty has been discussed in the main report.

All data is ENDF/B-V except for the thermal scattering data for UO_2 which is CRNL data. The Maxwellian average cross sections were taken from ENDF-328[2].

Results

The results are given in Table 2-I. There are two sets, A and B. The differences in these sets are described in Addendum 1. Set B is considered to be the better of the two.

As with the BAPL-UO_2 lattices we give a preference to the results with the Doppler broadening calculated at 293 K. Use of the higher temperature of 353 K decreased k_{eff} by 1.1 mk to 3.0 mk. Consistent with this decrease is an increase in the relative conversion ratio, RCR, by 0.65% to 1%. Concentrating on the results obtained using 293 K we see that values of k_{eff} are 3 mk high for the two tightest lattices R1 and R2, and 6 mk high for R3. The uncertainty in k_{eff} introduced by the uncertainty in B^2 is 1 mk for the two tightest lattices and 2 mk for R3. Values of RCR are 3% and 4% high. This could be interpreted as caused by the epithermal capture in U-238 being 4% to 5% high. This is a little higher than the average we obtained for the TRX and BAPL-UO_2 lattices.

Lattice descriptions are taken from documents [3,2] and are given in the appendix. Parts of the specifications (particularly sections related to the calculational methodology) which are not obligatory for the purpose of the project have been crossed out, but they are readable and for the sake of completeness they have been included in the distribution. Note that the full documents [3,2] are not required for carrying out the exercise and the Agency has no spare copies to distribute to the participants.

This is shown in Table 2-II where we compare the calculated and experimental values of δ^{28} and RCR for these lattices. The percentage error in the calculated value of δ^{28} probably arises from a similar percentage error in the epithermal capture in U-238. The relationship is not so direct in the case of the RCR.

Values of δ^{28} agree with experiment. However, the experimental uncertainties are large and consequently the ENDF/B-V data involved in fast fission in U-238 is not adequately checked by these lattices.

The ratios of fissions in Pu-239 to fissions in U-235 in the lattice compared to the values in a Maxwellian are in fair agreement with experiment, being high by 2.2 and 1.8 standard deviations. We conclude that the ratio of the fission cross sections of Pu-239 and U-235 are represented fairly well by ENDF/B-V.

The thermal-neutron spectrum indices, calculated using the preferred thermal scattering data, Set B, are low by 6% and 8%. Those obtained using Set A agree with experiment. The discrepancies between the experimental and calculated values could arise from errors in the Lu-176 cross section or in the thermal scattering matrix for H_2O. As pointed out in Addendum 1 there is some question about the accuracy of the Lu-176 data. Until this is resolved it is not possible to decide on the source of the discrepancies.

It should be noted that the values of L cannot be compared to the thermal spectrum indices, L*, used in Appendix I with the LTRIA lattice. L* used only subcadmium reaction rates. Calculated values of L for LTRIA, using Set B scattering data are 1.151 and 1.167 for the inner and outer fuel tubes, respectively. Thus they are between those for R1/100H and R2/100H. However, experimental values of L are not available for this lattice.

we are concerned with the differences between the SET A and SET B results for L - about 7% for both R1 and R3 lattices. In collapsing the pointwise data into multigroup form SET A used constant weighting up to 4 eV, whereas SET B used a Maxwellian up to 0.2 eV followed by a 1/E up to 820 keV. In addition SET B was produced using a revised version of NJOY. As far as L is concerned it is thought that the difference in the results mainly arises from the use of different weighting factors. In the energy range of 0.1 eV to 0.25 eV the calculated flux in the fuel varies from 3% to 6% higher when SET A is used. A similar effect was seen with the D_2O moderated LTRIIA lattice, discussed in Addendum 1. Calculations made with homogeneous mixtures of D_2O and U-235 have shown that the differences in spectra arise mainly from the use of different weighting functions.

Lu-176 has a resonance at 0.14 eV and thus capture in this nuclide is particularly sensitive to the flux in the range of 0.1 eV to 0.25 eV. Since Pu-239 has a resonance at 0.296 eV and Pu-241 at 0.257 eV, captures in these nuclides might be fairly dependent on the weighting factors. To eliminate this dependence the widths of the energy groups should be reduced. However, because of the large amount of work required to create new data libraries to use on a finer mesh, this has not been done. This problem should be reexamined if the data for Lu-176 is revised.

The number of neutrons absorbed in the stainless steel cladding in these lattices is greater than the number absorbed in the aluminum cladding of the TRX and BAPL lattice by factors of about 6 and 3, respectively. Thus the calculated reactivities for the R/100H lattices are more sensitive to errors in the cladding dimensions and density than for the aluminum clad lattices. The numbers of neutrons captured in the cladding, for one neutron being absorbed or lost by leakage, are 0.0324, 0.0334, and 0.0319 for R1/100H, R2/100H and R3/100H, respectively. For absorptions in H_2O the corresponding numbers are 0.0257, 0.0943 and 0.0193.

Summary

The values of k_{eff} for the lattices agree with those for the BAPL-UO_2 lattices - high by about 4 mk. Since ^{28} was not measured in the R/100 series it is not possible to draw any definite conclusions about the epithermal capture rate in U-238. However, from the RCR values it appears that the epithermal capture in U-238 is slightly high. This was the conclusion from the results from the other lattices. It should be noted that high values of RCR are inconsistent with high values of k_{eff}. If RCR is high we expect k_{eff} to be low. Some of the discrepancy may arise from uncertainties in the capture of the stainless steel cladding.

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TABLE 2-I

COMPARISON OF CALCULATED AND EXPERIMENTAL LATTICE PARAMETERS
FOR R1/100H, R2/100H and R3/100H

VOLUME RATIO	R1/100H H_2O/UO_2 = 1.001			R2/100H H_2O/UO_2 = 2.163			R3/100H H_2O/UO_2 = 0.779		
	UO_2 AT			UO_2 AT			UO_2 AT		
	293 K SET A	353 K SET A	293 K SET B**	293 K SET A	353 K SET A	293 K SET B**	293 K SET A	353 K SET A	293 K SET B**
B^2 cm^{-2} EXP	66.00±0.22			100.4±0.64			50.90±0.30		
k_∞	1.3696	1.36626	1.37027	1.34105	1.33952	1.34294	1.23863	1.21679	1.22119
k_{eff} EXP [1]	1.0025	0.99991	1.00322	1.0042	1.0031	1.00603	1.0025	0.99976	1.00337
ρ^{28}	0.00087	0.00087	0.00087	0.0021	0.0021	0.0021	0.0012	0.0012	0.0012
RCR CAL	4.284	4.324	4.280	2.293	2.306	2.289	4.995	5.04	4.991
RCR EXP	4.149±0.030						4.789±0.053		
δ^{28} CAL	0.0876	0.0872	0.0876	0.0385	0.0385	0.0384	0.1035	0.1029	0.1035
δ^{28} EXP	0.0928±0.0009 (±10%)* PLUS						0.1113±0.0018 (±10%)* PLUS		
ε^{49}_{25} CAL	1.622	1.622	1.606	1.323	1.323	1.310	1.691	1.695	1.676
ε^{49}_{25} EXP	1.589±0.009						1.661±0.009		
L IN FUEL CAL	1.162	1.162	1.091	1.25	1.119	1.119	1.093	1.09	1.03
L IN FUEL EXP	1.160±0.006						1.112±0.009		
δ^{28}	4.016	4.059	4.011	1.391	1.467	1.340	5.143	5.287	5.144
δ^{25}	0.245	0.245	0.245	0.0792	0.0793	0.0789	0.321	0.321	0.321
δ^{49}	0.108	0.108	0.109	0.0472	0.0472	0.0476	0.130	0.130	0.131
M^2 cm^2	39.525	39.499	39.502	32.976	32.960	32.931	41.756	41.726	41.735

* These errors have an additional common systematic error of ±10%.

** preferred values

RCR = captures U-238/fission U-235, ratio of lattice to Maxwellian

δ^{28} = fissions U-238/fission U-235

ε^{49}_{25} = fissions Pu-239/fission U-235, ratio of lattice to Maxwellian

L = (captures Lu-176/captures Mn-55) at some position in lattice / (captures Lu-176/captures Mn-55) in a Maxwellian spectrum

TABLE 2-II

A COMPARISON OF CALCULATED AND EXPERIMENTAL VALUES OF AND RCR FOR A NUMBER OF LATTICES

	LATTICE				
	TRX-1	TRX-2	BAPL-UO_2-1	BAPL-UO_2-2	BAPL-UO_2-3
$\frac{\delta^{28}_{c\,calc.}}{\delta^{28}_{c\,exp}}$	034±0 016*	. 012±0.019	1.005±0.007	1 035±0 009	..001±0.01.
	ZEEP-.	R1/100H	R3/100H		
$\frac{RCR\ calc.}{RCR\ exp}$	..017±0.004	1.032±0.007	. 042±0.011		

* uncertainty based on uncertainty quoted for δ^{28}_c from experiment

A.2 ZEEP Benchmark Specifications

APPENDIX C

SUGGESTED ZEEP BENCHMARKS

A. Benchmark Name and Description

ZEEP-1, -2 and -3, D_2O-moderated criticals, natural uranium.

B. System Description

ZEEP-1

This benchmark consists of a D_2O-moderated lattice of natural uranium metal rods, 32.57 mm in diameter. The rods were arranged in a triangular lattice having a pitch of 200 mm. The measured lattice parameters include B_m^2, δ^{28}, and RCR. The latter is defined in Section D. This lattice is useful for testing D_2O, U-235 and U-238 cross sections.

ZEEP-2 and ZEEP-3

ZEEP-2 and ZEEP-3 are the same as ZEEP-1 except the lattice pitches are 139.7 mm and 120.6 mm, respectively. Only B_m^2 was measured.

C. System Description

1. Infinite Lattice Calculation

a) Physical Properties

Temperature 20°C, density of fuel is 18.95 g/cm^3; purity of D_2O (atoms D/(atoms H + atoms D)) is 0.9977.

Region	Outer Radius, mm	Composition: Isotope	Concentration 10^{24} atoms/cm^3
Fuel	16.285	^{235}U	3.454×10^{-4}
		^{238}U	4.760×10^{-2}
Air Gap	16.470	O	5.0×10^{-5}
Cladding	17.490	Al	6.025×10^{-2}
(alternative — homogenize air gap and cladding			
Cladding + Air Gap	17.490	O	$7.\times 10^{-6}$
		Al	5.128×10^{-2})
Moderator	pitch in mm	^1H	1.529×10^{-4}
	ZEEP-1 200.0	^2H	6.633×10^{-2}
	ZEEP-2 139.7	O in H_2O	7.645×10^{-5}
	ZEEP-3 120.6		
		O in D_2O	3.316×10^{-2}
		(Total O)	3.324×10^{-2}

Moderator	(If cylindrical geometry is used) radius in cm
ZEEP-1	105.008
ZEEP-2	73.348
ZEEP-3	63.320

2. Leakage Calculation

To account for leakage use a homogenized multigroup B_1 calculation with a total buckling $B^2=6.99\ m^{-2}$ for ZEEP-1, $B^2=8.34\ m^{-2}$ for ZEEP-2, and $B^2=7.30\ m^{-2}$ for ZEEP-3.

3. Calculated Values

Results should be given for both the infinite and finite lattices for the following items: k; δ^{28}, the relative conversion ratio (RCR), and each region four group fluxes, and four group nuclear reactions rates and cross sections. The upper boundaries of the groups will be 10^7 eV, 821 keV, 5.53 keV, and 0.625 eV. Also give the modified conversion ratio, C*, for a Maxwellian with the moderator at 20°C.

D. Experimental Data

ZEEP-1

$$B_m^2 = 6.99 \pm 0.06\ m^{-2}$$

δ^{28} = ratio of U-238 fissions to U-235 fissions = 0.0675 ± 0.0014

$$RCR = \frac{\text{U-238 captures}}{\text{U-235 fissions}}\ \text{in the lattice} \Big/ \frac{\text{U-238 captures}}{\text{U-235 fissions}}\ \text{in a Maxwellian spectrum at moderator temperature (20°C)}$$

$$= C^*_{LATTICE} / C^*_{MAXWELLIAN}$$

$$= 1.260 \pm 0.005$$

ZEEP-2

$$B_m^2 = 8.34 \pm 0.03\ m^{-2}$$

ZEEP-3

$$B_m^2 = 7.30 \pm 0.28\ m^{-2}$$

E. Comments and Documentation

The physical properties of the lattice and buckling measurements at various pitches are described in Refs. 1 and 2. B_m^2 was not measured for the 200 mm lattice, but can be obtained by interpolation from the values for the lattices with pitches of 196.8 mm and 205.7 mm. It is pointed out that the fuel in the ZEEP rods represents early uranium production and although no exhaustive studies have been made there is no reason to suspect the presence of significant amounts of impurities.

δ^{28} and RCR were measured in 1963 by C.B. Bignam at AECL but have not been published. In an internal report he gave δ^{28} = 0.0676 (±2%) and ICR (U-238 captures/U-235 absorptions) = 0.7048 (±0.3%), measured at a moderator temperature of 24°C. The values quoted in Section D have been adjusted to refer to 20°C. RCR, the measured quantity, is not now available. The value given in Section D was obtained from ICR by using the same data as was used in 1963 in going from RCR to ICR. The techniques used in making these measurements are described in Ref. 3.

The value of $C^*_{MAXWELLIAN}$ derived at AECL from Maxwellian averages of Version V data is 0.654. Using this value and the value for RCR, C* for the cell is 0.824.

The uncertainties quoted for the RCR and δ^{28} are one standard deviation. The definition of the uncertainties quoted for the bucklings is not known. That for the lattice with a 200 mm pitch was taken to be the same as for the neighbouring pitches.

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A.3 BLN-ThO_2 Benchmark Specifications

THERMAL REACTOR BENCHMARKS NOS. 21-23

A. Benchmark Name and Type: BNL-ThO_2-1 through 3, H_2O moderated Thorium oxide exponential lattices

B. System Description

These experiments consist of H_2O moderated exponential lattices fueled by vibratory compacted particles of 3wt% $^{233}UO_2$ - 97wt%ThO_2. The fuel rods (O.D. 1.0922 cm) were clad in Zircaloy-2 and arranged in a triangular pattern in a 180 cm diameter x 180 cm deep aluminum tank erected on top of a thermal column. Measured parameters include B_m^2, ρ^{28} and the dysprosium disadvantage factor (ζ_{Dy}). Three lattices with moderator to fuel volume ratios of 1.0, 1.38 and 3.0 are specified.

These lattices are sensitive to cross sections for thermal and epithermal U233 fission, thermal and epithermal Th232 capture, and H_2O scattering.

C. Model Description

There are two principal methods of analysis:

- A heterogeneous infinite lattice cell calculation followed by a homogenized-core leakage calculation (either with the measured material B^2, or an explicit radial calculation with the measured axial B^2).

- An explicit description of the actual lattice in two dimensions with an axial leakage correction obtained from the homogenized-core description with the measured axial B^2.

It has been observed that the second method produces significantly different radial leakage than either of the homogenized-core approximations (Ref. 4).

1 Infinite Lattice Cell

a) Physical Properties

Region	Outer radius (cm)	Isotope	Concentration 10^{24} Atoms/cm^3
Fuel	0.546	^{16}O	$\sim 0.0883 \times 10^{-2}$
		^{232}Th	1.98115×10^{-2}
		^{233}U	6.1021×10^{-4}
		^{234}U	9.09×10^{-6}
		^{235}U	2.7×10^{-7}
		^{238}U	6.55×10^{-6}
		B	2.2×10^{-6}
Clad	0.63373	Zr	4.4355×10^{-2}
		Sn	5.03×10^{-4}
		Cr	7.92×10^{-5}
		Fe	9.58×10^{-5}
		Ni	3.51×10^{-5}
		Co	3.5×10^{-7}
		B	5.3×10^{-7}
		Cd	2.0×10^{-8}
		Hf	7.0×10^{-8}
Moderator	*	H	6.676×10^{-2}
		O	3.338×10^{-2}

*Triangular lattices with a pitch of 1.5923, 1.7188 and 2.1697 cm respectively

b) Suggested Method of Calculation

Integral transport theory, Monte Carlo or Multigroup Sn with special treatment of the resonance region.

2. Leakage Calculation

a) To account for leakage a homogenized B_1 calculation with the following total material bucklings should be used.

	Buckling [m^{-2}]	Axial Relaxation Length (cm)	No. of Rods
BNL-ThO_2-1	75.88 ± 2.0	39.57	511
BNL-ThO_2-2	86.06 ± 1.3	43.58	397
BNL-ThO_2-3	85.54 ± 0.8	45.18	271

b. An alternative treatment of leakage is to cylindricize the lattice region then use Sn or P_L theory with an axial buckling obtained from the relaxation length.

3. Explicit Full Core Model (Two Dimensions)

Figure 1 shows a 1/3-core 2-dimensional representation of the BNL-ThO_2-1 lattice. The model includes the water reflector (not shown) out to a radius of 90 cm, which coincides with the position of the tank wall. BNL-ThO_2-2, -3 is represented similarly except for the number of fuel rods. The outer fuel boundary is symmetricized in all cases.

The axial direction is not represented in the full-core Monte Carlo description. The correction for axial inleakage is obtained as in Section 2(b), with a negative axial buckling given by $-1/L_z^2$, where L_z is the measured axial relaxation length.

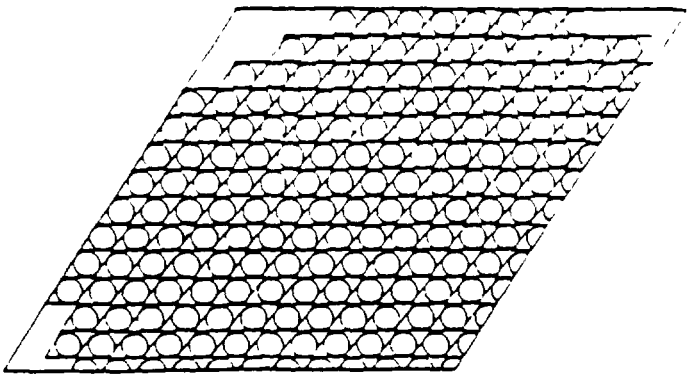
D. Experimental Data

	BNL-ThO_2-1	BNL-ThO_2-2	BNL-ThO_2-3
Pitch, cm	1.5923	1.7188	2.1697
Water/fuel vol. ratio	.997	1.384	3.0043
Number of rods	511	397	271
δ_{Dy}	1.219 ± 0.024	1.257 ± 0.024	1.325 ± 0.024
$\rho 02$	1.338 ± 0.042	903 ± 0.038	.421 ± 0.013

Note: parameters correspond to a thermal cutoff of 0.625 eV

$\rho 02$ = ratio of epithermal to therma. captures in ^{232}Th

δ_{Dy} = Dysprosium-164 disadvantage factor - Ratio of the activations of ^{164}Dy in the moderator to those in the fuel.



E. Comments and Documentation

The measurements are described in references 1 and 2. Reference 3 describes the analysis.

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