INTERNATIONAL ATOMIC ENERGY AGENCY

INDC(NDS)-468
Distr. G+TU

I N D C INTERNATIONAL NUCLEAR DATA COMMITTEE

Evaluated Nuclear Data for Th-U Fuel Cycle

Summary Report of the Second Research Coordination Meeting

IAEA, Headquarters

Vienna, Austria

6 – 9 December 2004

Prepared by

P. Schillebeeckx
Neutron Physics Unit
EC-JRC-IRMM
Geel, Belgium

and

A. Trkov
Nuclear Data Section
International Atomic Energy Agency
Vienna, Austria

December 2004

IAEA NUCLEAR DATA SECTION, WAGRAMER STRASSE 5, A-1400 VIENNA

INDC documents may be downloaded in electronic form from
http://www-nds.iaea.or.at/indc_sel.html or sent as an e-mail attachment. Requests for hardcopy or e-mail transmittal should be directed to services@iaeand.iaea.org or to:

Nuclear Data Section
International Atomic Energy Agency
PO Box 100
Wagramer Strasse 5
A-1400 Vienna
Austria

Produced by the IAEA in Austria

December 2004

INDC(NDS)-468
Distr. G+TU

Evaluated Nuclear Data for Th-U Fuel Cycle

Summary Report of the Second Research Coordination Meeting

IAEA, Headquarters

Vienna, Austria

6 – 9 December 2004

Prepared by

P. Schillebeeckx
Neutron Physics Unit
EC-JRC-IRMM
Geel, Belgium

and

A. Trkov
Nuclear Data Section
International Atomic Energy Agency
Vienna, Austria

Abstract

Highlights of the second research coordination meeting are given with respect to progress, and the agreed route forward to achieve the primary objectives of the coordinated research project on "Evaluated Nuclear data for Th-U Fuel Cycle". Participants debated their findings and requirements for such files, and formulated a list of assigned tasks.

December 2004

TABLE OF CONTENTS

1. Introduction

The meeting was opened by A.L. Nichols, Head of the Nuclear Data Section.

A. Trkov, Scientific Secretary, summarised the progress of the project:

- Thermal cross-section evaluations are still in progress.
- Resonance parameters evaluation is proceeding according to schedule.
- Evaluation of the parameters for the optical model is proceeding according to schedule.
- Most benchmark related actions are proceeding according to schedule, although Kyoto University benchmark could not be implemented due to unavailability of the data.

A. Ignatyuk was elected Chairman of the meeting and P. Schillebeeckx agreed to be rapporteur.

Participants presented their contribution to the project, and the status of the ^{232}Th data file was discussed in the first part of the meeting.

The other sessions were devoted to other nuclei (i.e., ^{232,233,234,236}U and ^{231,233}Pa), and the task assignments.

2. Summary of the meeting

2.1: Thermal, RRR and URR (Session Chairman: L. Leal)

a) The status of the evaluation of the thermal cross sections was presented by A. Trkov:

- A. Trkov had undertaken an evaluation of the thermal capture cross section following the same approach as for ^{238}U. However, renormalisation of experimental data to new standards had not been fully implemented on all the data - the total thermal cross section was not evaluated.
- New measurements for ^{232}Th(n, γ) are planned at Budapest in first half of 2005.
- Liu Ping performed an independent evaluation of the gamma emission probabilities for thermal capture of ^{232}Th. The results are in good agreement with those of A. Trkov.

b) The status of the evaluation of the resonance parameters was presented by L. Leal and P. Schillebeeckx:

- Evaluation in URR has been completed and includes the latest capture data of n_TOF.
- The consistency of the average resonance parameters resulting from the evaluation of RRR will be verified and compared with the new Maslov evaluation.
- L. Leal produced an evaluation in RRR, based on the transmission data of Olsen, the 60 m flight-path capture data of IRMM and the capture data of n_TOF (up to 100 eV).

Recommendation:

L. Leal and P. Schillebeeckx will continue to work on a strategy to recommend a resonance parameter file for RRR and URR. V. Maslov will perform an independent statistical analysis of the new resonance parameter set.

2.2: Nuclear model parameters, level schemes, double differential and photon production data of ^{232}Th (Session Chairman: A. Ignatyuk)

The evaluations performed at Obninsk (BROND3) and Minsk were presented by A. Ignatyuk and V. Maslov, respectively. In both evaluations, the most recent experimental data were considered, i.e., IRMM and n_TOF capture data. The evaluation of Ignatyuk also includes covariances.

R. Capote compared the different sets of optical potentials (Maslov, Ignatyuk, Soukhovitskij) and the dispersive coupled channel potential.

M. Sin presented the calculation of fission cross sections using EMPIRE. She noted that an optical potential needs to be recommended first in order to undertake a final calculation of the fission cross section.

Recommendation:

The new dispersive coupled channel potential is recommended for future consistent calculations of the total, elastic, inelastic and fission cross sections.

2.3: Integral data, evaluated data file verification, benchmarking and validation of ^{232}Th (Session Chairman: A. Trkov)

Progress in the preparation of benchmarks were presented by Ganesan for the Kamini ^{233}U fuelled reactor and PIE measurements of irradiated thorium bundles.

Further benchmarks from the ICSBE Handbook were analysed at CNDC, and presented by Liu Ping. The results show strong correlations between different cross sections, and will require great care in the interpretation of the benchmark results.

Ganesan agreed to provide experimental results and information related to the Indian PHWR thorium irradiation experiments, including burnup history of the fuel bundles undergoing PIE, PIE results and a complete description of the lattice and core (geometry and composition specifications).

V. Maslov will contact S.P. Simakov, Karlsruhe, to provide full specifications of the benchmarks on neutron leakage from thorium spheres.

2.4: Fission product yield and decay data of ^{232}Th (Session Chairman: V. Maslov)

V. Maslov commented on the CRP dedicated to minor actinides fission product yields and the Wahl systematics reported in LA-13928. However, this CRP did not consider ^{232}Th and the ^{232,234,236}U isotopes.

The presentation of Liu Ping on FP yield data analysis of Liu Tingjin suggests that the ENDF/B-VI evaluation shows good consistency with measured data, and is a good candidate for adoption within this CRP. The report will be sent to the evaluators of JEFF, ENDF/B and JENDL for comments. Final decision will be made based on the feedback.

The need to extend the existing files to higher energies was identified. V. Maslov discussed the possibility of extending the existing file for ^{232}Th by adding a few energy points between 14 and 200 MeV. The extension could be based on a multimode analysis of fission yields by S. Zhdanov et al.

2.5: Experimental data processing and formation of covariance file (Session Chairman: T. Kawano)

T. Kawano presented the capabilities of the SAMMY code to provide covariances both for RRR and URR. The SAMMY code also includes the retroactive option to reprocess resonance parameter files. The resulting covariance files can be processed by a new module ERRORJ (developed by G. Chiba), which is compatible with NJOY.

T. Kawano also presented the covariance matrix for the total cross section of ^{232}Th using the SOK and KALMAN code.

Liu Ping presented a covariance matrix for the fission cross section using the SPCC code.

A. Ignatyuk presented the covariance data for the total, capture, fission and (n, 2n) cross sections obtained from a statistical analysis of experimental data using the Obninsk code.

H. Leeb presented the covariance matrix for ^{232}Th and ^{151}Sm capture measurements at n_TOF using C_6D_6 detectors.

The difficulty of intercomparing different covariance data was discussed. The problem of different representations will be addressed by generating multigroup covariances in a limited group structure. A detailed comparison requires further interaction among participants.

2.6: Thermal and resonance parameter data of other nuclides (Session Chairman: L. Leal)

L. Leal presented the evaluation of ^{233}U in RRR (up to 600 eV) and URR (from 600 eV up to 40 keV); this evaluation will be included in ENDF/B-VII. V. Maslov remarked that there is an inconsistency in Leal's file.

Maslov's evaluation includes an independent URR evaluation from 600 eV to 40 keV.

The advantage of Leal's evaluation is the existence of covariance data. This evaluation is preferred, unless integral benchmark analysis indicates otherwise.

The following files are available for other isotopes:

^{232}U

- V. Maslov has a file up to 20 MeV. For RRR, the file is based on an adjusted parameter set from Mughabghab. RRR goes up to 200 eV, while URR extends from 1 up to 150 keV.
- An ENDF/B-VII file is also available. However, URR only goes up to 2 keV, and shows a discontinuity at this limit.
- Selection between ENDF/B-VII and Maslov's evaluation requires additional analysis. The discontinuity in capture cross section at 2 keV of ENDF/B-VII will be addressed by T. Kawano.

^{234}U

- Existing files: Maslov, JENDL 3.3 and ENDF/B-VII.
- P. Schillebeeckx will verify these files using the latest $^{234}U(n, f)$ IRMM data.

^{236}U

- Existing files: ENDF/B-VII and JENDL 3.3.
- P. Schillebeeckx (in collaboration with F. Gunsing) will verify the consistency of these files with the recent $^{236}U(n, \gamma)$ and $^{236}U(n, f)$ IRMM data.

^{231}Pa

- Existing file: Maslov in which JENDL 3.3 is adopted, and revised starting from unresolved region.

^{233}Pa

- Existing files: Maslov and Morogovskij.

Participants concluded that Maslov's evaluations can be recommended for $^{231,233}Pa$. V. Maslov will verify the consistency of the Morogovskij evaluation and his previous file.

2.7: Nuclear model parameters, level schemes, double differential and photon production data of other nuclides (Session Chairman: A. Ignatyuk)

R. Capote will perform calculations with the new dispersive coupled channel potential, starting from the thorium potential and adjust the potentials for the other nuclei. He will compare the results with existing data. For ^{233}U, he will also compare his results with the Maslov and ENDF/B-VII evaluations.

M. Sin will calculate the fission cross sections for $^{232,233,234,236}U$ and $^{231,233}Pa$ using the potential recommended by R. Capote, and compare with existing experimental data.

2.8: Experimental data processing, and formation of covariances for other nuclides (Session Chairman: T. Kawano)

No dedicated presentation.

Covariance data are required for ^{232}Th and ^{233}U only.

Covariance data for the other nuclides would be desirable, but are not essential deliverables.

2.9: Integral data, evaluated data file verification, benchmarking and validation of other nuclides (Session Chairman: A. Trkov)

A. Trkov presented candidate sources of integral benchmarks, which include the ICSBEP handbook, SIMBA data base for neutron activation analysis and work that is currently in progress for this CRP within India.

A. Ignatyuk mentioned benchmark experiments performed on BN-350 and analysed at Obninsk in 1998. The benchmarks refer to the irradiation of ^{232}Th in a fast reactor, and infer the ^{231}Pa(n, γ) cross section.

Data exist that result from lead slowing down measurements - not obvious to interpret, since they require a precise description of the experimental conditions.

In the final report, it should be added that it is desirable to do a sensitivity analysis for selective benchmarks.

2. 10 : Fission product yield and decay data of other nuclides (Session Chairman: V. Maslov)

Same status as for ^{232}Th.

2.11: Task assignment on thermal and resonance parameter data (Session Chairman: N. Janeva)

Actions:

- Liu Ping will send a draft paper about thermal evaluation to A. Trkov, P. Schillebeeckx, and L. Leal. (January 2005)
- A. Trkov will provide recommended thermal values for ^{232}Th. (February 2005)
- P. Schillebeeckx will verify the consistency of the RIPL parameters and the average resonance parameters resulting from the evaluation of RRR for ^{232}Th. He will also perform a comparison with the new Maslov evaluation. (January 2005)
- L. Leal and P. Schillebeeckx will recommend ^{232}Th average resonance parameters for adjustment of optical model parameters. (January 2005)
- P. Schillebeeckx will verify spin assignments when n_TOF data are available. (July 2005)
- L. Leal and P. Schillebeeckx will provide ^{232}Th recommended file for RRR. (July 2005)

- V. Maslov will perform an independent statistical analysis of the new resonance parameter set. (August 2005)
- For ^{233}Pa, V. Maslov will verify the consistency of the Morogovskij resonance parameter evaluation and a previous evaluation from the same evaluator. (March 2005)
- N. Janeva will provide A. Trkov with the input requirements to implement the HARFOR code in NJOY. (March 2005)
- P. Schillebeeckx will verify the consistency of the evaluated data files with the latest ^{236}U(n, γ) and ^{234,236}U(n, f) IRMM data. (July 2005)
- For other nuclides, existing evaluations are to be adopted. If necessary minor adjustments will be made by V. Maslov, A. Ignatyuk and L. Leal.

2.12: Task assignment on nuclear model parameters, level schemes, double differential and photon production data (Session Chairman: A. Ignatyuk)

Actions:

^{232}Th:

- R. Capote will adjust the parameters of the new dispersive coupled channel potential, taking into account the latest experimental data. (February 2005)
- V. Maslov and A. Ignatyuk will test this potential, and communicate final recommendations to M. Sin. (March 2005)
- M. Sin will finalise the calculations for the fission cross sections up to 60 MeV using the recommended potential. (August 2005)
- V. Maslov will provide the excitation cross sections for collective levels, which will be compared by R. Capote with the results obtained by DWBA. (March 2005)

Other nuclides:

- R. Capote will also use the new dispersive coupled channel potential for the other nuclides, starting from the thorium potential and adjust them for the other nuclei. (June 2005)
- M. Sin will calculate the fission cross sections for ^{232,233,234,236}U and ^{231,233}Pa using the potential recommended by R. Capote, and compare with existing experimental data. (August 2005)

Fission neutron spectra:

- T. Kawano will verify if a new JENDL evaluation is foreseen. (December 2004)

2.13: Task assignment on experimental data processing and formation of covariance files (Session Chairman: T. Kawano)

***Actions*:**

- L. Leal will provide ^{232}Th covariance data for RRR. (March 2005)
- P. Schillebeeckx will provide ^{232}Th covariance data for URR. (January 2005)
- A. Ignatyuk will provide the covariance data for ^{232}Th and ^{233}U data above URR. (April 2005)
- T. Kawano will provide covariance data for the total cross section evaluated with KALMAN. (April 2005)

- A. Trkov will produce a ^{232}Th covariance matrix for group constants using ERRORJ - discuss results before the WPEC meeting. (April 2005)
- Liu Ping will provide T. Kawano with the experimental data that were used to produce the covariance matrix for the ^{232}Th fission cross section. (December 2004)
- T. Kawano will process these data with SOK, and compare with Liu Ping's results. (January 2005)
- Liu Ping will provide covariance data for ^{233}U fission. (February 2005)
- T. Kawano will distribute his codes (SOK and KALMAN) together with manuals and input/output files to CRP participants. (March 2005)
- O. Iwamoto will collaborate with R. Capote and T. Kawano to calculate sensitivities of the new dispersive potential for ^{233}U and ^{232}Th. (April 2005)

2. 14: Task assignment on integral data, evaluated data file verification, benchmarking and validation (Session Chairman: A. Trkov)

Actions:

- A. Trkov will draft a list of benchmarks, which include criticality from the international criticality safety handbook. (January 2005)
- Ganesan will provide experimental results and information related to the Indian PHWR thorium irradiation experiments, including burnup history of the fuel bundles undergoing PIE, PIE results and a complete description of the lattice and core (geometry and composition specifications). (March 2005)
- Ganesan will investigate possible collaboration with KAERI (Republic of Korea) on the analysis of benchmarks performed in India. (March 2005)
- Ganesan will elaborate on the specifications and the analysis of the KAMINI benchmark. (May 2005)
- V. Maslov will try to provide full specifications of a benchmark performed by S.P. Simakov, Karlsruhe (both 14 MeV and Cf work). (December 2004)
- Liu Ping will repeat the analysis of the ^{232}Th criticality benchmarks using the most recent ENDF/B-VII data file. (March 2005)
- Liu Ping will analyse the criticality benchmarks for ^{233}U from the criticality handbook for both thermal and fast spectra. (July 2005)
- A. Trkov and P. Schillebbeeckx will check the possibility for changing the input file of the lead slowing down measurements. (January 2005)
- Action on all to identify anything that could be used for data validation with respect to minor actinides, i.e., ^{231}Pa and ^{232}U. (December 2005)

2.15: Fission product yield and decay data of other nuclides (Session Chairman: V. Maslov)

Actions:

- Liu Ping will provide another representation of the fission product yields to compare the different evaluated data files (i.e., ENDF/B-VI and JEF 3.1) with experimental data. (February 2005)
- A. Trkov will send the report of Liu Ping to the ENDF, JEF, JENDL evaluators for review. (December 2004)

- IAEA Nuclear data section will review the feedback reports on the above and take action accordingly. (May 2005)
- V. Maslov will verify the possibility to extend the existing file for ^{232}Th by adding a few energy points above 14 MeV up to 200 MeV. The extension will be based on a multimode analysis of fission yields by S. Zhdanov et al. (August 2005)

3. Next meeting

Since there will not be another RCM before the final meeting, participants could profit from ancillary discussions during the WPEC and/or GEN-IV meetings of April 2005. The final meeting will be held in late 2005 or early 2006 in either Ljubljana or Vienna. A. Trkov will determine the most suitable dates and venue, and inform the CRP participants.

APPENDIX 4.1

International Atomic Energy Agency
Second Research Coordination Meeting on
"Evaluated Nuclear Data for the Thorium-Uranium Fuel Cycle"
6 – 9 December 2004, IAEA Headquarters, Vienna, Austria
Meeting Room A2643

LIST OF PARTICIPANTS

AUSTRIA
Helmut Leeb
Atominstitut der Österreichischen Universitäten
AB Kernphysik
TechnischeUniversitaet Wien
Wiedner Hauptstrasse 8-10
A-1040 Vienna
Tel: +43 1 58801 14258
Fax: +43 1 58801 14299
E-mail: leeb@kph.tuwien.ac.at

BELARUS
Vladimir M. Maslov
Nuclear Data Evaluation Laboratory
Joint Institute for Power and Nuclear Research
Minsk-Sosny 220109
Tel: +375 17 2994441
Fax: +375 17 2994441
E-mail: maslov@sosny.bas-net.by
maslov@bas-net.by

BULGARIA
Natalia B. Janeva
Bulgarian Academy of Sciences
Institute for Nuclear Research and Nuclear Energy
Tzarigradsko Shaussee 72
BG-1784 Sofia
Tel:
Fax: +359 2 975 36 19
E-mail: pripesho@inrne.bas.bg

CHINA
Liu Ping
China Nuclear Data Center
China Institute of Atomic Energy
PO Box 275 (41)
102413 Beijing
Tel: +86 10 69 357 712
Fax: +86 10 69 357 7008
E-mail: ping@iris.ciae.ac.cn

INDIA
Srinivasan Ganesan
Reactor Physics Design Division
5th Floor, Central Complex
Bhabha Atomic Research Centre
Trombay, Mumbai-400085
Tel: +91 22 25595002
Fax: +91 22 25519613
E-mail: ganesan@magnum.barc.ernet.in

JAPAN
Osamu Iwamoto
Nuclear Data Center
Department of Nuclear Energy System
Japan Atomic Energy Research Institute
2-4 Shirakata
Tokai-mura, Naka-gun
Ibaraki-ken 319-1195
Tel: +81 29 282 5483
Fax: +81 29 282 5766
E-mail: iwamoto@ndc.tokai.jaeri.go.jp

ROMANIA
Mihaela Sin
Nuclear Physics Department
University of Bucharest
PO Box MG-11
RO-76900 Bucuresti-Magurele
Tel: +40 21 457 4419
Fax: +40 21 457 4521
E-mail: msin@pcnet.ro

RUSSIA
Anatoly Ignatyuk
Institute of Physics and Power Engineering
Bondarenko Sq. 1
249020 Obninsk, Kaluga Region
Tel: +7 08439 98035
Fax: +7 08439 68333
+7 09523 02326
E-mail: ignatyuk@ippe.obninsk.ru

UNITED STATES OF AMERICA
Luiz C. Leal
Nuclear Data and Information Analysis
Nuclear Science and Technology Division
Oak Ridge National Laboratory
Building 6011, Mail Stop 6370
PO 2008
Oak Ridge, TN 37831-6370
Tel: +1 865 574 5281
Fax: +1 865 574 6182
E-mail: leallc@ornl.gov

Toshihiko Kawano
Group T-16, MS-B283
Theoretical Division
Los Alamos National Laboratory
Los Alamos, NM 87545
Tel: +1 505 664 0513
Fax: +1 505 667 1931
E-mail: Kawano@lanl.gov

ADVISORS:
BELGIUM
Peter Schillebeeckx
Neutron Physics Unit
EC-JRC-IRMM
Retieseweg 111
B-2440 Geel
Tel: +32 14 571 475
Fax: +32 14 571 862
E-mail: peter.schillebeeckx@cec.eu.int

REPUBLIC OF KOREA
YongDeok Lee
Nuclear Data Evaluation Laboratory
Korea Atomic Energy Research Institute
P.O. Box 105
Yusong, Daejon 305-600
Tel: +82 42 868 2635
Fax: +82 42 868 2636
E-mail: ydlee@kaeri.re.kr

IAEA:
Andrej Trkov
Nuclear Data Section
Division of Physical and Chemical Sciences
Room A2316
Tel: +43 1 2600-21712
Fax: +43 1 26007
E-mail: A.Trkov@iaea.org

Alan L. Nichols
Nuclear Data Section
Division of Physical and Chemical Sciences
Room A2312
Tel: +43 1 2600-21709
Fax: +43 1 26007
E-mail: A.Nichols@iaea.org

Viktor Zerkin
Nuclear Data Section
Division of Physical and Chemical Sciences
Room A2318
Tel: +43 1 2600 21714
Fax: +43 1 26007
E-mail: V.Zerkin@iaea.org

Roberto Capote-Noy
Nuclear Data Section
Division of Physical and Chemical Sciences
Room A2317
Tel: +43 1 2600 21713
Fax: +43 1 26007
E-mail: R.Capote@iaea.org

APPENDIX 4.2

International Atomic Energy Agency
Second Research Coordination Meeting on
"Evaluated Nuclear Data for the Thorium-Uranium Fuel Cycle"
6 – 9 December 2004, IAEA Headquarters, Vienna, Austria
Meeting Room A2643

AGENDA

Monday, 6 December

08:30 – 09:20 Registration (IAEA registration desk, Gate 1)
09:30 – 10:00 Opening Session
  Opening (A.L. Nichols)
  Introductory remarks (A.Trkov)
  Election of Chairman and Rapporteur
  Discussion and adoption of the Agenda (Chairman)
10:00 – 11:00 Coffee break and Administrative Matters
11:00 – 12:15 Session 1: Thermal and resonance parameter data of ^{232}Th
  Chairman: L. Leal
    A. Trkov: On the Thermal Capture Cross Section
    L. Leal
    N. Janeva/P. Schillebeeckx
    Other
    General Discussion
12:15 – 14:00 Lunch
14:00 – 15:30 Session 2: Nuclear model parameters, level schemes, double differential and photon production data of ^{232}Th
  Chairman: A. Ignatyuk
    V. Maslov
    A. Ignatyuk
    O. Iwamoto
    M. Sin
    R. Capote Noy
    Other
    General Discussion on:
      - Selection of OMP set
      - Model code
      - Energy range
15:30 – 16:00 Coffee break
16:00 – 17:00 Session 3: Integral data, evaluated data file verification, benchmarking and validation of ^{232}Th
  Chairman: A. Trkov
    S. Ganesan
    Liu Ping
    General Discussion
17:00 – 17:45 Session 4: Fission-product yield and decay data of ^{232}Th
  Chairman: V. Maslov
    Liu Ping
    General Discussion
17:45 onwards Reception A23

Tuesday, 7 December

08:30 – 10:15 Session 5: Experimental data processing and formation of covariance files of ^{232}Th

Chairman: T. Kawano

A. Ignatyuk

Liu Ping

T. Kawano

H. Leeb

Other

General Discussion

10:15 – 10:45 Coffee break

10:45 – 12:15 Session 6: Thermal and resonance parameter data of other nuclides

Chairman: L. Leal

- Currently available resonance parameter evaluations
- Status and work plan

12:15 – 14:00 Lunch

14:00 – 15:30 Session 7: Nuclear model parameters, level schemes, double differential and photon production data of other nuclides

Chairman: A. Ignatyuk

- Availability and selection of nuclear model parameters
- Availability and status of codes for calculations
- Work plan

15:30 – 16:00 Coffee break

16:00 – 17:30 Session 8: Experimental data processing and formation of covariance files of other nuclides

Chairman: T. Kawano

- Status and work plan

Wednesday, 8 December

08:30 – 09:30 Session 9: Integral data, evaluated data file verification, benchmarking and validation of other nuclides

Chairman: A. Trkov

Discussion

09:30 – 10:15 Session 10: Fission-product yield and decay data of other nuclides

Chairman: V. Maslov

Discussion

10:15 – 10:45 Coffee break

10:45 – 12:15 Session 11: Task assignment on thermal and resonance parameter data

Chairman: N. Janeva

12:15 – 14:00 Lunch

14:00 – 15:30 Session 12: Task assignment on nuclear model parameters, level schemes, double differential and photon production data

Chairman: A. Ignatyuk

15:30 – 16:00 Coffee break

16:00 – 17:30 Session 13: Task assignment on experimental data processing and formation of covariance files

Chairman: T. Kawano

Thursday, 9 December

08:30 – 09:30 Session 14: Task assignment on integral data, evaluated data file verification, benchmarking and validation

Chairman: A. Trkov

09:30 – 10:15	Session 15: Task assignment on fission-product yield and decay data Chairman: V. Maslov
10:15 – 10:45	Coffee break
10:45 – 12:15	Session 16: Drafting of summary report Chairman: A. Ignatyuk
12:15 – 14:00	Lunch
14:00 – 15:30	Session 17: Closing session Review of the summary document Concluding remarks Date of the next meeting Closing of the meeting

GUIDELINES

General:
- Please check the Th-U CRP web page http://www-nds.iaea.org/Th-U/index.html frequently for announcements and up-to-date information.
- For all administrative queries, contact Ms. Janet Roberts on J.Roberts@iaea.org
- For technical matters, contact the technical officer of the project, Andrej Trkov on A.Trkov@iaea.org with a copy to Ms. Roberts.

Presentations:
- Oral presentations at the meeting are deliberately short.
- Presentations should *not* describe details of the theoretical advances, but primarily inform the other participants (not necessarily experts in the field) of the status.

Meeting:
- Chairman should delegate the chairing of the subgroup sessions to subgroup leaders.
- Subgroup leaders are expected to help the rapporteur to assemble the draft summary of the meeting, particularly regarding task assignments (sessions 2.11- 2.15).

APPENDIX 4.3

TASK ASSIGNMENTS (by date)

Date	Participant	Agenda no.	Task
December 2004	Kawano	2.12	fisson neutron spectra: to verify if a new JENDL evaluation is foreseen.
December 2004	Liu Ping	2.13	to provide Kawano with the experimental data that were used to produce the covariance matrix for the ^{232}Th fission cross section.
December 2004	Maslov	2.14	to try to provide full specifications of a benchmark performed by Simakov, Karlsruhe (both 14 MeV and Cf work).
December 2004	Trkov	2.15	to send the report of Liu Ping to the ENDF, JEF, JENDL evaluators for review. (see May 2005, IAEA Nuclear Data Section)
January 2005	Liu Ping	2.11	to send a draft paper about thermal evaluation to Trkov, Schillebeeckx, and Leal.
January 2005	Schillebeeckx	2.11	to verify the consistency of the RIPL parameters and the average resonance parameters resulting from the evaluation of RRR for ^{232}Th, and to perform a comparison with the new Maslov evaluation.
January 2005	Leal and Schillebeeckx	2.11	to recommend ^{232}Th average resonance parameters for adjustment of optical model parameters.
January 2005	Schillebeeckx	2.13	to provide ^{232}Th covariance data for URR.
January 2005	Kawano	2.13	to process the experimental data used to produce the covariance matrix for the ^{232}Th fission cross section with SOK, and compare with Liu Ping's results.
January 2005	Trkov	2.14	to draft a list of benchmarks, which include criticality from the international criticality safety handbook.
January 2005	Trkov and Schillebbeeckx	2.14	to check the possibility for changing the input file of the lead slowing down measurements.
February 2005	Trkov	2.11	to provide recommended thermal values for ^{232}Th.
February 2005	Capote	2.12	^{232}Th: to adjust the parameters of the new dispersive coupled channel potential, taking into account the latest experimental data. (see March 2005, Maslov and Ignatyuk)
February 2005	Liu Ping	2.13	to provide covariance data for ^{233}U fission.

February 2005	Liu Ping	2.15	to provide another representation of the fission product yields to compare the different evaluated data files (i.e., ENDF/B-VI and JEF 3.1) with experimental data.
March 2005	Maslov	2.11	for ^{233}Pa, to verify the consistency of the Morogovskij resonance parameter evaluation and a previous evaluation from the same evaluator.
March 2005	Janeva	2.11	to provide Trkov with the input requirements to implement the HARFOR code in NJOY.
March 2005	Maslov and Ignatyuk	2.12	^{232}Th: to test this potential, and communicate final recommendations to Sin. (see February 2005, Capote)
March 2005	Maslov	2.12	^{232}Th: to provide the excitation cross sections for collective levels, which will be compared by Capote with the results obtained by DWBA.
March 2005	Leal	2.13	to provide ^{232}Th covariance data for RRR.
March 2005	Kawano	2.13	to distribute his codes (SOK and KALMAN) together with manuals and input/output files to CRP participants.
March 2005	Ganesan	2.14	to provide experimental results and information related to the Indian PHWR thorium irradiation experiments, including burnup history of the fuel bundles undergoing PIE, PIE results and a complete description of the lattice and core (geometry and composition specifications).
March 2005	Ganesan	2.14	to investigate possible collaboration with KAERI (Republic of Korea) on the analysis of benchmarks performed in India.
March 2005	Liu Ping	2.14	to repeat the analysis of the ^{232}Th criticality benchmarks using the most recent ENDF/B-VII data file.
April 2005	Ignatyuk	2.13	to provide the covariance data for ^{232}Th and ^{233}U data above URR.
April 2005	Kawano	2.13	to provide covariance data for the total cross section evaluated with KALMAN.
April 2005	Trkov	2.13	to produce a ^{232}Th covariance matrix for group constants using ERRORJ - discuss results before the WPEC meeting.
April 2005	Iwamoto	2.13	to collaborate with Capote and Kawano to calculate sensitivities of the new dispersive potential for ^{233}U and ^{232}Th.

April 2005	All		since there will not be another RCM before the final meeting, participants could profit from ancillary discussions during the WPEC and/or GEN-IV meetings.
May 2005	Ganesan	2.14	to elaborate on the specifications and the analysis of the KAMINI benchmark.
May 2005	IAEA Nuclear data section	2.15	to review the feedback reports and take action accordingly. (see December 2004, Trkov)
June 2005	Capote	2.12	other nuclides: to use the new dispersive coupled channel potential for the other nuclides, starting from the thorium potential and adjust them for the other nuclei.
July 2005	Schillebeeckx	2.11	to verify spin assignments when n_TOF data are available.
July 2005	Leal and Schillebeeckx	2.11	to provide ^{232}Th recommended file for RRR.
July 2005	Schillebeeckx	2.11	to verify the consistency of the evaluated data files with the latest ^{236}U(n, γ) and ^{234,236}U(n, f) IRMM data. (see Maslov, Ignatyuk and Leal)
July 2005	Liu Ping	2.14	to analyse the criticality benchmarks for ^{233}U from the criticality handbook for both thermal and fast spectra.
August 2005	Maslov	2.11	to perform an independent statistical analysis of the new resonance parameter set.
August 2005	Sin	2.12	^{232}Th: to finalise the calculations for the fission cross sections up to 60 MeV using the recommended potential.
August 2005	Sin	2.12	other nuclides: to calculate the fission cross sections for ^{232,233,234,236}U and ^{231,233}Pa using the potential recommended by Capote, and compare with existing experimental data.
August 2005	Maslov	2.15	to verify the possibility to extend the existing file for ^{232}Th by adding a few energy points above 14 up to 200 MeV. The extension will be based on a multimode analysis of fission yields by S. Zhdanov et al.
December 2005	All	2.14	to identify anything that could be used for data validation with respect to minor actinides, i.e., ^{231}Pa and ^{232}U.

	Maslov, Ignatyuk and Leal	2.11	for other nuclides, existing evaluations are to be adopted. If necessary minor adjustments will be made. (see July 2005, Schillebeekx)

APPENDIX 4.4

PRESENTATIONS BY PARTICIPANTS

Appendix 4.4.1

Evaluation of the ^{232}Th neutron cross sections between 4 keV and 140 keV

P. Schillebeeckx*/N. Janeva**
*EC-JRC, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium
**Institute for Nuclear Research and Nuclear Energy, 1784 Sofia, Bulgaria

An evaluation of the ^{232}Th neutron total and capture cross sections has been performed in the energy region between 4 keV and 140 keV. The evaluation results from a simultaneous analysis of capture, transmission and self-indication measurement data, including the most recent capture cross section data obtained at the GELINA facility of the Institute for Reference Materials and Measurements at Geel (B)[1] and at the n-TOF facility at CERN (CH)[2]. The experimental data have been analysed in terms of average resonance parameters exploiting two independent theoretical approaches – the Characteristic Function model[3,4] and the Hauser-Feshbach-Moldauer approach[5] that is implemented in the SAMMY code[6]. The resulting parameters are consistent with the resolved resonance parameters deduced from the transmission measurements of Olsen et al. at the ORELA facility[7].

Since the present version of HARFOR[3,4] does not include the in-elastic scattering reaction, the application of the code is limited to about 50 keV. We derived the mean level spacing D_0, the average radiation widths $<\Gamma_\gamma>_{0,1}$, the neutron strength functions S_1 and S_2 and the effective scattering radius R' from a simultaneous fit of our capture data together with the transmission data of Uttley et al.[8] and the self-shielding factors measured by Oigawa et al.[9] The radiation width for d-wave resonances was fixed at the value for s-wave resonances. The results are listed in Table 1 and compared with the evaluation of Maslov et al.[10]

We also used the SAMMY code[4], which incorporates the FITACS algorithms[5], to parameterize the average capture cross section between 4 and 140 keV. We fitted the capture data of Ref. 1 together with the capture data obtained at the n-TOF facility of CERN[2] and cross sections of Ref. 8,11-18. In the analysis a normalisation factor was adjusted, which we varied within the uncertainty limits quoted in the corresponding reference. The final recommended average parameters are given in Table 1. These parameters are consistent with the values deduced from a statistical analysis of resolved resonance parameters. The average radiation width for p-wave neutrons does almost not differ from the one for s-wave neutrons, as already suggested by Olsen et al.[7] For the effective scattering radius we obtain values R' = 9.53(0.2) fm. This value relates to a distant level parameter R_∞ = - 0.141, which is consistent with the results of optical model calculations. The neutron strength function for p-wave resonances is also close to the value reported by Corvi et al.[19]

Table 1. The Evaluated Average Resonance Parameters of ^{232}Th For The URR

R' / fm	D_o / eV	S_ℓ (x 10^{-4})			$<\Gamma_\gamma>_\ell$ / meV			Ref.
		0	1	2	0	1	2	
9.43	17.385	0.94	2.15	1.15	21.3	21.3	21.3	Maslov et al.[10]
9.53	17.28	0.935	1.81	1.18	23.90	24.40	23.90	HARFOR[3,4]
(0.2)	(0.50)	(0.05)	(0.03)		(0.30)	(0.20)		
9.53	17.28	0.935	1.84	1.18	24.00	24.40	24.00	FITACS[5]/
(0.2)			(0.02)	(0.03)	(0.20)	(0.20)		SAMMY[6]

References:

1. Borella, A., Volev, K., Schillebeekx, P., Corvi, F., Koyumdjieva, N., Janeva, N., and Lukyanov, A., Nucl. Sci. Eng., (accepted for publication).
2. Aerts, G., Gunsing, F., and the n-TOF collaboration, ND2004, Santa Fe.
3. Koyumdjieva, N., Janeva, N., and Lukyanov, A., Z. Phys., A353, 31 (1995).
4. Koyumdjieva, N., Janeva, N., and Volev, K., Nucl. Sci. Eng., 137(2), 194 (2001).
5. Fröhner, F., Report GA-8380, Gulf General Atomic (1968).
6. Larson, N., ORNL/TM-9179/R6 ENDF-364, July 2003.
7. Olsen, D., Ingle, R., and Portney, J., Nucl. Sci. Eng., 82, 289 (1982).
8. Uttley, C., Newstead, C., and Diment, K., "Neutron Strength Function Measurements in the Medium and Heavy Nuclei", Proc. Conf. Nuclear Data for Reactors, 17 - 21 October, Paris, vol. 1, p. 165, (1966).
9. Oigawa, H., Fujita, Y., Kobayashi, K., Yamamoto, S., and Kimura, I., J. Nucl. Sci. Technol., 28(10), 879 (1991).
10. Maslov, V., et al., INDC(BLR)-016, IAEA, (2003).
11. Grigoriev, Yu., et al., EXFOR : entry num. 41372.
12. Poenitz, W., Whalen, J., and Smith, A., Nucl. Sci. Eng., 78, 333 (1981).
13. Iwasaki, T., Baba, M., Hattori, K., Kanda, K., Kamata, S., and Hirakawa, N., in Contribution to the Specialists' Meeting on Fast Neutron Scattering on Actinide Nuclei, R-NEANDC, EXFOR: entry num. 21766, (1981).
14. Kobayashi, K., Fujita, Y., and Yamamuro, N., J. Nucl. Sci. Techn., 18 (11), 823 (1981).
15. Poenitz, W., and Smith, D., ANL/NDM-42, (1978).
16. Macklin, R., and Winters, R.R., Nucl. Sci. Eng., 78, 110 (1981).
17. Vertebnyj et al., IAEA-410, p.257, EXFOR: entry num. 40929, (1986).
18. Fujita, Y., et al., EXFOR entry num. 12858.
19. Corvi, F., Pasquariello, G., and Van Der Veen, T., "p-wave assignment of ^{232}Th resonances" in *Proc. Int. Conf. Neutron Physics and Nuclear Data*, Harwell, UK, p. 712, (1978).

Appendix 4.4.2

Comparison of different average parameters for ^{232}Th in the URR

P. Schillebeeckx*/N. Janeva**
*EC-JRC, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium
**Institute for Nuclear Research and Nuclear Energy, 1784 Sofia, Bulgaria

In this report we compare the total and capture cross sections for ^{232}Th resulting from a set of average resonance parameters. The average parameters are:

1. the average parameters based on our evaluation using SAMMY/FITACS and HARFOR. The evaluation is based on a simultaneous analysis of capture, transmission and self-indication measurement data, including the most recent capture cross section data obtained at the GELINA facility (Nucl. Sci & Eng accepted) and at the n-TOF facility (Aerts et al. ND2005)
2. parameters obtained by L. Leal and presented at the last CRP meeting. L. Leal provided values for the scattering radius, average level spacing and average radiation width but did not include the average neutron strength function (or average reduced neutron width). Therefore, we fitted the experimental data (as for point 1) fixing his values for the scattering radius, level spacing and radiation width and adjusted the reduced neutron widths. The adjusted values are in italics.
3. parameters in the RIPL data base. In this data base we only find values for the s-wave level spacing, neutron strength function and radiation width. The other values, i.e., scattering radius and the average parameters for p- and d-waves, were taken from our evaluation (see point 1).

The average parameters are listed in Table 1 and the resulting total and capture cross sections are compared in Fig. 1. The experimental data is shown in the figure too.

Table 1. The Evaluated Average Resonance Parameters of ^{232}Th For The URR

R' / fm	**D_o / eV**	**S_ℓ (x 10^{-4})**			**$<\Gamma_\gamma>_\ell$ / meV**			**Ref.**
		0	1	2	0	1	2	
9.53 (0.2)	17.28	0.935	1.84 (0.02)	1.18 (0.03)	24.00 (0.20)	24.40 (0.20)	24.00	FITACS/SAMMY (IRMM)
9.72	16.57	*0.85*	*1.58*	*1.17*	24.4	24.4	24.4	L. Leal (ORNL)
9.53	16.60	0.87	*1.84*	*1.18*	24.0	*24.4*	*24.0*	RIPL

We also used NJOY to process the evaluated file produced by SAMMY_URR. The results are shown in Fig. 2. Obviously below the first in-elastic channel the results are identical to those obtained with SAMMY/FITACS. However, above the threshold of the first in-elastic channel discrepancies are observed in capture as well as in total cross sections.

When comparing the results obtained with Leal's and our parameters, we want to point out the difference in the scattering radius and the neutron strength functions. In Fig. 3 we show the difference in potential scattering contribution using these parameters. These differences can only be judged after the final analysis in the RRR and the total cross section at thermal energies.

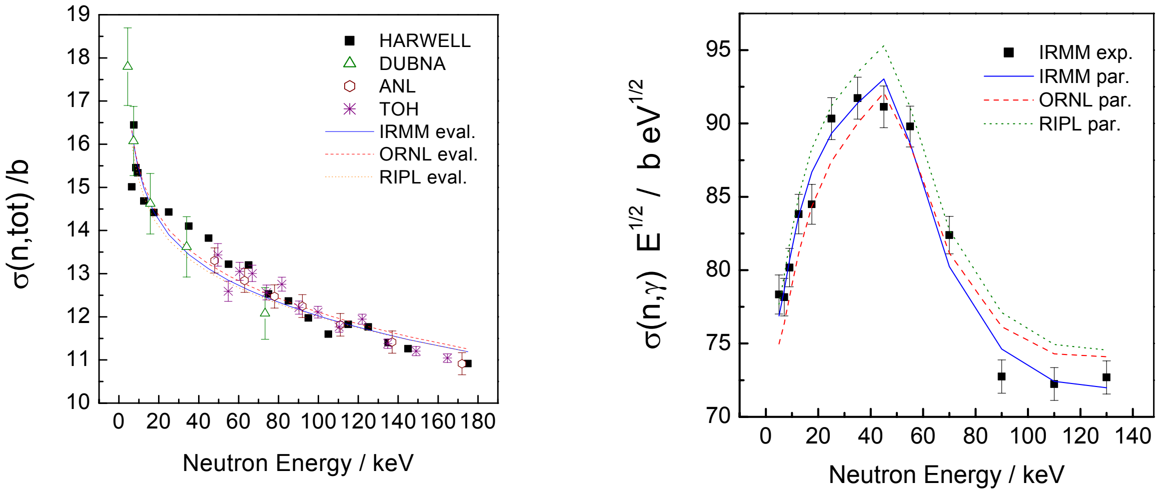

Fig. 1. Capture and total cross-sections produced with the SAMMY/FITACS for different average parameters sets (see Table 1).

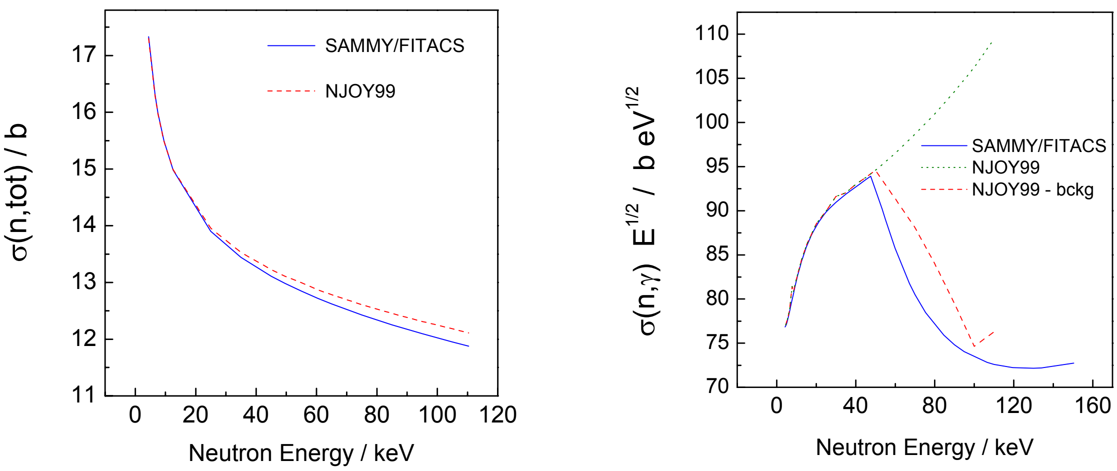

Fig. 2. Capture and total cross-sections produced with the NJOY and SAMMY/FITACS codes for the energy range [4-120] keV.

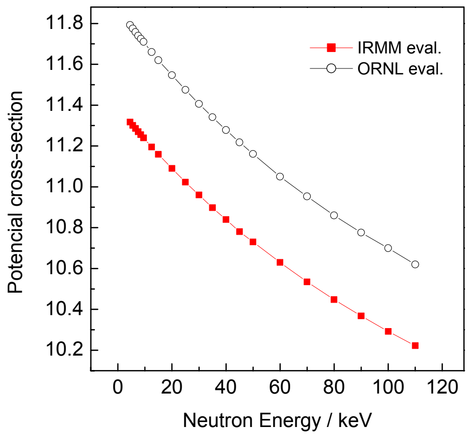

Fig. 3. Potential cross-sections (in barn) produced with the NJOY for the energy range [4-120] keV.

Appendix 4.4.3

^{232}Th evaluation in the energy range from 0 to 4 keV

L. Leal
Oak Ridge National Laboratory, USA

A preliminary resolved resonance evaluation for the ^{232}Th cross sections performed in the energy region from 10^{-5} eV to 4 keV was presented at the Second Research Coordination Meeting (CRP) on Evaluated Nuclear Data for Th-U Fuel Cycle. The motivation for the new evaluation was as follow:

a) Determination of the external resonances for an accurate calculation of the effective scattering radius for fitting the transmission data consistently in the entire energy region. The contributions of the external levels to the total cross section are shown in Fig. 1 which shows the interference between the potential and the resonant contributions in the scattering channel.

b) Improve the statistical spin distribution for s-wave and p-wave.

c) Include new thermal cross section values.

d) Include new capture cross section measurements.

The ^{232}Th nucleus has ground state spin and parity of $J^{\pi}=0^{+}$. The states of the ^{233}Th compound nucleus excited by the capture of s-wave neutrons ($l=0$) in the ^{232}Th nucleus have $J^{\pi}=1/2^{+}$, and for p-wave neutrons ($l=1$) the states have $J^{\pi}=1/2^{-},3/2^{-}$. The resonance parameters evaluation in the ENDF/B-VI library includes only the s-wave spin 1/2+ and the p-wave spin 1/2-. When starting a Reich-Moore analysis of the experimental data in the resolved resonance region, the resonances should be partitioned among the spin states s-wave (1/2+) and p-wave (1/2-, 3/2-). The computer code SUGGEL was used to distribute the s- and p-wave resonance spins. The new set of resonance parameters was used to fit the experimental data. The experimental data base used in the fitting is shown in Table 1. Fitting of three sets of transmission data of Olsen et al.[1] in the energy from 1200 to 1600 eV is shown in Fig. 2. The preliminary set of resonance parameters represents the cross section reasonably well. However, the average resonance parameters show very poor statistics. The results of the statistical distribution of the resonance parameters from 0 to 4 keV is shown in Table 2. Comparison of the histogram nearest neighbor-spacing distribution for l=0 and j= $J^{\pi}=1/2^{+}$ with the Wigner distribution is shown in Fig. 3. The agreement is very poor. Work is underway to improve the statistics of the resonance parameters by including small resonances.

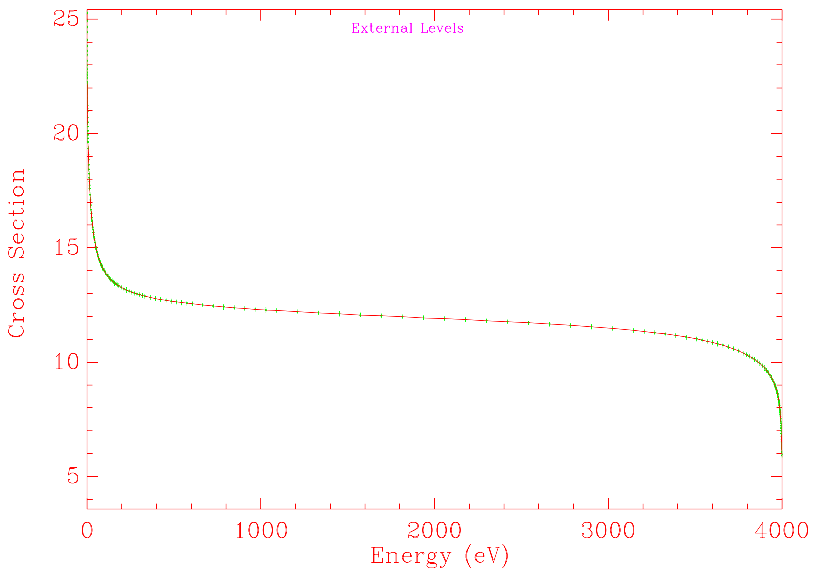

Fig. 1. Contribution of the external resonances to the total cross section in the energy range 0 to 4 keV

Table 1. Selected Measurements for the ^{232}Th evaluation.

Energy Range (eV)	*References*	*Measurements Type*	*Thickness (at/b)*	*Flight Path Length (m)*
82.29 to 580	*Garg et al. Columbia*	*TotalCross Section*	-	*200*
212.32 to 4000 T=77 K	*Ribon et al. CEA*	*Total Cross Section*	-	*103.7*
0.008 to 15	*Olsen et al. ORELA*	*Total Cross Section*	-	*22.532*
15 to 4000	*Olsen et al. ORELA*	*Transmission*	*8 samples 0.0001608 to 0.19308*	*40.016*
10 to 4000	*GEEL*	*Capture*	*1 sample 0.003176*	*58.386*
10 to 100	*NTOF*	*Capture*	*1 sample 0.004109*	*185.2*

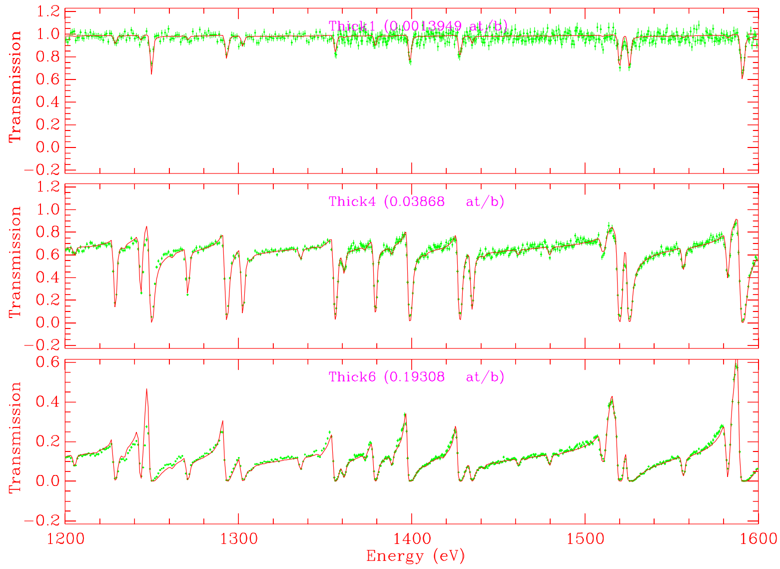

Fig. 2. Experimental and calculated neutron transmission in the energy range from 1.2 to 1.6 keV.

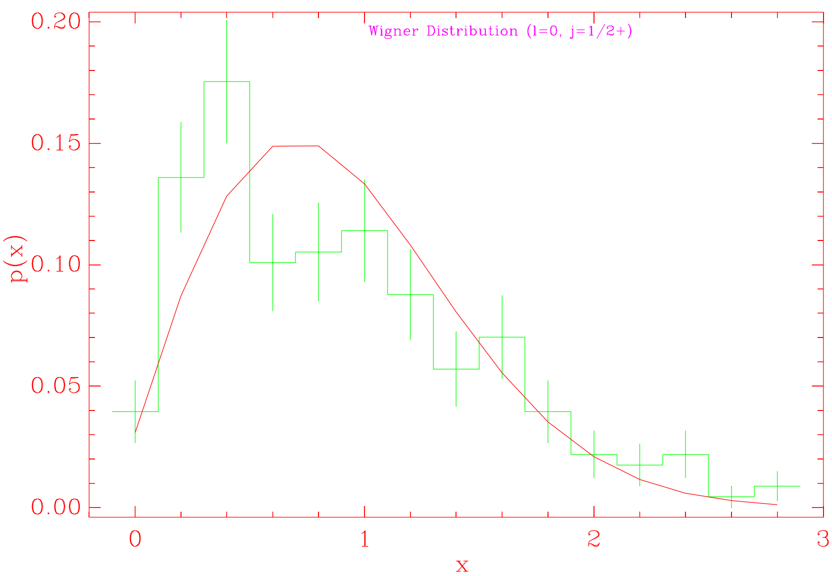

Fig. 3. Nearest neighbor-spacing (histogram) distribution compared to the Wigner distribution.

Reference

1. Olsen, D.K., ORNL/TM-8056 (1982), ENDF-319

Appendix 4.4.4

Work performed on ENDF format proposal for unresolved resonance region

N. Janeva
Institute for Nuclear Research and Nuclear Energy
1784 Sofia, Bulgaria

Some additional work has been performed on ENDF format proposal for unresolved resonance region. The scientific background for this is the statistical model of the characteristic function of R-matrix elements distribution and its realization by the code HARFOR. The main advantage of this method and computer code is the possibility of estimation the cross sections and the corresponding corrections in the analysis of transmission and self-indication experimental data as well as for reactor constant calculation (self-shielding factors). This approach is unique that offer the possibility of calculation the self-shielding factors in the unresolved region directly from average resonance parameters.

The Characteristic function method and code HARFOR have been used for calculations of average cross sections and self-shielding factors and tested against the same values calculated by the NJOY Nuclear Data Processing System used for converting evaluated nuclear data in the ENDF format into libraries useful for applications. The experimental and calculated self-shielding factors for neutron capture using HARFOR for a dilution cross section σ_0 = 1 barn were compared. We included the calculations using the resonance parameters from ENDF 6.8 and from the evaluation of the most recent data of Geel for the ^{232}Th Cross-Sections between 4 and 140 keV. Calculated self-shielding factors for ^{232}Th for diluted cross-section σ_0=1,100 barn with the average resonance parameters from ENDF 6.8 in energy range (4-50) keV using NJOY and HARFOR were compared too. The comparison was performed also between calculated self-indication factors for neutron capture for ^{232}Th for diluted cross-section σ_0=1,100 barn with the average resonance parameters from ENDF 6.8 in energy range (4-50) keV using NJOY and HARFOR.

Our results illustrate once more the efficiency of the method and code HARFOR for calculation of the average resonance cross sections and especially their functionals. The additional information to our proposal for ENDF format is in preparation.

The new experimental data for ^{232}Th cross sections in the resolved and unresolved resonance region and the practical interest to the precision of these, require detailed analysis of the data on the base of the existing schemes and methods of evaluation. The methodology of R-matrix formalism accepted in code SAMMY has been used with some development for unresolved resonance region for effective accounting of the resonance parameters fluctuations. The result of cross sections averaging, of ^{232}Th in particular, over the large energy interval containing many resonances is presented by Hauser-Feshbah formulae. For radiative capture cross section the function, accounting for the resonance fluctuation effects, was chosen roughly the same as in the resolved region. In this approach the values of radius and strength functions can be obtained by fitting to the experimental data.

The combined analysis of the total and radiation cross sections in the energy region 4-100 keV confirms the following parameters set, that is same as the set obtained in the resonance analysis of the recent GELINA ^{232}Th capture experimental data. ENDF 6.8 data file is used for ^{232}Th total cross section.

The average resonance parameters of ^{232}Th for energy interval 4-100 keV confirmed by our analysis are the following:

R= 9.43/fm, s_0=0.94($\times 10^{-4}$), s_1=1.96($\times 10^{-4}$), s_2=1.24($\times 10^{-4}$)

The energy dependence of radius and strength functions was not taken into account, but it is necessary at E≥100 keV. There exist unresolved problems of the evaluation of neutron resonance data mainly in the intermediate energy region between resolved and unresolved resonances and these are connected with the detailed description of intermediate structure.

The requirement for high precision in the resonance analysis imposes the accounting of neutron width energy dependence that lead to some deformation of resonances though in the single level approximation. This deformation is most apparent near the inelastic scattering threshold and certainly for the lowest resonances.

We consider the Breit-Wigner resonance in radiative capture cross section assuming that in small energy interval near the threshold of inelastic scattering energy variation of the elastic width can be neglected as well as the corresponding phase shift. For the case when the inelastic channel momentum is zero we presented the formula for level shape bellow and over the inelastic threshold and the calculated resonance deformation in dependence of the position of the resonance in respect to the threshold.

The similar consideration for the analysis of low lying resonances allows to express the result of Doppler effect accounting for through standard functions and to interpret the peculiarities of the resonance curve.

Appendix 4.4.5

Th-U cycle elements measured at the n_TOF facility at CERN

H. Leeb
Atominstitut of the Austrian Universities, Vienna University of Technology
Wiedner Hauptstrasse 8-10, A-1040 Wien, Austria

One of the central goals of the EC-project n_TOF-ND-ADS was the measurement of capture, fission and (n,xn) cross sections relevant for the Th-U cycle. In the measurement campaigns at CERN of 2002, 2003 and 2004 the data of following isotopes relevant for the Th-U cycle have been taken:

Capture Cross Sections			**Fission Cross Sections**		
Isotope	**Detector**	**Campaign**	**Isotope**	**Detector**	**Campaign**
Th-232	C_6D_6	CERN 2002/03	Th-232	PPAC	CERN 2002/03
U-233	TAC	CERN 2004	U-233	FIC	CERN 2003
U-234	TAC	CERN 2004	U-234	FIC, PPAC	CERN 2003
U-236	C_6D_6	Geel 2004	U-236	FIC	CERN 2003

TAC Total Absorption 4π Calorimeter; FIC Fission Chamber
C_6D_6 C_6D_6 liquid scintillator detector; PPAC Parallel Plate Avalanche Counters

The measurements within the n_TOF-ND-ADS project have been completed in November 2005 and the project will be finished with end of 2004. There will be no measurement campaign at the n_TOF facility at CERN in 2005 because of the shutdown of the PS due to necessary modifications for the Large Hadron Collider.

So far a complete analysis of the radiative neutron capture data of ^{232}Th in the energy region between 1keV and 1MeV was performed. The data were normalised to the pair of saturated resonances at 20 eV and the uncertainties due to pulse height weighting technique, background due to scattered neutrons and in-beam γ-rays, multiple scattering and self absorption, finite energy resolution, isotopic composition, beam fraction and its energy dependence were taken into accout. The statistical uncertainties are in average of the order of 1.5% while the systematic errors are typically at about 6%. A complete covariance matrix of the uncertainties has been determined. The analysis of the resonance region is still pending, but first resonance analyses with SAMMY of the resonance region between 1 and 10 eV are very promising.

Extended measurements of the ^{232}Th(n,f) reaction with the PPAC detectors were performed in the measurement campaigns of 2002 and 2003 and the analysis of the data is still going on. It should be remarked that the data are measured in reference to ^{235}U and ^{238}U. First results based on the raw data show the expected behaviour, but quantitative conclusions are not possible at present.

Furthermore first measurements of the $^{232}Th(n,3n)$ and $^{232}Th(n,5n)$ cross sections via prompt γ-spectroscopy were performed at the facility at Louvain-la-Neuve. At present the analysis of these data is still in progress.

During the measurement campaign in 2003 the reactions $^{236}U(n,f)$ and $^{234}U(n,f)$ have been measured with the FIC and the latter also with the PPAC. For both data sets the analyses are in progress and only preliminary results are available.

With the start of the measurement campaign 2004 a new 4π total absorption calorimeter (TAC) with 40 BaF_2 crystals has been in operation. The new detector significantly improves the capability for capture measurements of small capture cross sections. First measurements of the radiative neutron capture of ^{243}Am show high sensitivity of the detector system and the excellent energy resolution. During the campaign 2004 the TAC has been used to take data on radiative capture of ^{233}U, ^{234}U, ^{237}Np, ^{240}Pu, and ^{243}Am. Due to the new detector system the analyses will take some time because all features of the TAC have to be established before.

Within the n_TOF-ND-ADS project also the measurement of $^{236}U(n,f)$ was scheduled. Because of safety concerns the measurement of $^{236}U(n,f)$ was not possible at the n_TOF facility at CERN. Therefore, this measurement has been performed at Geel in 2004 and to my knowledge the analysis had not been finished so far.

The n_TOF-ND-ADS project is partly supported by the EC under contract FIKW-CT-2000-00107 and by the funding agencies of the participating institutes.

Appendix 4.4.6

Recent neutron data developments for Th-U fuel cycle

V.M. Maslov
Joint Institute for Nuclear and Energy Research
220109, Minsk-Sosny, Belarus

Recent capture cross section measurements at IRMM(Geel) [1] and n_TOF Collaboration (CERN) [2], total cross section measurements at LANL and LLL [3] up to E_n~500 MeV, fission cross section measurements up to E_n~200 MeV at PNPI (Russia) [4], surrogate fission cross section measurements at LLL (Livermore) [5] and experimental investigations of the average energies of prompt fission neutron energies for ^{238}U(n,F) reaction [6] at LANL are extremely important for major improve-ments of the quality of the evaluated data for Th-U fuel cycle data. Coupled with theoretical modelling of capture cross sections [7], direct excitation of vibrational collective bands [8,9], pre-fission neutron influence on the prompt fission neutron spectra and multiplicities [10,11], ^{232}Th and other Th-U fuel cycle relevant evaluated neutron cross sections and secondary neutron spectra could be much improved [12-13] and extended up to E_n~200 MeV [14-17].

^{232}Th neutron capture cross section

Our previous evaluation [12,13] is quite compatible with the newest measured data [1,2] below E_n~50 keV, small discrepancy around ~50 keV could be easily diminished by slight increase of the S_1 value of p-wave strength function (Fig. 1). The increase of the $S_{\gamma o}$ value by ~10% allows to describe the newest data [1,2] trend above ~200 keV, but at lower energies these data fit will need severe lowering of the S_0 or S_1 values. To maintain a capture data fit in a 4-50 keV energy range, the contribution of the p-wave was decreased. To reproduce the energy dependence of the calculated capture cross section in the energy range of 30-500 keV the contributions of d- and f-waves were increased, total, elastic and inelastic scattering cross section data is also maintained.

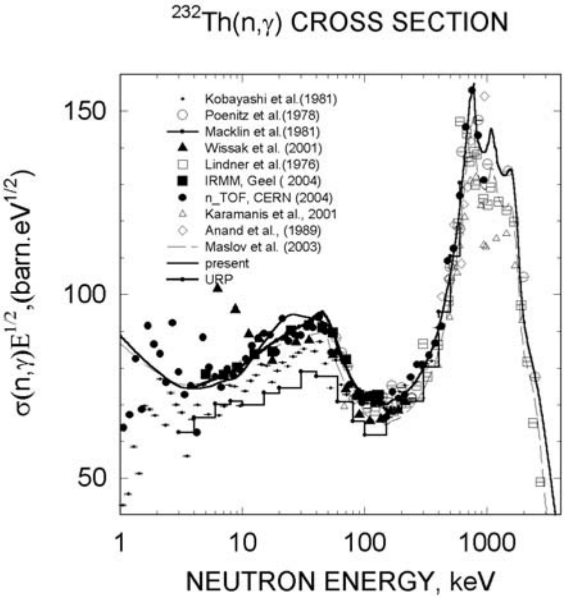

Fig. 1.

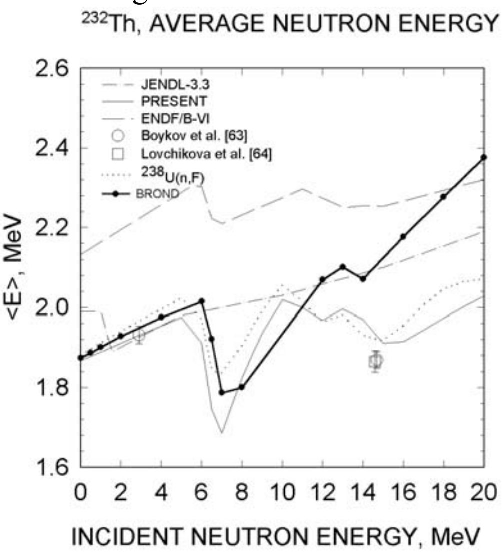

Fig. 2.

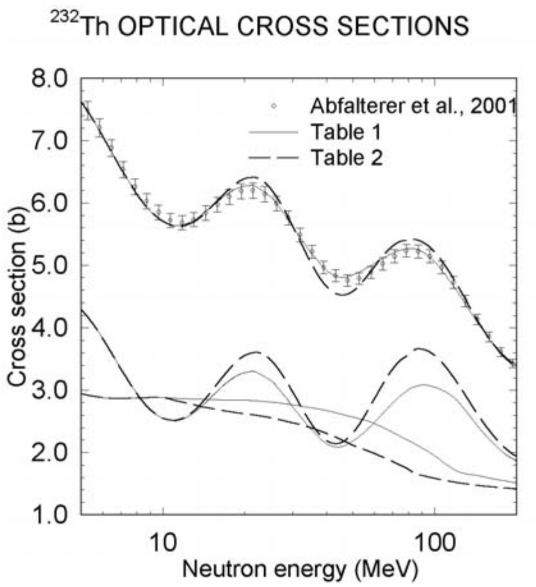

Fig. 3.

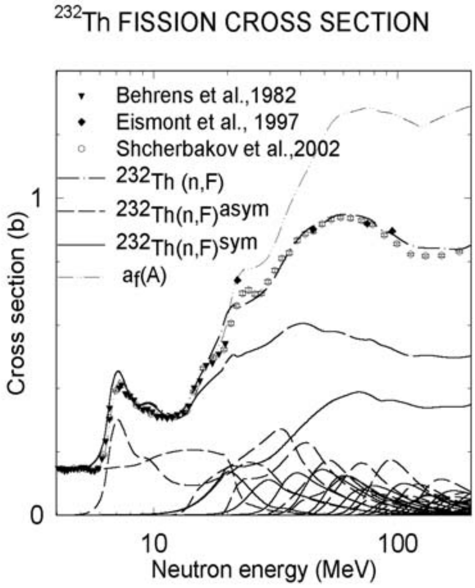

Fig. 4.

^{232}Th fission cross sections and prompt fission neutron spectra

Relative contributions of multi-chance (emissive) ^{232}Th(n,xnf) and first-chance (non-emissive) ^{232}Th(n,f) fission reactions to the observed fission cross section of ^{232}Th(n,F), much depend upon the compound ^{233}Th nuclide fissility, as well as fissilities of the $^{233-x}$Th nuclei. Due to a low fissility of the compound nuclide ^{233}Th and a strong increase with decreasing neutron number of the fissilities of $^{233-x}$ Th nuclei, which emerge after emission of pre-fission neutrons, the multiple-chance fission structure is characterized by an appreciable contribution of the ^{233}Th(n,xnf) reactions, x≥1, to the observed fission cross section [13]. This peculiarity may have important implication on the prompt fission neutron spectra and multiplicity, due to the high contribution of the fission events after pre-fission neutron emission. The influence of the pre-fission (n,xnf) neutrons on the prompt fission neutron spectra (PFNS) for the ^{232}Th(n,F) reaction could be demonstrated with the average energy of PFNS <E>, calculated using the procedures described in [10,11] (Fig. 2).

^{232}Th intermediate energy neutron-induced fission

The rigid rotator optical potential is capable to give a fair description of the measured data base for ^{232}Th up to E_n~200 MeV (Fig. 3). Neutron-induced fission data for ^{232}Th nuclide up to E_n~200 MeV could be reproduced using the approaches described in [14-17]. Description of the observed fission cross section for the ^{232}Th(n,F) reaction [4] up to E_n~200 with the reaction cross section, predicted with the optical potential labelled "Table 2", could be attained only in case when more fissions come from neutron-deficient Th nuclei, which is compatible with the emissive fission chance distribution coming from the description of the symmetric fission branching ratio for the ^{238}U(n,F) reaction [14-17]. Difference of the reaction cross sections on Fig. 3 might be correlated with the direct inelastic scattering of the vibrational bands [18]. Symmetric fission branching ratio for the ^{232}Th(n,F) reaction is predicted based on the systematics of separation of parallel outer saddle points for symmetric and asymmetric fission. Predicted splitting of the observed fission cross section ^{232}Th(n,F) into symmetric ^{232}Th(n,F)^{sym} and asymmetric ^{232}Th(n,F)^{asym} fission components is shown on Fig. 4.

Conclusions

Newest ^{232}Th neutron capture data in the energy range of 1 keV - 1 MeV are reproduced consistently with the total cross section data. Unresolved resonance parameters are obtained. Consistency of neutron-induced fission cross section data of short-lived Th nuclei and surrogate data extracted from transfer reactions is demonstrated. Pre-fission neutron influence on prompt fission neutron multiplicity and spectra is revealed. Nucleon optical model potential for ^{232}Th is obtained, based on consistent analysis of differential elastic and inelastic scattering data and total cross section data. Rigid rotator coupled channel model reproduces experimental neutron total cross section data up to 200 MeV. Observed neutron-induced fission cross section data for ^{232}Th are reproduced up to 200 MeV within Hauser-Feshbach preequilibrium model. Symmetric and asymmetric fission mode partitioning of the observed fission cross section is predicted. Other developments are decribed elsewhere [19-22].

References

1. Volev, K., et al., Abstr. of the International Conference on Nuclear Data for Science and Technology, September 26 - October 1, 2004, Santa Fe, USA, p. 176.
2. Aerts, G., Gunsing ,F., The n_TOF Collaboration, Abstr. of the International Conference on Nuclear Data for Science and Technology, September 26 - October 1, 2004, Santa Fe, USA, p. 284.
3. Abfalterer, W.P., et al., Phys. Rev.,C63, 044608 (2001).
4. Shcherbakov, O., et al.,Proc. International Conference on Nuclear Data for Science and Technology, October 7-12, 2001, Tsukuba, Japan, p. 230, 2002.
5. Younes, W., and Britt H.C., Phys. Rev. C 68, 034610 (2003).
6. Ethvignot, T., et al., Phys. Lett. B 575 (2003) 221.
7. Maslov, V.M., et al., Nucl. Sci. and Eng., 143 (2003) 177.
8. Maslov, V.M., et al.,Proc. International Conference on Nuclear Data for Science and Technology, October 7-12, 2001, Tsukuba, Japan, p. 148, 2002.
9. Maslov, V.M., et al., Izvestiya Rossiskoi Akademi Nauk. Seriya Fizicheskaya, 67, 1599 (2003).
10. Maslov, V.M., et al., Phys. Rev. C 68, 034607 (2004).
11. Maslov, V.M., et al., EuroPhysics Journal A, 18 (2003) 93.
12. Maslov, V.M, et al., INDC(BLR)-016, IAEA, Vienna, 2003.
13. Maslov, V.M., Nucl. Phys., A743 (2004) 236.
14. Maslov, V.M., Nucl. Phys., A 717 (2003) 3.
15. Maslov, V.M., et al., Nucl.Phys. A, 736, 77 (2004).
16. Maslov, V.M., Phys. Lett. B, 581, 55 (2004).
17. Maslov, V.M., EuroPhysics Journal A, (2004), A, 21 (2004) 281.
18. Fotiades, N., et al., Phys. Rev. C 68, 034610 (2003).
19. Maslov, V.M., et al., Abstr. of the International Conference on Nuclear Data for Science and Technology, September 26 -October 1, 2004, Santa Fe, USA, p. 365.
20. Maslov, V.M., et al., Abstr. of the International Conference on Nuclear Data for Science and Technology, September 26 -October 1, 2004, Santa Fe, USA, p. 110.
21. Maslov, V.M., et al., Abstr. of the International Conference on Nuclear Data for Science and Technology, September 26 -October 1, 2004, Santa Fe, USA, p. 153.
22. Maslov, V.M., et al., Abstr. of the International Conference on Nuclear Data for Science and Technology, September 26 - October 1, 2004, Santa Fe, USA, p. 154.

Appendix 4.4.7

Implementation in the reaction code system EMPIRE-2.19 of an advanced formalism for fission cross-section calculation

M. Sin
Nuclear Physics Department, University of Bucharest, Romania

The implementation in the reaction code system EMPIRE-2.19 of an advanced formalism for fission cross-section calculation has been completed. The formalism is based on the optical model for fission and can be applied for nuclei exhibiting double- or triple-humped barrier starting from sub-barrier excitation energies.

The optical model for fission, initially developed to describe the resonant structure of the fission cross section at sub-barrier excitation energies due to the vibrational states in the second well of a double-humped fission barrier, was extended to light actinides by including the relations for the transmission coefficients through a complex triple-humped fission barrier. The real part of the fission barrier is parameterised as a function of the nucleus deformation by five smoothly joined parabolas. The imaginary potential is introduced only in the deformation range corresponding to the second well because the tertiary well is supposed to be shallow enough to neglect the damping of class III vibrational states. The transition states are assumed to be rotational states built on vibrational or non-collective band-heads. As the excitation energy increases, the shell effect, which causes the splitting of the outer barrier, diminishes and the outer humps lump into a single one. Therefore, in the present formalism, triple-humped barriers are associated only to the discrete transition states; the contribution of continuum to the fission coefficients is calculated considering a double-humped barrier. The parameters of the second single barrier equivalent with the outer humps are being determined from the condition of equal transmission coefficients. The saddle-point transition states in continuum are described by level densities (BCS below the critical energy and a modified version of Fermi Gas above) accounting for collective enhancements specific to the nuclear shape asymmetry at each saddle point .

The neutron cross sections of ^{232}Th in the energy range 0.01-30 MeV for all relevant channels have been calculated with the EMPIRE 2.19 code. The direct interaction cross sections and the neutron transmission coefficients for the elastic channel were obtained within Coupled Channel method using ECIS03 code (as incorporated in Empire 2.19 code). The dispersive coupled channel optical model parameters of Soukhovitskii et al. were used for the neutron and proton channels. For the compound nucleus cross sections calculation the HRTW version of the statistical model with decay probabilities deduced in the optical model for fission was used. To improve the accuracy of the second and third chance fission evaluation, beside ^{232}Th(n,f), the ^{232}Th(γ,f) and ^{230}Th(n,f) reactions have been simultaneously analysed.

Consistent sets of parameters describing the double- and triple-humped fission barrier of the light actinides and very good agreement with the measured fission cross section have been achieved using the new treatment of the fission channel implemented in EMPIRE 2.19 code. The results confirm the attribution of the gross resonant structure in fission probability of these light actinides to the undamped vibrational states in the tertiary well.

Sensitivity tests indicate a significant dependence of the fission barrier parameters on the optical model parameters and also on the pre-equilibrium models.

Appendix 4.4.8

Progress in the preparation of Indian experimental benchmarks on thorium irradiations in PHWR and KAMINI reactor

S. Ganesan
Reactor Physics Design Division, Bhabha Atomic Research Centre, Trombay,
Mumbai-400085 India

Indian nuclear programme envisages [1-3] extensive utilization of thorium for power production in the coming decades. Identical loading of thorium bundles was used in KAPS-1 & 2, KAIGA-1 and 2 and RAPS-3 and 4 to attain flux flattening in the initial core. The thorium oxide used is about 400 kg in all the 35 bundles put together in a reactor. The bundles loaded in KAPP-1 & 2 have already been discharged from the core. Samples were obtained from one of the irradiated ThO_2 bundles and have been analyzed experimentally by alpha spectrometry for ^{232}U and by thermal ionization mass spectrometry for ^{233}U, ^{234}U, ^{235}U and ^{236}U by two different groups from FRD and FCD [4, 5] in BARC. The previous analyses by two teams [4, 6] gave a factor of 6 to 8 under-prediction in the production of ^{232}U. The discrepancy was traced [7] to be due to the fact that the effective one group values of cross sections for isotopes of thorium fuel cycle and the use of assumptions in the ORIGEN code are not applicable to the irradiation of thorium in our PHWRs. New results [8] of sensitivity of different modeling approaches such as single cell versus super cell model and treatment of (n, 2n) process (pseudo-fission versus explicit) to prediction of isotopic contents of urania were obtained.

India is actively participating in this IAEA-CRP to share our information and to benefit from the developments related to the use of thorium around the world. India recognizes the importance of new and improved nuclear data in the design of advanced reactors [9] such as INPRO project of the IAEA. Within the scope of the CRP, the following two deliverables from India are envisaged in a focused manner:

- Thorium Irradiation experiments and burn up measurements in PHWRs.

In the 2nd CRP Meeting, the exact numerical values of specifications of geometry and irradiation history of the irradiated Thoria bundles for KAPS2 PHWR were presented. All the available experimental results of Post Irradiation Examination including burn-up monitors were presented [10].

- KAMINI experimental benchmark.

  Considerable data has already been released to the IAEA. Further work is underway to prepare international quality description of the benchmark, with quality such as in the state-of-art NEA Nuclear Science Committee document. For instance, a detailed MCNP Modeling is being performed by P. Mohanakrishnan et al., and by C.P. Reddy et al. at IGCAR, Kalpakkam. The future plans for further refining of benchmarks and scope of activities and contributions were outlined [10]. Collaborative efforts with other countries such as Korea are helpful as benchmarking exercise is new to India.

Acknowledgements: The author (CSI) thanks all co-participants [10] for their generous contributions. Thanks are due to R. Srivenkatesan and R. K. Sinha for fruitful discussions.

References:

1. Kakodkar, A., NUPOWER, Vol. 15. No.1 to 4, 46 (2002).
2. Kamala Balakrishnan and A. Kakodkar, Ann. Nucl. Energy, **21**, 1, (1994).
3. Sinha, R.K., *"Compact High Temperature Reactor,"* IAEA Consultancy Meeting on"Small reactors without on-site fuelling", March 15-17, 2004.
4. Achuthan P.V., et al., "Analysis of Irradiated Thoria Dissolved Solution," Report BARC/2003/ I /002 (2003).
5. Aggarwal S.K., et al., "Determination of Burn-up of Irradiated Thoria using TIMS," Paper presented at ISMAS Silver Jubilee Symposium on Mass Spectrometry held at NIO, Dona Paula, Goa, Jan. 27-31, 2003, ISMAS-SJS-2003, Contributed papers, Vol. II, Ed. (Aggarwal S.K.), pp. 888-891 (2003).
6. Mukherji S., and Srivenkatesan, R., Proceedings of the 14th National Symposium on Radiation Physics, NSRP-14, GND University, Amritsar, Nov. 1 – 3, 2001
7. Ganesan, S., *"Integral Benchmarks With Reference To Thorium Fuel Cycle,"* IAEA Coordinated Research Project on "Evaluated Data for the Thorium-Uranium fuel cycle," First Research Co-ordination Meeting, 25 to 29 August 2003, Vienna, Austria, Proceedings edited by A. Trkov and available as INDC report: INDC(NDS)-447 (Dec. 2003), pp. 29-52; See electronic document at: www-nds.iaea.or.at/reports/indc-nds-447.pdf See also S. Mukherji et al., Paper No. (NRT1-184), presented at the 1st National Conf. on NUCLEAR REACTOR SAFETY, November 25-27, 2002, BARC.
8. Jagannathan, V., Ganesan S., and Srivenkatesan, R., "A study on the factors influencing the theoretical estimation of ^{232}U and other U isotopic contents in thoria bundles irradiated in PHWRs," Proceedings of INSAC2003, Kalpakkam on "Nuclear Fuel Cycle Technologies: Closing the Fuel Cycle," December 17-19, 2003.
9. Ganesan, S., "New reactor concepts and new nuclear data needed to develop them," Invited talk presented at the Int. Conf. on Nuclear Data for Science and Technology ("ND2004"), Sept. 26 – Oct. 1, 2004, Santa Fe, NM, USA.
10. Ganesan, S., PowerPoint Presentation in this Second Research Coordination Meeting (RCM).

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: services@iaeand.iaea.org
fax: (43-1) 26007
telephone: (43-1) 2600-21710
Web: http://www-nds.iaea.org