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TITLE

Evaluation of some neutron nuclear data for 232-Th, 233-U, and 231,232,233-Ra (part of a coord.programme on intercomparison of actinide neutron nuclear data)

FINAL REPORT FOR THE PERIOD

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NUCLEAR DATA SERVICES

DOCUMENTATION SERIES OF THE IAEA NUCLEAR DATA SECTION

CERTIFIED BY:

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# NUCLEAR DATA EVALUATIONS FOR Th-232 and Pa-233

Final report on the

IAEA Research Contract 2061

Note: For further details see the report INDC(RUM)-10 and INDC(ROM-12. The evaluated numerical data files are available from the IAEA Nuclear Data Section under the accession-numbers

INDL-9090 for Th-232
INDL-9193 for Pa-233

superseding

INDL/A-9990 for Th-232
INDL/A-9993 for Pa-233.

FINAL REPORT

a. I. Contract Number: 2061/R1/RB

II. Title of Project: "Nuclear Data Evaluation for $^{233}Pa$", in the framework of the IAEA-NDS Coordinated Research Programme on the Intercomparison of Evaluations of Actinide Neutron Nuclear Data.

III. Institute were research is being carried out:

Institute of Nuclear Power Reactors,

Piteşti - Romania

IV. Chief scientific investigator: G.Vasiliu

V. Time period covered: 1980 - 1981

b. Description of research carried out:

In the lack of experimental data (available only for total cross section in EAFOX library) many of the neutron nuclear data for $^{233}Pa$ have been estimated using theoretical models /1/.

The evaluated data have been typical for ENDF/B library, and of interest in reactor calculations.

The data have been compared with the symilar evaluations from japonese JENDL library.

The evaluated data performed under this contract are as follows:

- The decay data have been evaluated based on ENDSF lybrary and reference /2/, and the mean energies per decay $\langle E_\beta \rangle$ and $\langle E_\gamma \rangle$ have been estimated based on England /3/ and Reich /4/ considerations.

- The total, elastic and radiative capture cross sections for thermal and resolved resonance range, have been calculated using the evaluated Breit-Wigner-Single-level parameters, using the program ETRES, up to 38.5 eV and the total cross section has been compared with experimental values.

The relevant references used for resonance parameters have been those of Simpson /5/ and Harris /6/, as well as BNL-325 compilation /7/.

Using the evaluated resolved resonance parameters and Gyulassy's considerations /8/, we estimated the averaged parameters for unresolved resonance energy range (38.5 eV - 10 KeV).

Elastic, capture and total background corrections have been included in the file 3 to assure the continuities between resonance region and fast smooth cross section region.

The program AVERAGE-3 has been used to calculate the total, elastic and capture cross sections on this energy range.

The cross sections in the fast energy range have been evaluated using theoretical models.

- Total and elastic cross sections have been estimated using spherical optical and statistical models up to 2 MeV by the code ELIESE /9/.

The coupled channel theory has been used above 2 MeV using the program JUPITOR /10/.

The compound nucleus contributions have been taken into account up to 5 MeV.

The optical potential parameters used are based on Madland-Young's Systematics for actinide nuclei /11/.

Their method to adjuste the spherical optical parameters to be used in coupled channel calculations for this mass region, has been also adopted for $^{233}$Pa.

- Inelastic cross sections have been computed for the first 17 excited levels /12/ up to 0.3661 MeV, as well as for the continuum region above this energy, using the program ELIESE.

- Fission cross section has been evaluated based on Lynn's systematics /13/ using the Hausen-Feshach statistical model up to 3 MeV (with program MASTER) and evaporation model above 3 MeV (with program STAT10D).

The thresholds for the second and third fission chances have been considered 6.2 MeV and 12.717 MeV respectively.

The fission cross section acopted in the range of the first plateau, is 0.9 bn according to Mehrens and Howerton systematics /14/ up to 11 MeV.

Also, at 1.5 MeV, a value of 778.3 mb is obtained, in agreement to Von Gunten's value /15/ of 775±190 mb.

- The radiative capture cross section between 0.01 MeV and 3.2 MeV has been calculated using the program MASTER. Two level density models (constant temperature and Fermi gas) have been used.

Above 3 MeV we adopted the JENDL values and above 15 MeV, those obtained from consistency.

- The (n, 2n) and (n, 3n) cross sections have been computed by program STAT10D too, with the thresholds at 6.517 MeV and

12.079 MeV respectively, using Gilbert and Cameron's parameters /16/.

- The average number of neutrons per fission, has been estimated using Howerton's systematics /17/, and his semiempirical formula, which takes into account the contributions of (n, n'f) and (n,2nf) processes.

- Elastic angular distributions of secondary neutrons have been evaluated by optical and statistical models, from 10 KeV up to 20 MeV, bellow 10 KeV beeing isotropic.

The calculated values have been fitted by Legendre polynomials using the program SAD/18/. The transformation matrix from CM to LAB peference system is given also.

- The inelastic angular distributions of Secondary neutrons have been assumed to be isotropic.

- The energy distributions of Secondary neutrons from (n, n') reactions, have been obtained in the framework of evaporation model /19/ using the density level parameter evaluated by back-shifted Fermi gas model /20/.

The energy distributions for (n,2n) and (n, 3n) were estimated by Le Couteur's neutron cascade theory in the framework of statistical model.

The energy distribution for fission neutrons was evaluated using the Terrel's formula /21/.

c. Results obtained

The final set of evaluated data has been expressed in ENDF/B format, for the energy range $10^{-5}$eV - 20 MeV and has been supplied on magnetic tape to IAEA - Nuclear Data Section.

d. Concluding drawn

A general conclusion is that the $^{233}Pa$ interactions are poor represented in the literature by experimental data.

In these circumstances, this evaluation was based mainly on theoretical calculations, but we hope that it will be useful for preliminary calculations of Th-U nuclear energy systems.

The increasing importance of Th-U nuclear reactor alternative makes it desirable that $^{233}Pa$ neutron interactions be much more in the attention of the experimentalists.

e.I, Published results

Authors: G.Vasiliu, S.Iateescu, S.Răpcanu, V.Avrigeanu, M.Ciocaru, N.Drăgan, T.Stadnicov, O.Bujoreanu.

Title: Nuclear data evaluation for Pa-233

Journal: INDC (ROM) - 12, Distr. L+$S_p$, May 1980.

e. II Other relevant literature references:

1. G.Vasiliu et al, INDC(ROM)-12, L+$S_p$, 1980
2. Nucl.Data Sheets, 24, 289, 1978
3. T.R.England et al., LA-6116-MS, (ENDF-233), 1975
4. C.W.Reich et al., ANCR-1157 (ENDF-120), 1974
5. F.B.Simpson et al., NSE, 28, 133, 1967
6. H.R.Harris, WAPD-TM-814, 1969
7. S.F.Mughabghab et al., BNL-325, vol.1, 1973
8. M.Gyulassy et al., NSE, 53, 482, 1974.
9. S.Igarasi, JAERI-1224, 1972
10. T.Tamura, ORNL-4152, 1967.

11. D.G.Madland, P.G.Young, Conf. Harwell, 349, 1978

12. C.M.Lederer et al., Table of isotopes, 1978

13. J.E.Lynn, AERE-7468, 1974

14. J.W.Behrens et al., NSE, 65, 1979

15. Von Gunten, NSE, 27, 85, 1967

16. A.Gilbert, A.G.W.Cameron, Can.J.Phys., 43, 1446, 1965

17. R.J.Howerton, NSE, 62, 438, 1977

18. E.M.Kennington et.al., ANL-1306, 1967

19. K.J. Le Couteur, Amsterdam, 1959

20. W.Dilg et al., Nucl.Phys. A 217, 269, 1973

21. J.Terrel, Symp. Salzburg, vol.II, 3, 1965.

## Summary


Title: Nuclear Data Evaluation for Pa-233

Research Institute: Institute of Nuclear Power Reactors

Pitesti - Romania

Chief Scientific Investigator: G.Vasiliu

Period of Contract: 1980-1981.

Scientific Background and Scope of Project:

To supply to scientific community the updated evaluated neutron nuclear data for the actinide nuclei based on experimental data and on nuclear reaction theoretical models (particularly for Pa-233).

Experimental method: No

Results obtained: A new file containing the evaluated neutron data for $^{233}$Pa has been obtained in ENDF/B format, which contains:

- decay data
- Breitt-Wigner Single Level resonance parameters
- total, elastic, inelastic (total and partial for excited levels and continuum) radiative capture, fission, (n,2n), and (n,3n) cross sections
- angular distributions of secondary neutrons and transformation matrix from CM to LAB system
- energy distributions of secondary neutrons
- average number of neutrons emitted per fission.

The data have been checked against the physical consistency and format correctness, and some of them, compared with JENDL-1 evaluation .

## Conclusions

The increasing importance of Th-U nuclear reactor alternative, makes desirable that $^{233}Pa$ neutron interactions to be much more in the attention of the experimentalists.

The reported results can be considered as an step of knowledge regarding neutron nuclear data of $^{233}Pa$.

## Papers Published on Work Done under the Contract

Nuclear Data Evaluation for Pa-233, by:

G.Vasiliu, S.Mateescu, S.Răpeanu, V.Avrigeanu, M.Ciodaru, H.Drăgan, T.Stadnicov, O.Bujoreanu,

published as:

IAEA-INDC (ROM) - 12, $L+S_p$, 1981.

# FINAL REPORT

a. I. Contract number: 2061/RB

II. Title of Project: "Nuclear Data Evaluation for Th-232", in the framework of the IAEA-NDS Coordinated Research Programme on the Intercomparison of Evaluations of Actinide Neutron Nuclear Data.

III. Institute were research is being carried out:

Institute of Nuclear Power Reactors,

Pitesti - Romania

IV. Chief scientific investigator: G.Vasiliu

V. Time period covered: 1978 - 1982.

b. Description of research carried out

The typical neutron nuclear data for Th-232 have been evaluated based on EXFOR data base, as well as theoretical models, for $10^{-5}$ eV - 20 MeV energy range.

The final data set includes the data reported in reference /1/ and reviewed in 1980 and 1981.

The evaluated data performed under this contract are as follows:

The decay data are based on ENDSF library and Wapstra data /2/.

The fission yield data for fission neutrons spectrum adopted from Meek and Rider /3/.

The total, elastic, and capture cross sections in the thermal range ($10^{-5}$ - 10 eV) are based on Cooper's formula for elastic and Lundgren's formula for capture, taking into account also the newer measurements reported by Little /4/.

For the resolved resonance range (10 eV - 4 KeV), from the main references /5/ - /8/ used, we selected Breitt-Wigner Single Level parameters for 374 resonance (231 - s wave resonances and 143 - p wave resonances).

In order to take into account the effect of the missing p-wave resonances, between 3-4 KeV, we have included also for total and capture cross sections background corrections into file 3 data.

The unresolved resonance energy range (4 KeV - 50 KeV) the mean parameters have been estimated from resolved resonance according to Gyulassy's formalism /9/.

The computed radiative capture resonance integral are in good agreement with experimental values.

For the fast energy range (50 KeV - 20 MeV) the total cross section was evaluated based on experimental data and taking into account the consistency between partial cross sections.

The elastic cross sections, between 50 KeV and 0.5 MeV was evaluated from experimental data, between 0,5 MeV and 4 MeV, the integrated angular distributions have been adopted.

Above 4 MeV, the elastic cross section was adopted from ENDL library.

The elastic angular distributions have been computed between 0.5 MeV and 1.25 MeV using a spherical optical model (ELIESE program) and between 1.25 MeV and 20 MeV using coupled channel theory (JUPITOR). The parameters were taken from Haouat/10/. We obtained a good agreement with the available experimental angular distributions.

Bellow 0.4 MeV the angular distributions were assumed to be isotropic.

The elastic angular distributions are given by Legendre coefficients.

The average cosinus of the scattering angle for elastic scattering, and average logarithmic energy decrement for elastic scattering have been derived from angular distributions date.

The inelastic cross sections of 9 excited levels included are based on Meadows data /11/; the level energies have been taken from Table of isotopes /12/.

The total inelastic cross section has been obtained as difference between the evaluated total cross section and all the other components.

The continuum inelastic cross section has been obtained as difference between total inelastic and sum of the partial inelastic cross sections.

The corresponding angular distributions of the secondary neutrons have been assumed to be isotropic and also included.

The capture cross section up to 14.5 MeV has been evaluated from experimental data. Above this energy the evaluated curve has been extrapolated to obtain a value of 0.003 bn at 20 MeV, according to references /13/,/14/.

The fission cross section is based on experimental data, including the newer measurements of Behrens /15/, Nordborg /16/, as well as evaluated data of Meadows /11/.

The average number of neutrons per fission was evaluated using the experimental data and Howerton's systematics /17/.

The (n,2n) cross section was evaluated using experimental data, and statistical model - program STAPRE - used also for (n,3n) cross section evaluation.

The angular distributions of secondary neutrons for (n,2n), (n,3n), fission and continuum inelastic reactions, assumed to be isotropic, have been included in the file 5.

The energy distributions of secondary neutrons from inelastic, (n,2n), (n,3n) and fission processes were included.

The (n,2n) and (n,3n) secondary neutrons energy spectra have been included according to ENDF/B-II.

The temperatures of the Maxwellian prompt neutron fission spectrum adopted have been computed using Terrel's formula /18/.

The evaporation spectrum temperatures of the (n,n') continuum secondary neutron have been derived from Dilg's level density formula /19/ and systematics.

C. Results obtained

The final set of evaluated data has been expressed in ENDF/B format, for the energy range $10^{-5}$eV - 20 MeV and are supplied on magnetic tape to IAEA - Nuclear Data Section.

It is to be mentioned that our evaluation on $^{232}$Th distributed through IAEA - Nuclear Data Section is already positively quotted (at NEANDC Specialists' Meeting on Fast Neutron Scattering on Actinide Nuclei, held in Paris, 23-25 Nov. 1981), as well as by Antsipov /20/.

d. Conclusions drawn

The evaluated data file supplied as a result of this evaluation contains for Th-232 the most important neutron data of interest in $^{232}$Th - $^{233}$U reactor calculations, within the limits of experimental data available and of theoretical models accuracy.

e. I. Published results

Authors: G.Vasiliu, S.Mateescu, D.Gheorghe, M.Ciocodaru, E.Bădescu, N.Drăgan, O.Bujoreanu, C.Crăciun, L.Pintilieseu, M.Zaharcu, A.Popescu, T.Statnicov, V.Avrigeanu.

Title: Nuclear Data Evaluation for Th-232.

Journal: INDC (RUM)-10, Distr.L+$S_p$, Febr.1979, Rev. April 1980.

e.III. Other relevant literature references:

/1/. G.Vasiliu et al, INDC(RUM)-10, L+$S_p$, 1980

/2/. A.H.Wapstra, K.Bos, Atomic Data and Nucl. Data Tables, 19, 175, 1977

/3/. M.E. Meek, B.F.Rider, NEDO-12154, 2, 1977.

/4/. R.C.Little et all. , EPRI-NP-1704, 1981.

/5/. F.Rahn et al., Phys. Rev., C5, 1854, 1972.

/6/. L.Forman et al., Conf.on Neutron Cross Sections and Technology, Knoxwille, 1971

/7/. R.L.Macklin et al, Nucl.Sci.Eng., 64, 849, 1977

/8/. S.F.Mughabghab et al, BNL-325, 3rd ed, vol.1, 1973

/9/. M.Gyulassy et al, Nucl.Sc.Eng.53, 482, 1974

/10/. G.Haouat et al, INDC (FR) 43/L, NEANDC (E)180, L, 1977

/11/. S.Meadows et al. ANL/NDM-35, 1978

/12/. C.M.Lederer et al., Table of isotopes, 7th ed, 1978

/13/. B.A.Magurno, BNL-NCS-50446, 1975

/14/. D.I.Garber, R.R.Kinsey, BNL-325, vol.II 1973

/15/. J.W.Behrens et al, UCID-17442, 1977

/16/. C.Nordborg et al, Conf.Harwell, 1978

/17/. R.J.Howerton, Nucl.Sci.Eng. 62, 438, 1977

/18/. J.Terrel, Proc.Sym.of Phys. and chemistry of fission, Saltzburg, 1965, IAEA

/19/. W.Dilg et al, Nucl.Phys., A217, p.269-298, 1973

/20/. G.V.Antsipov et al, INDC (CCP)-192, Distr. G, 1982

## Summary


Title: Nuclear Data Evaluation for Th-232

Research Institute: Institute of Nuclear Power Reactors - Pitesti
Romania

Chief Scientific Investigator: G.Vasiliu

Period of Contract: 1978 - 1982

Scientific Background and Scope of Project: To supply to scientific Community the updated evaluated neutron nuclear data for the actinide nuclei based on experimental data on nuclear reaction theoretical models (particularly fot Th-232).

Experimental method: No

Results obtained: A new file containing the evaluated neutron data for Th-232 has been obtained in ENDF/B format, which cover the energy range between $10^{-5}$ eV - 20 MeV containing:

- The total, elastic and capture cross sections for thermal resonance and fast energy range.

The resonance region is described by Breitt-Wigner Single Level parameters for resolved resonances and average parameters for unresolved resonances.

- The inelastic, (n,2n), (n,3n) and fission cross sections from threshold to 20 MeV.

- The inelastic excited level cross sections.

- The average cosinus of the scattering angle for elastic scattering.

- The average logaritmic energy decrement for elastic scattering.

- The angular distributions of secondary neutrons for elastic scattering, as well as for inelastic, (n,2n), (n,3n) and fission processes.

- The energy distributions of secondary neutrons from inelastic, (n,2n), (n,3n) and fission processes.

- The decay data

- The fission yields

- The average number of neutrons emited per fission.

Conclusions

The present evaluation of $^{232}Th$ represent un updated file containing the relevant data for reactor calculations, but, according to WRENDA requirements, new measurements are desirables.

Papers Published on Work Done under the Contract

Nuclear Data Evaluation for Th-232, by:

S.Vasiliu, S.Matcescu, D.Cheorghe, M.Cio daru, E.Bădescu, N.Drăgan, O.Bujoreanu, C.Crăciun, L.Pintiliescu, M.Zaharcu, D.Popescu, T.Statniiov, V.Avrigeanu,

published as:

INDC (RUM) - 10, Distr. L+Sp, 1980.