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INTERNATIONAL NUCLEAR DATA COMMITTEE

IAEA Advisory Group Meeting on Transactinium Isotope Nuclear Data

Karlsruhe, F.R.G., 3-7 November 1975

Summary Report

Edited by A. Lorenz

Nuclear Data Section
International Atomic Energy Agency

March 1976

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Abstract

The IAEA Nuclear Data Section, in cooperation with the OECD Nuclear Energy Agency, convened an Advisory Group Meeting on Transactinium Isotope Nuclear Data at Karlsruhe, FRG, from 3-7 November 1975. The meeting was attended by 45 representatives from 13 countries and 3 international organizations. It was the first international meeting on this topic.

The general conclusion of the meeting participants was that transactinium isotopes are becoming more and more important in nuclear technology, and that the present knowledge of nuclear data required to evaluate the effects of actinides in nuclear technology is not satisfactory. One of the basic recommendations, which resulted from the meeting was to initiate an internationally coordinated programme to measure, calculate, and evaluate needed transactinium isotope nuclear data which would span the next ten years. The principal aim of this effort would be to improve the status of actinide nuclear data required for nuclear technology.

I. INTRODUCTION

In addition to the main fertile and fissile isotopes (i.e. Th 232, U 233, U 235, U 238 and Pu 239), transactinium isotopes, comprising all isotopes heavier than actinium (i.e. Z $\geq$ 89), play important roles in the nuclear fuel cycles of both thermal and fast reactors, and have found increasing areas of applications in life sciences and industry. The quantitative appraisal of the role and applications of these isotopes can only be done with an adequate knowledge of their nuclear characteristics, that is their nuclear data. Exact values of thermal and resonance neutron cross sections, fast neutron cross sections, and nuclear decay parameters of transactinium isotopes are required to calculate their effect in thermal and fast power reactors and to assess their impact on the nuclear waste management.

The Nuclear Data Section, in cooperation with the OECD Nuclear Energy Agency, convened an Advisory Group Meeting on Transactinium Isotope Nuclear Data whose principal purpose was to bring together users and producers of transactinium isotope nuclear data in order to comprehensively survey the requirements and priorities, and review the status of knowledge of transactinium isotope nuclear data with the specific aim to formulate recommendations and measures for the coordination of future work.

In order to meet these objectives, the meeting was organized around seventeen comprehensive review papers (Appendix A), covering the full scope of applications in one session, and an extensive review of the status of transactinium nuclear data in a second session. These review papers, which in themselves are timely reports on important topics, provided the basis for the discussions during the first three days of the meeting and for the preparation of the conclusions and recommendations during the last two days of the meeting (see Meeting Programme Appendix B).

Forty five scientists, representing both the nuclear data user and producer communities, from thirteen countries and 3 international organizations, took part in the meeting (Appendix C).

The transactinium isotope nuclear data which were discussed at the meeting fall into three general areas of applications

- thermal reactors and their fuel cycle,
- fast reactors and their fuel cycle, and
- nuclear waste management and isotope applications.

In order to arrive at comprehensive sets of conclusions and recommendations, and meaningful summary statements regarding the requirement and status of transactinium isotope nuclear data for each of these three categories, the participants were assigned to three separate working groups during the last two days of the meeting. The working groups, formed according to the three data categories listed above, prepared written summary statements which were discussed during the plenary session on the last day of the meeting.

The meeting produced one set of general recommendations (part II of this report), and three reports on each of the three general areas of applications, each with its own conclusions and recommendations, and comparisons of transactinium isotope nuclear data requirements and status (part III of this report).

The general recommendations and the reports of the three working groups are included in this report. The review and contributed papers written specifically for this meeting will be published separately as part of the IAEA-report series.

II. GENERAL RECOMMENDATIONS

Preamble

The participants of the IAEA Advisory Group Meeting on Transactinium Isotope Nuclear Data noted

a. that transactinium isotopes are becoming more and more important in nuclear technology; and

b. that the present knowledge of nuclear data required to evaluate the effects of transactinium isotopes in nuclear technology is not satisfactory.

General Recommendation 1

1.1. In view of the above, the meeting recommends that an internationally coordinated effort be implemented, and pursued during the next ten years so as to improve the status of transactinium neutron nuclear data required for nuclear technology. The results from the first phase of this effort should be made available and reviewed after the first three to five years of this effort.

1.2. This international effort should comprise the following three components:

a. a coordinated programme of differential and integral neutron nuclear data measurements with a free exchange of information;

b. a coordinated effort in nuclear theory computations designed to supplement the experimental information, and

c. a coordinated programme for the evaluation of transactinium isotope neutron nuclear data.

1.3. It is understood that the IAEA Consultants' Meeting on the use of Nuclear theory in Neutron Nuclear Data Evaluation to be held at ICTP Trieste, in December 1975, as well as future meetings on this topic will deal with nuclear theory calculations of neutron nuclear data of transactinium isotopes. More detailed aspects of the suggested measurement programme are discussed under specific conclusions and recommendations, given below.

1.4. The evaluation programme should initially be concerned with two or more independent evaluations by different laboratories for mutually agreed important nuclides where differential measurements exist, supplemented by nuclear theory calculations.

1.5. The IAEA should co-ordinate the evaluation programme by:

a. convening meetings of the evaluation groups concerned in order to coordinate methods and techniques at regular intervals, and

b. sponsoring comprehensive analyses and comparisons of evaluations for the benefit of all users of transactinium isotope nuclear data.

1.6. The IAEA should reconvene another specialists' meeting on transactinium nuclear data at such a time when the evalations, accompanying sensitivity studies, and measurements, have been completed so that the users of these nuclear data have the opportunity to assess the extent to which existing and future requirements for transactinium isotope nuclear data have been met.

General Recommendation 2

The meeting recommends that an Actinide Newsletter be published consisting of brief descriptions of measurements, compilation activities, and computer calculations carried out world-wide pertaining to the applications discussed at this meeting. It requests Dr. S. Raman of the Oak Ridge National Laboratory to coordinate all aspects concerning the preparation, publication, and distribution of such a newsletter.

General Recommendation 3

3.1. The meeting recommends that analytical results on irradiated fuel, together with the necessary reactor information (cell version) and initial fuel composition, be made available to the International Atomic Energy Agency for use by member states in order to check the reliability of calculation codes and nuclear data input.

Integral experiments have been performed in a number of reactors and different fuel types. The results of some of these experiments have not yet been distributed to enable any comparison to be carried out. Other fuel material has not yet been analysed. It would be desirable to complete existing experiments and their results be made available to the IAEA.

3.2. For this purpose, data resulting from experiments with (a) high burn-up fuel material from a Light Water Reactor (LWR) operating on the uranium cycle, (b) LWR irradiated fuel containing recycled plutonium, (c) fuel from a High Temperature Reactor, and (d) fuel from a Fast Reactor, could be used as standards. The NEACRP is willing to support this activity.

3.3. From the experience obtained so far, from the two- and three dimensional IAEA reference cases on thermal reactors proposed at the IAEA Reactor Physics Burn-up Panel in 1973, it would be useful to carry out a simpler but nevertheless representative analysis of the growth and decay of actinide nuclides for typical reference cases (LWR, HTR, LMFBR). The NEACRP is willing to support this exercise.

General Recommendation 4

The meeting recommends to develop an international cooperative research project to be coordinated by the IAEA on the measurement and evaluation of needed decay data of transactinium nuclides. The presently available accuracies in half-lives, alpha intensities and gamma-ray intensities of a number of transactinium nuclides need to be imporved to fulfil the needs for fuel analysis, safeguards applications, mass determination and the preparation of standards. New measurements, evaluations of the existing data, intercomparisons between the laboratories concerned, and exchanges of samples and techniques are recommended in order to arrive at accurate and worldwide consistent sets of these data.

General Recommendation 5

The neutron dose rates generated by (α,n) reactions in different kinds of glasses constitute a hazard during waste handling. It is therefore recommended that cross sections pertinent to elements used in nuclear waste vitrification be made available.

General Comment

1. Integral cross section measurements obtained by post-irradiation analysis of spent fuel or test irradiations can be used to check differential cross section data, provided all information (on flux, energy spectrum, reactor operation condition etc.) can be made available. Standard reference experiments are useful for this purpose.

2. Should differential cross section data not be sufficiently accurate or not available, measurement of integral cross sections can be performed easily; this information, however, is pertinent only to a specific reactor and its mode of operation.

III. CONCLUSIONS AND RECOMMENDATIONS OF WORKING GROUPS

A. Report of the Working Group on the Requirements of TND for Thermal Reactors (Chairman: R.M. Nunn)

I. Introduction

This report is concerned with the requirements, status and availability of TND in the context of thermal reactors. It is in order to make the following introductory remarks:

(i) During the discussion of the working group it became apparent that there were requirements for TND which had not been identified in the review papers, and, more importantly, that the status of some of the data required had not been included in the reviews.

(ii) Some of the reviewers had not made specific recommendations as to requirements for data or other required actions, and this increased the difficulties of the working group in reaching satisfactory conclusions and recommendations during the time available for discussion.

(iii) So far as nuclear power plants are concerned, the importance of some of the actinides has emerged only over the last few years, and the requirements for data are in many instances concerned with problems which have only recently been identified. In many cases, the development is inadequate to fully define the accuracy requirements for TND.

II. Requirements and Status of TND

The requirements for TND stem from the recognition of the importance of actinides in a wide range of reactor problems, but the actinides themselves can be grouped into two categories:

(i) Those which may be present in only very small quantities (e.g. U 232 and its daughters, or Cm 242), but which, because of their unique properties, assume considerable importance.

(ii) Those which are present in comparatively large quantities (e.g. the plutonium and americium isotopes), and because of either their decay or neutronic properties are important.

1. Core design and fuel analysis for code evaluation

a. Core design

The requirements for transactinium nuclear data for the design of thermal reactors (RP.A2) are connected with the need to derive several reactor parameters, namely: reactivity, power distribution, burn-up, kinetic response, temperature coefficients and others. In these calculations the data of prime importance are the fission and capture cross sections and it is possible to divide the transactinium nuclei into two groups.

(i) Nuclei of importance in the major (Th-U, U-Pu) fuel cycles: U 234, U 236, Pu 240, Pu 241 and Pu 242.

The requirements and data available for these nuclei have been subjected to extensive study in the past. Nevertheless, in some instances there are long outstanding and detailed requirements for data on these nuclides which have not been met. In specific cases the requests are satisfied by a combination of the available data and the results of fuel analyses.

(ii) The isotopes listed in Table 1, column 1.

Cross section requirements for these nuclei are related to reactivity calculations and are presented in Table 1. The requested accuracies quoted in Table 1 for Pa and U isotopes are based on considerations of the Th-U fuel cycle. For Am and Cm isotopes the accuracies are based on calculations for Pu recycling in thermal reactors.

The calculation of the internal neutron source strength, required for subcritical reactivity measurements during refuelling of reactors, demands a knowledge of the neutron output due to Cm 242 and to a lesser extent, Cm 244. The group is of the opinion that an accuracy of $\pm$ 50% in the calculation of the source strength should be sufficient and, consequently, the requirements for the related data are less stringent than those derived from consideration of core physics.

b. Fuel analysis

Destructive and non-destructive analyses of irradiated fuel lead to a heavy isotopic assay which can validate the computer codes and the data used to predict fuel burn-up. Judicious use of these techniques on selected fuel elements may differentiate deficiencies in computer codes from defects in the input data. The nuclear data requirements for these analyses are mainly the half-lives and decay schemes of the isotopes listed in Table 3. Except for the Am and Cm isotopes the data requirements are less stringent than those required for quality control (sect. II.2.a.). For the Am and Cm isotopes the half-life data appear to be adequate (see Table 3).

2. Fresh-fuel fabrication, transport and handling

The problems (and hence requirements) depend upon the type of fuel employed, and fall into five broad categories:

(i) Quality control at the fabrication plant and enrichment checks prior to loading into the reactor - i.e. destructive and non-destructive assay methods.

(ii) Health physics problems associated with fabricating, storing, handling and transportation of the fuel, particularly for fuel with energetic γ and neutron emission.

(iii) Criticality control (neutronics).

(iv) Safeguards (destructive and non-destructive assay).

(v) Fuel design.

a. Quality control and enrichment checks

The fuel fabricator will operate to tight product specification and for this purpose employs both destructive and non-destructive methods of fuel analysis. No TND cross section data are required, but the analyses require accurate data on half-lives, decay schemes and energies. The group accepted the view of Dierckx (RP.A8) on data requirements, and a comparison of the requirements and status is given in Table 3. It would appear that the half-life data for Pu 238 are inadequate. For two nuclides, Pu 239 and Pu 241, the panel noted discrepancies which suggested that the data may also be inadequate (see footnote to Table 3). In the opinion of Dierckx (RP.A8) the decay schemes are adequately known. This is confirmed by the classification of Reich (RP.B7).

b. Prediction of the isotopic content of fresh fuels

There are no requirements for fresh uranium fuel. Recycle uranium fuels may be contaminated with U 232 to an extent which affects the design and operation of fuel fabrication plants, and of fuel handling procedures. Recycle plutonium fuels present wellknown fabrication problems, and for these, and for the design of fuel handling arrangements, TND are required to predict the likely composition of these fuels - particularly for the buildup of Pu 238 and Pu 240. Recycle Th/U 233 fuel will be heavily contaminated with U 232 and this will require the provision of remote fabrication and handling facilities.

The requirements for TND are listed in Table 1. Except for the (n,2n) cross sections, the available cross section data would seem to be adequate. The information on (n,2n) cross sections and companion (γ,n) cross sections was insufficient to judge the status of the data. From the number of measurements carried out and the evaluations available, it seems likely that the status will meet the requirements.

c. Criticality control

TND required are adequately covered by the requirements for core design (Section II.1.a. this report, also report of Fast Reactor Working group).

d. Safeguards requirements

Safeguards requirements were not discussed in detail by the group but should be covered by the requirements for fuel analysis discussed previously (also see RP.A8).

e. Fuel design

Actinides influence fuel design, from consideration of their in-reactor performance (covered by II.1. above) and through consideration of their impact on fuel fabrication problems and on subsequent in-reactor chemical performance. For the latter, only very approximate TND are required (total Pu content and total fission fraction in plutonium) and the requirements from fuel fabrication are covered by II.2.b. above.

f. Reactor shutdown heating

The contribution of actinides to total decay heat is small, and at short shutdown times the dominant actinide is Np 239. No cross-section data for this isotope is available: the accuracy requirement is for $\sigma(n,abs)$ to an order of magnitude.

g. Discharge fuel handling, storage and transport

For fuel handling, the major requirement is for accurate (i.e. ~± 10 %) predictions of total heat production. The dominant heat source is fission product decay, and the important actinides are Cm 242 and Cm 244. The accuracy requirements are stated in Table 1 and compared in Table 2. It would appear that the presently available data are adequate. For pond storage of discharged fuel, actinides do not give rise to significant problems. For dry storage, the accuracy requirements will be similar to those required for irradiated fuel handling.

For fuel transportation, heat production and neutron emission (especially) are both of importance. The heat requirements are similar to those required for fuel handling and the prediction of neutron output is required with ~20 % accuracy. The requirements would appear to be met by available data (see Table 2).

III. Future Requirements

This report has considered requirements presently identified by those associated with nuclear power plants. Because of the very recent recognition of the importance of some actinides, it is difficult to predict future requirements. However, now that actinide build-up codes are freely available it is necessary that data is available for calculating the build-up of all actinides to obtain estimates of inventories of the longer lived (> 20 min) isotopes to an accuracy of at least a factor of 10. As a very approximate guide it is suggested that the cross-sections involved in the predictions should be known to an accuracy of 30-50 %.

IV. Summary and Conclusions

1. As a basis for discussing the status of neutron cross-section data, the group used the review paper by Benjamin (RP.B1) supplemented by the paper of James (RP.B2).

2. In the main, available cross-section data appear to meet present requirements. There are exceptions and these are marked * in Table 2. The more important of these are:

   a. The long-standing requirement for Pu 240 resonance data, especially for low energy (< 20ev) resonances does not appear to have been met. These data are of particular importance to reactor design.

b. Very limited data exist for Np 239 and Pu 236 (reviewed in RP.Bl), a 100 % accuracy is required. Data for Am 242m and Cm 243 were reviewed in RP.Bl, and a 50 % evaluation of these data has recently been completed (private communication from R.W. Benjamin, 19 February 1976).

3. The half-life data for Pu 238, Pu 239 and Pu 241 do not meet the requirements for fuel quality control and may not meet the requirements for burn-up analyses.

4. Insufficient data were presented to properly assess the status of the (γ,n) and $(n,2n)$ cross-sections required to determine the buildup of important nuclides (U 232, Pu 236 and Pu 238), or for the neutron yield from (α,n) reactions.

5. Integral measurements are a powerful means of checking both data and codes and are of great importance in establishing overall prediction uncertainties for power reactors. These measurements are encouraged.

6. For data beyond Cm 244 in Table 2, no requests have been identified. However, data adequate to predict the buildup of these isotopes to an accuracy of at least a factor of 10 should be made available. Sensitivity studies are needed to identify whether this is achievable with existing data.

V. Recommendations

1. Accurate resonance parameters for Pu 240, particularly below 20 ev, should be obtained as soon as possible. The 1 ev resonance is of prime importance.

2. The status of cross section data for Np 239 and Pu 236 should be carefully assessed and the need for measurements ascertained. The status of Am 242m and Cm 243 was assessed in RP.Bl.

3. For the remaining data marked with an asterisk in Table 2, evaluations should be carried out to determine whether existing data meet the requirements.

4. An assessment should be carried out to ensure that evaluations of (n,2n) cross sections and of (α,n) and (γ,n) yields have led to an estimated error which satisfies the requirements shown in Table 1.

5. Evaluations should always include realistic estimates of errors.

Table 1

Cross Section Accuracy Requirements for Specific Thermal Reactor Fuel Cycle Applications

(accuracies given in percent)

Reaction and Isotope	Core Design	Fresh Fuel	Decay Heat	Discharge Fuel	Transport
Th 232 (n,2n)		20			
Pa 231 (n,γ)	10				
Pa 233 (n,γ)	10				
U 232 (n,γ)	30				
233 (n,2n)		30			
234 (n,γ)	5				
236 (n,γ)	4				
238 (n,2n)		50			
Np 237 (n,γ)	10	50			
239 (n,2n)		50			
239 (n,Abs)	100		100		
Pu 236 (n,Abs)		50			
238 (n,γ)	30				
239 (n,2n)					
*240 (n,γ)	1				
*241 (n,γ)	3				
(n,f)	1				
($\bar{\nu}$)	0.5				
*242 (n,γ)	5		50	30	20
Am 241**(n,γ)	10			30	20
Am 241***(n,γ)	50				
m242 (n,γ)	50				
m242 (n,f)	30				
243 (n,γ)	10				
Cm 242 (n,γ)	50				
244 (n,γ)	50				

* But note detailed requests are outstanding.
** for production of ground state Am 242.
*** for production of isomeric state.

For α emitters (α,n) yields (in UO_2) are required. For Cm 242 and Cm 244 to 100 %, likewise for other isotopes.

(γ,n) production rates are required for Th 232, U 233, U 238, Np 239, Pu 239 to ~100 % accuracy.

Table 2

Comparison of Requirements and Status of Cross Section Data for Thermal Reactor Applications

Isotope	$\sigma_{n\gamma}$			σ_{nf}			$I_{n\gamma}$			I_{nf}		
	Requested accuracy (1)	2200m Data accuracy	Request not satisfied (= *)	Requested accuracy (1)	2200m Data accuracy	Request not satisfied (= *)	Requested accuracy (2)	Data accuracy	Request not satisfied (= *)	Requested accuracy (2)	Data accuracy	Request not satisfied (= *)
Pa 231	10	10					20	7				
Pa 233	10	12	*				10	4				
U 232	30	2		30	12		30	6		30	13	
U 234	5	1.5					5	12	*			
U 236	4	6	*				4	6	*			
U 237	100	33					100	18	no cut off given			
Np 237	100	2					10	8				
Np 239	100	?	*									
Pu 236	100	–	*				100	–	*			
Pu 238	30	4		50	3		50	10				
Pu 240	2	0.5					1	12	*			
Pu 241	3	3		1	<1%		10	5				
Pu 242	10	4–5					5	4				
Am 241(GS)	10	3					10	9				
Am 241(IS)	50	8					50	9				
Am 242m	50	–	*	30	4		50	–	*	30	7	
Am 243	15	5					10	3	*			
Cm 242	50	50					50	30				
Cm 243	50	–	*	50	7		50	–	*	50	21	
Cm 244	50	20					50	10				
Cm 245	50	10		50	25		100	7		100	5	
Cm 246	100	20		30	15		30	7		30	7	
Cm 247	30	15		30	15		30	15		30	7	
Cm 248	50	10					30	10				
Bk 249	30	50					30	50				
Cf 249	50	6		30	3		70	10		60	10	
Cf 250	50	15		30	–		70	7		50	–	
Cf 252	50	10		30	10		70	4		50	15	
Cf 252	30	8		30	10		50	8		50	20	
Cf 253	100	20		30	20		200	25		60	25	
Es 253(GS)	30	–					30	5				

Footnotes:

(1) The requested accuracy is for an average value over a reactor spectrum. The measured accuracy quoted is for 2200m values. These will meet the requests in the absence of serious non-$1/_v$ cross-section behaviour. All accuracies are given in %.

(2) Resonance integral (I) has been used as a means of parametrising the non-thermal requirements. In general, differential cross sections for major resonances will be required.

Comment:

Data requirements for isotopes beyond Cm 244 are associated with future requirements. See section 3. They are purely speculative, and a sensitivity analysis is required.

Table 3

Comparison of Requirements and Status of Half-life and Decay Data for Thermal Reactor Applications

Isotope	Half-life data *		Decay Scheme Status (see RP.B7, Table I)	Needed for
	Required Accuracy (%)	Achieved Accuracy (%)		
Pu 238	0.5	1	A	Quality Control
Pu 239	0.5	1	A	
Pu 240	1	1	A	
Pu 241	1	3	$A(\beta^-), B(\alpha)$	
Am 241	4	1	A	Burnup Analysis
Cm 242	2	1	A	
Cm 244	2	1	B	

* The achieved accuracies quoted above are statistical confidence levels of 1σ and do not reflect the range of currently available data. In some instances working group 3 has assessed larger uncertainties taking this latter point into account.

B. Report of the Working Group on the Requirements of TND for Fast Reactors (Chairman: J.Y. Barré)

I. Introduction

The requests to be considered are for present-day fast reactors.

Problems considered are of three categories:

(i) in-core problems for reactivity and breeding gain

(ii) out-of-core problems for handling, reprocessing, manufacturing and shielding

(iii) fuel analysis for code tests and operation of the plants.

Only the U-Pu fuel cycle for fast reactors is considered in this document.

Any use of Th 232, including the U-Th cycle will be considered at the appropriate time.

It is not the intention here to determine requests for the higher Pu isotopes Pu 240, Pu 241, Pu 242. Requests for these isotopes have been made in many previous documents. The most challenging of these requests are for the capture cross-section of Pu 240 to about 5% and the fission cross-section of Pu 241 to about 1.5%. The capture cross-sections for Pu 241 and Pu 242 are normally requested to about 8%. The fission cross-sections of Pu 240 and Pu 242 are usually requested to about 2% and 4%, respectively.

In the long term, actinides may be recycled in a fast reactor to avoid the need to store them for thousands of years. Perhaps the most extreme version of this idea is for the fast reactor to be fuelled by the higher actinides. In this case, the accuracy requirements for these isotopes would be similar to those presently required for the plutonium isotopes. Fuel handling problems would be considerably increased due to the activity involved, and the data for decay heat and neutron emission would need to be known to high accuracy. Until more complete sensitivity studies are carried out, it is not possible to determine quantitative requests for cross-sections for this type of actinide recycle.

II. Requests

The table below lists the accuracy requirements for the isotopes which are considered to be of major importance for fast reactors.

Accuracy Requirements (in percent)

	Cross-Sections			$\bar{\nu}$	Half-life
	(n,γ)	fission	(n,2n)		
Np 237	30	50	50	50	
Np 239	20	50		50	
U 238			50		
Pu 236	50	50			
Pu 238	20	7		4	0.5
Pu 239			50		
Am 241	5	15		10	1
Am 242m	50	15		10	
Am 243	10	30		25	
Cm 242	50	25		15	3
Cm 244	50	50			3

Comments:

a. (n, gamma) cross-sections:

The most stringent requirements on accuracy for these cross-sections are fixed by the in-core reactivity estimate. The exceptions are the two curium isotopes, which limits are set by the fuel handling considerations, and Pu 236 (see comment f).

b. fission cross-sections:

Most of the required accuracies are again fixed by the reactivity effect. The curium isotopes accuracy is determined by the fuel handling.

c. Nu values:

These are fixed by the reactivity effects.

d. Alpha-decay half-lives:

Since they are considered to be sufficiently well known for most fast reactor purposes, half-lives of the isotopes for alpha-particle decay are listed only for some isotopes. An exception to this statement is for fuel analysis where the required accuracies are 0.5 % for Pu 239, and 1 % for Pu 240 and Pu 241.

e. Half-lives for spontaneous fission are required for the isotopes Cm 242 and Cm 244 to within 15 %. This accuracy is needed to estimate the rate of neutron production for fuel handling assessments.

f. Plutonium 236 and neptunium 237 are included in the table because they both lead to the production of uranium 232. The gamma-activity of the daughter of this latter isotope causes problems in the subsequent handling and refabrication of the uranium.

g. To predict nuclide concentration of actinides one has to be careful in choosing coarse energy group structure in the whole burnup calculation (see RP.A3).

h. For the capture cross-sections the energy range (0.5-100 keV) and for fission 1 keV - 2 MeV have to be taken into account (except for threshold fission).

i. After fuel unloading, the cooling and storage time play important roles with respect to the actinide concentration (especially for Am 241). This can influence the requested accuracies according to the fuel cycle chosen.

j. The information on (γ,n) cross sections is presently insufficient to be able to analyse the importance of this problem compared to $(n,2n)$ reactions: example Np 237 for Pu 236 production. Orders of magnitude for these cross-sections would be useful. The same problem exists for the (α,n) cross-section on oxygen (neutron dose).

III. Summary of Data Status for Transactinium Nuclear Data for fast Reactors

1. Theoretical

Fission probabilities from reactions such as (d,pf) and (t,pf) have been inferred for all the actinide isotopes of current fast reactor interest. These and the measured fission cross-sections, when available, can be used in theoretical calculations of σ_{nf} and $\sigma_{n,\gamma}$ in the energy range of interest to fast reactors. We estimate that the reliability of such calculations is ± 25 % for the isotopes of U, Np, Pu and Am, ± 30 % for the medium isotopes of Cm (say Cm 244, Cm 245) and deteriorating to ± 50 % for other isotopes of Cm, Bk and Cf. For Th and Pa, $\sigma_{n,\gamma}$ can be predicted by present techniques to ± 25 %, but the fission cross-sections appear to be overpredicted by perhaps a factor of 2, although modifications to the theory have been suggested which could improve this situation.

2. Experimental

Np 237: fission cross-sections above threshold agree to less than 10 % but capture data show ≃ 50 % discrepancy. No plans are known for measurement.

Pu 238: estimated accuracy of σ_{nf} is ± 10 % above threshold; $\sigma_{n,\gamma}$ below 300 keV is probably good to ± 30 %, on the average over the range of interest.

Pu 240: capture cross-section data to less than 10 % below 100 keV to ± 20 % at 300 keV. Fission data accuracy is estimated at ± 10 % above threshold; recent results by Behrens at LLL should provide corroboration.

Pu 241: alpha measurements currently in progress at ORELA are expected to yield data comparable to Pu 240; Behrens' fission ratios on Pu 241 should provide highly accurate results (≃ 1-2 %).

Pu 242: capture measurements at RPI with accuracy ≤ 10 % available below 100 keV. Fission measurements above threshold also agree to ≃ 10 %.

Am 241: absorption cross-section measurements at ORNL have an accuracy of 5-10 %; however the uncertainty in the fission cross-section shape and discrepancies with integral measurements suggest that the capture cross-section is probably uncertain to 30 %. A remeasurement of fission to verify the gross structure reported by Seeger et al, between 1 and 100 keV, is urgently needed.

Am 242: we estimate that uncertainties as large as ± 50 % exist in current fission data. Measurements with a better sample are planned at LLL. No radiative capture measurements exist and there are no plans for making this extremely difficult measurement.

Am 243: the fission cross-section is probably known to ± 10 % above threshold, but no radiative capture measurements have been made. These are urgently needed; the accuracy obtainable with current theoretical techniques is probably not sufficient to satisfy fast reactor needs.

Cm 242: no experimental data exist in the region of fast reactor interest.

IV. Specific Recommendations for Provisional Data

Comparison of these remarks on data status with the requirements in Table 4 reveals the following immediate data gaps:

1. Am 241. Fission cross-section needs verification in the region 1-100 keV (highly dissimilar data exist here). A measurement of the capture cross-section in this region and above is also highly desirable, particularly since there are now apparent discrepancies between experimental and theoretical differential data on the one hand, and integral data, on the other.

2. Am 242m. The capture cross-section, or alternatively very accurate measurements of both fission and absorption, are required.

3. Am 243. Capture cross-section is required.

4. Pu 240. Better capture data are required.

5. Pu 241. Perhaps new ORELA measurements now being made will fill gap here.

6. Pu 242. Capture data are required.

7. Cm 242. Capture and fission data are required.

8. Cm 244. Capture data are required.

9. Np 237. Capture data are required.

It should be stressed that while some of the above gaps can be filled by theory to within the presently needed accuracy, this does not absolve the data measuring community from measuring data on the higher transuranium isotopes, not least for the purpose of checking the theory.

V. General Remarks

The comparison of TND requests and status is summed up in Table 4.

1. For fast reactor core physics, the accuracies needed are well defined and probably not reached for all the nuclei involved.

2. For fast reactor fuel cycle,
   - it is probably necessary to have more precise knowledge of the different fuel cycles and strategies envisagod,
   - the mode of operation of fast reactors may play a role in the accuracies needed, and
   - the improvement of plutonium recovery in reprocessing plants may affect the desired accuracies.

3. For medium and long-term perspectives,
   - the accuracies actually quoted could change by some factor when the number of operating reactors will increase, and
   - if one is to envisage special fast reactors for actinide recycling, better accuracies for some of the transactinium isotopes will be needed.

General Recommendations:

1. The transactinium evaluated neutron nuclear data should be improved over the next five years in the framework of an international collaboration:

   for microscopic data:

   a. One should improve the availability of transactinium samples for laboratories already qualified to perform the measurements or for laboratories which are developing measurement techniques.

   b. Evaluations should be exchanged and compared. They must include error estimates on evaluated data.

   for integral data:

   Integral experimental results should be exchanged and compared with calculations. It seems necessary to confirm the transactinium neutron nuclear data coming from differential measurements and evaluations by integral results on irradiated fuels and critical experiments.

For data already available discrepancies should be examined and resolved.

2. Fuel cycle strategies should be better defined.

3. There should be an appropriate international diffusion of experimental, calculated and evaluated transactinium nuclear data in a form suitable for the users.

Table 4

Comparison of Requirements and Status of Nuclear Data for Fast Reactor Applications

Nuclide	Data Type	Main Energy Range	Accuracy % Achieved	Accuracy % Required	Comment	Origin	Needs
Np 237	(n,γ)	.5 - 100 KeV	≃ 50	30	± 25 % from theory	A2,	
	(n,f)	above threshold	< 10	50	± 25 % from theory	A4,	In-core cycle,
						A5	fuel handling,
	(n,2n)	above threshold	?	50			and fabrication
	$\bar{\nu}$	above threshold	?	50			
Np 239	(n,γ)	.5 - 100 KeV	?	20	± 25 % from theory	A2	In-core cycle
	(n,f)	above threshold	?	50	± 25 % from theory	A4,A5	and decay heat
	$\bar{\nu}$	above threshold	?	50			
U 238	(n,2n)	above threshold	?	20		A4	Fuel fabrication
Pu 236	(n,γ)	.5 - 100 Kev	?	50	± 25 % from theory	A4	Fuel fabrication
	(n,f)	1 KeV - 2 MeV	?	50	± 25 % from theory	A5	and Pu recycling
Pu 238	(n,γ)	.5 - 100 KeV	30	20	± 25 % from theory	A2	In-core cycle, and
	(n,f)	1 KeV - 5 MeV	<10	7	± 25 % from theory	A5	fuel fabrication,
	$\bar{\nu}$	1 KeV - 5 MeV	?	4			and fuel control
	$T_{1/2}$ (α)		1	0,5		A8	
Pu 239	(n,2n)	above threshold	?	50		A5	Fuel fabrication
Am 241	(n,γ)	.5 - 100 KeV	30	5	± 25 % from theory	A2,	In-core cycle,
	(n,f)	1 KeV - 5 MeV	30 ?	15	± 25 % from theory	A5	fuel fabrication,
	$\bar{\nu}$	1 KeV - 5 MeV	?	10			fuel control, and Cm 242 production.
	$T_{1/2}$ (α)		1	1		A8	
Am 242m	(n,γ)	.5 - 100 KeV	?	50		A2	
	(n,f)	1 KeV - 2 MeV	50	15			In-core cycle
	$\bar{\nu}$	1 KeV - 2 MeV	?	10			
Am 243	(n,γ)	.5 - 100 KeV	?	10	± 25 % from theory	A2	In-core cycle
	(n,f)	above threshold	10	30	± 25 % from theory	A5	and Cm 244
	$\bar{\nu}$	above threshold	?	25			production
Cm 242	(n,γ)	.5 - 100 KeV	?	50	± 30 % from theory	A4,	
	(n,f)	1 KeV - 2 MeV	?	25	± 30 % from theory	A5	Fuel handling, storage,
	$\bar{\nu}$	1 KeV - 2 MeV	?	15			transport, and
	$T_{1/2}$ (s.f.)		1	3		A8	control.
Cm 244	(n,γ)	.5 - 100 KeV	?	50	± 50 % from theory	A4,	Fuel handling, storage,
	(n,f)	above threshold	30 ?	50	± 50 % from theory	A5	transport, and
	$T_{1/2}$ (s.f.)		1	3		A8	control

C. Report of the Working Group on the Requirements of TND in Waste Management and isotope applications (Chairman: L. Hjaerne)

This working group was the 'catch-all' for everything other than the explicit applications of actinide cross sections in thermal and fast reactor development, design and operation. Hence the subject matter for discussion in the working group was concerned with various energy and non-energy applications of actinide nuclear data, with some emphasis on the back end of the nuclear fuel cycles, which is a matter of much current interest.

The working group first brought together a list of requests for actinide cross section data. From that list were then excluded all those requests which have obviously been met by measurements. The working group then attempted to assign priorities to the individual requests according to the urgency and timeliness of the needs in the various laboratory and national programmes, as expressed in reports and papers available at the time of the meeting. The criteria for priorities are of the usual kind described in WRENDA-75 (INDC(SEC)-46, June 1975). Data requests which have been assigned priority 1 have, in other words, been selected for maximum practicable attention. Priority 2 has been assigned to requests for data which will be required during the next few years in the energy programs, particularly in the area of waste management. It was convenient to list all $\bar{\nu}$-requests in a separate table (Table 7). Decay data in Table 6 are more difficult to categorize according to priorities, as this would often mean a subjective comparison of incomparable entities and the working group therefore abstained from making such an excercise. Table 5 lists the actinide cross section requirements for energy and related applications.

Table 5

Comparison of Requirements and Status of Cross Section Data for Energy and Isotope Applications

Nuclide (half-life)	Data type	Energy range	Achieved Accuracy	Required Accuracy	Needs	Reference Review Paper	Priority
Th 232 ($1.407x10^{10}$y)	(n,3n) (n,2n)	fast fast	no no	50 % 50 %	Fuel handling Fuel handling	A6 A6	3 3
	delayed neutron yield				Spectrum measurement	A9	3
U 233	(n,2n)	fast	10 % (fission spectrum)	10 %	Fuel handling	A1	2
Np 237 ($2.1x10^6$y)	(n,2n) (γ,n)	—	12 %	10 %	Radioisotope Power Sources	A1	2
Pu 236 (2.8y)	(n,γ) (n,f)	resonance	no	20 %	Fuel handling	A1	3
Pu 238 (8.8y)	(n,3n)	resonance and fast	no	50 %	Fuel handling	A1	3
	(n,f)	resonance and fast	40 %	20 %	Actinide re-cycling	A6	2
Pu 239 (24000 y)	(n,2n)	fast	no	10 %	Fuel handling	A1	2
Pu 240 (6540 y)	(n,γ) resonance parameters	1 ev resonance		5 %	Discrepancies	B1	2
Pu 242 ($3.9x10^5$y)	(n,γ)	fast	no	30 %	Actinide recycle	A6	1
Am 241 (433 y)	(n,γ) branching ratios	thermal, fast (cut-off energies unknown)	10 %	10 %	Radioisotope power sources, fuel handling and others	A1 B1	1
Am 242g (16 h)	(n,γ) (n,f) total	thermal, fast	no	50 %	Actinide recycle	A1 A6	3
Am 242m (152 y)	(n,γ) (n,f) total	thermal, fast		20 %	Actinide recycle	B1 B6 B1	1
Am 243 ($7.37x10^3$y)	(n,γ) (n,2n)	fast		50 %	Actinide recycle Radioisotope power sources	A1, A6 A1	1 3
Cm 242 (163 d)	(n,γ) (n,f) total	thermal, resonance fast fast thermal, resonance	(50 %) no no no	20 % 30 % 20 % 20 %		B1 A6 A6 B1	2 2 2 2
Cm 243 (30 y)	(n,γ) Γ_t (n,f)	all resonance fast	no 20 % ?	30 % 15 % 20 %		A1, A6 B1 A6	2 2 2
Cm 244 (17.9 y)	(n,γ) (n,f)	fast fast	no ?	30 % 20 %		A6 A6	2 3
Cm 245 ($8.5x10^3$y)	(n,γ) α	fast fast	no no	50 % 20 %		A6	2 2
Cm 246 ($4.76x10^3$y)	(n,γ)	thermal, resonance fast	20 % no	10 % factor 2		B1 A6	2 3
Cm 247 ($1.54x10^7$y)	(n,f)	thermal, resonance 30 eV fast	no 20 %	5-10 % 10 %		WRENDA 75 B4	3 3
Bk 249 (311 d)	$I_{n\gamma}$	(cut-off energies unknown)	10 %	10 %		B1	2
Cf 250 (13.1 y)	(n,γ) (n,f)	thermal resonance	15 % no	10 % 10 %		B1 B1	2 3
Cf 251 (900 y)	(n,f)	thermal, resonance	no	10 %		B1	2

Table 6

Comparison of Requirements and Status of Half-life and Decay Data for Energy and Isotope Applications

Nuclide	Data Type	Achieved Accuracy *	Required Accuracy	Needs	Reference Review Paper
Th 232	yield of 55-s and 22-s delayed-neutron groups	unknown	5 %	neutron spectrum determination	A8
U 233	yield of 55-s and 22-s delayed neutron groups	unknown	5 %	neutron spectrum determination	A8
U 234	α-intensity	3 %	1 %	mass determination	A9
	γ-intensity	factor of 5	5 %	nondestructive and destructive fuel assay	A8
U 235	$T_{1/2}$ (α)	2 %	1 %	mass determination fuel assay	A8, A9
	α-intensities	10 %	1 %	mass determination	A9
	γ-intensities	unknown	1 %	fuel assay, mass determination	A8, A9
	yield of 55-s and 22-s delayed neutron groups	unknown	5 %	neutron spectrum determination	A8
U 236	$T_{1/2}$ (α)	2 %	1 %	mass determination	A8, A9
U 238	α-intensities	5 %	1 %	mass determination	A9
	yield of 55-s and 22-s delayed neutron groups	unknown	5 %	neutron spectrum determination	A8
Np 237	α-intensities	20 %	1 %	mass determination	A9
	yield of 55-s and 22-s delayed neutron groups	unknown	5 %	neutron spectrum determination	A8
Pu 238	$T_{1/2}$ (α)	1.5 %	0.5 %	destructive fuel assay	A8
	"	"	"	Calorimetry	A8
	"		0.02 %	high-precision mass standard	(Aten)
	γ-intensities	25 %	1 %	nondestructive fuel assay	A8
	L-x ray intensity	?	30 %	health-physics applications	A9
	α-intensities	1 %	0.1 %	mass determination	A9
Pu 239	$T_{1/2}$ (α)	1 %	0.2 %	destructive fuel assay, calorimetry, mass determination for safeguards	A8
	γ- intensities	10 %	1 %	nondestructive fuel assay for safeguards	A8
	specific power	1 %	0.2 %	calorimetry	A8
	L-x rays	100 %	30 %	chemical research	A9
	α-intensities	2 %	1 %	mass determination	A8
	yield of 55-s and 22-s delayed neutron groups	unknown	5 %	neutron spectrum determination	A8
Pu 240	$T_{1/2}$ (α)	5 %	0.2 %	destructive fuel assay, calorimetry, mass determination	A8
	γ-intensities	factor of 4	1 %	nondestructive fuel assay	A8
	α-intensities	1 %	0.2 %	mass determination	A8
	L-x ray intensity	unknown	30 %	chemical research	A9
Pu 241	$T_{1/2}$ (α)	5 %	1 %	destructive fuel assay	A8
		"	2 %	fast reactor	A8
	γ-intensities	5 %	1 %	nondestructive fuel	A8
Pu 242	$T_{1/2}$ (α)	5 %	1 %	mass determination	A9
	α-intensities	10 %	4 %	mass determination	A9
Am 241	γ-intensities	2 %	1 %	intensity standards	A9
	L-x ray intensity	5 %	1 %	intensity standards	A8
	yield of 55-s and 22-s delayed neutron groups	unknown	5 %	neutron spectrum determination	A8
Cm 242	$T_{1/2}$ (α)	1 %	0.1 %	decay correction in destructive fuel assay	A8
Cf 252	$T_{1/2}$ (α)	1 %	0.2 %	decay correction	A9

* In the column "Achieved Accuracy" the listed values generally represent the range of the measured data.

Table 7

Comparison of Requirements and Status of Neutron Induced $\bar{\nu}$ Data for Energy and Isotope Applications

Nuclide	$\bar{\nu}$	Energy	Achieved Accuracy	Required Accuracy	Priority	Reference Review Paper
Pa 231	$\bar{\nu}_{pr}$	fast	–	10 %	3	A6
U 232	"	fast	–	10 %	3	A6
Np 237	"	fast	–	10 %	2	A6
Pu 238	"	fast	–	10 %	2	A6
Pu 242	"	fast	10 %	3 %	2	B1
Am 241	"	fast	–	10 %	2	A6
Am 242	"	fast	–	10 %	2	A6
Am 243	"	fast	–	10 %	2	A6
Cm 242	"	fast	–	10 %	2	A6
Cm 243	"	fast	–	10 %	2	A6
Cm 244	"	fast	–	10 %	2	A6
Cm 245	"	fast	–	20 %	3	A6
U 236	$\bar{\nu}$ del	fast	–	10 %	2	B1
Pu 240	"	fast	–	20 %	2	B1
Pu 241	"	all	–	10 %	2	B1
Pu 242	"	fast	–	20 %	3	B1

Appendix A

ADVISORY GROUP MEETING ON TRANSACTINIUM ISOTOPE NUCLEAR DATA

Karlsruhe, FRG, 3-7 November 1975

LIST OF REVIEW PAPERS

A. Survey of TND Applications

1. General Survey of Applications of Actinide Nuclear Data in the Nuclear Fuel Cycle and the Nuclear Industry. (S. Raman)

2. Importance of TND in the Physics Design of Fast and Thermal Reactor Cores. (J.Y. Barré, J. Bouchard)

3. Sensitivity Studies of Build-up of Actinides during Normal Reactor Operations. (H. Kuesters)

4. Importance of TND for Engineering Design and Operations of Reactors. (R.G. Nunn)

5. Importance of TND for Fuel Handling (excluding waste management). (R.F. Burstall)

6. European Programmes in Waste Management (Incineration) of Actinides. (L. Koch)

7. US Programmes in the Waste Management (Incineration) of Actinides. (S. Raman)

8. Importance of TND for Fuel Analysis. (R. Dierckx)

9. Importance of TND in Non-reactor Applications. (A.H.W. Aten, Jr.)

B. Review of TND Status

1. Status of Measured Neutron Cross Sections of Transactinium Isotopes for Thermal Reactors. (R.W. Benjamin)

2. Status of Neutron Cross Sections of Transactinium Isotopes in the Resonance Energy Region - Linear Accelerator Measurements. (G.D. James)

3. Status of Neutron Cross Section of Transactinium Isotopes in the Resonance and Fast Energy Regions - Underground Nuclear Explosion Measurements. (M.S. Moore)

4. Status of Measured Neutron Cross Section of Transactinium Isotopes in the Fast Region. (S. Igarasi)

5a. Status of Transactinium Isotope Evaluated Neutron Data in the Energy Range 10^{-3} eV to 15 MeV. (S. Yiftah)

5b. Evaluation and Theoretical Calculation of TND. (J.E. Lynn)

6. Status of Alpha Decay Data of the Transactinium Isotopes. (A.G. Zelenkov/S.A. Baranov)

7. Status of Beta and Gamma Decay and Spontaneous Fission Data from Transactinium Isotopes. (C.W. Reich)

Appendix B

ADVISORY GROUP MEETING ON

TRANSACTINIUM ISOTOPE NUCLEAR DATA

Karlsruhe, FRG, 3-7 November 1975

MEETING PROGRAMME

Monday, 3 November

- Opening addresses by J.J. Schmidt and Prof. Böhm
- Outline of meeting procedure and objectives
- Organization of Working Groups
- Appointment of chairmen
- Presentation and discussion of Review Papers A1 to A5.

Tuesday, 4 November

- Presentation and discussion of Review Papers A6 to A9, and B1 to B4
- Short meeting of Working Groups.

Wednesday, 5 November

- Presentation and discussion of Review Papers B5 to B7
- Visit to the Karlsruhe Nuclear Research Centre.

Thursday, 6 November

- Independent work sessions of working groups to draft conclusions and recommendations.

Friday, 7 November

- Final plenary session for the presentation, discussion and adoption of recommendations and working group reports.

ADVISORY GROUP MEETING ON TRANSACTINIUM ISOTOPE NUCLEAR DATA

Karlsruhe, FRG, 3-7 November 1975

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