International Atomic Energy Agency

INDC(NDS)-105/N

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

Second Coordinated Research Meeting on the Measurement and Evaluation of Transactinium Isotope Nuclear Data

Aix-en-Provence, 30 April - 1 May 1979

SUMMARY REPORT

Prepared by A. Lorenz
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International Atomic Energy Agency

November 1979

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

Reproduced by the IAEA in Austria
November 1979

79-10201

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SUMMARY REPORT

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Abstract

The second meeting of the participants in the IAEA coordinated research programme to measure and evaluate required nuclear decay data of transactinium isotopes, was convened by the IAEA Nuclear Data Section on 30 April - 1 May 1979 in Aix-en-Provence, France.

The meeting participants reviewed the current measurement programmes, continued with the review of proposed transactinium isotope decay data, and recommended the release of a list of proposed half-life values which will be subject to revision based on comments received.

I. SUMMARY OF THE MEETING

Introduction

The second meeting of the participants in the IAEA Coordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data, was convened by the IAEA Nuclear Data Section on 30 April and 1 May 1979, in Aix-en-Provence, France. The meeting was chaired by A. Lorenz, IAEA Nuclear Data Section.

The participants in this meeting are listed in Appendix 1.

Meeting Objectives

The principal objectives of this meeting were to review the status of measurements performed by the participants in this programme, to review and extend the list of proposed half-lives, to initiate the review of the status and accuracy of gamma-ray and alpha emission spectra for the transactinium isotopes, and to consider the correlation of the data reviewed by this group with existing data files.

The Adopted Agenda is given in Appendix 2.

Conclusions and Results of the Meeting

The meeting reviewed the existing and planned programmes for the measurement and evaluation of transactinium isotope nuclear decay data of each participating research group. In particular, the meeting

- decided to release as a separate report the list of proposed half-life values compiled by this group for consideration by the scientific community,
- started a detailed review of the status and accuracies of the α and γ radiation spectra emitted by transactinium isotopes,
- discussed the INDC proposal to coordinate the data considered by this group with data in the Evaluated Nuclear Structure and Decay Data File (ENSDF) and other computerized libraries of nuclear decay data.

The participants agreed that a convenient date for the next meeting of the participants of this coordinated research programme would be 12-13 June 1980 in Vienna, directly preceding the scheduled meeting of the International Nuclear Data Committee.

The Actions which resulted from this meeting are listed in Appendix 3. The list of papers contributed to the meeting is given in Appendix 4.

II. MEETING PROGRAMME

A. Review of Actions from 1978 Meeting (Agenda Item 2)

- Action 78- 4 : Vaninbroukx was asked to repeat same action for 1979 report (see Action 79-2)
- Action 78- 6 : this Action was recommended to be continued (see Action 79-13)
- Actions 78- 7 and 8: discussion resulted in Action 79-12
- Action 78-17 : consideration of this Action led to an extended discussion of the requirements of decay data for safeguards purposes. The European Safeguards Research and Development Association (ESARDA) was described for transactinium decay data. The interest of this group in the functions and activities of ESARDA resulted in Actions 79-5, -6 and -7.

B. Progress Reports (Agenda Items 3 and 4)

1. M. Kulakov (USSR)

   Report: "Measurements and Evaluations of Actinide Isotope Nuclear Data"; V.M. Kulakov and L.L. Sokolovskij (Kurchatov Institute, Moscow) (contributed paper CP-1; translated and published in INDC(CCP)-135/LN, September 1979)

2. A.L. Nichols (UK)

   Report: "Heavy Element Decay Data: Progress Report for the IAEA Coordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data (May 1979)"; A.L. Nichols and M.F. James (AEE, Winfrith) (contributed paper CP-4; included in this report as Appendix 5)

   "UK Computer Codes for the Storage and Retrieval of Decay Data (April 1979)"
   A. Tobias, G. Evangelides and D.G. Vallis (contributed paper CP-6, included in this report as Appendix 6)

3. A.J. Fudge (UK)

   Report: "Report to IAEA Coordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data (May 1979)"
   A.J. Fudge (AERE, Harwell) (contributed paper CP-3, included in this report as Appendix 7)

4. G. Malet (France)

Report: "Report of the Laboratoire de Metrologie des Rayonnements Ionisants"
G. Malet (IMRI, Saclay) (contributed paper CP-7, included in this report as Appendix 8)

5. C.W. Reich (USA)

Report: "Status Report"
C.W. Reich (INEL, Idaho Falls)
(contributed paper CP-8, included in this report as Appendix 9)

6. H. Umezawa (Japan)

Report: "Preparation of Pure Curium-242 and Measurement of the Nuclear Decay Data"
H. Umezawa (JAERI, Tokai)
(contributed paper CP-11, included in this report as Appendix 10, published separately as JAERI-memo-8219, April 1979)

7. R. Vaninbroukx (CBNM, Geel)

Report: "Status Report from C.B.N.M.-J.R.C."
R. Vaninbroukx (CBNM, Geel) (contributed paper CP-12 and included in this report as Appendix 11)

"Half-life of Pu-239: Present Status"
R. Vaninbroux (C.B.N.M., Geel) (contributed paper CP-13, included in this report as Appendix 12)

8. W.B. Ewbank (NDP, Oak Ridge)

Report: "Nuclear Data Project"
R.L. Auble et al (contributed paper CP-10, included in this report as Appendix 13)

C. Review of Half-life Tables (Agenda Items 5 and 6)

One of the objectives of this coordinated research programme is to arrive at a consistent set of transactinium isotope decay data which satisfy the accuracies required by the data users. At its first meeting (April 1978), this group singled out a set of isotopes requiring a half-life accuracy of 1 % or better, and supplemented it by isotopes identified to be of importance in specific fields of applications. It is the intent of this group to review the lists of decay data that it proposed at yearly intervals, and publicize this information for the benefit of the scientific community. These tabulations are also intended as a useful guide to identify the needs for further decay data measurements.

The group reviewed the half-life data listed in Tables 3 and 4 published in the Summary Report of the first meeting of this group (INDC(NDS)-96/N), and gave the following recommendations:

1. Adjustment of half-life data

   (i) decrease in the uncertainty given to Th-228 half-life from .003 to .002

   (ii) change the Pu-237 half-life to 45.4 ± 0.2 days, to take into account a 1977 measurement

   (iii) change the Pu-240 half-life to $(6.55 \pm 0.02).10^3$ years, to reflect the variance in the Oetting and Jaffey values

2. Decision to combine the proposed half-lives (Table 3) and the proposed spontaneous fission half-lives (Table 4) in one list, and publish this list in a separate report. The revised (combined) list of proposed half-life values is to be released as INDC(NDS)-108/N, and given wide circulation so as to elicit as wide a range of comments and criticism as possible.

3. Decision to supplement the list of isotopes included in Tables 3 and 4 with some of the minor actinides (e.g. Np, Am, and Cm isotopes) and other isotopes in the decay sequences of the major actinides. The supplementary list of decay data is given in this report as Table 1.

D. Review of the Status and Accuracy of the Alpha and Gamma-ray Emission Spectra (Agenda Items 7 and 8)

The Group reviewed the status of the alpha and gamma-ray data for selected transactinium isotopes on the basis of a preliminary selection brought to the meeting by Reich and Nichols (see Appendix 4, contributed papers 4, 5, 8 and 9). As a result of this review, the Nuclear Data Section was asked to consolidate the suggested recommended data into tabulations which could be used for a subsequent appraisal of the existing "best data" before the next meeting of this group. It is anticipated that the resulting provisional tables of proposed $I\alpha$ and $I\gamma$ values for the selected transactinium isotopes will be published in the meeting report of the next meeting of this group (i.e. 1980).

The isotopes for which the $E\alpha/I\alpha$ and the $E\gamma/I\gamma$ values and their uncertainties are being reviewed as part of this effort are listed in Table 2.

E. Coordination of CRP Activities with the Structure and Decay Data Evaluation Programme of the Nuclear Data Project at Oak Ridge (Agenda Item 9)

The Group discussed the following recommendation made by the International Nuclear Data Committee at its October 1978 meeting:

Half-life and Decay Data Compilation and Evaluation

"The NDS and INDC Members should endeavour to keep scientists who are working on the evaluation and compilation of half-life and decay data informed of the ENSDF* programme and ask them to correlate their work with the ENSDF programme where appropriate. The aim should be to make the ENSDF data file the international reference source."[1]

In response to this recommendation the Group concluded the following:

"Members of this coordinated research project are aware of the ENSDF programme and this Group does coordinate its work with the ENSDF programme when appropriate. ENSDF is basically a nuclear structure data file representing the evaluated status of measurements, and specific parameters such as $\bar{\upsilon}$ and the associated energy release from spontaneous fission may not be included. There are also a number of applications in which the measured data alone (and hence ENSDF) are insufficient to solve specific problems. In these two instances the ENSDF data need to be supplemented with data from other sources and with estimates of those asyet unmeasured data.

The Group also noted that there are certain important transactinium isotopes that may require more frequent re-evaluation than is provided by the ENSDF programme. ENSDF should be encouraged to achieve a more frequent re-evaluation of these important isotopes."

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* The Evaluated Nuclear Structure Data File maintained by the Nuclear Data Project at Oak Ridge.

[1] Report of INDC Subcommittee A to the 10th Meeting of the International Nuclear Data Committee, (1979)

TABLE

PROPOSED EXTENDED PROVISIONAL TABLE OF HEAVY ELEMENT DECAY DATA

Note: Only measured spontaneous fission data are included in this table. The uncertainties, as defined in the report of the first meeting of this group (INDC(NDS)-96/N), correspond to 1σ confidence levels expressed in terms of the last significant figure(s) for that datum.

Nuclide	Decay Mode	Branching Fraction	Total half-life
206 -Hg	β^-	1	8.15(10)m
206 -Tl	β^-	1	4.20(2)m
207 -Tl	β^-	1	4.77(3)m
* 207m-Tl	IT	1	1.33(11)s
209 -Tl	β^-	1	2.20(7)m
209 -Pb	β^-	1	3.253(14)h
211 -Pb	β^-	1	36.1(2)m
214 -Pb	β^-	1	26.8(9)m
211 -Bi	β^- α	0.00273(4) 0.99727(4)	2.17(4)m
215 -Bi	β^-	1	7.4(6)m
211 -Po	α	1	0.516(3)s
* 211m-Po	α	> 0.998(2)	25.5(3)s
214 -Po	α	1	165(3) μs
215 -Po	β^- α	0.000004(2) 1	1.78(1)ms
216 -Po	α	1	0.15(1)s
218 -Po	β^- α	0.0002(1) 0.9998(1)	3.05(9)m
215 -At	α	1	0.10(2)ms
218 -At	β^- α	0.001(1) 0.999(1)	1.6(4)s
219 -At	β^- α	0.03(1) 0.97(1)	0.9(1)m

Nuclide	Decay Mode	Branching Fraction	Total half-life
218 -Rn	α	1	35(6)ms
219 -Rn	α	1	3.96(5)s
220 -Rn	α	1	55.6(1)s
222 -Rn	α	1	3.825(1)d
223 -Ra	α	1	11.43(1)d
224 -Ra	α	1	3.66(4)d
226 -Ra	α	1	1600(7)y
228 -Ra	β^-	1	5.75(3)y
228 -Ac	β^-	1	6.13(9)h
231 -Th	β^-	1	25.52(1)h
234 -Th	β^-	1	24.10(3)d
235 -Th	β^-	1	6.9(2)m
235 -Pa	β^-	1	24.2(3)m
235m-U	IT	1	26(2)m
240 -U	β^-	1	14.1(2)h
240 -Np	β^-	1	65(3)m
240m-Np	β^- IT	0.9989(3) 0.0011(3)	7.4(2)m
241 -Np	β^-	1	16.0(2)m
243 -Pu	β^-	1	4.956(3)h

Nuclide	Decay Mode	Branching Fraction	Total half-life
245 -Pu	β^-	1	10.5(1)h
246 -Pu	β^-	1	10.85(2)d
240 -Am	EC α	1 1.9(7) x 10^{-6}	50.8(3)h
244 -Am	β^-	1	10.1(1)h
244m-Am	β^- EC	0.99959(3) 0.00041(3)	~ 26 m
245 - Am	β^-	1	2.05(1)h
246 -Am	β^-	1	39(3)m, 25.0(2)m exact identities unknown
246m-Am	β^-	1	
241 -Cm	EC α	0.990(1) 0.010(1)	32.8 (2)d
243 -Cm	EC α	0.0024(4) 0.9976(4)	30(2)y
245 -Cm	α	1	8520(100)y
247 -Cm	α	1	1.56(5) x 10^7 y
249 -Cm	β^-	1	64.15(3)m
250 -Cm	α/β^- sf	not measured 0.7(3)	not measured
250 -Bk	β^-	1	192.40(40)m
251 -Cf	α	1	898(44)y
253 -Cf	β^- α	0.9969(4) 0.0031(4)	17.81(8)d

* These nuclides are not products of actinide decay. They are included here for completeness.

Table II

Nuclides included in the initial review of Eα/Iα and Eγ/Iγ data

α-emission data	γ-emission data
-	Pa 233
	U 233
U 234	U 234
U 235	U 235
U 236	-
-	U 237
U 238	U 238
-	U 239
Np 237	-
-	Np 239
Pu 238	Pu 238
Pu 239	Pu 239
Pu 240	Pu 240
-	Pu 241
Pu 242	-
Am 241	Am 241

LIST OF PARTICIPANTS

Appendix 1

Participants in the Coordinated Research Programme are indicated by an asterisk.

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Appendix 2

Second Meeting of the CRP on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data

Cadarache, France, 30 April and 1 May 1979

Adopted Agenda

1. Introductory items.
2. Review of Actions from April 1978 meeting.
3. Progress reports and activities forecast from CRP members.
4. Reports from observers.
5. Review and extension of list of proposed half-life values and their accuracies (see Table 3 of last meeting's report).
6. Review and extension of list of proposed spontaneous fission half-lives (see Table 4 of last meeting's report).
7. Review of the status and accuracy of the gamma-ray emission spectra ($E\gamma, I\gamma$).
8. Review of the status and accuracy of the alpha emission spectra ($E\alpha, I\alpha$).
9. Coordination of CRP activities with the structure and decay data evaluation programme of the Nuclear Data Project at Oak Ridge (see INDC recommendation: Memorandum dated 7 February 1979).
10. Next meeting of this CRP group.

Appendix 3

LIST OF ACTIONS

1. All participants	Review the distribution list and send in corrections and additions
2. Vaninbroukx	Transmit to IAEA/NDS for distribution to group, the 1979 TND decay data status file compiled for NEANDC
3. Kulakov	Investigate the availability of trans-actinium isotope samples for TND measurements for sale outside the USSR
4. Vaninbroukx	Transmit to IAEA/NDS for distribution to group, the description of the AS-76 experiment
5. IAEA/NDS Lorenz	Obtain the membership and description of activities of the European Safeguard R & D Association (ESARDA) from Harry, (ECN Petten), Chairman of the non-destructive group of ESARDA
6. Reich	Send to IAEA/NDS any information on ESARDA from the USA
7. IAEA/NDS Lorenz	Request from H. Ottmar at KFK the report on Pu gamma-ray intensities used for the measurement of isotopic composition in interlaboratory comparisons (ref. NBS Standards 946, 947 and 948)
8. IAEA/NDS Lorenz	Translate and distribute Soviet reports submitted to this meeting
9. All participants	After receiving the "combined" half-life list, specify references of the values given and annotate values with comments where necessary
10. Nichols	Review Table 2 in CP-4 (Nichols & James) and communicate to IAEA/NDS a tabulation of all reliably measured values (see Action 11)

11. Lorenz IAEA/NDS	Combine Tables 3 and 4 of INDC(NDS)-96/N, extend it with values given in Table 2 of CP-4 and add contributed references and annotations. (This table is to include measured values only)
12. Ewbank	Retrieve information on current T1/2, Iγ and Iα etc. measurements from the "Secondary Sources" file and transmit to IAEA/NDS for distribution to the group.
13. All Participants	Send to IAEA/NDS, 10 copies of every report considered pertinent to this project, for distribution to the group.

Appendix 4

LIST OF CONTRIBUTED PAPERS

1. "Measurements and Evaluations of Actinide Isotope Nuclear Data". (V.M. Kulakov). Translated and included in INDC(CCP)-135/LN.

2. "New Measurements of Partial Decay Half-Lives of the Isomeric State of AM-242m". (A.G. Zelenkov, et al.). Translated and included in INDC(CCP)-135/LN.

3. "Report to IAEA Coordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data" (May 1979). (A.J. Fudge). Included in this report as Appendix 7.

4. "Heavy Element Decay Data: Progress Report for the IAEA Co-ordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data (May 1979). (A.L. Nichols and M.F. James). Included in this report as Appendix 5.

5. "Current Status of Evaluated Heavy Element Decay Data for Reactor Calculations: Problems and Anomalies". (A.L. Nichols). Review paper B2 presented at the Second IAEA Advisory Group Meeting on Transactinium Isotope Nuclear Data, Cadarache, May 1979.

6. "UK Computer Codes for the Storage and Retrieval of Decay Data" (April 1979). (A. Tobias, G. Evangelides and D.G. Vallis).

7. "Report of the Laboratoire de Metrologie des Rayonnements Ionisants". (G. Malet). Included in this report as Appendix 8.

8. "Status Report". (C.W. Reich). Included in this report as Appendix 9.

9. "Report on the IAEA Co-ordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data". (C.W. Reich). Review paper B1 presented at the Second IAEA Advisory Group Meeting on Transactinium Isotope Nuclear Data, Cadarache, May 1979.

10. "Nuclear Data Project". (R.L. Auble, et al). Included in this report as Appendix 13.

11. "Preparation of Pure Curium-242 and Measurement of the Nuclear Decay Data" (H. Umezawa). Included in this report as Appendix 10.

12. "Status Report from C.B.N.M.-J.R.C. to the Second Coordinated Research Meeting on the Measurement of Transactinium Nuclear Decay Data". (R. Vaninbroukx). Included in this report as Appendix 11.

13. "Half-Life of ^{239}Pu: Present Status". (R. Vaninbroukx). Included in this report as Appendix 12.

14. "List of Available Enriched Pu Isotopes at CBNM - Mass Spectrometry". (P. de Bievre).

15. "Half-Life of the $(1/2^+)$ State of the U-235 Isomer". (V.I. Zhudov, et al).

16. "International Conversion Electron Spectrum for the $(1/2^+)$ State of the U-235 Isomer". (V.I. Zhudov, et al).

17. "Cogend: A Code to Generate Nuclear Decay Scheme Data in ENDF/B Format". (A. Tobias).

18. "Extensions to Cogend for ENDF/B-V Output of Spontaneous Fission Decay Data". (A. Tobias).

19. "A Brief Description of the ENDF/B-V Format Adopted for Use in the UK Decay and Fission Product Yield Data Files". (A. Tobias).

20. "A Brief Description of ENDF/B-IV Format Data for Inventory and Decay Heating Calculations". (A. Tobias).

21. "Determination of Plutonium Isotopic Composition by Gamma Spectrometry: Results from Interlaboratory Comparison Measurements Organized by ESARDA". (H. Ottmar, H. Eberle).

22. "Subcommission on Geochronology: Convention on the Use of Decay Constants in Geo- and Cosmochronology". (R.H. Steiger and E. Jaeger).

23. "The Pu-239 Half-Life". (H.D. Lemmel).

Heavy Element Decay Data: Progress Report for the IAEA Co-ordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data (May 1979)

A L Nichols, M F James
AEE Winfrith, Dorchester, Dorset, UK

Abstract

A computer file of heavy element decay data is being constructed in the UK. The ENDF/B-V format has been adopted. At present the evaluation effort is over half completed, with 95 decay schemes having been evaluated, of which 68 are actinides.

1 Introduction

The aim is to produce a comprehensive, computer-based file of heavy element decay data in ENDF/B-V format[1] for use in reactor calculations. This work is being carried out under the auspices of the UK Chemical Nuclear Data Committee, a sub-committee of the UK Nuclear Data Committee[2].

The IAEA advisory group meeting on transactinium isotope nuclear data[3,4] recommended new evaluations of the existing data to be made and for realistic estimates of data uncertainties to be included. The UK data file described here is designed to meet these specific requirements. The format adopted for the file is ENDF/B-V as defined in the USA[1,5] to allow rapid intercomparisons between the equivalent UK and USA[6,7] evaluated data.

Discussions with scientists at the CEGB Berkeley Nuclear Laboratories, UK, produced a list of heavy element nuclides requiring decay data evaluation[8]. This list has been used as the major guide for this evaluation effort, with significant additions from other sources[9,10]. It consists of 119 nuclides (table 1) of which 95 (including 68 actinides) have been evaluated, leaving 24 (including 7 actinides) to be completed within the next year. These include the reactor fuel actinides, all the principal actinide reactor products up to 253-Es and their major decay chain nuclides down to 206-Hg.

The spontaneous fission decay data are still being evaluated; a separate note will be issued when this task has been completed.

2 The Decay Data

The evaluated data required to produce the ENDF/B-V file include:

(i) half life,
(ii) Q-values,
(iii) branching fractions,
(iv) alpha decay data,
(v) beta decay data,
(vi) gamma decay data, including internal conversion coefficient data
and (vii) spontaneous fission decay data, including details of the mean number of neutrons per fission and continuous spectral data.

Data uncertainties are also included. These evaluated data are used as input to COGEND[11,12] which generates the final data in ENDF/B-V format. COGEND permits output in either ENDF/B-IV or V format as specified by the user.

3 Data Evaluation Philosophy

Throughout all of this evaluation considerable reference information has been derived from the publications[13] of the Nuclear Data Project based at Oak Ridge, USA. However, we have made considerable efforts to derive the proposed, complete decay schemes from the original publications, rather than rely on the compilations of Nuclear Data Sheets and the Evaluated Nuclear Structure Data File (ENSDF). This detailed approach proved to be necessary because preliminary attempts to adopt ENSDF data comprehensively produced omissions, discrepancies, and minor inconsistencies.

Every effort has been made to produce a consistent decay scheme and data set from the published data. If the most recent experimental data overwhelmingly support a particular data set, these decay data have been adopted wholesale. However, when uncertainty prevails, all of the published data have been

evaluated. When these efforts to produce a consistent decay scheme have failed, various deductions have been made involving nuclear level properties, resulting in unobserved emissions being proposed. The procedures to deal with these data inconsistencies have been adopted at the discretion of the evaluator. The introduction of such data is based on firm theoretical concepts. A good example of this involves the inability to observe low energy, highly converted gamma transitions by means of gamma spectroscopy. Such decay modes must exist and, after suitable consideration by the evaluator, these transitions were frequently incorporated into the file to produce a complete decay scheme. The presence of these proposed emissions in the data is noted in the Hollerith field comments that follow the list of references used in the evaluation. Finally, if a satisfactory decay scheme could not be produced, the incomplete nature of the data is noted in the Hollerith field comments.

The mass tables of Wapstra et al[14] have been used extensively and, if necessary, the internal conversion coefficients have been deduced from the tabulations of Hager et al[15].

Considerable efforts were made to evaluate all the published plutonium decay data, because of their association with reactor costs and the increasing importance of their gamma data in non-destructive inventory measurements and the determination of isotopic composition.

4 A Summary of Selected Decay Data: A Tabulation of the Basic Data

Table 2* lists the basic decay properties that have been evaluated and their associated uncertainties. For obvious reasons of space this list is only a very small fraction of the data evaluated for the file. It represents a summary of a few selected decay properties and contains all heavy element nuclides that have been evaluated to date. The number(s) in brackets is the standard deviation expressed in terms of the last significant figure(s) for that datum.

For each nuclide, the observed decay modes, half-life data and branching fractions are given. The half-life data include the calculated spontaneous fission half lives when appropriate. The decay mode Q-values are also listed, followed by the transition probability of the emission directly populating the ground nuclear level of the daughter state from the parent state.

The decay scheme consistency values are an attempt to determine the quality of the evaluated decay data. They represent a measure of the consistency of the decay data comprising a comprehensive decay scheme. The value given is the percentage deviation between the effective Q-value and the calculated Q-value. The effective Q-value is the weighted sum of the Q-values of the nuclide:

$$\text{effective Q-value} = \sum_{i}^{\text{all decay modes}} Q_i \, BR_i$$

where BR_i is the branching ratio of the i-th decay mode. The calculated Q-value is the sum of the individual decay components (α, β^+, β^-, etc) which constitute the total decay. Percentage deviations above 5% are regarded as high and indicate a poorly defined decay scheme as proposed by the evaluator.

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*Spontaneous fission decay data are being evaluated and have not been included in this table.

If the measured, evaluated data do not produce a relatively complete decay scheme, this consistency check cannot be carried out.

A consistency value < 5% indicates the construction of a reasonably consistent decay scheme; however, it should be noted that a detailed study of the decay properties may still be lacking because of specific activity problems and/or availability of sample. A consistency value > 5% denotes an inconsistent, evaluated decay scheme despite a reasonable quantity of published data. When the decay data are regarded as fragmentary, the decay scheme consistency is listed as "incomplete" in table 2.

5 The UK Chemical Nuclear Data Committee Heavy Element Decay Data File

The data are stored on a standard label 1600 bpi magnetic tape and each record length is a card image (80) with a block size of 8000. Tests of data validity are made by members of the UK Data File Sub-committee, although comprehensive tests of this particular file are difficult to envisage and full approval of this file by the sub-committee has yet to be given. Information concerning all UKCNDC data files can be obtained from:

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Acknowledgements

The authors would like to thank the following people:

Mr A Tobias for his help and advice; Mr J Story for his sound advice and encouragement; Ms V Bowditch for preparing the computer-based data file.

References

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TABLE 1: UK CHEMICAL NUCLEAR DATA COMMITTEE FILE OF HEAVY ELEMENT DECAY DATA (APRIL 1979)

Nuclide	Evaluated	Nuclide	Evaluated	Nuclide	Evaluated
206-Hg	Yes	224-Ra	Yes	236-Pu	Yes
206-Tl	Yes	225-Ra	No	237-Pu	Yes
207-Tl	Yes	226-Ra	Yes	238-Pu	Yes
207m-Tl	Yes	228-Ra	Yes	239-Pu	Yes
208-Tl	No	225-Ac	No	240-Pu	Yes
209-Tl	Yes	227-Ac	No	241-Pu	Yes
210-Tl	No	228-Ac	Yes	242-Pu	Yes
209-Pb	Yes	227-Th	No	243-Pu	Yes
210-Pb	No	228-Th	Yes	244-Pu	Yes
211-Pb	Yes	229-Th	No	245-Pu	Yes
212-Pb	No	230-Th	Yes	246-Pu	Yes
214-Pb	Yes	231-Th	Yes	240-Am	Yes
210-Bi	No	232-Th	Yes	241-Am	Yes
210m-Bi	No	233-Th	No	242-Am	Yes
211-Bi	Yes	234-Th	Yes	242m-Am	Yes
212-Bi	No	235-Th	Yes	243-Am	Yes
213-Bi	No	231-Pa	Yes	244-Am	Yes
214-Bi	No	232-Pa	Yes	244m-Am	Yes
215-Bi	Yes	233-Pa	Yes	245-Am	Yes
210-Po	No	234-Pa	No	246-Am	Yes
211-Po	Yes	234m-Pa	No	246m-Am	Yes
211m-Po	Yes	235-Pa	Yes	241-Cm	Yes
212-Po	No	232-U	Yes	242-Cm	Yes
212m-Po	No	233-U	Yes	243-Cm	Yes
213-Po	No	234-U	Yes	244-Cm	Yes
214-Po	Yes	235-U	Yes	245-Cm	Yes
215-Po	Yes	235m-U	Yes	246-Cm	Yes
216-Po	Yes	236-U	Yes	247-Cm	Yes
218-Po	Yes	237-U	Yes	248-Cm	Yes
215-At	Yes	238-U	Yes	249-Cm	Yes
217-At	No	239-U	Yes	250-Cm	Yes
218-At	Yes	240-U	Yes	249-Bk	Yes
219-At	Yes	236-Np	Yes	250-Bk	Yes
218-Rn	Yes	236m-Np	Yes	249-Cf	Yes
219-Rn	Yes	237-Np	Yes	250-Cf	Yes
220-Rn	Yes	238-Np	Yes	251-Cf	Yes
222-Rn	Yes	239-Np	Yes	252-Cf	Yes
221-Fr	No	240-Np	Yes	253-Cf	Yes
223-Fr	No	240m-Np	Yes	253-Es	Yes
223-Ra	Yes	241-Np	Yes		

TABLE 2: SELECTED, EVALUATED HEAVY ELEMENT DECAY DATA

Nuclide	Decay Mode	Half-life	Branching ratio	Q-value (keV)	Intensity of ground state transition (%)	Decay scheme consistency (%)
206-Hg	β^-	8.15(10)m	1	1307(20)	61(12)	0.2296
206-Tl	β^-	4.20(2)m	1	1533.5(34)	99.994(1)	0.0005
207-Tl	β^-	4.77(3)m	1	1422(6)	99.75(5)	-0.0008
207m-Tl	IT	1.33(11)s	1	1341(6)	-	-0.0066
209-Tl	β^-	2.20(7)m	1	3974(15)	zero	0.0433
209-Pb	β^-	3.253(14)h	1	644.6(12)	100	0.0000
211-Pb	β^-	36.1(2)m	1	1373(6)	90.8(4)	0.0004
214-Pb	β^-	26.8(9)m	1	1024(12)	5.6(6)	-0.1583
211-Bi	β^-	2.17(4)m	0.00273(4) 0.99727(4)	579(6) 6751.1(6)	0.273(4) 83.6(4)	0.0234
215-Bi	β^-	7.4(6)m	1	2250(100)	-	incomplete
211-Po	α	0.516(3)s	1	7594(2)	98.917(19)	0.0203
211m-Po	α	25.5(3)s	1.00(2)	9057(8)	7.04(14)	incomplete
214-Po	α	165(3) µs	1	7833.73(6)	99.9895(6)	0.0219
215-Po	β^- α	1.78(1) ms	0.000004(2) 1.00	721(7) 7526.5(8)	0.0004(2) 99.94(2)	0.0238
216-Po	α	0.15(1)s	1	6909.2(5)	99.998(1)	0.0591
218-Po	β^- α	3.05(9)m	0.0002(1) 0.9998(1)	256(13) 6114.88(10)	0.02(1) 99.9989(1)	0.0203
215-At	α	0.10(2)ms	1	8178(4)	99.95(2)	0.0170
218-At	β^- α	1.6(4)s	0.001(1) 0.999(1)	2887(13) 6873(15)	0.1(1) 3.6(3)	incomplete
219-At	β^- α	0.9(1)m	0.03(1) 0.97(1)	1700(80) 6387(50)	3(1) 97(1)	0.0232

TABLE 2: SELECTED, EVALUATED HEAVY ELEMENT DECAY DATA (continued)

Nuclide	Decay Mode	Half-life	Branching ratio	Q-value (keV)	Intensity of ground state transition (%)	Decay scheme consistency (%)
218-Rn	α	35(6)ms	1	7266.4(20)	98.84(5)	0.0217
219-Rn	α	3.96(5)s	1	6946.3(3)	80.8(23)	0.0111
220-Rn	α	55.6(1)s	1	6404.88(12)	99.93(2)	0.0198
222-Rn	α	3.825(1)d	1	5590.50(30)	99.928(21)	0.0193
223-Ra	α	11.43(1)d	1	5979.1(4)	0.87(17)	incomplete
224-Ra	α	3.66(4)d	1	5789.05(16)	95.1(4)	-0.0023
226-Ra	α	1600(7)y	1	4867.3(15)	94.45(5)	-0.0612
228-Ra	β^-	5.75(3)y	1	45.6(10)	3(3)	-0.0375
228-Ac	β^-	6.13(1)h	1	2137(7)	zero	-0.7350
228-Th	α	1.91313(88)y	1	5520.26(25)	72.7(4)	0.0272
230-Th	α sf	7.7(3) x 10^4 y 3.0(30) x 10^{17} y	1 2.5(25) x 10^{-13}	4770.6(15)	76.3(3)	
231-Th	β^-	25.52(1)h	1	389(2)	0.022(10)	0.1293
232-Th	α sf	1.405(6) x 10^{10} y 3(3) x 10^{21} y	1 5(5) x 10^{-12}	4081(4)	77(3)	
234-Th	β^-	24.10(3)d	1	198.5(20)	72.5(15)	0.2140
235-Th	β^-	6.9(2)m	1	1440(80)	-	incomplete
231-Pa	α	32760(110)y	1	5148.2(8)	11.0(3)	0.2357
232-Pa	β^- EC	1.31(2)d	1 3(1) x 10^{-5}	1337(10) 486(12)	zero 3(1) x 10^{-3}	-0.4149
233-Pa	β^-	27.0(1)d	1	572.3(24)	4.9(5)	-0.7254
235-Pa	β^-	24.2(3)m	1	1410(50)	97(1)	incomplete
232-U	α sf	72(2)y 8(4) x 10^{13} y	1 1.0(5) x 10^{-12}	5413.7(2)	68.6(4)	
233-U	α	1.5925(40) x 10^5 y	1	4908.9(12)	84.5(5)	-0.0890

TABLE 2: SELECTED, EVALUATED HEAVY ELEMENT DECAY DATA (continued)

Nuclide	Decay Mode	Half-life	Branching Ratio	Q-value (keV)	Intensity of ground state transition (%)	Decay scheme consistency (%)
234-U	α sf	2.446(7) x 10^5 y 2(1) x 10^{16} y	1 1.26(6) x 10^{-11}	4856.4(18)	72.2(3)	
235-U	α sf	7.038(5) x 10^8 y 3.5(18) x 10^{18} y	1 2(1) x 10^{-10}	4679.0(25)	6.0(6)	
235m-U	IT	26(2)m	1	0.073(5)	100	0.0000
236-U	α sf	2.3416(39) x 10^7y 2.0(10) x 10^{16} y	1 1.2(6) x 10^{-9}	4573(7)	77.5(9)	
237-U	β^-	6.75(1)d	1	519.4(11)	zero	0.9026
238-U	α sf	4.468(10) x 10^9 y 8.2(2) x 10^{15} y	1 5.4(2) x 10^{-7}	4270.3(39)	76.8(40)	
239-U	β^-	23.50(5)m	1	1267(3)	18.9(40)	0.0196
240-U	β^-	14.1(2)h	1	500(60)	zero	-0.0522
236-Np	β^- EC	1.15(12) x 10^5 y	0.089(2) 0.911(2)	500(20) 950(50)	zero zero	-1.5882
236m-Np	β^- EC	22.5(4)h	0.48(1) 0.52(1)	537(8) 985(10)	39.7(8) 42.5(8)	0.2432
237-Np	α	2.14(1) x 10^6 y	1	4957.3(11)	2.7(3)	0.0378
238-Np	β^-	2.117(2)d	1	1291.9(11)	zero	-0.0922
239-Np	β^-	2.355(4)d	1	721.5(19)	zero	0.0693
240-Np	β^-	65(3)m	1	2090(60)	zero	incomplete

TABLE 2: SELECTED, EVALUATED HEAVY ELEMENT DECAY DATA (continued)

Nuclide	Decay Mode	Half-life	Branching ratio	Q-value (keV)	Intensity of ground state transition (%)	Decay scheme consistency (%)
240m-Np	β^- IT	7.4(2)m	0.9989(3) 0.0011(3)	2110(80) 20(10)	9.5(4) 0.11(3)	-0.4538
241-Np	β^-	16.0(2)m	1	1360(100)	74(18)	-0.0487
236-Pu	α sf	2.851(8)y $3.5(10) \times 10^9$ y	1 $8.1(23) \times 10^{-10}$	5867.7(10)	68.1(8)	
237-Pu	EC α	45.3(2)d	0.99995(2) 0.00005(2)	218(6) 5747(6)	77.3(29) 0.00053(20)	1.2098
238-Pu	α sf	87.7(2)y $4.70(5) \times 10^{10}$ y	1 $1.86(6) \times 10^{-9}$	5593.27(20)	71.5(7)	
239-Pu	α (235-U) α(235m-U) sf	24115(80)y $5.5(5) \times 10^{15}$ y	0.00055(10) 0.99945(10) $4.4(4) \times 10^{-12}$	5243.5(7) 5243.4(7)	zero 73.3(7)	
240-Pu	α sf	6537(10)y $1.313(30) \times 10^{11}$ y	1 $4.95(20) \times 10^{-8}$	5255.96(16)	73.51(36)	

TABLE 2: SELECTED, EVALUATED HEAVY ELEMENT DECAY DATA (continued)

Nuclide	Decay Mode	Half-life	Branching ratio	Q-value (keV)	Intensity of ground state transition (%)	Decay scheme consistency (%)
241-Pu	β^- α	14.6(5)y	0.9999755(8) 0.0000245(8)	20.81(20) 5139.3(11)	99.99755(8) $9.3(8) \times 10^{-6}$	-0.0009
242-Pu	α sf	$3.76(3) \times 10^{5}$ y $6.84(8) \times 10^{10}$ y	1 $5.50(6) \times 10^{-6}$	4983.1(12)	79.7(27)	
243-Pu	β^-	4.956(3) h	1	582(4)	59.4(50)	0.0347
244-Pu	α sf	$8.28(10) \times 10^{7}$ y $6.6(4) \times 10^{10}$ y	0.99875(6) 0.00125(6)	4665.8(10)	80.5(8)	
245-Pu	β^-	10.5(1)h	1	1260(30)	zero	incomplete
246-Pu	β^-	10.85(2)d	1	374(10)	zero	incomplete
240-Am	EC α	50.8(3)h	1 $1.9(7) \times 10^{-6}$	1320(20) 5700(300)	zero zero	0.1178
241-Am	α sf	432(2)y $1.147(24) \times 10^{14}$ y	1 $3.77(10) \times 10^{-12}$	5637.94(13)	0.35(10)	
242-Am	β^- EC	16.02(4)h	0.827(3) 0.173(3)	661.2(18) 747.7(16)	37.1(1) 6.7(1)	0.0210
242m-Am	IT α sf	152(7)y $9.5(30) \times 10^{11}$ y	0.99524(14) 0.00476(14) $1.6(6) \times 10^{-10}$	48.63(5) 5633.7(15)	99.52(1) zero	
243-Am	α sf	7380(40)y $3.3(3) \times 10^{13}$ y	1 $2.2(3) \times 10^{-10}$	5438.8(10)	0.16(9)	
244-Am	β^-	10.1(1)h	1	1429.0(20)	zero	0.0213
244m-Am	β^- EC	26(2)m	0.99959(3) 0.00041(3)	1498(12) 140(17)	80(5) 0.041(3)	-1.0079
245-Am	β^-	2.05(1)h	1	896(2)	81.7(27)	0.0465
246-Am	β^-	39(3)m	1	2285(55)	zero	incomplete
246m-Am	β^-	25.0(2)m	1	2290(50)	zero	-0.4800

TABLE 2: SELECTED, EVALUATED HEAVY ELEMENT DECAY DATA (continued)

Nuclide	Decay Mode	Half-life	Branching ratio	Q-value (keV)	Intensity of ground state transition (%)	Decay scheme consistency (%)
241-Cm	EC α	32.80(2)d	0.990(1) 0.010(1)	764(6) 6184.3(15)	zero 0.0015(7)	-0.5633
242-Cm	α sf	162.8(5)d 6.6(7) x 10^6 y	1 6.8(7) x 10^{-8}	6215.76(13)	74.1(11)	
243-Cm	EC α	30(2)y	0.0024(4) 0.9976(4)	7.3(24) 6167.4(10)	0.24(4) 1.4(2)	incomplete
244-Cm	α sf	18.11(2)y 1.344(7) x 10^7 y	1 1.347(2) x 10^{-6}	5901.80(11)	76.4(2)	
245-Cm	α	8520(100)y	1	5623.4(19)	0.58(1)	0.3207
246-Cm	α sf	4790(180)y 1.83(6) x 10^7 y	0.9997386(5) 0.0002614(5)	5476.2(26)	79(1)	
247-Cm	α	1.56(5) x 10^7 y	1	5353(4)	13.8(7)	0.0060
248-Cm*	α sf	3.70(3) x 10^5 y 4.11(2) x 10^6 y	0.9174(3) 0.0826(3)	5161.8(3)	75.1(4)	
249-Cm	β^-	64.15(3)m	1	903(9)	zero	0.0430
250-Cm	α sf	2.6(20) x 10^4 y 1.13(5) x 10^4 y	0.3(3) 0.7(3)	5270(50)	-	
249-Bk	β^- α sf	320(6)d 1.87(8) x 10^9 y	1 1.45(8) x 10^{-5} 4.7(2) x 10^{-10}	126.4(19) 5526.0(10)	100.0(5) 7(1) x 10^{-5}	
250-Bk	β^-	192.40(40)m	1	1775(8)	4.68(234)	-0.0357
249-Cf	α sf	360(12)y 6.9(5) x 10^{10} y	1 5.2(2) x 10^{-9}	6295.6(7)	2.17(5)	
250-Cf	α sf	13.08(9)y 1.70(9) x 10^4 y	0.99923(3) 0.00077(3)	6128.9(6)	83.4(12)	
251-Cf	α	898(44)y	1	6172.4(14)	2.8(3)	-0.1080

TABLE 2: SELECTED, EVALUATED HEAVY ELEMENT DECAY DATA (continued)

Nuclide	Decay Mode	Half-life	Branching ratio	Q-value (keV)	Intensity of ground state transition (%)	Decay scheme consistency (%)
252-Cf[f]	α sf	2.722(10)y 85.3(5)y	0.96908(8) 0.03092(8)	6217.0(5)	81.6(3)	
253-Cf	β^- α	17.81(8)d	0.9969(4) 0.0031(4)	289(10) 6126(5)	99.69(103) zero	-0.9353
253-Es	α sf	20.47(3)d $6.4(2) \times 10^5$ y	1 $8.7(3) \times 10^{-8}$	6739.6(3)	89.8(2)	

•248-Cm $T_{\frac{1}{2}}$(total) = $3.39(3) \times 10^5$ y

[f] 252-Cf $T_{\frac{1}{2}}$(total) = 2.638(10) y

Appendix 6

UK COMPUTER CODES FOR THE STORAGE AND RETRIEVAL OF DECAY DATA (APRIL 1979)

STORAGE CODES FOR ENDF/B DECAY DATA

The evaluator's task is made easier if he does not have to construct his primary evaluated data in the relatively complex ENDF/B format[1,2]. Certain decay parameters require extensive standard calculations for their derivation, for example, mean beta energies, X-ray and Auger electron emissions. A computer code has been developed to produce ENDF/B-IV and V data from suitable input data, and a number of decay scheme parameters are calculated automatically from the input data using built-in mathematical procedures and data tables. This generation and storage code has been called COGEND, a code to generate and store decay scheme data in ENDF/B format[3,4].

RETRIEVAL CODES FOR ENDF/B-IV AND V DATA

A simple retrieval code has been developed for the extraction of gamma spectral data from the UKCNDC data files in ENDF/B-IV format. Data extracted from the files are subsequently arranged in order of increasing energy using standard utility programs[5]. It is intended to further develop this retrieval code for the extractionof alpha, beta or gamma spectra from either ENDF/B-IV or V format data files. The exact form of an extracted spectral item has yet to be defined but will include the identity of the decaying nuclide (Z, A values), its radioactive half-life and the energy and intensity of the most intense spectral line(s).

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CASCADE

CASCADE is a program for the computerised storage and radiochemical interpretation of nuclear decay schemes. The program converts data describing a decay scheme into a set of arrays representing the intensities and compositions of radiation emission sequences. Available decay scheme data can be supplemented by stored theoretical data such as internal conversion coefficients and EC/positron ratios.(1)

Recent improvements have been made to the suite of programs associated with CASCADE. The major input data base is NSDF/ENSDF with the options to produce output decay data in ENDF/B-IV and V formats. Certain errors in the input data can be corrected and a comments section can be added. The program can now handle spontaneous fission, neutron and proton emission, along with the more common decay modes. One of the aims of these developments is that CASCADE output data could be used to aid in the improvement and maintenance of the evaluated UKCNDC data files, including the heavy element decay data file.(2)

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Appendix 7

Report to IAEA Co-ordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data (May 1979)

A. J. Fudge
AERE. Harwell, Oxon. U.K.

The programme outlined in the report to the CRP meeting in 1978 is still being followed. In order to get the programme under way decisions had to be made from a number of considerations. Firstly, the availability of material of suitable purity; and secondly on the need for data.

The following areas of work have been covered during this period:

(a) Investigation of production purification and assay routes for the nuclides.

(b) Procurement and calibration of equipment.

(c) Measurement of required data.

Production, purification and assay

No new production procedures have been carried out this year, but preparations have been started for a number of irradiations in reactors and accelerators.

Purification procedures have been investigated and adapted to produce material in the required form and purity. This has been found to be more exacting in some cases than at first envisaged in order to obtain parent nuclides in an adequate state of purity from daughter products. In some cases a compromise between separation factors and time of separation has had to be made. The assay of the material has also had to be carried out after the measurement of the emissions in some cases.

The exacting needs of accuracy for the programme has necessitated the preliminary recalibration of the measuring equipment in some cases. In particular, the efficiency calibration for the gamma and X-ray detectors for liquids has required a much more exacting procedure than previously used for this type of measurement. Measurement of self absorption factors of gamma rays in solutions of different concentrations has been a necessary preliminary in order to reduce the errors to acceptable levels.

The basic methods used for obtaining the $T_{\frac{1}{2}}$, I_α and I_γ data are as follows:

(a) $T_{\frac{1}{2}}$ - specific activity measurements of known amounts of a nuclide with calibrated detectors.

(b) I_α - high resolution ($\sim$ 12 KeV) alpha spectrometry measurements.

(c) I_γ - high resolution measurements with a range of detectors on solutions and evaporated sources.

(d) $T_{S.F.}$ - ion chamber and solid state detector measurements of sources similar to those used in I_α measurements. Fission fragment counting on catcher foils and track recorders are being studied.

Conversion electron measurements are also being investigated for a number of nuclides to complete decay schemes.

Progress

237-Neptunium was the first nuclide to be investigated. After some unsuccessful attempts to separate parent and daughter products adequately a successful ion exchange procedure has now been achieved and a set of preliminary I_γ measurements carried out. Self absorption factors for gamma rays of a wide range of energies for the sources used has been evaluated. The gamma ray energies and abundances are now being compared with values obtained by other experimenters. Preliminary $T_{\frac{1}{2}}$ and T_α values have also been obtained. It is hoped to publish this work at the end of this year.

Work on other nuclides has been delayed by the installation of suitable glove boxes but these are expected to be available for commissioning and calibration very shortly. Preliminary work has also begun on the isotopes of uranium.

Appendix 8

SECOND MEETING OF THE CRP ON THE MEASUREMENT AND EVALUATION OF TRANSACTINIUM ISOTOPE NUCLEAR DECAY DATA

CADARACHE - FRANCE - 30 AVRIL ET 1erMAI 79

REPORT OF THE LABORATOIRE DE METROLOGIE DES RAYONNEMENTS IONISANTS

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1) Measurement of the ^{241}Am Gamma Ray Spectrum -

The energies and intensities of the ^{241}Am gamma rays have been determined in the energy region between 26 and 962 keV using an high purity germanium detector for energies in the range 26 - 70 keV and a Ge(Li) detector for highest energies.

Intensity of the 26,344 keV gamma ray has been founded to be equal to 2.35 ±0.07 % in good agreement with previous values 2.4 ± 0.1. The uncertainty of this case is assumed to be equal to the quadratic sum of systematic and random errors for a statiscal confidence level of 0.68. Systematic errors are due mainly to calibration (1 %) and determination of activity (1 %).

All results will be published by the end of this year.

2) Measurement of the ^{239}Pu Gamma Ray Spectrum-

All energies and absolute intensities have been determined but results are not available because they are an important part of a thesis to be presented in the second part of this year. As soon as possible a preprint will be sent to Agency.

3) Measurement of the ^{238}Pu and ^{240}Pu Gamma Ray Spectrum -

All experiments on ^{238}Pu and ^{240}Pu sources have been done. Calculations are now in progress and results are to be expected by the end of this year.

We use :

for ^{238}Pu two sources : one of 108 μCi in activity and the other one in sealed can of 100 mCi.

and for ^{240}Pu two sources : one of 97 μCi in activity and the other one of 57 μCi specially.

All these are more than 98 % in isotope composition.

4) Intercomparison of Plutonium -

We are also involved in a Plutonium intercomparison organized by ESARDA on NBS Standards. This intercomparison took us a lot of time and caused our late in the other works.

Appendix 9

Status Report

U. S. Participation in the IAEA Coordinated Research Program on the Measurement of Transactinium Isotope Nuclear Decay Data

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Within the U.S., work at a number of laboratories is being carried out to provide data relevant to the objectives of the CRP. Absolute α-transition intensity measurements are being carried out at Argonne National Laboratory by I. Ahmad. At INEL, we are involved in absolute γ-ray intensity measurements. The Half-Life Evaluation Committee is involved in the measurement and evaluation of half-life values for selected Pu isotopes. This latter group consists of individuals at the following six laboratories: Argonne National Laboratory; Lawrence Livermore Laboratory; Los Alamos Scientific Laboratory; Mound Laboratory; National Bureau of Standards; and Rocky Flats Laboratory.

Half-Life Evaluation Committee: The present plans of this committee are the measurement of accurate half-life values for ^{239}Pu, ^{240}Pu and ^{241}Pu. The first phase of this work, the measurement of the ^{239}Pu half-life, has now been completed. The results have been published as a collection of papers in the August, 1978 issue of The International Journal of Applied Radiation and Isotopes. The value of the ^{239}Pu half-life recommended from this work is

$$T_{\frac{1}{2}}(^{239}\text{Pu}) = 24{,}119 \pm 26 \text{ y.}$$

The members of this committee are currently measuring the half-lives of ^{240}Pu and ^{241}Pu. The measurement procedures for ^{240}Pu are similar to those employed for ^{239}Pu. The ^{240}Pu sample material has been acquired and has been distributed to the participating laboratories for characterization, and measurements have gotten underway. The ^{241}Pu half-life measurement is of a more limited scope, involving only a mass-spectrometric technique. This investigation was undertaken earlier than the ^{240}Pu study but, because of the nature of the measurement, will not be completed until some time after the ^{240}Pu work is finished. At the present time, the early results from this study suggest a value of $\sim$ 14.4 y for the ^{241}Pu half-life, in reasonable agreement with independent measurements at the U. S. National Bureau of Standards and at the CBNM in Geel, Belgium.

ANL: Absolute α-intensity measurements will be initiated this Spring. The first isotopes to be studied will be ^{238,239,240,242}Pu. Samples, containing a nominal few μg amounts of Pu, will be prepared by isotope separation. A small (25 mm^2 area) Si surface-barrier counter, with an energy resolution of ∿ 12 keV, will be used to count the α particles. The counting geometry will be at 1% or lower; and measurements will be taken at several geometries, to assess the effects of electron-α summing.

INEL: The measurement of the absolute γ-ray intensities from the β^- decay of ^{233}Pa has been completed. 4π β-γ coincidence techniques were utilized to determine the absolute disintegration rates of the ^{233}Pa sources (obtained from milking an ∿ 0.5-g sample of ^{237}Np). The value obtained for the absolute intensity of the prominent 311.9-keV γ ray was

$$I_\gamma(311.9 \text{ keV}) = 38.6 \pm 0.5 \text{ photons/100 decays.}$$

These results have been accepted for publication in the journal Nuclear Science and Engineering.

The next nuclides for which absolute I_γ measurements will be made are ^{239}Pu and ^{240}Pu. High-purity samples of ^{239}Pu(99.995% in mass 239) and ^{240}Pu ($\lesssim$ 1% contribution to the α activity from ^{238}Pu) have been acquired for these measurements.

To permit absolute-intensity measurements of γ rays from actinide samples to be made with precisions of 1% or better, careful attention must be given to all aspects of the measurement process. The improvement of our techniques of precision γ-ray spectrometry to make possible measurements with this required precision has gotten underway this year. An early emphasis of this activity is a careful study of the shapes of full-energy γ-ray peaks observed in spectra measured using Ge-based spectrometers. This has as its object the development of a method of reliably and consistently determining the number of events contained in these peaks. To do this requires a means of treating the effects of "tailing" in the peaks and accounting for the spectral distribution underlying the peaks in a reproducible manner. Careful analysis of these effects reveals that the contribution of tailing, even in reasonably good Ge-semiconductor spectrometers, can be 1-2% of the peak area and extends over several tens of channels. If peak-area determinations to a precision of 1% or so are desired, these effects can be accounted for fairly simply. However, if the overall intensity data are desired to a precision of < 1%, the contribution of the uncertainty in peak area must be significantly reduced, say to the order of a few tenths of a percent. To achieve this precision, a careful investigation of all facets of γ-ray peak-shape analysis is required.

Appendix 10

PREPARATION OF PURE CURIUM-242 AND MEASUREMENT OF THE NUCLEAR DECAY DATA

Progress Report to IAEA
on the Research Agreement No. 2170/CF

March 1979

H. Umezawa

Japan Atomic Energy Research Institute

Introduction

Nuclear decay data of ^{242}Cm have been pointed out to be high sensitivity in estimating build-up and consumption of the transplutonium nuclides in reactor fuels[1]. Besides, the partial half-life of ^{242}Cm for spontaneous fission decay is particularly important in relation to the safety problems of spent fuel handling, since it is the largest source of neutrons radiated from spent nuclear fuels.

Curium-242 can be very purely prepared by means of milking decay products from 152-y ^{242m}Am. In the present work, americium was extracted from a plutonium bearing fuel specimen and purified for curium and other actinides. Curium-242 grown was separated from the americium after allowing to stand it for a several-month period. Several samples of ^{242}Cm were prepared for measurement and alpha activities have been measured with a proportional counter and a silicon surface barrier detector. Measurements of spontaneous fissions are studying at present.

Materials

A specimen was taken out of a plutonium bearing fuel rod which had been irradiated with neutrons in the HALDEN HWR up to 1% burnup (FIMA). The specimen was composed of about 4g of the mixed oxide of plutonium (2.5%) and uranium (97.5%) and a 1.8-g piece of zircaloy-2 sheath of rod. The oxide was dissolved with concentrated nitric acid. Final volume of the solution was adjusted to 200ml and 5ml of it was subjected to present experiment.

The transplutonium elements were separated from the fuel solution by our standard method which has been reported elsewhere[2]. The transplutonium elements group extracted contained some yttrium in addition to americium, curium and other possibly accumulated actinides of higher atomic numbers.

Collaborators: S. Okazaki, S. Usuda, S. Ichikawa, T. Suzuki, H. Okashita

Purification of americium from curium and the other elements was carried out by ion-exchange chromatography using DIAION CPK08 resin (39μ) as cation exchanger and 0.5M 2-methyllactate of pH 3.55 as elutriating solution. Dimensions of ion-exchange column used were 5mm in diameter and 290mm long. Flow rate of the elutriating solution was set 10ml/h and the column was operated at room temperature. The chromatographic separation was repeated to get higher purity of americium.

Gamma-ray spectrometry with a Ge(Li) detector was applied to determine each of americium nuclides. Results are given in Table 1.

Growth and Milking of ^{242}Cm

Figure 1 shows the paths of radioactive disintegrations occurred in the americium prepared. Although ^{241}Am and ^{243}Am coexisted with ^{242m}Am which is the ancestor of questioned nuclide, ^{242}Cm has grown as the only curium nuclide in the americium and could be extracted in pure by performing the same chemical treatment as the purification on the americium after allowing to stand it for an appropriate period for the growth of ^{242}Cm.

Americium was first purified on 21 July 1978 and the milking of daughter nuclides was made on 31 October 1978. Figure 2 shows the chromatogram of ion-exchange separation of curium from the americium. In this process curium could be separated from the other actinides, too. The amount of ^{242}Cm obtained from the first run was about 0.1μCi. Scaling up ten times is possible and repeated milking from the purified americium will provide a 1-μCi source periodically.

Measurement of Half-life

Six samples were prepared for the measurement of half-life by depositing a drop of the hydrochloric acid solution of purified ^{242}Cm on a platinum plate of 24mm in diameter and 0.2mm thick.

Alpha activities of those samples are being measured with a windowless proportional counter. Decay of the alpha activity has been followed for 4 months. Efficiency of the counter has slowly changed within a one or two percent range through the whole period of the measurements. The deviation was estimated by measuring a reference sample of ^{238}Pu at all times and corrected based on a step function fitted to the data of the reference sample which is shown in Fig. 3.

The decay curves thus obtained were analyzed with a computer program FRANTIC-2 [3]. Results obtained so far from the decay measurements on the ^{242}Cm samples are summarized in Table 2. The measurements will be continued further to obtain more accurate results.

Measurement of Spontaneous Fissions

Only two reports have been published on the partial half-life data of spontaneous fission decay of ^{242}Cm. Hanna et al.[4] have obtained $(7.2\pm0.2)\cdot10^6$y from the measurements of the ratio of fission fragments to alpha particles with a gas counter. On the other hand, Armani and Gold[5] have reported $(6.09\pm0.18)\cdot10^6$y as results of absolute neutron measurements calibrated with a ^{252}Cf reference source. Those measurements need to get a ^{242}Cm sample of the order of millicurie. Such a strong source of alpha activities, however, is not adequate to the precise determination of the activities.

Measuring the ratio of fissions to alpha particles emitted would provide the most reliable results for the present question. Solid state track detectors may be possibly applied to the measurement of fissions on a 1-μCi source of ^{242}Cm, of which alpha activities are well determined with a conventional counter. Tests on the use of mica detectors are under way at present using ^{242}Pu samples, since the rate of spontaneous fission has been fairly well studied on the nuclide[6].

Electroplating of Actinides

Procedures for electroplating the actinides on platinum metal plates were developed using isopropylalcohol and dimethylsulfoxide as electrolyte. A trace amount of plutonium, americium or curium could be deposited within a limited area of 20mm^2 on a platinum plate. Electroplating fixes relevant nuclides very firmly and rubbing plated surface with chamois looses only a few percent of activity. The techniques are applied to the sample preparation for the measurement of spontaneous fissions.

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Table 1. Isotopic composition of americium extracted from a spent fuel sample

Nuclide	Number of atoms	Atomic abundance
^{241}Am	7.0×10^{16}	98.03 %
^{242m}Am	1.1×10^{14}	0.15
^{243}Am	1.3×10^{15}	1.82

Table 2. Results of half-life measurements on ^{242}Cm samples

Sample No.	Half-life (day)
1	164.79
2	163.41
3	163.94
4	160.66
5	164.74
6	162.12
Mean	163.28
Standard deviation	1.62

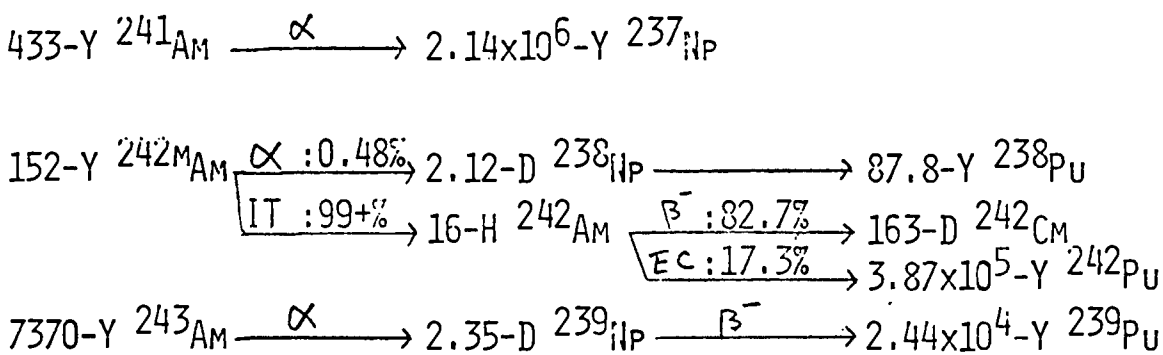

Fig. 1. Possible paths of radioactive disintegrations in an americium sample separated from spent fuels

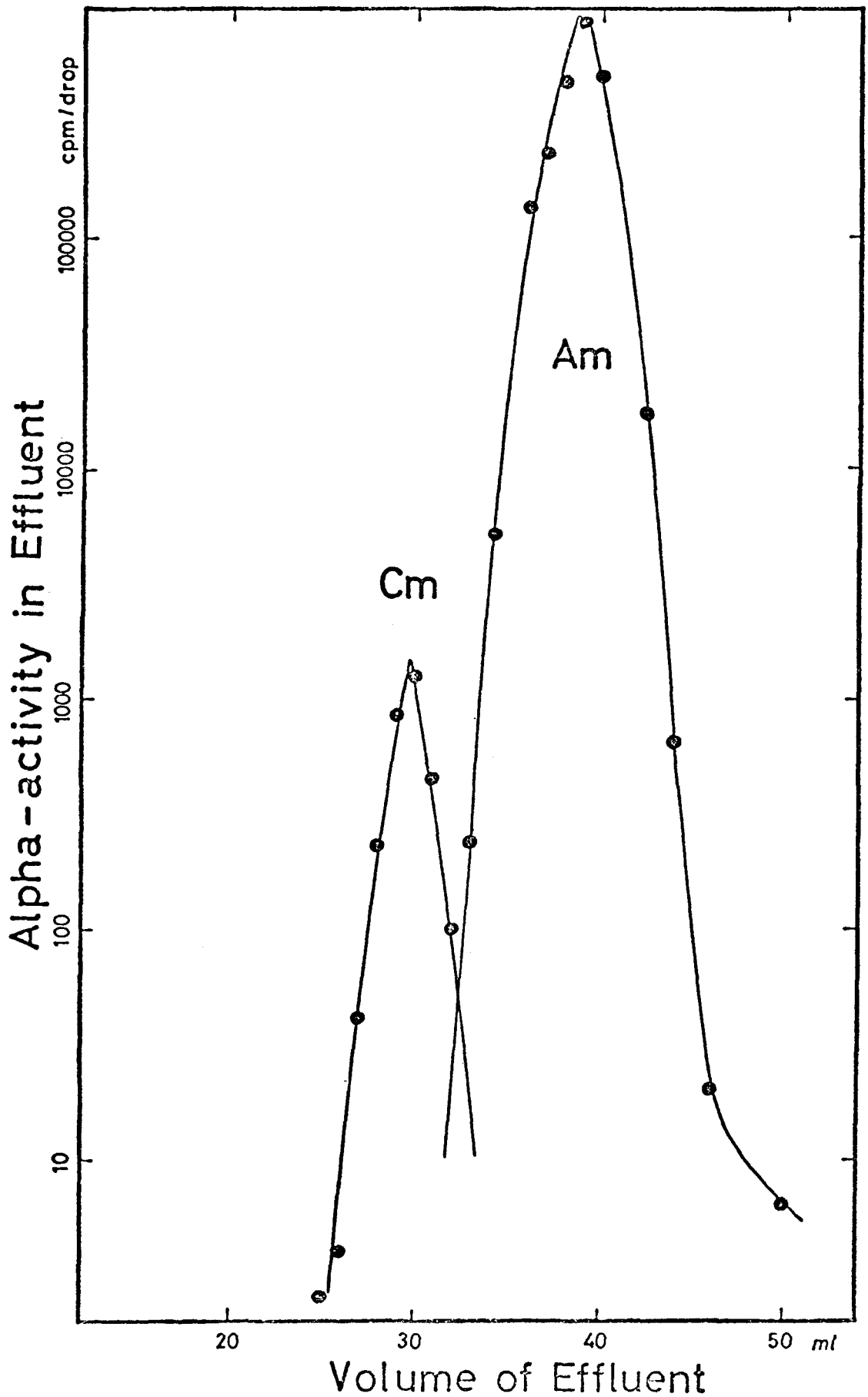

Fig. 2. Ion-exchange chromatogram of the separation of curium from americium

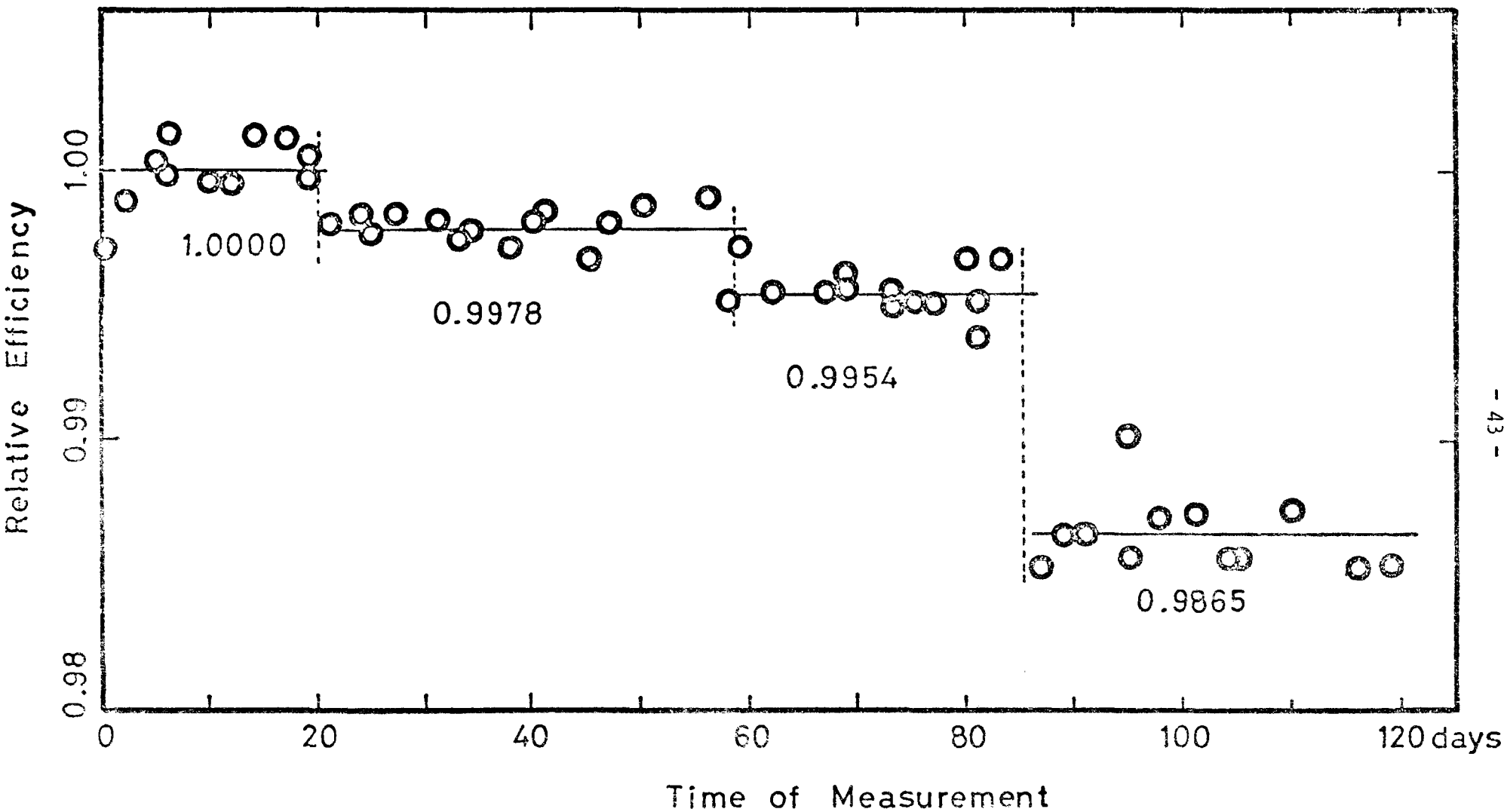

Fig. 3. Deviation of counting Efficiency with time

Appendix 11

STATUS REPORT FROM C.B.N.M.- J.R.C. TO THE SECOND COORDINATED RESEARCH MEETING ON THE MEASUREMENT OF TRANSACTINIUM NUCLEAR DECAY DATA

R. Vaninbroukx

INTRODUCTION

A small group of 4-5 people is part time active in the field of the determination of decay data of actinides. About 2 man-year of real effort is devoted to it.

MEASUREMENTS AND EVALUATION

1. Half-life of ^{239}Pu

The measurements of this half-life are finished. The ^{239}Pu content of the samples was determined by mass spectrometric isotope dilution techniques. The α-emission rates were determined by counting α particles in a defined solid angle of low geometry and by liquid scintillation techniques. The results are summarized in Table 1.

Table 1. Specific α-emission rate and half-life of ^{239}Pu

Method	Specific α-emission ($s^{-1}/\mu g$ ^{239}Pu)	Half-life (years)
Low geometry	2298 $\pm$ 3	(2.4085 $\pm$ 0.0030)10^4
Liquid scintillation	2295 $\pm$ 3	(2.4114 $\pm$ 0.0030)10^4
Mean	2296 $\pm$ 3	(2.4100 $\pm$ 0.0030)10^4

In the status file on the ^{239}Pu half-life, prepared for NEANDC, these results are compared to the results published recently by the U.S.A. Half-life Evaluation Committee [1] and a value of (24 114 $\pm$ 25)yr is recommended. The quoted uncertainty, corresponding to a 68 % confidence level, takes into account random and systematic uncertainties.

2. Half-life of ^{241}Pu

The determination of the half-life of ^{241}Pu has been continued using the following methods :

1. Mass-spectrometric determination of the ^{241}Pu decay by measurements of the change in the $^{241}Pu/^{240}Pu$ ratio and the $(^{241}Pu/^{240}Pu)/(^{240}Pu/^{239}Pu)$ ratio of ratios as a funtion of time;
2. Measurement of the ^{241}Am ingrowth by α counting in a defined low geometry solid angle, and by γ counting using Si(Li) detectors, calibrated for the 60 keV line of ^{241}Am.

The results (final results for the method based on the ^{241}Am ingrowth measurements and preliminary ones for the direct decay measurements using mass-spectrometric techniques, MS) have been compared with other preliminary results obtained at the National Bureau of Standards (NBS), Washington, and the Atomic Energy Research Establishment (AERE), Harwell. All these results are listed in Table 2.

Table 2. Recent preliminary values for the half-life of ^{241}Pu

Laboratory	Sample	Period of observation (years)	Half-life (years)
AERE - MS Ref. (2)	1	24	14.25 ± 0.10 14.31 ± 0.10
- MS Ref. (3)	2-A	6	14.24 ± 0.12 14.53 ± 0.12
	2-B	7	14.53 ± 0.08 14.33 ± 0.11
- Ingrowth Ref. (4)	2	-	14.56 ± 0.15
NBS - All MS Ref. (5)	SRM 946	6	14.406)
	SRM 947	6	14.402)
	SRM 948	12	14.387) 14.38 ± 0.07
	UK-131	10	14.368)
	5d5a-2e	8	14.322)
	5d5a-7e	8	14.383)
CBNM - MS	ORNL	3	14.45 ± 0.14
- Ingrowth	ORNL	1.5	14.60 ± 0.10

3. Intensities of the 10-50 keV photons in the decay of ^{238}Pu and total internal conversion coefficient of the 43.5 keV transition

The intensities of the photons emitted in the energy range 10-50 keV in the decay of ^{238}Pu have been determined experimentally. Two calibrated Si(Li) detectors were used. The detectors were calibrated using reference samples of suitable radionuclides. The photon intensities for the peak efficiency calibration were obtained from a survey of literature data and from our own experimental work. The accuracy of the calibration curves is estimated to be 2-3 % on a 68 % confidence level. Four ^{238}Pu sources, prepared from an isotopically pure ^{238}Pu sample, were measured with both detectors. The results of these measurements are summarized in Table 3. The quoted uncertainties, corresponding to a 68 % confidence level, take into accoun systematic and random effects.

Table 3. Photon intensities in the decay of ^{238}Pu

Radiation	Mean energy (keV)	Intensity (photons/decay)
U-L_ℓ X	11.6	0.0026 ± 0.0001
U-L_α X	13.6	0.0408 ± 0.0012
U-$L_{\eta,\beta}$ X	17.2	0.0570 ± 0.0017
U-L_γ X	20.2	0.0137 ± 0.0004
Total LX		0.1141 ± 0.0034
γ-43	43.48	$(3.93 \pm 0.12)\ 10^{-4}$

The values obtained for the LX intensities are about 25 % lower than those measured by VASILIK and MARTIN [6] but they agree within less than 2 % with those of BEMIS and TUBBS [7]. Our value of (0.114 + 0.003) for the total LX intensity is exactly the same as that obtained by SWINTH [8] using a solid state (X-ray)-(α particle) coincidence counter. The intensity obtained for the 43.5 keV γ ray is in close agreement with the result of GUNNINK et al. [9].

As a byproduct of these measurements one can deduce the total internal conversion coefficient for the 43.5 keV transition. The result of (730 ± 40) is somewhat lower than other experimental results but is in reasonable agreement with the theoretical value of (715 ± 20).

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Appendix 12

Half-Life of ^{239}Pu : Present Status

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Application

The half-life of ^{239}Pu is important for several reasons, as for example in the evaluation of fission constants since it can influence the final evaluated values of these constants. Furthermore, an accurate knowledge of the half-life is needed for the accurate mass determination of ^{239}Pu samples using α-counting techniques.

Status and Recent Results

The values reported up to July 1976 were given in the 1976-status report [1] where the use of a value of $(2.411 \pm 0.010) \times 10^4$ years was suggested. Recently, final results of measurements performed in several laboratories of the U.S.A. [2] and at C.B.N.M. [3] became available. These results are summarized in Table 1. The quoted deviations are the standard deviations of the individual measurements.

Table 1. Values of the Half-life of ^{239}Pu measured by the Member Laboratories of the USA Half-life Evaluation Committee (1-8) and at CBNM (9-10)

Nr	Laboratory	Technique	Measured half-life (years)	
1	Mound	Calorimetry	24 101 ± 20	
2	LLL	Calorimetry	24 102 ± 20	
3	NBS	α-particle counting	24 112 ± 16	
4	ANL	α-particle counting	24 124.2± 13.6	24 119 ± 26
5	LLL	α-particle counting	24 019 ± 21(★)	
6	LASL	Mass spectrometry	24 164 ± 14	
7	LLL	Mass spectrometry	24 089 ± 23	
8	ANL	Mass spectrometry	24 138.6± 13.7	
9	CBNM	α-particle counting (Low geometry)	24 085 ± 14	
10	CBNM	α-particle counting (Liquid scintillation)	24 114 ± 13	

(★) Value not included by the USA Evaluation Committee in the computation of the average value.

The mean of the 9 results included in the computation of the average is 24 114 years with a standard deviation of the individual values of 25 years. The standard error of the mean (SE) of these 9 results is 8 years. Taking, somewhat arbitrarily, the number of participating laboratories (6), applying each their own methods, as degrees of freedom, the student t-factor (t_s), corresponding to a 68.3 % confidence level, becomes 1.09. Possible systematic uncertainties on the results were estimated by Lucas (measurement Nr 3) and at CBNM to be less than 50 years. Combining random and systematic uncertainties according to GRINBERG et al. [4] the overall uncertainty becomes ($t_s \cdot$ SE + 1/3 syst. unc.), corresponding to a 68.3 % confidence level. The overall uncertainty on the mean result of the 9 measurements is 25 years.

Conclusions and Recommendations

The mean of the results of the recent measurements, where well defined Pu materials were used and several independent methods were applied, is in excellent agreement with the value suggested in 1976 and with the value of $(2.411 \pm 0.003) \times 10^4$ yr recommended by the "First Coordinated Research Meeting on the Measurement of Transactinium Isotope Nuclear Data", I.A.E.A., Vienna, April 1978 [5].
Therefore, the use of this mean value with its uncertainty, on a 68.3 % confidence level, is recommended :

$$T_{1/2}(^{239}Pu) = (24\ 114 \pm 25)\ \text{yr}.$$

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Appendix 13

(For inclusion in Physics Division Annual Report)
February 1, 1979

NUCLEAR DATA PROJECT

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I. INTRODUCTION

The Nuclear Data Project (NDP) is a comprehensive information analysis center which provides the basic research community with indexed references and collections of critically evaluated nuclear structure data. The systematic publication in *Nuclear Data Sheets* of new evaluations provides nuclear structure physics with an information service far in advance of what is available to most areas of science. The computer files of evaluated data developed by the NDP also present the basic research scientist with a valuable tool for looking at extensive nuclear level information in order to make comparison with new measurements or new theoretical calculations.

These computer files of nuclear data also are being used as a means of making the results of basic research quickly and easily available to a broader audience. Radioactivity information, in particular, has wide application in fields such as nuclear medicine, reactor engineering, environmental impact assessment, and nuclear waste management. Often the specialists in these areas have neither the time nor the training to make effective use of the data generated by basic nuclear research. The NDP has made important progress during the last few years toward providing a channel through which the results of new nuclear measurements can be transferred to any engineer or scientist who needs evaluated data to factor into his or her own work.

The Evaluated Nuclear Structure Data File (ENSDF) developed and implemented by the NDP contains a documented summary of the current status of nuclear measurements. The supporting systems for ENSDF make it possible to assemble various collections of data and to present them in a form that is convenient for further study or application. Nuclear Data Project's MEDLIST program, which provides tables of both atomic and nuclear radiations, has been applied to over 1000 decay schemes in ENSDF. Earlier collections of MEDLIST-type output[3,4] have been widely used in both basic and applied research. *Citation Index* notes that nearly a third of the citations to the "Radioactive Atoms" publications[3] are from journals such as *Journal of Radiation Chemistry, Health Physics, Journal of Geophysical Research, Journal of Nuclear Medicine.*

Special collections of computer-readable radioactivity data have been assembled from ENSDF by MEDLIST for use by ORNL programs concerned with nuclear waste management[5] and Monte Carlo studies of accelerator-target cooling problems.[6]

The NAS-NRC study[7] by the Committee on Data Needs for Science and Technology places the principal responsibility for utilization of scientific data on the specialists who create and understand those data. By making the results of nuclear structure measurements easily available to specialist and non-specialist alike, the Nuclear Data Project is helping nuclear science to maintain its high quality and quantity of accessible information.

II. ACTIVITIES

A. DATA EVALUATION

As part of the international network for nuclear structure data evaluation, the Nuclear Data Project has continuing responsibility for approximately 100 mass chains in three regions: A = 45-69, 101-118, and 195-up. Since each evaluator can prepare about four new evaluations per year, a commitment of ~6 PY (person-years) per year is needed to maintain ENSDF and *Nuclear Data Sheets* up-to-date with the planned four-year-cycle time.

Since the new evaluation groups would necessarily begin slowly, an additional commitment was made by the ORNL Physics Division to provide a staff level of 8 PY during 1977-1978. A total of 50 new mass-chain evaluations was prepared and published during these two years, and six more from temporary or former NDP evaluators are nearly complete as of the beginning of 1979. Figure 1 gives the publication status of the mass chains for which NDP is responsible. (Ten older mass chains from other regions were also revised recently by NDP staff.) For comparison, the status of all published mass chains is shown in Fig. 2.

In addition to its evaluation responsibility, NDP is committed to maintaining uniform, high standards for ENSDF (and consequently for *Nuclear Data Sheets*) by providing training for new evaluators, followed by a thorough review of the first few mass chains prepared by each new evaluator. The NDP staff members have organized training seminars for 28 new data evaluators in order to introduce them to NDP evaluation techniques, analysis programs, and conventions used in ENSDF and *Nuclear Data Sheets*.

During 1977-1978, NDP staff have reviewed 14 mass chains prepared by new evaluators from six other data evaluation centers. About half of these have already been published in *Nuclear Data Sheets* or accepted for publication. Others are undergoing final revisions before acceptance.

B. NUCLEAR STRUCTURE REFERENCES

Nuclear Data Project's Nuclear Structure References (NSR) file continues to grow, with the addition of approximately 5000 indexed new research works each year. About half of the additions are journal publications; the other half consists of reports, conference abstracts, preprints, etc. The keyword indexing system used in the NSR file since 1964 has been shown[8] to allow more complete retrievals from the nuclear structure literature than the much larger INIS system (extended from the former *Nuclear Science Abstracts*).

The NSR file is used routinely to direct interested users to the nuclear structure literature. Special reference collections are assembled in partial response to most of the 100 information requests processed each year. A shorter version of the NSR file (1969 to present) is available for interactive search through the remote terminals of the DOE/RECON network. This file is queried an average of two times every working day.

Each month an SDI (selective dissemination of information) service is provided from new entries to the NSR file. The service is used by data evaluators from the international network and by other extensive users of new nuclear structure data.

An index to the new literature is published three times per year as "Recent References" issues of *Nuclear Data Sheets*. "Recent References" includes both isotope and reaction indexes for both journal and non-journal literature. A second indexed cumulation of journal literature was published in 1978.[9]

The NSR file is used as an international standard for the systematic computer storage and exchange of indexed reference information. Two copies of the complete indexed file have been distributed to international data evaluation centers. The regular distribution of computer-readable copies of the new literature summarized in "Recent References" will begin in 1979.

C. EVALUATED NUCLEAR STRUCTURE DATA FILE

Nuclear Data Project's Evaluated Nuclear Structure Data File (ENSDF) has grown considerably since our last report. The file now contains 6600 distinct sets of evaluated nuclear information. This includes:

1950	sets of adopted level properties
1850	decay schemes
3020	nuclear reaction data collections, including
230	(n,γ) reactions
225	(d,p) reactions
500	(charged-particle,xnγ) reactions

A set of adopted levels and their properties is now included for every nucleus. Several complete collections of level properties have been assembled from ENSDF; e.g., all levels with lifetimes between 1 ps and 1 fs, odd-parity states in even nuclei. A collection of levels with spontaneous-fission branching has recently been published.[10]

All decay scheme information in ENSDF is now as complete as the measurements warrant. Normalization information is included wherever available, and details of electron capture and internal conversion have been added systematically, so that complete tables of atomic and nuclear radiations can be assembled for more than 1000 decay schemes. This information is being prepared for distribution in microfiche form.

The ENSDF computer format has been adopted as an international standard for the systematic storage and exchange of nuclear structure data. At six-months intervals, beginning in 197 NDP has prepared complete copies of ENSDF on magnetic tape for distribution through international data centers.

D. PUBLICATIONS

The Nuclear Data Project is the editorial and publications office for the journal *Nuclear Data Sheets*. The NDP prepares camera-ready copy which is sent to Academic Press for publication and distribution. Implementation of the ENSDF system, with computer programs to select information from the data file, organize it into tables or drawings, and assemble the tables or drawings onto pages, has revolutionized the preparation of copy for *Nuclear Data Sheets*. The principal advantage of the computer system is the elimination of much redundant data copying and most proofreading. Although the same data item may appear in several places in the data sheets and drawings, it is contained only once in ENSDF, and must therefore be correctly entered only one time. Tables or drawings are also prepared in a precisely reproducible way. The computer programs have helped to establish and maintain greater uniformity among manuscripts from different evaluators, so that the user needs to adjust to fewer style variations.

Each year NDP prepares approximately 2100 pages of camera-ready copy for publication in three volumes of *Nuclear Data Sheets*. Since each page goes through several scientific and editorial reviews, the preparation of this much material (including revisions and corrections) would be enormously time consuming without the ENSDF system. Each manuscript goes through at least three draft stages. In each draft, corrected numbers or revised text appear as requested in all appropriate places; drawings or tables may be added, re-ordered, or deleted; data columns in each table may be interchanged; and selected data items may be omitted. The special NDP print train, which includes 164 different characters (Greek letters and special symbols, as well as standard characters), allows publication quality copy to be prepared by a standard line printer at over 500 lines per minute. Final editing and arrangement of material on the publication copy are completed by hand.

Manuscripts are now being received from several data evaluation centers other than NDP. Twenty percent of the new evaluations published during 1978 were prepared by non-NDP evaluators. The distribution of mass-chain responsibility requires that this fraction increase to more than fifty percent. Maintaining tolerant limits on the style variations used by many different evaluators has added to the editorial work for *Nuclear Data Sheets*. The ENSDF system has avoided a much more substantial problem in the production of manuscripts.

E. INFORMATION REQUESTS

The Nuclear Data Project receives about two requests for information each week. Most are easily answered by a combination of ENSDF listings and references to new literature on some special topic. Occasionally, more challenging requests are received which require some new effort. The ENSDF system includes several program steps, which can be modified to define very sophisticated conditions which must be met before any data are retrieved from the data file or displayed in a table. It is a simple task to revise one of these programs to prepare requested tables such as:

E0 γ transitions in heavy nuclei,
γ rays with high multipolarity (E4, M4, and higher),
β^+ radiations tagged with parent, half-life, and intensity,
β^- transitions with log ft $\leq$ 5.

F. NEW DIRECTIONS

When ENSDF was extended in early 1978 to include adopted level properties for every nucleus, it became possible to prepare many new and enlightening displays of nuclear level systematics. Several such displays have been shown at meetings of the American Physical Society. Three examples are shown here (Figs. 3-6) to demonstrate the power of the ENSDF system as a teaching tool and as a technique for exploring systematic properties of nuclear levels.

Figure 3 shows the N and Z dependence of the energies of the first 2^+ states in even nuclei. The surface clearly shows the low energy associated with the two deformed regions, and the projections illustrate the effects of shell closures. In Fig. 4 the surface has been rotated to show the onset of deformation in the region of $Z > 50$, $50 < N < 82$. A similar effect can also be observed for $Z < 50$.

Figure 5 shows the energy ratio of the first 4^+ and first 2^+ states, compared with the value 2.24 predicted for "soft" nuclei by Mariscotti et al.[11] The plateaus of strong deformation [$E(4^+)/E(2^+) \approx 3.33$] are evident.

Figure 6 illustrates the behavior of the energy ratio for the second and first 2^+ states in even nuclei. The reasonably constant value of this ratio is interrupted only in the two regions of strong nuclear deformation. The "saddle" in the lanthanide peak indicates a minor shell closure near $Z = 66$. A closed shell in this region has been suggested previously from systematics of reduced widths for α decay (see Ref. 12), although the evidence is less compelling because of the difficulty in obtaining sufficiently precise data.

III. NATIONAL/INTERNATIONAL EVALUATION NETWORKS

Beginning in 1975, a program was initiated by ERDA (now DOE) to increase non-U.S. participation in nuclear structure data evaluation. The National Nuclear Data Center (NNDC) at Brookhaven was designated to coordinate the U.S. program and to interface this program with non-U.S. efforts. NDP continues to provide indexed references, computer data files, and mass-chain publication, as well as the principal scientific direction and most of the new evaluations.

Besides NDP, the U.S. Nuclear Data Network (NDN) includes data evaluation groups at Brookhaven (NNDC), Idaho (INEL), Berkeley (Table of Isotopes), Pennsylvania (Light Nuclei), and NBS (Photonuclear Data Center). The Nuclear Data Network, which meets once or twice each year, provides a forum for reviewing progress, discussing problems, and establishing future priorities. NDN also contributes to development of standards and procedures which will be recommended for the international network.

The international network for nuclear structure data evaluation has been established through the International Atomic Energy Agency's Working Group on Nuclear Structure and Decay Data (IAEA/NSDD). The preliminary form of the international network was established at Vienna in 1976.[13]

In November 1977, the Nuclear Data Project hosted a meeting of the IAEA/NSDD working group.[14] At the Oak Ridge meeting the distribution of mass-chain responsibility was ratified, with NDP receiving continued responsibility for approximately 100 mass chains. Continuing programs (University of Pennsylvania, University of Utrecht) for evaluation of data on light nuclei were recognized; responsibility for 59 mass chains was assigned to three other U.S. centers; and 60 mass chains were assigned to non-U.S. centers. Procedures were also established for monitoring progress toward a four-year cycle for revision of all mass chains.

The formats developed by NDP for its reference file (NSR) and evaluated data file (ENSDF) have been adopted by the international network as standards for exchange of bibliographic and

numeric information in computer-readable form. NDP continues its responsibility to maintain and regularly distribute copies of both computer files.

NDP is also expected to carry out a detailed review of the first few mass chains prepared by each new center and to provide for a review of every revised mass chain. Acceptable new evaluations are prepared by NDP for publication in *Nuclear Data Sheets.*

In 1977, all 33 mass chains published in *Nuclear Data Sheets* were prepared with active involvement of NDP staff. Of the 24 mass chains published in 1978, three were prepared at another U.S. center (BNL/NNDC), and two were prepared at non-U.S. centers.

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1. Part-time assignment to Nuclear Data Project.

2. Technical support staff.

3. M. J. Martin, *Nucl. Data Tables* A8, 1 (1970); M. J. Martin, *Radioactive Atoms - Supplement* ORNL-4923 (November 1973); M. J. Martin, *Nuclear Decay Data for Selected Radionuclides,* ORNL-5114 (March 1976).

4. D. C. Kocher, *Nuclear Decay Data for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities*, ORNL/NUREG/TM-102 (August 1977).

5. A. G. Croff, R. L. Haese, and N. B. Gove, *Updated Decay and Photon Libraries for the ORIGEN Code,* ORNL/TM-6055 (February 1979).

6. R. G. Alsmiller, Jr., T. A. Gabriel, and J. Barish, *Photon Dose Rate from Induced Activity in the Beam Stop of a 400-GeV Proton Accelerator,* ORNL/TM-6238 (February 1978).

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9. W. B. Ewbank, R. L. Haese, F. W. Hurley, and M. R. McGinnis, *Nucl. Data Sheets* 24, 445 (1978).

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11. M. A. J. Mariscotti, G. Scharff-Goldhaber, and B. Buck, *Phys. Rev.* 178, 1864 (1969).

12. W.-D. Schmidt-Ott and K. S. Toth, *Phys. Rev.* C13, 2574 (1976).

13. *IAEA Advisory Group Meeting on Nuclear Structure and Decay Data for Applications, Summary Report,* INDC(NDS)-79/LN, IAEA, Vienna, Austria (December 1976).

14. *IAEA Advisory Group Meeting on Nuclear Structure and Decay Data, Summary Report,* INDC(NDS)-92/LN, IAEA, Vienna, Austria (March 1978).

FIGURE CAPTIONS

ORNL-DWG 79-8771

Fig. 1. Status of mass-chain evaluations in NDP's regions of responsibility.

ORNL-DWG 79-8772

Fig. 2. Status of all mass-chain evaluations, $A \geq 5$.

ORNL-DWG 77-18618

Fig. 3. Energies of first 2^+ states in even nuclei (from ENSDF).

ORNL-DWG 77-18617

Fig. 4. Same as Fig. 3, but from a different perspective.

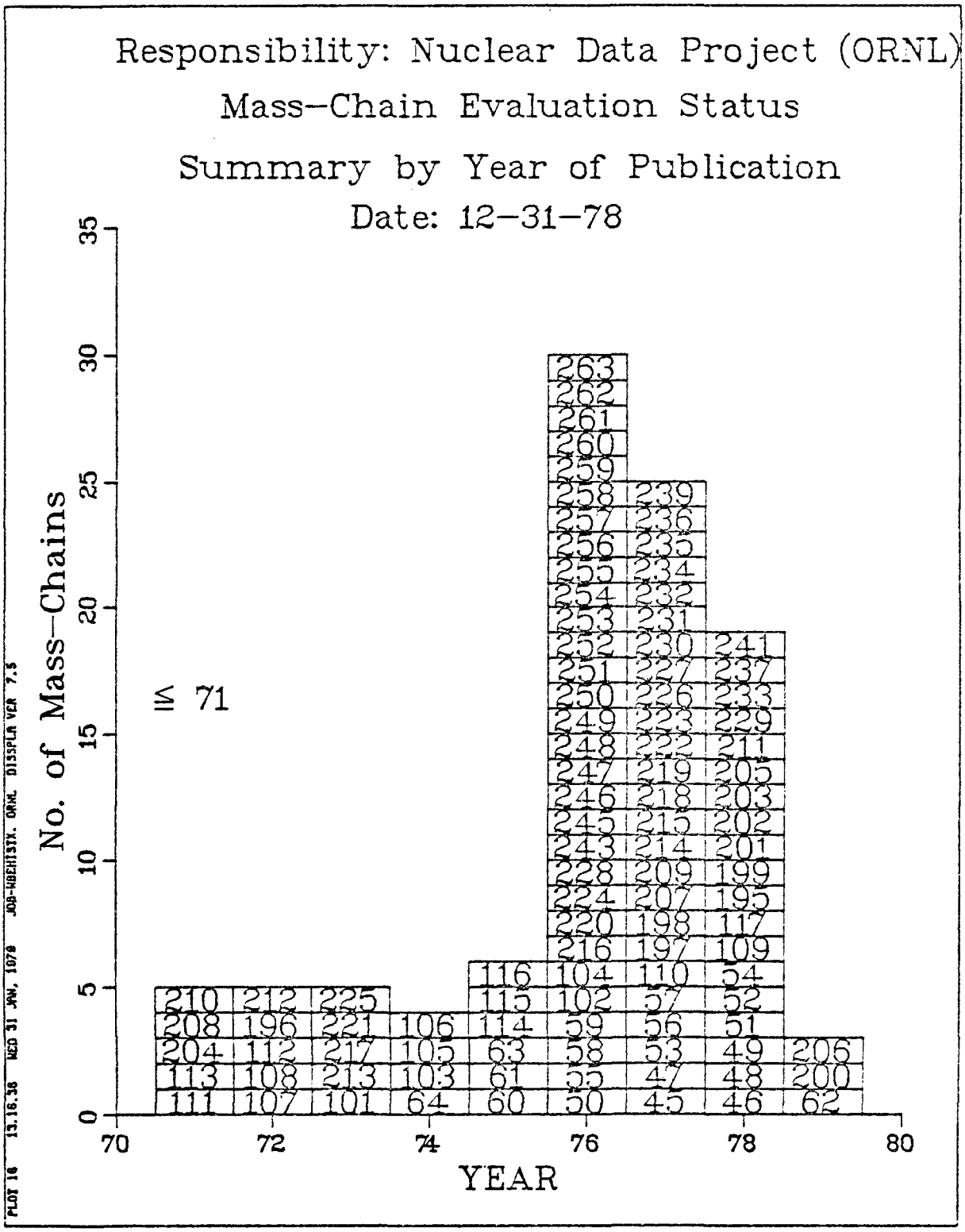
ORNL-DWG 78-14650

Fig. 5. Energy ratio $R = E(4^+)/E(2^+)$ for even nuclei, compared with $R = 2.24$ for "soft" nuclei and showing the rotational plateaus with $R = 3.33$.

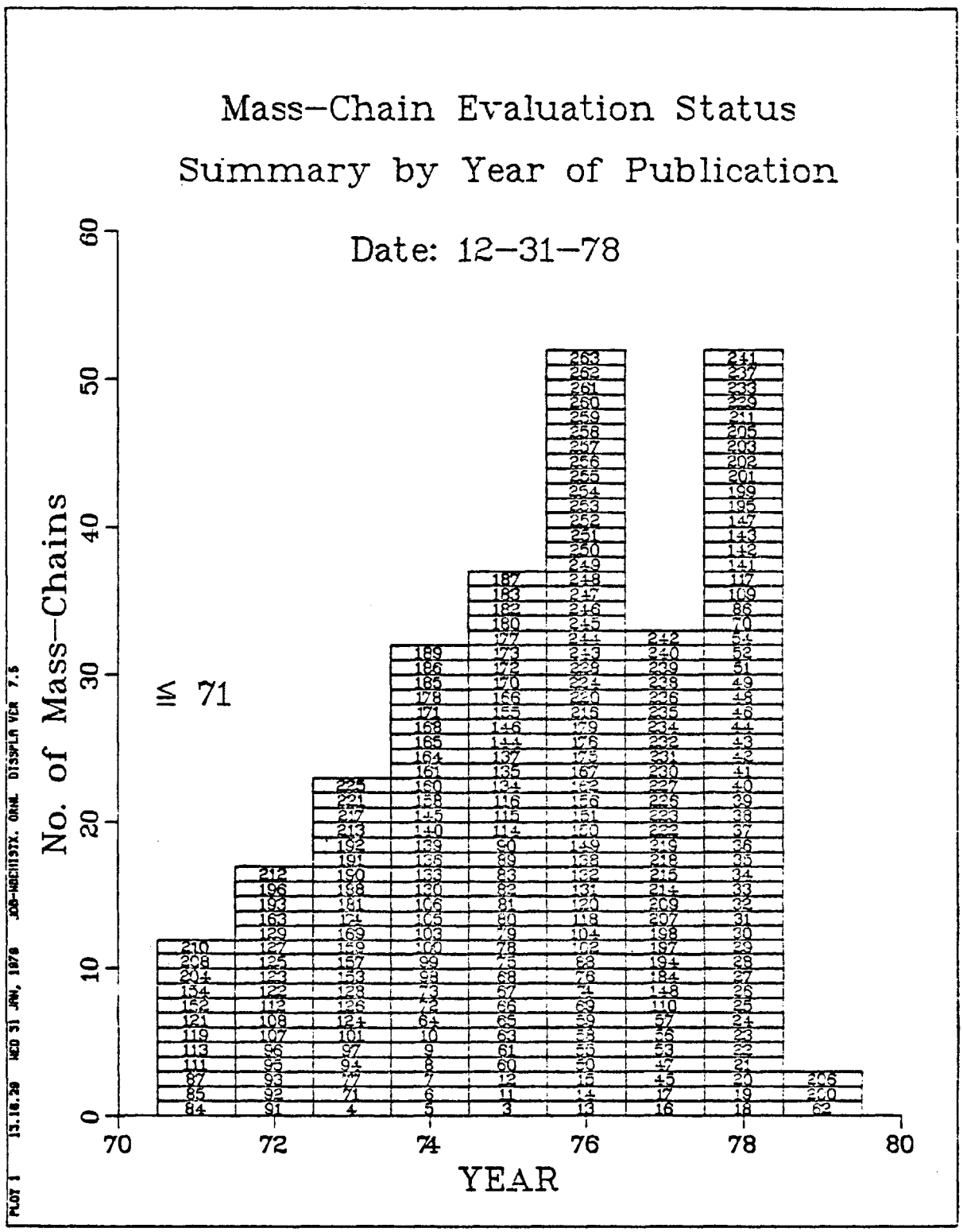
ORNL-DWG 78-11852

Fig. 6. Energy ratio $E(2_2^+)/E(2_1^+)$ for even nuclei shows effects of a minor shell closure near $Z = 66$.

ORNL-DWG 79-8771

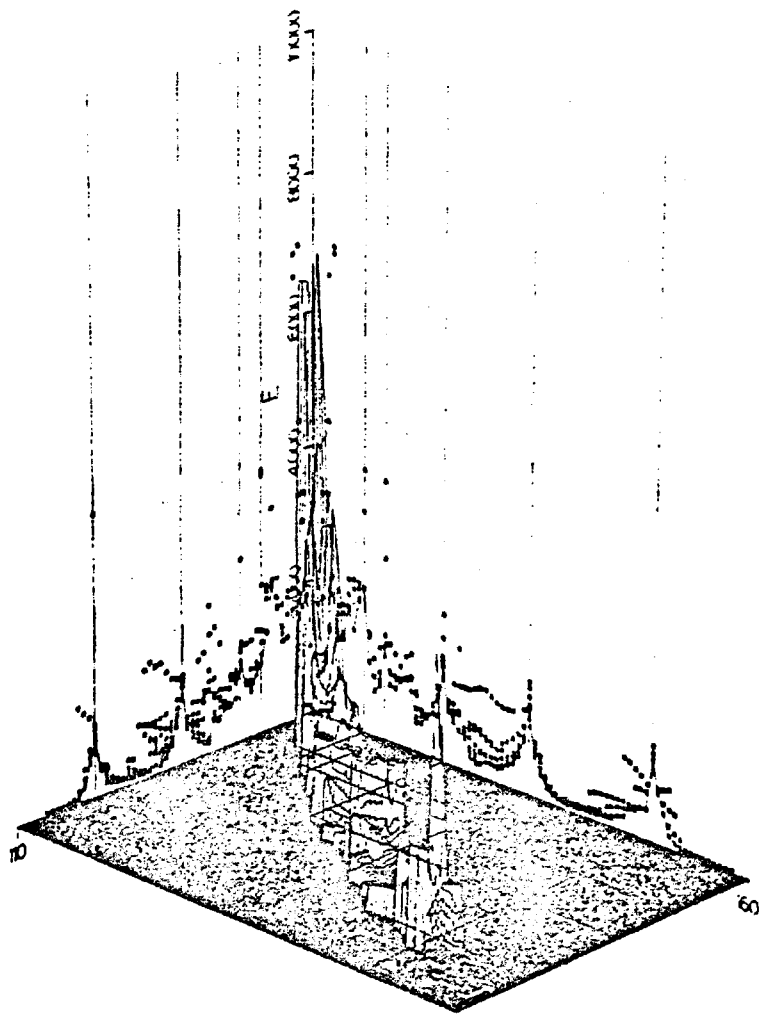


ORNL-DWG 79-8772

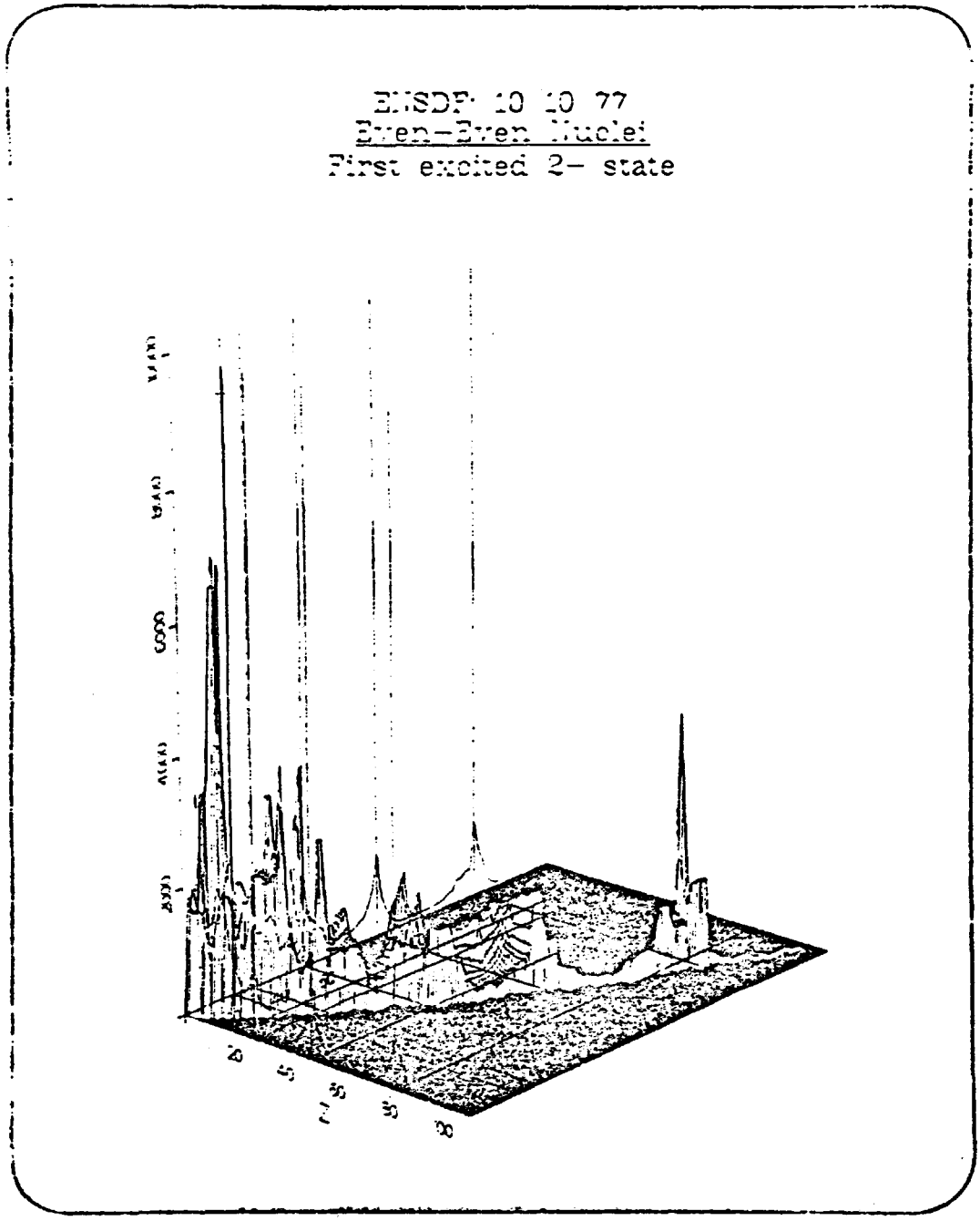


ORNL-DWG 77-18618

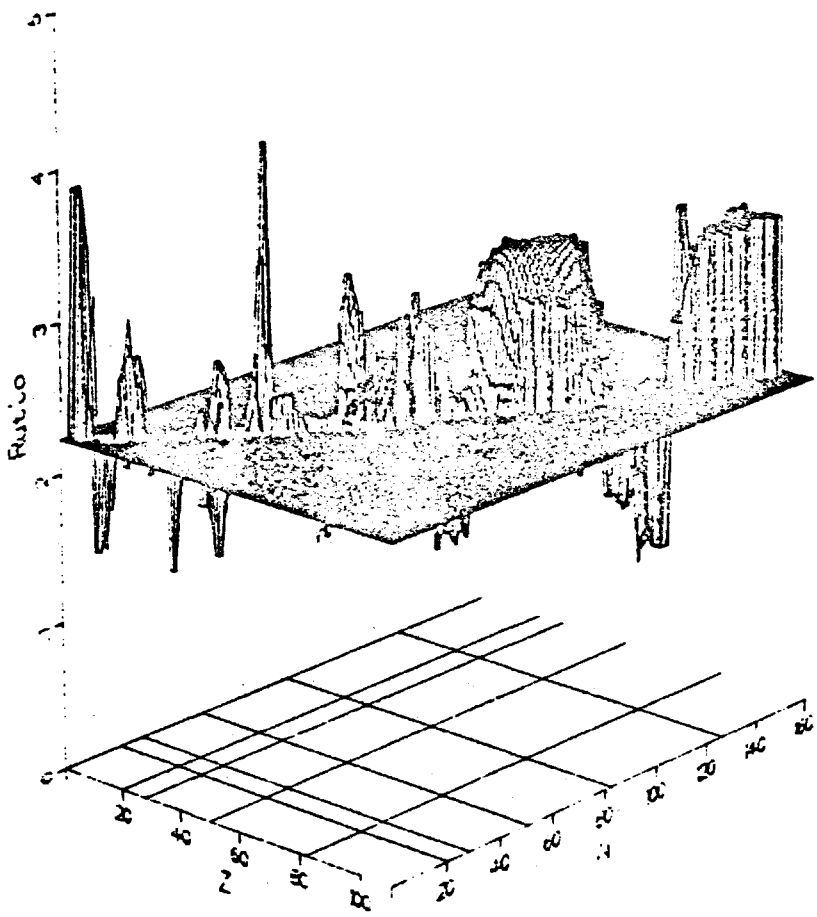
ENSDF: 10/10/77
Even-Even Nuclei
First excited 2- state



ORNL-DWG 77-18617



ENSDF 2/20/78
Even-Even Nuclei
Ratio E(4-), E(2-)



ORNL-DWG 78-11852

ENSDF: 3/20/78
Even-Even Nuclei
Ratio E(2+')/E(2+)