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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

Sixth Research Coordination Meeting on the Measurement and Evaluation of Transactinium Isotope Nuclear Data

Idaho Falls, USA
21-24 June 1983

SUMMARY REPORT

Prepared by A. Lorenz
Nuclear Data Section
International Atomic Energy Agency

November 1983

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SUMMARY REPORT

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Abstract

Proceedings of the sixth meeting of the participants in the IAEA Coordinated Research Programme to measure and evaluate the required nuclear decay data of heavy element radionuclides, convened by the IAEA Nuclear Data Section on 21-24 June 1983 at Idaho Falls, USA.

The meeting participants reviewed the data requirements, updated and extended the recommended list of half-lives, and continued to review the status of alpha and gamma radiation spectra emitted in the decay of transactinium isotopes.

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I. SUMMARY OF THE MEETING

Introduction

The sixth meeting of the participants in the IAEA Coordinated Research Programme (CRP) on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data, convened by the IAEA Nuclear Data Section and hosted by EG and G Idaho, Inc., was held at Idaho Falls, USA, on 21-24 June 1983. The welcoming address was given by Dr. John W. Morfitt, Chief Scientist of EG and G Idaho, Inc. The meeting was chaired by A. Lorenz, IAEA Nuclear Data Section.

The participants in this meeting are listed in Appendix 1.

Objectives

This coordinated research programme aims specifically at improving the quality and accuracy of nuclear decay data required to calculate the effects of transactinium isotopes on the fuel cycle of both thermal and fast reactors, to assess their impact on nuclear waste management, to improve the accuracy of safeguard techniques, and to improve the knowledge of their nuclear characteristics required in many applications in science and industry.

The principal objectives of this meeting were to review the status of measurements performed by the participants in this programme, to review the list of proposed half-lives, and to continue the review of the status and accuracy of gamma-ray emission spectra for the heavy element radionuclides. Another objective of this meeting was to define the format and content of the final report of this project.

The Adopted Agenda is given in Appendix 2.

Conclusions and Results of the Meeting

The meeting reviewed the current and projected programmes for the measurement and evaluation of heavy element radionuclide nuclear decay data of each research group participating in the CRP.

In particular, the meeting

- updated the list of proposed heavy element radionuclide half-lives published in INDC(NDS)-139/NE (December 1982), and agreed on the release of the new update of this list;
- performed a comprehensive review of the measurement and evaluation status of all decay data for the radionuclides identified at the IAEA Meetings on Transactinium Nuclear Data; and
- discussed in detail the format and content of the final report of this project.

Specific Actions which resulted from this meeting are listed in Appendix 3.

The participants of this CRP agreed to have their next and final meeting at IAEA Headquarters in Vienna, in November 1984.

II. Meeting Programme

1. Progress Reports

1.1. A.J. Fudge (UK/AERE, Harwell)
Progress report included in Appendix 5.

1.2. R. Vaninbroukx (CBNM, Geel)
Progress report included in Appendix 6.

1.3. H. Okashita (JAERI, Tokai)
Progress report included in Appendix 7.

1.4. C.W. Reich (INEL, Idaho)
Progress report included in Appendix 8.

1.5. N. Coursol (LMRI, Saclay)
Progress report included in Appendix 9.

2. Review of Recommended List of Half-Lives

The Group reviewed the "Proposed Recommended List of Transactinium Isotope Decay Data", INDC(NDS)-139/NE (December 1982), and made the changes listed below, taking into account measurements and evaluations performed since September 1982.

2.1. Changes in the half-life compilation

U 233- The reference to the half-life value for U233 was changed to the actual report in which it was originally published, namely BNL-NCS-51320 "The Uranium Half-Lives: A Critical Review", N.E. Holden (January 1981). (H08101).

U 238- The Group recommended the adoption of the spontaneous fission half-life for U238, recommended by Holden (H08101):

$$T_{1/2}(SF) = (8.08 \pm 0.26) \times 10^{15} \text{ years}$$

which also changes the branching fraction value to

$$BF_{SF} = (5.53 \pm 0.18) \times 10^{-7}$$

Pu239- In order to comply with the generally accepted value of the half-life of Pu239, and the latest CBNM evaluation, this value was changed back to the originally recommended value of

$$T_{1/2} = (2.411 \pm 0.003) \times 10^{4} \text{ years}$$

Pu240- Although recognizing the new half-life value of 6.564 ± 11 years for Pu240, recommended by the US Half-life Evaluation Committee, the Group decided not to adopt this new value until completion of the current evaluation being done by Vaninbroukx (CBNM).

Pu241(α)- The Group decided to adopt the evaluated Pu241 alpha decay half-life value of (6.00 ± 0.05) x 10^5 years which resulted from the recently completed review of this value by Vaninbroukx (CBNM). (See Annex I of Appendix 5 to this report). The corresponding change in the branching fraction is:

$$BF_\alpha = (2.41 \pm 0.04) \times 10^{-5}$$

Pu241(β)- In view of four on-going measurements to determine the total half-life of Pu241 (Harwell, NBS, CBNM and INEL), the Group made the following statement:

> "Discrepancy between the new mass-spectrometric measurements and integral measurements have not yet been reconciled, therefore we do not feel justified to reduce the recommended uncertainty of this value at this time".

Cf252- Based on a recent review of latest measurements and existing data, by J.R. Smith (INEL) (see Appendix 11), the Group recommended to change the Cf252 half-life to 2.645 ± 0.007 years.

2.2 Statement on the spontaneous fission half-lives

There are a number of nuclides for which the required accuracy of the spontaneous fission half-life has not been achieved. It is apparent that no work is currently planned or going on to improve these data; it is therefore anticipated that no changes in the presently recommended values will be forthcoming.

2.3. Review of accuracy requirements

In view of the difficulty in achieving the recommended accuracies for the half-lives of the nuclides listed below, the Group recommended that these be reviewed in order to confirm the need for these requirements (see Action No. 8).

	Accuracy Required	Accuracy Achieved
Th-229	1.0 percent	2.2 percent
U -232	0.5 "	1.4 "
Am-242m	1.0 "	4.8 "
Cm-246	1.0 "	2.1 "
Cf-252(α)	0.2 "	0.4 "

3. Data on Radionuclides used as Calibration Standards

3.1. Recommended changes

The following changes in the half-lives of radionuclides used as calibration standards (see INDC(NDS)-145) were suggested by Coursol (LMRI) and accepted by the Group. The changes are based on recent evaluations performed at the LMRI.

	Old value	New value
Be 7	53.29(7)d	53.20(15)d
F 18	109.77(5)m	109.74(3)m
Co 57	271.73(14)d	271.77(10)d
Y 88	106.6(2)d	106.62(3)d
Nb 95	35.05(10)d	34.98(2)d
Te 99m	6.007(2)h	6.007(12)h
Cd 109	463.1(8)d	462.6(4)d
In 111	2.802(3)d	2.8045(8)d
In 113m	99.49(6)m	99.48(3)m
Sn 113	115.10(17)d	115.08(3)d
Cs 131	9.68(6)d	9.69(1)d
Cs 134m	2.91(2)h	2.913(2)h
Cs 137	30.18(5)y	30.15(6)y
Ce 144	284.9(2)d	285.0(2)d
Ir 192	74.1(2)d	73.83(7)d

These changes will be incorporated in the IAEA data base; however, no revision of INDC(NDS)-145 will be issued at this time. In addition, the Group recommended that the nuclear data for radionuclides used as calibration standards be evaluated independently of the work performed by this Group (see recommendation below on page 5).

3.2. Recommended Evaluation of Calibration Standards

The Group made the following recommendation regarding the decay properties of calibration standards:

> "In view of the importance of the use of reference standards for the calibration of the detectors used in the measurements of gamma-ray emission probabilities it is essential that a common data base be used for these reference nuclides. In order to create such a data base it is recommended that an evaluation be carried out by a competent evaluator using the data base given in INDC(NDS)-145 for the most commonly used radionuclides and gamma-ray transitions."

4. Summary of Current Status of Measurements and Evaluation

The current status of all measurements and evaluations, planned or being performed, for the radionuclides which have been considered by this Group is summarized in Table I. This table is annotated by the following comments.

COMMENTS TO TABLE I

Th229 Currently accepted value of the half-life is $(7.34 \pm 0.16).10^3$y has an uncertainty of 2.2 percent. The requested accuracy of 1 percent is difficult to realize. The decay scheme is being done by Reich (INEL) who will also do the final evaluation.

Th233 A new measurement of P_γ is to be done at Harwell.

Pa231 The P_γ data measurements performed at Harwell have to be completed and published. Final evaluation is in progress at Winfrith (Nichols).

Pa233 Final Harwell P_γ values are to be published together with the Np237 results. Additional data to be forthcoming from CBNM by end of '83. Final evaluation to be done by Reich (INEL).

U232 (decay chain) The currently accepted half-life value is (69.8 ± 1.0)y, with an uncertainty of 1.4 percent. The requested accuracy is 0.5 percent. New half-life measurement is foreseen at Harwell. The measurement of P_γ by INEL has been completed with 1-2 percent accuracy, and published. Final evaluation to be done by Vaninbroukx (CBNM).

U233 — P_γ measurements at Harwell will be finished in 1984. INEL data have been submitted for publication in 1983. Reich (INEL) to do the final evaluation.

U234 — P_α will be measured by Bortels (CBNM). P_γ measurements being done at JAERI and CBNM. Current P_γ measurements on-going at CBNM, Harwell and JAERI. Final evaluation to be performed by Nichols (Winfrith).

U235 — No work on P_α is planned anywhere to improve accuracy of existing data. Latest P_γ values have been sent by Harwell to CBNM, P_γ values measured at INEL are being finalized. Final evaluation to be performed by Vaninbroukx (CBNM).

U236 — No work on P_α or P_γ is planned to improve the accuracy of existing data. No final evaluation is planned.

U237 — Harwell will have new P_γ results. Final evaluation to be performed by Lagoutine (LMRI).

U238 — No new measurements of P_α are planned to improve accuracy of existing data. On-going P_γ measurements at Harwell will not be finalized until 1985/1986, and will not be ready in time for final report. There is no hope to achieve the requested P_γ accuracy of 1 percent. No final evaluation is contemplated.

U239 — New evaluated values of P_γ have recently been published by Holloway et al. ("Decay Scheme Data for ^{239}U, ^{154}Eu and $^{140}Ba/^{140}La$", S.P. Holloway, et al. Proc. Nuclear Data for Science and Technology, 287-290. (1982 Antwerp Conference). K.H. Boeckhoff (ed.). 1983 ECSC, EEC, EAEC, Brussels and Luxembourg). Final evaluation to be done by Nichols (Winfrith).

Np237 — Evaluation of the Np237 half-life as reported in ENSDF by Ellis (1978) is based on one single value. It has been recommended by A.L. Nichols (AEEW) and A.B. Smith (ANL) to remeasure this value to confirm the original measurement. It was suggested that CBNM perform this measurement. P_α test measurements are in progress at CBNM. A "best" detector will be selected in collaboration with Schlumberger. Also, Reich (INEL) will enquire with Ahmad (ANL) if the Np237 P_α can be measured to better than existing accuracy. New P_γ values from Harwell are to be published, CBNM plans to finalize its P_γ measurements by end 1983. The final evaluation is to be performed by Reich (INEL).

Np238 — No P_γ measurement is planned to improve the accuracy of existing data. No final evaluation is foreseen.

Np239 — P_γ measurement may be performed at CBNM subject to availability of adequate sample at Harwell or CBNM. Reich to investigate if measured values exist at INEL. Final evaluation to be done by Vaninbroukx (CBNM).

Pu236 — No P_γ measurements are planned to improve existing accuracy. Questionable if required accuracy can be achieved. Not enough data for adequate final evaluation.

Pu238 — All P_γ measurements (CBNM, INEL and LMRI) have been performed. Final evaluation by Lagoutine (LMRI) in progress.

Pu239 Recent P_α measurements by Ahmad (ANL) have an accuracy of better than 1 percent. Additional P_α measurements planned at LMRI. Final P_γ values from Harwell to be sent to JAERI. Final evaluations to be performed at JAERI.

Pu240 The half-life is to be evaluated by Vaninbroukx (CBNM). Recent P_α measurements by Ahmad (ANL) have an accuracy of better than 1 percent. All P_γ measurements by INEL and LMRI completed. Final evaluation by Coursol (LMRI) is on-going.

Pu241 The α half-life recently measured at CBNM satisfies the 1 percent accuracy requirement. Measurements of the total (β) half-life are on-going at CBNM and Harwell. Final evaluation of the half-lives of Pu241 will be performed by Vaninbroukx (CBNM). See separate statement on the β (total) half-life. New P_γ data will be forthcoming from Harwell and INEL. Final evaluation has been initiated by Lagoutine (LMRI).

Pu242 Subject to availability of adequate sample, new P_γ measurement may be performed at CBNM. Final evaluation to be performed by Vaninbroukx.

Am241 P_γ measurement (of 59.9 keV line) is in progress at CBNM. Final evaluation to be performed by Bambynek (CBNM).

Am242m The required accuracies of both total and spontaneous fission half-lives for this radionuclide have not been achieved. Required accuracy of 1 percent of the total half-life is difficult to achieve. A new measurement of the SF half-life has been recommended in order to achieve at least a 5 percent accuracy. No final evaluation is planned for this radionuclide.

Cm242 Although difficult to achieve the required accuracy of 3 percent, a new measurement of the spontaneous fission half-life is recommended. Measurement of the total half-life is on-going at JAERI and Harwell. No new P_γ measurements are foreseen. Final evaluation is to be performed by Okashita (JAERI).

Cm243 P_α measurement may be performed by Ahmad (ANL). No final evaluation is planned.

Cm244 P_α measurement may be performed by Ahmad (ANL). Final evaluation to be performed by Lagoutine (LMRI).

Cm245 P_α measurement may be performed by Ahmad (ANL). No plans for further measurement. No final evaluation planned.

Cm246 Questionable whether required accuracy of half-life of 0.2 percent can be achieved. P_α measurement may be performed by Ahmad (ANL). No plans for further measurements. No final evaluation planned.

Cf252 Unlikely that the required accuracy of 0.2 percent for the half-life can be achieved. Total half-life being evaluated by Holden (BNL). Final evaluation planned to be performed by J.R. Smith (INEL).

Table I

Summary of the Current Status of Measurements and Evaluations

Nuclide	Half-life Accuracy (E = evaluation) (M = measurement)	E_α/P_α Accuracy (WIP = work in progress)	E_γ/P_γ Accuracy	Comments (FE = final evaluation)
Th229	not achieved	not requested	not achieved (WIP)	FE by Reich
Th230	achieved (M80)	not requested	not requested	no final evaluation
Th233	achieved (E78)	not requested	not achieved (WIP)	no final evaluation
Pa231	achieved (E77)	not requested (WIP)	not achieved (WIP)	FE by Nichols
Pa233	achieved (E78)	not requested	not achieved (WIP)	FE by Reich
U 232 (decay chain)	not achieved (WIP)	achieved	achieved (WIP)	FE by Vaninbroukx
U 233	achieved (E81)	achieved	achieved (WIP)	FE by Reich
U 234	achieved (E81)	not achieved (WIP)	not achieved (WIP)	FE by Nichols
U 235	achieved (E81)	not achieved	not achieved (WIP)	FE by Vaninbroukx
U 236	achieved (E81)	not achieved	not achieved	no final evaluation
U 237	not requested	not requested	not achieved (WIP)	FE by Lagoutine
U 238	achieved (E81)	not achieved	not achieved	no final evaluation
U 239	achieved (E77)	not requested	not achieved (WIP)	FE by Nichols
Np236	achieved (M81)	not requested	not requested	no final evaluation
Np 236m	achieved (E77)	not requested	not requested	no final evaluation
Np237	achieved (E78) (WIP)	not achieved (WIP)	not achieved (WIP)	FE by Reich
Np238	achieved (E77)	not requested	not achieved	no final evaluation
Np239	achieved (E77)	not requested	not achieved (WIP)	FE by Vaninbroukx
Pu236	achieved (E77)	achieved	not achieved	no final evaluation
Pu238	achieved (E77)	achieved (80)	not achieved (WIP)	FE by Lagoutine
Pu239	achieved (ME78)	not achieved (WIP)	not achieved (WIP)	FE by Okashita
Pu240	achieved (E77)	not achieved	not achieved	FE by Coursol

Table I (continued)

Nuclide	Half-life Accuracy (E = evaluation) (M = measurement)	E_α/P_α Accuracy (WIP = work in progress)	E_γ/P_γ Accuracy	Comments (FE = final evaluation)
Pu241 (α)	achieved(M83)	not requested	not achieved (WIP)	FE by Lagoutine
Pu241 (β)	not achieved (WIP)			
Pu242	achieved (E78)	achieved	not achieved (WIP)	FE by Vaninbroukx
Am241	achieved (E78)	not requested	not achieved (WIP)	FE by Bambynek
Am242 (tot)	achieved (E78)	not requested	not requested	no final evaluation
Am242 (SF)	not achieved			
Am242m (tot)	not achieved	not requested	not requested	no final evaluation
Am242m (SF)	not achieved			
Cm242 (tot)	not requested	not requested	not achieved	FE by Okashita
Cm242 (SF)	not achieved (WIP)			
Cm243	achieved (E81)	not achieved (WIP?)	not achieved	no final evaluation
Cm244 (tot)	achieved (E81)	not requested (WIP?)	not achieved (WIP)	FE by Lagoutine
Cm244 (SF)	achieved (E78)			
Cm245	achieved (E81)	not achieved (WIP?)	not achieved	no final evaluation
Cm246	not achieved	not achieved (WIP?)	not achieved	no final evaluation
Cf252 (α)	not achieved	not requested	not requested	FE by Reich (J.R. Smith)
Cf252 (SF)	achieved (E78)			

Appendix 1

List of Participants

Coursol, N.	LMRI Centre d'Etudes Nucleaires de Saclay B.P. No. 21 F-91190 Gif-sur-Yvette
Fudge, A.J.	Chemistry Division (B.220) U.K. Atomic Energy Authority Atomic Energy Research Establishment (AERE) Harwell, Didcot, Oxon. OX11 ORA United Kingdom
Helmer, R.G. (part-time observer)	Idaho National Engineering Lab. EG and G Idaho Inc. P.O. Box 1625 Idaho Falls, Idaho 83415 U.S.A.
Lorenz, A. (Scientific Secretary)	IAEA Nuclear Data Section
Okashita, H.	Division of Physics Japan Atomic Energy Research Institute (JAERI) Tokai-Mura, Naka-Gun Ibaraki-Ken 319-11 Japan
Reich, C.W.	Idaho National Engineering Lab.
Smith, J.R. (part-time observer)	Idaho National Engineering Lab.
Vaninbroukx, R.	Bureau Central des Mesures Nucleaires Steenweg naar Retie B-2440 Geel Belgium

Appendix 2

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

Idaho Falls, 21-24 June 1983

Adopted Agenda

1. Introductory Items
2. Progress reports and activity forecasts
3. Review of Actions from September 1982 meeting
4. Review of new measurements and evaluations, and update of half-life data compilation
5. Guest presentation by J.R. Smith (INEL) on the Cf-252 half-life
6. Review of the (E_γ/P_γ) and (E_α/P_α) data status for all considered radionuclides
7. Discussion of final report
   - Outline and content
   - Status of work assignments
   - Plan to formulate final draft
8. Next meeting

Appendix 3

Actions

1.	Vaninbroukx	Perform an evaluation of the Am241 half-life before the next CRP meeting.
2.	Lorenz	Arrange to have review article on transactinium isotope half-lives published in Nuclear Constants 4(48) translated into English and distribute translation to CRP participants.
3.	Reich	Discuss with Ahmad (ANL) the possibility to perform the measurement of ($E\alpha/P\alpha$) for Np237 and Cm243, 244, 245, 246.
4.	Vaninbroukx	Review with Knitter (CBNM) the spontaneous fission data for U238 including the measurements by Carvalho et al. and Baptista et al. (see action 8, September 1982 meeting).
5.	Lorenz	Inquire with the Baranov Group (Kurchatov Institute) about the status of their $P\alpha$ data evaluations. (See Actions 15, September 1982 meeting).
6.	Lorenz	Send CRP copies of AEEW-R1407 "Radioactive Heavy Element Decay Data for Reactor Calculations" by A.L. Nichols and M.F. James.
7.	Vaninbroukx	Perform an evaluation of the Pu240 half-life (unless evaluated by Holden (BNL)).
8.	Fudge	Inquire with Robin about the required accuracies recommended at the 1979 Cadarache meeting.
9.	Vaninbroukx	Inquire about the availability of an adequate sample of Np237 to perform a new Np237 half-life measurement at CBNM.
10.	Vaninbroukx	Resolve the Pu240 balance problem and communicate results to Coursol.
11.	All CRP Members	Inform all other CRP members if you are aware of any requested decay data value where data are discrepant, very old or not measured at all.
12.	Reich	Send to all members a list of all transactinium isotope half-lives included in the current ENSDF data base, and indicate which of the CRP adopted values are to be changed to the ENSDF values.
13.	Lorenz	Based on the reports of all CRP meetings, draw up a list of all half-life values which were adopted by the CRP.

Appendix 4

Actinide Decay Data References Submitted to the Meeting

- Dale G. Olson. Gamma Intensities for ^{226}Ra and Daughters, and ^{235}U. Nucl.Instr.Meth. 206(1983)313-316.

- S.P. Holloway, J.B. Olomo, T.D. MacMahon, and B.W. Hooton. Decay Scheme Data for ^{239}U, ^{154}Eu and $^{140}Ba/^{140}La$. Proc. 1982 Antwerp Conf. on Nuclear Data for Science and Technology. K.H. Boeckhoff (Ed.). 1983 ECSC, EEC, EAEC, Brussels and Luxembourg.

- M.F. Banham and R. Jones. Gamma-Ray-Spectroscopy Measurements for Actinide Decay Scheme Studies with Particular Reference to ^{231}Pa and ^{235}U. (unpublished).

- E.L. Garner, L.A. Machlan. Mass Spectrometric Measurements to Determine the Half-Life of ^{241}Pu. Proc. 1979 ANS Topical Meeting (pp 34-41). T.R. Canada and B.S. Carpenter (Eds.) US NBS Special Publication 582 (1980).

- Bound Electron Beta Decay. The case of ^{187}Rh. (unauthored, undated, unpublished).

- R. Vaninbroukx. Remarks on the Half-Lives of ^{241}Pu and ^{241}Am (February 1983) (Internal CBNM report GE/R/RN/02-83).

- G. Bortels, B. Denecke and R. Vaninbroukx. Alpha-Particle and Photon Emission Probabilities in the ^{238}Pu - ^{234}U Decay. (May 1983). (Internal CBNM report GE/R/RN/14-83).

- R.J. Gehrke, V.J. Novick and J.D. Baker. Gamma-ray Emission Probabilities for the ^{232}U Decay Chain. (1983) (Submitted for publication).

- C.W. Reich, R.G. Helmer, J.D. Baker and R.J. Gehrke. Emission Probabilities and Energies of Gamma-ray Transitions from the Decay of ^{233}U. (1983) (Submitted for publication).

- R.G. Helmer and C.W. Reich. Emission Probabilities and Energies of Gamma-ray Transitions from the Decay of ^{238}Pu. (1983). (Submitted for publication).

- I. Ahmad. Relative Alpha Intensities of Several Actinide Nuclides. (1983) (submitted for publication).

- N. Coursol. Evaluated Nuclear Decay Data for ^{240}Pu. (may 1983) (Draft)

- F. Lagoutine. Evaluated Nuclear Decay Data for ^{241}Pu-^{237}U. (May 1983) (Draft).

- F. Lagoutine. Evaluated Nuclear Decay Data for ^{244}Cm. (May 1983) (Draft).

- N. Coursol and F. Lagoutine. Evaluation of Non-neutron Nuclear Data for the ^{226}Ra Decay Chain. (1982) (Draft).

Appendix 5

Report to the I.A.E.A. Co-ordinated Research Programme on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data (June 1983)

Introduction

The work carried out in Chemistry Division at Harwell during the past year has concentrated on improving the measurement of gamma rays with energies particularly at less than 100 keV. Improvements to the calibration procedure for the detectors has reduced the uncertainties but the measurement of many of these low energy gamma rays is complicated by the presence of X-rays. Preliminary measurements on ^{232,233,234} and ^{237}U are now in progress.

Work continues in conjunction with the University of Cambridge on the possible effect of chemical composition on low energy β decay rates.

The decay scheme of ^{239}U has been published by workers at Imperial College, London and Harwell.

Evaluation and compilation of decay data has continued at A.E.E. Winfrith.

Decay Scheme Measurements

The measurements of the gamma ray emission probabilities (I_γ) for ^{231}Pa and ^{235}U have now been completed. A preliminary publication of this data has been made to the meeting of the I.C.R.M. Seminar on Applied Radionuclide Metrology held at C.B.N.M. (Geel) in May 1983. The results have been sent to Nichols and Vaninbroukx and is being submitted for full publication in the near future. A number of new measurements have been made on these materials using the evaporated filter paper source technique (Tourwé) in order to obtain measurements of gamma rays with energies less than 50 keV. A planer H.P. Ge and a Si(Li) detectors were used. Calibration sources covering the range 6 - 60 keV were used and a 4th order polynomial curve fitted to the efficiency values indicated an uncertainty of ±5%. Further work is in progress to improve on the uncertainties of the gamma-ray emission probabilities in this energy range. Further measurements on ^{237}Np sources now in equilibrium with ^{233}Pa daughter.

Measurements have been made on ^{237}U sources prepared from the α decay of ^{241}Pu. The measurements will be repeated on ^{237}U produced from the neutron irradiation of highly enriched ^{236}U together with $\beta\gamma$ coincidence measurements. Chemical purification of enriched ^{232}U, ^{233}U and ^{234}U has been started with a view to establishing their gamma ray emission probabilities by:-

Work on the investigation of the effect of the state of chemical combination on the BETA decay constant has been started at the University of Cambridge under the direction of Dr. A. MADDOCK. It had been suggested that this effect might account for the variability in the half life of ^{241}Pu.

Further information on the decay of ^{187}Re has been found for both the total and continuum decay modes, these indicate that the fraction decaying directly to the bound state and hence that control could be affected by the presence of orbital electrons is not more than 10%. A matched pair of re-entrant ion-chambers with a common atmosphere are being constructed in a shielded, temperature controlled, cell. It is proposed to prepare two sources containing approximately equal quantities of ^{106}Ru in the metallic and highest oxidation states and observe their differential decay rates in this equipment. Consideration will then be made for ^{241}Pu measurements.

Measurement of the decay scheme of ^{239}U has been made jointly between Imperial College, London and Nuclear Physics Division at Harwell. The results, to the required accuracy of ±2% were published in the proceedings of the International Conference on Nuclear Data for Science and Technology Antwerp 6-10 Sept. 1982.

Measurements continue to be made by Glover and Wiltshire at Harwell on the α and S.F. half life of ^{242}Cm and the half life and α branching ratio of ^{235}Np. This work is hoped to be available for publication later this year.

A.J. Fudge

Chemistry Division,
A.E.R.E., Harwell.

10th June 1983

Appendix 6

STATUS REPORT 1983

JRC-CBNM Participation in the IAEA Coordinated Research Programme on the Measurement and Evaluation of Transactinium Nuclear Decay Data

R. Vaninbroukx
Central Bureau for Nuclear Measurements, B-2440 Geel, Belgium

INTRODUCTION

The status of the work carried out at CBNM during the period September 1982 to May 1983 is presented. Reported are the measurements on the half life of ^{241}Pu, the alpha- and photon-emission probabilities in the ^{238}Pu - ^{234}U decay and the gamma-ray-emission probabilities in the ^{237}Np-^{233}Pa decay. In addition, evaluations of the partial-alpha half life of ^{241}Pu and the total half lives of ^{241}Pu and ^{241}Am were made and related comments are given.

MEASUREMENTS

1. Half life of ^{241}Pu

P. De Bièvre, M. Gallet, R. Werz

A paper describing the ^{241}Pu half-life measurements by isotope mass spectrometry has been accepted for publication in Int. J. Mass Spectrometry. It has the following abstract :
"The decrease of the $^{241}Pu/^{240}Pu$ ratio due to the decay of ^{241}Pu and of the ratio of isotope ratios $\frac{^{241}Pu/^{240}Pu}{^{240}Pu/^{239}Pu}$ was measured with high-precision isotope mass spectrometry over a period of six years using a 93 % isotopically enriched sample. The resulting value for the ^{241}Pu half life is (14.33 $\pm$ 0.02)a.".

2. Alpha-particle- and photon-emission probabilities in the ^{238}Pu-^{234}U decay

G. Bortels, B. Denecke, R. Vaninbroukx

The work is finished and a paper on the measurements and results has been presented at the Seminar on Alpha-Particle Spectrometry and Low-Level Measurements, Harwell, 10-13 May 1983. The Proceedings of this Seminar

will be published in Nucl. Instr. and Meth. The paper has the following abstract :

"Emission probabilities for the alpha particles of 5358, 5456 and 5499 keV in the decay of ^{238}Pu have been measured using Si surface-barrier detectors Sources of ^{238}Pu, produced by evaporation in vacuum, were measured in various solid angles. Similar sources were used for the measurement of emission probabilities for photons, LX and prominent gamma rays, following the decay of ^{238}Pu. These measurements were performed with calibrated high-purity-Ge and Si(Li) detectors. The disintegration rates of the sources were measured by alpha counting in a well-defined small solid angle. The results also include values for the total internal conversion coefficients. The results give a consistent set of data for the prominent alpha-particle and gamma-ray transitions in the decay of ^{238}Pu."

3. Gamma-ray-emission probabilities in the ^{237}Np-^{233}Pa decay

R. Vaninbroukx, B. Denecke

The gamma-ray-emission probabilities for about 25 gamma rays in the energy range 29 keV to 416 keV are being determined. Sources with ^{237}Np amounts ranging from 16 μg to 660 μg, corresponding to activities varying between 440 Bq and 17200 Bq, are used.
The disintegration rates of the sources are measured by alpha counting under well-defined low-geometry solid angles. The gamma-ray-emission rates are measured using calibrated Si(Li) and high-purity-Ge detectors.
The measurements are nearly finished. A few small corrections have still to be determined. The results will be available at the end of 1983.

EVALUATIONS

1. Partial-alpha half life of ^{241}Pu

R. Vaninbroukx

The measurements described in the literature have been reviewed and assessed. A weighted mean value has been deduced. The recommended value and its uncertainty on the 68 % confidence level is $(6.00 \pm 0.05)10^5$a. Details on this evaluation are given in Annex 1.

2. Remarks on the total half lives of ^{241}Pu and ^{241}Am

R. Vaninbroukx

In an attempt to clarify the well-recognized discrepancy between the results of the ^{241}Pu half-life determinations by the ^{241}Am-ingrowth method and those

from recent direct-decay measurements by mass spectrometry, the ^{241}Pu and ^{241}Am half-life determinations described in the literature have been reviewed and assessed. From the review it can be concluded that the mean result (14.36 ± 0.02)a of the three most recent ^{241}Pu half-life measurements by mass spectrometry [1-3] cannot be reconciled to the recommended half life of (432.6 ± 0.4)a for ^{241}Am, a value that seems to be well established. A careful search for systematic effects in ^{241}Pu half-life measurements should be performed and for the moment being one should in no case reduce the uncertainty on the recommended ^{241}Pu half life.

Direct decay measurements by measuring the change in the emission rates of the 148.6 keV and 208.0 keV gamma rays using high-purity-Ge detectors have been started. We expect that this method, which up to now never has been applied, can help to solve the discrepancy.

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Review of the Partial Alpha Half Life of ^{241}Pu

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ABSTRACT

This review is prepared as part of the CBNM contribution to the IAEA Coordinated Research Programme on the Measurement and Evaluation of Transactinium-Isotope Nuclear Data. It evaluates the experimental data and proposes a recommended value for the partial alpha half life of ^{241}Pu.

This recommended value with its uncertainty corresponding to the 68 % confidence level is: $T_{1/2}(\alpha) = (6.00 \pm 0.05)10^5$ a.

1. INTRODUCTION

Although the partial α half life of ^{241}Pu is about $4 \cdot 10^4$ times longer than its total half life, the contribution of ^{241}Pu to the α-particle emission of typical irradiated Pu samples may amount up to a few tenths of a percent. The accuracy required for the partial α half life, mainly for destructive fuel assay, is $\pm$ 1 %[1, 2].

As part of the CBNM contribution to the IAEA Coordinated Research Programme, the reported measurements are briefly described and assessed. Where necessary, the published data have been recalculated using the most recent recommended nuclear constants [3] for the decay parameters involved. The results are summarized in Table 1. From the listed individual results a weighted mean value has been calculated using the inverse squared uncertainties as weights. The consistency of the set of data is checked according to Topping [4] by comparing the external and internal standard errors.

2. REPORTED MEASUREMENTS

There are three reported values of about $4 \cdot 10^5$ a [5-7] which are, according to the authors, the results of rough determinations. They are mentioned for the sake of completeness but not further considered here.

Bigham et al. (1958) [8] determined the partial α half life by measuring the α-activity ratio $^{241}Pu/^{(239+240)}Pu$ by α-particle spectrometry on a Pu sample for which the isotopic composition was determined by mass spectrometry. The sample contained about 50 % ^{241}Pu.

Brown et al. (1960) [9] deduced their result from measurements of the α-activity ratio ^{241}Pu/total Pu, the total Pu α-particle emission ratio and the isotopic composition of the sample. Somewhat surprisingly, no ^{242}Pu was observed, and the ^{241}Pu α-particle peak content was thereby not corrected for a possible ^{242}Pu contribution, in a sample containing 77 % ^{241}Pu.

Smith (1961) [10] used for his measurements on a Pu sample with 96 % ^{241}Pu a combination of α-particle spectrometry yielding the α-activity ratio ^{241}Pu/total Pu and α- and β-counting techniques giving the α-particle emission rate, the ^{241}Am growth rate and the β-particle emission rate of the daughter ^{237}U. The result is mainly based on the measurement of the α/β branching ratio of ^{241}Pu.

Bertolini et al. (1966) [11] determined the partial α half life from measurements of the ^{237}U and ^{241}Am growth in a purified Pu sample with 17 % ^{241}Pu. They used Ge(Li) γ-ray detectors which were calibrated with reference sources prepared from standardized ^{237}U and ^{241}Am solutions.

Ahmad et al. (1968) [12] investigated the α decay of ^{241}Pu with α-γ coincidence techniques, using high-resolution semiconductor detectors. The authors measured the α/β branching ratio. The value for the partial α half life can be calculated from this ratio and the adopted total half life of ^{241}Pu of (14.4 $\pm$ 0.2)a [3].

Vaninbroukx (1978) [13] used a purified Pu material containing 93 % ^{241}Pu. The ^{241}Pu content of the samples was determined by isotope dilution mass spectrometry. The result was derived from α-particle spectrometric measurements of the α-particle emission rates $^{241}Pu/^{(239+240)}Pu$ and from measurements of the ^{237}U and ^{241}Am ingrowth using calibrated solid-state detectors.

3. RESULTS

The results are summarized in Table 1. Where necessary, they have been recalculated using the recommended nuclear constants [3]. The agreement between the external and internal standard errors shows that the set if individual data, values and weights, is consistent. Adopting for the six independent results a value of 5 as degrees of freedoms, the Student t factor is 1.11. The overall uncertainty corresponding to the 68 % confidence level is then 0.05 x 10^5 a. The final and recommended value of the ^{241}Pu partial α half life is : $T_{1/2}(\alpha) = (6.00 \pm 0.05)10^5$ a.

Table 1. Experimental values for the partial α half life of ^{241}Pu

Authors	Published result (in 10^5a)	Nuclear constants used by the authors	Value recalculated with the recommended nuclear constants (in 10^5a)
Bigham et al.[8]	6.42 ± 0.32	$T_{1/2}(^{239}Pu)$ 2.44 10^4a $T_{1/2}(^{240}Pu)$ 6.58 10^3a	6.35 ± 0.32
Brown et al.[9]	5.72 ± 0.12	$T_{1/2}(^{239}Pu)$ 2.44 10^4a $T_{1/2}(^{240}Pu)$ 6.60 10^3a $T_{1/2}(^{241}Am)$ 461.3a	5.84 ± 0.12
Smith [10]	5.62 ± 0.20	$T_{1/2}(^{241}Am)$ 453a $T_{1/2}(^{241}Pu)$ 13.3a $T_{1/2}(^{237}U)$ 6.75d	5.97 ± 0.20
Bertolini et al. [11]	5.8 ± 0.1	$T_{1/2}(^{241}Am)$ 458a $T_{1/2}(^{241}Pu)$ 13.2a $T_{1/2}(^{237}U)$ 6.75d	5.98 ± 0.10
Ahmad et al.[12]	α/β = (2.45 ± 0.08)10^5	$T_{1/2}(^{241}Am)$ 432.7a	5.88 ± 0.21
Vaninbroukx [13]	6.04 ± 0.06	Same as the recommended nuclear constants[3]	6.04 ± 0.06
Weighted mean			6.00
External standard error			± 0.039
Internal standard error			± 0.044
Recommended value			6.00 ± 0.05

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Appendix 7

PROGRESS REPORT FOR THE IAEA COORDINATED RESEARCH PROGRAMME ON THE MEASUREMENT OF TRANSACTINIUM ISOTOPE NUCLEAR DECAY DATA

June 1983

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With respect to the measurement of transactinium isotope nuclear data, the remeasurement of ^{242}Cm half-life has been initiated by Usuda et al. to clarify the discrepancy among the data recently measured by different institutions [1], and the measurement of gamma-ray intensities of ^{239}Pu has been completed by Yoshizawa et al. [2]. The present author reviewed the recommended list of gamma-ray spectra on ^{239}Pu and made the change taking into account measurements performed since 1976.

1. Measurements of ^{242}Cm Half-life

Recent review [1] has stimulated to initiate the remeasurement of ^{242}Cm half-life in our Institute. Three independent methods were adopted for the measurement: Gross α counting using 2π gas flow proportional counter; α spectrometry with Si surface barrier detector; and X-γ spectrometry with low-energy photon spectrometer detector(LEPS). The ^{242}Cm sources were prepared by milking ^{242}Cm from a neutron-irradiated and purified ^{241}Am. To avoid the contamination of Am nuclides the milked ^{242}Cm was purified twice by using the previously reported procedure [3].

At this stage the decay following time and the number of measured data are not sufficient to evaluate the half-life value; 100-160 days and about 20 points. A preliminary analysis is tried to the α counting and the α spectrometry data obtained so far. The results are shown in Table 1. The measurements will be continued more than one half-life time.

2. Measurements of Gamma-ray Intensities of ^{239}Pu

Progress of this work, performed by Yoshizawa et al. of the Hiroshima University, has been reported in the past Coordination Meetings. Recently the final results have been concluded in which the measured data of relative and absolute gamma-ray intensities of ^{239}Pu were covered on the energy range from 129.3 to 769.4 keV [2]. Table 2 shows the results in comparison with others reported. Yoshizawa's data will contribute to the evaluation of gamma-ray emission probabilities of ^{239}Pu.

3. Review on Selected Emission Probabilities of ^{239}Pu

Most of the evaluated gamma-ray emission probabilities data of ^{239}Pu,

tabulated in the latest Proposed Recommended List of Heavy Element Radionuclide Decay Data[4], do not achieve the required accuracy, i.e., better than 1%. Recent measured data are, however, appeared to have the increased accuracies and to meet the requirement.

There are 4 available data sets measured since 1976: Gunnink's[5], Despres's [6], Helmer's[7] and Yoshizawa's[2]. Fourteen gamma-rays were selected to evaluate corresponding to the Proposed Recommended List, i.e., 129.28, 144.19, 161.45, 171.35,179.17, 189.34, 195.65, 203.52, 255.33, 297.43, 332.80, 344.96, 375.02 and 413.69 keV. Except for the addition of detector efficiency errors to the Gunnink's data, no modification was applied to the reported data during evaluation. The results are shown in Table 3 as the weighted mean, $\Sigma X_i \cdot W_i / \Sigma W_i$, with the external standard error, $[\Sigma(X_i-X)^2 \cdot W_i/(n-1)\Sigma W_i]^{1/2}$ and the internal standard error, $(1/\Sigma W_i)^{1/2}$. Here, X_i and W_i are the individual results and their weights, i.e., the reciprocals of their variance. n denotes the number of data treated, 4. For the convenience of comparison the individual data used are also given in the Table along with some astonishing energy data reported by Helmer et al [7]. The values of gamma-ray emission probabilities higher than about 5×10^{-4}% are appeared to meet the accuracy requirement.

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Table 1. Preliminary results of the half-life measurements of ^{242}Cm (100-160 days counting).

Methods	Sample name	Number of measurements	Half-life (days)	χ^2 (d.f.)
Gross α counting	82-Cm-10 (0.01μCi)	26	162.55 ± 0.66*	4.0 (24)
	82-Cm-11 (0.1)	21	161.24 ± 0.49*	9.3 (19)
	82-Cm-12 (0.3)	24	159.13 ± 0.83*	139.0 (22)
	82-Cm-13 (0.3)	24	159.83 ± 0.80*	112.7 (22)
	82-Cm-14 (0.06)	23	162.80 ± 0.34*	3.5 (21)
	Mean (n=5)		161.11 ± 0.72**	
α spectrometry	82-Cm-03 (1.2 μCi)	21	162.17 ± 0.22*	38.0 (19)
	82-Cm-06 (0.5)	21	161.07 ± 0.47*	83.5 (19)
	Mean (n=2)		161.62 ± 0.55*	

d.f.: Degree of freedom.

* : Standard deviation for the half-life value of the best-fit decay curve.

** : Statistical external error of mean = $\sqrt{\Sigma(x-\bar{x})^2/n(n-1)}$.

TABLE 2. Gamma-ray intensities for ^{239}Pu. Parentheses denote the experimental errors.

Gamma-ray energy (keV)	Relative intensities (%)		Intensities per decay (10^{-5} %)			
	Present	Helmer et al.	Present	Gunnink et al. [a]	Despres et al.	Helmer et al.
129.3	433(6)	435	648(10)	626(13)	623(4)	641(5)
141.7	2.7(8)	2.0(3)	4.1(12)	3.20(9)	2.8(4)	
143.4	20.6(5)	20.9(4)	30.8(8)	1.73(8)	2.8	
144.2				28.3(6)	29.6(15)	
146.1	8.3(4)	8.7(4)	12.4(6)	119.0(25)	11.2(11)	
161.4	8.3(4)	8.52(17)	12.4(6)	12.0(24)	12.5(7)	
171.3	7.3(4)	7.57(17)	11.0(6)	11.05(24)	10.5(6)	
179.2	4.36(20)	4.52(13)	6.5(3)	6.58(15)	6.5(5)	
188.2	0.59(7)		0.89(11)	1.09(11)		
189.3	5.52(12)	5.65(9)	8.27(19)	8.30(23)	8.30	
195.7	7.26(16)	7.30(13)	10.88(25)	10.64(22)	10.2(7)	
203.5	38.7(5)	38.7(6)	58.0(9)	56.0(11)	55.7(26)	56.8(4)
225.4	1.01(9)	1.00(9)	1.51(14)	1.56(7)	1.40	
237.4	1.40(10)		2.10(14)	1.44(6)	1.41	
242.1				0.73(5)		
243.4	2.64(16)	1.65(13)	3.96(25)	2.53(7)	2.53	
244.9				0.51(5)		
249.0	0.46(8)	0.48(4)	0.69(13)	0.72(7)	0.697	
255.4	5.30(11)	5.52(13)	7.94(18)	8.05(23)	7.9(6)	
263.9	1.70(12)	1.83(17)	2.54(19)	2.61(9)	2.47	
281.2	0.11(6)		0.16(8)	0.22(3)	0.204	
285.3	0.08(6)		0.12(9)	0.19(4)	0.2	
297.5	3.31(8)	3.39(9)	4.96(13)	5.02(14)	4.8(5)	
302.9	0.32(5)	0.33(4)	0.48(8)	0.51(4)	0.436	
307.9	0.31(5)	0.35(9)	0.47(8)	0.55(4)	0.473	
311.7	1.6(3)	1.74(13)	2.3(5)	2.58(7)	2.43	
316.4	0.85(6)	0.87(17)	1.27(9)	1.36(5)	1.33	
319.7	3.68(9)		5.51(13)	0.48(5)		
320.9		3.74(13)		5.36(12)	5.37	
323.8	3.51(7)	3.65(9)	5.26(11)	5.42(12)	5.08	
332.8	33.0(4)	33.5(5)	49.5(7)	50.6(10)	47.6(20)	49.2(4)
336.1	7.59(16)	7.52(17)	11.37(25)	11.34(23)	10.7(8)	
341.5	4.42(14)	4.35(17)	6.63(20)	6.62(14)	6.6(6)	
345.0	37.3(4)	37.7(6)	55.8(7)	55.9(11)	54.5(19)	
361.9	0.74(4)	0.96(9)	1.11(5)	1.22(7)	1.15	
367.1	5.83(9)	6.26(13)	8.72(14)	8.65(17)	8.61	
368.6	5.98(9)	5.96(13)	8.96(14)	9.03(18)	8.66	
375.0	104.7(10)	105.2(13)	156.5(18)	157.0(31)	155(5)	154.7(12)
380.2	20.64(20)	20.7(3)	30.9(4)	30.51(60)	29.8(16)	
382.8	17.51(17)	17.48(26)	26.2(3)	25.87(50)	25.4(20)	
392.5	8.3(11)	37.2(6)	12.4(16)			
393.1	28.7(11)		43.0(17)	55.27(11)	54.3(22)	

TABLE 2. Gamma-ray intensities for ^{239}Pu (Continued).

Gamma-ray energy (keV)	Relative intensities (%)		Intensities per decay (10^{-5} %)			
	Present	Helmer et al.	Present	Gunnink et al. a)	Despres et al.	Helmer et al.
399.5	0.45(7)	0.39(4)	0.67(11)	0.610(27)		
411.2	} 100.0(10)	100.0(13)	150.0(18)	0.7(3)		
413.7				148.9(30)	148(5)	145.5(9)
422.6	8.37(10)	8.17(17)	12.54(18)	11.93(24)	11.9(9)	
426.7	1.83(4)		2.74(7)	2.33(6)	2.25	
430.1	0.481(27)		0.72(4)	0.430(16)	0.426	
445.7	0.57(5)	0.78(9)	0.85(7)	0.870(25)	0.908	
451.5	12.68(17)	12.87(17)	18.99(28)	18.9(4)	19.2(12)	
457.6	0.101(26)		0.15(4)	0.149(3)	0.160	
481.5	0.299(19)	0.48(4)	0.448(29)	0.460(10)	0.477	
493.1	0.054(14)		0.081(21)	0.0868(30)	0.0875	
550.5	0.034(13)		0.051(20)	0.0422(27)	0.0463	
598.0	0.128(15)		0.192(22)	0.167(6)	0.197	
612.8	0.068(15)		0.102(23)	0.095(5)	0.154	
617.1	} 0.300(20)	0.39(4)	0.45(3)	0.134(7)	0.508	
618.3				0.204(7)		
633.2	0.157(14)		0.235(22)	0.253(6)	0.267	
637.8	0.202(18)		0.303(28)	0.256(6)	0.290	
640.1	0.613(21)	0.70(9)	0.92(3)	0.820(17)	0.867	
646.0	1.022(26)	0.91(9)	1.53(4)	1.489(30)	1.55	
649.3	0.067(21)		0.10(3)	0.071(5)		
652.1	0.443(21)	0.54(7)	0.66(3)	0.655(14)	0.657	
654.9	0.097(20)		0.15(3)	0.225(5)	0.179	
658.9	0.645(21)	0.54(6)	0.97(3)	0.969(21)	0.991	
664.6	0.113(15)		0.169(22)	0.1657(40)	0.170	
674.1	0.035(14)		0.052(21)	0.0515(19)	0.0600	
686.0	0.100(15)		0.150(23)	0.0873(30)	0.0986	
690.8	0.060(14)		0.090(21)	0.0557(30)	0.0652	
701.1	0.046(15)		0.069(22)	0.0512(18)	0.0594	
703.7	0.302(17)		0.452(25)	0.395(8)	0.417	
717.7	0.183(15)		0.274(23)	0.274(6)	0.296	
727.9	0.109(16)		0.163(23)	0.0124(7)	0.0149	
756.4	0.235(16)		0.352(24)	0.347(7)	0.38	
769.4	0.806(21)		1.21(3)	1.120(23)	1.25	

a) Error of detector efficiency of 2 % was added to the error listed in their table.

Table 3. Evaluation of gamma-ray emission probabilities of ^{239}Pu

Energy (keV)		Emission probability							
INDC-139/NE	Helmer	INDC-139/NE	Helmer	Gunnink	Despres	Yoshizawa	E.V.	σ_i	σ_e
129.28±0.03	129.296±0.001	6.20±0.06(E-3%)	6.41 ±0.05	6.26 ±0.13	6.23±0.04	6.48 ±0.10	6.31	±0.03	±0.06
144.19±0.08	144.201±0.003	2.86±0.10(E-4%)	3.07 ±0.06*	0.17 ±0.008 2.83 ±0.06	0.28 2.96±0.15	3.08 ±0.08	3.05	±0.04	±0.02
161.45±0.05	161.482±0.012	1.30±0.04(E-4%)	1.25 ±0.03*	1.20 ±0.24	1.25±0.07	1.24 ±0.06	1.248	±0.025	±0.004
171.35±0.08	171.396±0.006	1.09±0.02(E-4%)	1.11 ±0.03*	1.105±0.024	1.05±0.06	1.10 ±0.06	1.102	±0.017	±0.009
179.17±0.08	179.220±0.012	6.39±0.13(E-5%)	6.65 ±0.20*	6.58 ±0.15	6.5 ±0.5	6.5 ±0.3	6.59	±0.11	±0.03
189.34±0.07	189.360±0.010	7.76±0.15(E-5%)	8.31 ±0.15*	8.30 ±0.23	8.30	8.27 ±0.19	8.30	±0.10	±0.01
195.65±0.07	195.679±0.008	1.07±0.04(E-4%0	1.07 ±0.02	1.064±0.022	1.02±0.07	1.088±0.025	1.071	±0.013	±0.008
203.52±0.04	203.550±0.005	5.60±0.11(E-4%)	5.68 ±0.04	5.60 ±0.11	5.57±0.26	5.80 ±0.09	5.69	±0.03	±0.03
255.33±0.07	255.384±0.015	8.03±0.08(E-5%)	8.12 ±0.20*	8.05 ±0.23	7.9 ±0.6	7.94 ±0.18	8.02	±0.11	±0.05
297.43±0.07	297.46 ±0.03	5.00±0.05(E-5%)	4.98 ±0.13*	5.02 ±0.14	4.8 ±0.5	4.96 ±0.13	4.98	±0.08	±0.02
332.80±0.04	332.845±0.003	5.05±0.05(E-4%)	4.92 ±0.04	5.06 ±0.10	4.76±0.20	4.95 ±0.07	4.94	±0.03	±0.03
344.96±0.06	345.013±0.004	5.61 (E-4%)	5.54 ±0.10*	5.59 ±0.11	5.45±0.19	5.58 ±0.07	5.56	±0.05	±0.02
375.02	375.054±0.003	1.58±0.02(E-3%)	1.547±0.012	1.570±0.031	1.55±0.05	1.565±0.018	1.554	±0.009	±0.005
413.69±0.03	413.713±0.005	1.51±0.02(E-3%)	1.455±0.009	0.007±0.003 1.489±0.039	1.48±0.05	1.500±0.018	1.465	±0.008	±0.011

E.V.: Evaluated value, $\Sigma(X_i \cdot Wi)/\Sigma W_i$.
σ_i : Internal standard error, $(1/\Sigma W_i)^{12}$.
σ_e : External standard error, $[\Sigma(X_i - E.V.)^2 \cdot W_i/(n-1)\Sigma W_i]^{12}$.
* : Evaluated from the relative intensity data.

Appendix 3

Report on the Participation of U.S. Laboratories in the Work of the IAEA Coordinated Research Program on the Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data

Idaho Falls, Idaho

June 21-24, 1983

C. W. Reich

In this report, we present the current status of the work being carried out in various U.S. laboratories that is specifically oriented toward the objectives of this IAEA CRP. Reported below are the gamma-ray emission-probability measurements, and related studies, at INEL, the half-life measurements being done by the participants in the U.S. Half-Life Evaluation Committee, and the absolute α -intensity measurements at ANL.

I. GAMMA-RAY SPECTROSCOPY AT INEL

A. Gamma-Ray Emission-Probability Measurements for Selected Isotopes of Pu and U. (R. G. Helmer, C. W. Reich)

^{240}Pu: The results have been published. [See R. G. Helmer and C. W. Reich, Int'l. J. Appl. Radiat. Isotopes 32, 829 (1981).]

^{239}Pu: The results have been published. [See R. G. Helmer, C. W. Reich, R. J. Gehrke and J. D. Baker, Int'l. J. Appl. Radiat. Isotopes 33, 23 (1982).]

^{238}Pu: A paper presenting the results of the measurement of the emission probabilities and energies of the three prominent gamma-ray transitions has been accepted for publication in the International Journal of Applied Radiation and Isotopes.

^{233}U: The measurement of the emission probabilities of thirteen prominent gamma rays in the energy range from 29 to 321 keV has been completed and the results submitted for publication in International Journal of Applied Radiation and Isotopes. These data are given in Table I. In addition, precise values for the energies of 32 gamma-ray transitions from ^{233}U decay have been determined. These are reported in the paper.

^{232}U: Emission probabilities for several gamma rays from members of the ^{232}U decay chain have been determined by R. J. Gehrke, V. J. Novick and J. D. Baker of our laboratory. A paper describing these results has been submitted for publication in the International Journal of Applied Radiation and Isotopes. Selected data from this study are presented in Table II.

^{235}U: The emission probabilities and energies of the six prominent gamma rays from the decay of ^{235}U have been measured. Because of the low specific activity of ^{235}U, relatively large amounts of source material were used in preparing the samples for gamma-ray counting and some of the samples had rather large diameters. Observed differences in the measured emission-probability values from the different sources have been linked to the different distributions of material within the sources. The measurement of correction factors to take these effects into account has been completed; and the correction of the measured emission-probability values for these effects is presently being carried out.

^{241}Pu: Two separate experiments have been undertaken to measure the emission probability of the 148-keV gamma ray from the decay of ^{241}Pu. Source material with an isotopic purity of 98.90% ^{241}Pu (as of July, 1976) is being used in these studies. The first experiment was an approach similar to that used in our earlier determination of the gamma-ray emission probabilities for $^{238-240}Pu$. In this case, the

gamma-emission rates from three separate sources will be measured using calibrated Ge detectors. The decay rate of this source material will be determined by isotope-dilution mass spectrometry using solutions of ^{239}Pu and ^{240}Pu previously calibrated by NBS.

The second experiment is being carried out by Professor H. Willmes of the University of Idaho and one of his graduate students. In this approach, the grow-in of the 59-keV gamma ray, from the decay of the daughter activities ^{237}U and ^{241}Am, is being followed for an initially pure ^{241}Pu sample. The $P_\gamma(148)$ value will be determined from the time dependence of the peak areas and $P_\gamma(59)$, which is well known.

B. Variation of Ge Detector Efficiency with Source Diameter and Radial Source Position. (R. G. Helmer)

To provide the necessary link between our original point-source efficiency calibration and our Pu and U measurements, it has been necessary to determine the correction for the point-source efficiencies to apply to these disk sources. In addition, for one nuclide, the sources were also nonuniform, with the material deposited primarily near the outer radius of the sources. Hence, it has been necessary to also determine the variation of the efficiency with the radial position of the source material. In the process of measuring the corrections to meet our needs, three methods have been explored which provide information about the variation of the γ-detection efficiency with source diameter and radial position of a point source. These involve (1) a simple calculation of the geometry factor, (2) measurements with a set of calibrated disk sources, and (3) measurements with a multiple γ-ray point source.

The results from the first two determinations agree quite well. The results from the third method were integrated over a disk source area to compare with the results of the first two methods. The agreement was not as good as expected; the discrepancy is presumed to arise from experimental ambiguities in the last method.

II. ACTIVITIES OF THE HALF-LIFE EVALUATION COMMITTEE
(ANL, LLNL, LANL, Mound, NBS, NBL, and Rocky Flats)

As reported at the previous CRP meeting in Geel, the measurements of the ^{240}Pu half-life by the various participating laboratories have been completed and papers prepared for publication. W. Strohm, chairman of the Committee, indicates that the Committee members are now in a position to recommend a value for this quantity. The value they recommend is 6,564±11 years.

This value differs slightly (by 2 years) from that given in a recently communicated manuscript of the summary paper of the measurement activity. W. Strohm indicates that this is due to a somewhat reduced weighing given to one of the calorimetry-based measurements in the final evaluation.

III. MEASUREMENT OF RELATIVE ALPHA INTENSITIES
(I. Ahmad, ANL)

A paper reporting the results of the measurements of the relative intensities of the prominent alpha groups from the decays of ^{233}U, $^{238-240}Pu$ and ^{241}Am has been submitted for publication in Nuclear Instruments and Methods. The following is the abstract of that paper.

> The relative intensities of alpha groups in the decays of ^{233}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am have been measured with a high-resolution semiconductor detector. Isotopically enriched and essentially massless sources, prepared by an electromagnetic isotope separator, were used in this investigation. All spectra were recorded at low geometries in order to reduce distortions in alpha intensities due to α-e^- coincidence summing and had resolutions (FWHM) of ~13 keV. For all of the nuclides studied, intensities have been measured with higher accuracies than previously reported. The intensities of the ^{240}Pu alpha groups obtained in this work are significantly different from the literature values. For other nuclides our intensities agree with previous measurements.

TABLE I

EMISSION PROBABILITIES OF SELECTED PROMINENT γ-RAYS FROM THE DECAY OF ^{233}U

γ-ray Energy (keV)	Emission Probability ($\gamma/10^5$ decays) Detector		
	8-cm^{3}Ge	114-cm^{3}Ge	Average[d]
29.1	12.0 ± 0.3[a]	---	12.0 ± 0.3
42.4[b]	86.2 ± 1.3[c]	---	86.2 ± 1.3
54.7	18.2 ± 0.3	---	18.2 ± 0.3
119.0	4.06 ± 0.05	4.07 ± 0.06	4.06 ± 0.04
120.8	3.31 ± 0.04	3.32 ± 0.03	3.32 ± 0.03
135.3	2.29 ± 0.02	2.33 ± 0.02	2.32 ± 0.02
146.3	6.51 ± 0.05	6.62 ± 0.06	6.57 ± 0.06
164.5	6.20 ± 0.05	6.26 ± 0.06	6.23 ± 0.05
208.2	2.25 ± 0.03	2.31 ± 0.02	2.29 ± 0.03
245.3	3.60 ± 0.04	3.63 ± 0.04	3.62 ± 0.03
291.3	5.34 ± 0.05	5.40 ± 0.05	5.37 ± 0.05
317.2	7.75 ± 0.07	7.77 ± 0.06	7.76 ± 0.07
320.6	2.92 ± 0.04	2.88 ± 0.03	2.90 ± 0.03

a. Includes a correction of 1% from presence of daughter γ ray.
b. Decay-scheme studies indicate that this peak is a doublet.
c. Includes a correction of 0.3% for presence of a daughter γ ray.
d. Since the efficiencies of the two detectors are correlated, the uncertainty in the average is not allowed to be smaller than

$$\sqrt{\sigma^2(\varepsilon) + (0.4)^2}\ \%.$$

TABLE II

γ-RAY EMISSION PROBABILITIES OF DAUGHTER ACTIVITIES IN ^{232}U DECAY CHAIN WHEN IN EQUILIBRIUM

Isotope	Energy (keV)	Ref. 14	Ref. 8[a]	Deduced from 1_α & α_t	Adopted from our measurement
^{232}U	57			0.198±0.009[b]	0.200 ±0.004
	129			0.068±0.003[c]	0.0686±0.0007
^{228}Th	84	1.21±0.06			1.248 ±0.029
	216				0.261 ±0.003
^{224}Ra	241	3.95±0.13	4.03±0.09		4.17 ±0.04
^{220}Rn	549				0.130 ±0.003
^{212}Pb	238		43.6 ±0.6	43 ±1[d]	43.3 ±0.4
^{212}Bi,	39			1.166±0.023[e]	1.05 ±0.04
	288				0.337 ±0.004
^{212}Bi,	727		7.03±0.20		6.58 ±0.05
^{208}Tl	583		30.52±0.17	30.52 ±0.17[f]	30.52 ±0.17
	2614			35.86 ±0.06[f]	35.86 ±0.06

a Intensities of Ref. 8 renormalized to $I_\alpha(583) \equiv 30.52 \pm 0.17$ to agree with the normalized value determined in the present experiment.

b Deduced from alpha intensity, I_α, from Ref. 12 and measured total conversion coefficients from Ref. 24.

c Determined from Refs. 12 and 24 and ^{232}U relative γ-ray intensities from present experiment.

d Determined relative to 100 for ^{208}Tl 2614-keV γ ray with ^{208}Tl in equilibrium as reported in Ref. 21.

e Determined from α to β intensity ratio for decay of 60-min ^{212}Bi (see text), α intensities to ^{208}Tl levels from Ref. 23, measured total conversion coefficients from Ref. 25 and decay scheme of Ref. 21.

f See text (based on alpha intensity measurements of Refs. 9-11 and ^{208}Tl decay scheme.)

Appendix 9

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

F. Lagoutine, N. Coursol, J. Legrand
CEN Saclay, France

Summary of progress report from LMRI

1) Evaluation of data-decay

Since 1973 the LMRI has been working in evaluation and updating nuclear decay data, especially for some fission products, transactinium isotope, activation products and radionuclides for medical use.

More than a hundred radionuclides have already been evaluated and all results are presented in Table de Radionucléides of LMRI.

2) LMRI-participation in the coordinated research programme (CRP).

- Evaluation of decay data was performed for ^{240}Pu, ^{241}Pu, ^{244}Cm and ^{237}U.
- The half life adopted values are those of INDC (NDS)-139/NE, december 1982, except for the ^{240}Pu half-life. The adopted value is reported by Walter Strohm (1983).
- Evaluated data include branching ratios, alpha, beta and gamma energies and intensities and associated uncertainties.

Comments

- ^{240}Pu KX-ray intensities.- Evaluator noted a discrepancy between the values calculated from decay scheme and measurement (Gunnink-76).
- About the required half-life accuracies assigned at Cadarache meeting 1979. Mr Robin's answer : no changes to be made on
- ^{226}Ra decay-chain

Some of the LMRI's recommanded values for α-, β- particle and γ-ray-emission probabilities per decay of ^{226}Ra in radioactive equilibrium with its daughter products were presented at ICRM-Seminar on Applied Radionuclide Metrology, Geel, 16-17 may, 1983, Belgium.

All ^{226}Ra decay chain data will be published in first part of volume 3 of LMRI Radionuclides Table.

Appendix 10

PROGRESS REPORT FOR THE IAEA CO-ORDINATED RESEARCH PROGRAMME ON THE MEASUREMENT AND EVALUATION OF TRANSACTINIUM ISOTOPE NUCLEAR DECAY DATA (MAY 1983)

A L Nichols
AEE Winfrith
Dorchester
Dorset, UK

A report has been published(1) which describes in detail the contents of the UK Heavy Element Decay Data library (UKHEDD-1). These computerised data files are in ENDF/B-V format and have been prepared under the auspices of the UK Chemical Nuclear Data Committee. Inevitably the library is already dated, and I propose to revise specific files by mid-1985 in terms of the CRP decay data recommendations.

Gamma decay data have been measured recently for 231-Pa by M F Banham and co-workers at AERE Harwell, and this work and earlier relevant publications have been collected together in order to re-evaluate these data for the CRP. However, recent evaluation efforts have concentrated on the development of a new UK Activation Product Decay Data library (UKPADD-2): decay data for approximately 410 radionuclides will be included for fission and fusion reactor calculations(2).

References

(1) A L Nichols, M F James, Radioactive Heavy Element Decay Data for Reactor Calculations, AEEW - R 1407, 1981.

(2) A L Nichols, Revision of the Evaluated UKCNDC Activation Product Decay Data Library, ICRM Seminar on Applied Radionuclide Metrology, May 1983 Geel, to be published in the International Journal of Applied Radiation and Isotopes.

NOW IT'S THE ^{252}CF HALF-LIFE DISCREPANCY

J.R. Smith, EG&G Idaho, Inc.

I. Introduction

Recent developments suggest the existence of a discrepancy among determinations of the half-life of ^{252}Cf. This paper summarizes a description of the problem as presented to the participants in the IAEA Coordinated Research Program on Measurement and Evaluation of Transactinium Isotope Nuclear Decay Data, in June, 1983.

II. ^{252}Cf Half-Life Measurements

Californium-252 is a standard for the neutron multiplicity factor $\bar{\nu}$ (average number of neutrons per fission) and for measurements of fission rates and neutron source strengths. Since ^{252}Cf decays at the rate of approximately 2% per month, the accuracy of any intercomparison depends upon how well the half-life and composition of the source are known.

At the time our investigations of the ^{252}Cf $\bar{\nu}$ problem were getting well under way, the half-life picture was essentially as summarized by Bozorgmanesh[1] in the thesis reporting his measurements of $\bar{\nu}$ for ^{252}Cf. His summary table included the first seven values (2-8) listed in Table 1. Bozorgmanesh used the weighted mean value 2.638 $\pm$ 0.003 y, in the analysis of his data. This weighted value is the same as Spiegel's published value[8], and almost identical with a later measurement by Mozhaev[9]. We used the value 2.638 y in the first analysis of our ^{252}Cf $\bar{\nu}$ data, and it appeared to agree with our data exceptionally well.

In November 1980, a workshop was held to discuss the status of $\bar{\nu}$ for ^{252}Cf. At this workshop Spiegel dropped the first of his two bombshells that have destroyed the serenity of the half-life picture. He revealed that he had uncovered an error in his calculation of the time between two measurements of the ^{252}Cf source on which his half-life value was based. With the corrected time scale the half-life became 2.653 $\pm$ 0.001 y. He had been in correspondence with Alberts on the

subject; in fact, it may have been upon the insistence of Alberts that the time scale was investigated. Alberts had from his own measurements derived the value 2.648 ± 0.002 y. Spiegel and Alberts prepared a joint paper to announce their agreement on the higher half-life value.[10]

This change in half-life was upsetting, because it was just large enough to require re-examination of the manganese bath measurements over the course of the dilution experiment that was part of our ^{252}Cf $\bar{\nu}$ measurement program.[11] We would have preferred to stay with the older half-life, 2.638 y. Could retention of a value be justified after it had been disavowed by its author? While the Spiegel value had seemed to dominate the picture, it was not the only number on the table. It thus seemed appropriate to examine the other measurements for possible systematic effects.

The measurement by Metta[4], 2.646 ± 0.004 y, was the first one to produce a half-life value with good precision. It was determined by observing the change in the fission rate of a ^{252}Cf foil in a fission chamber by 2π counting. During the course of our $\bar{\nu}$ experiment, we had observed a significant decrease in the 2π calibration values, due to self-transfer of the ^{252}Cf within the chamber. It is possible that Metta's half-life value could be low because of the effects of self-transfer.

Our experience in the ^{252}Cf experiments showed that the neutron-fission coincidence method yielded fission-rate estimates that were independent of the effects of self-transfer, as long as the neutron-fission angular correlation function was properly considered. The Mozhaev[9] measurements were a variant of the neutron-fission coincidence technique, in which the neutron pulse was used to stop a TAC runout which had been started by a fission pulse. However, Mozhaev's neutron detector was fixed on the axis of the fission chamber. This is the position of a minimum in the neutron-fission angular correlation function, and self-transfer makes the minimum deeper as time goes on. There is thus the possibility that Mozhaev's half-life value may also have been shortened by the effects of self-transfer.

DeVolpi[5] reported a relatively short half-life value, 2.621 ± 0.006 y It was based on measurements of the neutron yield of a sealed ^{252}Cf source in a manganese bath. There should not have been a problem with self-transfer. There was, however, a severe problem with the experimental equipment and techniques. During the course of his measurements, DeVolpi changed both his ^{56}Mn counting system and his method of calibrating the manganese bath. There was a substantial discontinuity between source-strength measurements with the older, less precise counting configuration, and the revised system. DeVolpi adjusted the ^{252}Cf half-life to minimize this discontinuity. His adjustments do not constitute a valid determination of the half-life.

Mijnheer's value[7], 2.659 ± 0.010 y, is also based on measurements of the neutron emission rate of a ^{252}Cf source by the manganese bath method. It is the highest value in Table I. Not having seen the original data, I can't comment on the possibility of changes in the system efficiency.

These considerations served to undermine confidence in the lower half-life values, without conclusively establishing confidence in the higher values. Since the fission-rate studies had shown the neutron-fission coincidence technique to be essentially immune from distortions by self-transfer, as long as the whole angular correlation function is measured, it seemed appropriate to recalibrate one of the fission chambers and derive a half-life value consistent with the methodology of our ^{252}Cf $\bar{\nu}$ measurements. The resulting half-life was 2.651 ± 0.003 y[11] where the error represents the regression error of the fitting procedure.

The new value falls between the Alberts and revised Spiegel values. The ^{252}Cf half-life seemed well established at last. Then Spiegel dropped his second bombshell.[13] In reviewing the histories of other ^{252}Cf source measurements made at NBS, he found that he deduced different half-lives for different sources. His values were all within the range encompassed by other measurements, but they were all obtained by the same experimenter, using the same method of measurement (comparison to the Ra-γ-Be source NBS-I in the NBS manganese bath) and the same method of allowing for the effects of other Cf isotopes.

Why should Speigel observe such a variety of half-lives when the techniques are the same, and the measurements overlap in time? The most obvious thing to question is the source composition. In a test calculation the $^{252}Cf/^{250}Cf$ atom fraction was changed from 0.64/0.19 to 0.50/0.30. A second test calculation predicted the decay of two sources, originally of the same $^{252}Cf/^{250}Cf$ ratio but with a seven-year difference in age at the start of the decay history. For each calculation, the sources were assumed to be of equal strength. In each calculation the difference in predicted strengths of the sources became approximately 0.7% to 0.8% at the end of a half-life. Over the same period the cumulative difference in decay corrections based on 2.638 y and 2.651 y reaches about 0.4%. It is evident that errors in source age or composition can lead to differences in decay corrections comparable to those produced by the range of half-lives in question. However, the test calculations used differences in age and composition that are much larger than those reasonably expected to be present. There could be a certain amount of contamination by (α,n) or (γ,n) neutrons, but these should be a very small fraction of the fission neutron intensity and should also follow the half-life of the parent Cf isotopes. The possibility of substantial errors in the characterization of ^{252}Cf sources, whether in the isotopic analysis or in the presence of unidentified neutron emitters, should be investigated.

The uncertainty in the ^{252}Cf half-life is causing some problems in the comparison of neutron source strengths. For several years a ^{252}Cf source has circulated among laboratories of the world as a comparison source. Table III shows a summary by Axton[14] of the effect of half-life upon the source comparison. The summary shows that the degree of agreement is dependent upon the ^{252}Cf half-life assumed in the analysis of the data. The agreement is somewhat enhanced by use of the shorter half-lives. From measurements made at NBS at the beginning and end of the tour of the source, it would appear that a half-life near 2.64 y should be favored.

We did not participate directly in that source comparison because of funding restrictions. However, Axton has measured a source that was also measured as part of our ^{252}Cf $\bar{\nu}$ investigations. There too, the 2.638 y half-life value produced a substantially improved agreement.

There appears to be substantial support for ^{252}Cf half-life values near both 2.638 and 2.651 y. This difference contributes significant uncertainties to intercomparisons of neutron source-strength measurement techniques. The fault could lie in the inadequate characterization of the composition of ^{252}Cf sources. Further investigations should be pursued to identify the cause of this discrepancy. Pending resolution of the discrepancy, it would be well to adopt an intermediate value, with error bars covering the range of uncertainty. The value 2.645 ± 0.008 y is suggested as the interim value for the half-life of ^{252}Cf.

TABLE I. ^{252}Cf HALF-LIFE VALUES

Author		T 1/2 (Y)
L. Magnussen[2]	(1954)	2.2 ± 0.2
T. Eastwood[3]	(1957)	2.55 ± 0.15
D. Metta[4]	(1965)	2.646 ± 0.004
A. DeVolpi[5]	(1969)	2.621 ± 0.006
V. Shchebolev[6]	(1973)	2.628 ± 0.010
B. Mijnheer[7]	(1973)	2.659 ± 0.010
V. Spiegel[8]	(1974)	2.638 ± 0.007
V. Mozhaev[9]	(1976)	2.637 ± 0.005
W. G. Alberts[10]	(1980)	2.648 ± 0.002
V. Spiegel[10]	(1980)	2.653 ± 0.001
J. R. Smith[11]	(1981)	2.651 ± 0.003
F. Lagoutine[12]	(1981)	2.639 ± 0.007

TABLE II. CALIFORNIUM NEUTRON SOURCE MEASUREMENTS AT NBS[13]

Source	Number of Measurements	Duration in Half-lives	Starting Date	Half-life(y) (Log Fit)	Half-life(y) (Semi-log fit)
NEEDLE #3	3	4.43	9/6/68	2.651	2.653
SR-CF-132	4	3.95	1/1/73	2.642	2.647
NS-39	7	3.52	12/11/71	2.635	
	6	2.45	10/17/74		2.638
	5	1.82	6/10/76		2.643
	4	1.38	8/13/77	2.648	
	3	0.68	6/18/79		2.659
	2	0.22	9/8/80		2.700
NS-54	10	3.26	11/24/73	2.632	2.632
	9	2.84	1/6/75		2.631
	8	2.79	2/23/75		2.632
	7	2.77	3/14/75		2.632
	6	2.34	4/29/76		2.634
	5	2.31	6/1/76		2.634
	4	2.03	2/27/77		2.635
	3	1.57	5/22/78		2.635
	2	1.22	4/25/79		2.631
NS-79	5	2.80	1/2/75	2.631	
NS-86	3	0.73	6/6/76	2.619	
NS-92	4	1.52	3/22/77	2.657	

TABLE III.* EFFECT OF ^{252}Cf HALF-LIFE UPON NEUTRON SOURCE-STRENGTH COMPARISONS

Half-Life (y)	2.638	2.645	2.650	2.651
Difference between INEL and NPL (Percent) Source NZS 90	.113	.304	.406	.424
Standard Deviation of 7 measurements of itinerant source by 7 laboratories (Percent)	.397	.428	.461	.469
NBS measurement of itinerant source before and after (Percent)	-.132	.200	.434	.481

* Prepared by E. J. Axton

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