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Nuclear Data for the Efficiency Calibration of Germanium Spectrometer Systems:

Measurements from the Laboratories of the International Committee for Radionuclide Metrology α-, β-, and γ-Ray Spectrometry Group

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Nuclear Data for the Efficiency Calibration of Germanium Spectrometer Systems:

Measurements from the Laboratories of the International Committee for Radionuclide Metrology α-, β-, and γ-Ray Spectrometry Group

D. D. Hoppes and F. J. Schima, Editors

Center for Radiation Research
National Measurement Laboratory
National Bureau of Standards
Washington, DC 20234

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

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ABSTRACT

Members of the Alpha-, Beta-, and Gamma-Ray Spectrometry Group of the International Committee for Radionuclide Metrology agreed in 1979 to collect the nuclear data from any measurements in their laboratories that were pertinent to the calibration of the efficiency of germanium spectrometer systems. This report is composed of the contributions from 14 laboratories, as listed in part II. The contributions follow in part III. If a self-contained contribution was received, it has been incorporated without editing. Less formal communications, or references to published articles, are discussed in short comments prepared by the compilers. Part IV is a compilation of a selected portion of the data, arranged by radionuclide.

Key words: compilation; efficiency data; half lives; measurement uncertainties; photon probabilities per decay; relative photon-emission probabilities.

CONTENTS

*Comments by the compilers, based on information supplied by the laboratory.

NUCLEAR DATA FOR THE EFFICIENCY CALIBRATION OF GERMANIUM SPECTROMETER SYSTEMS: MEASUREMENTS FROM THE LABORATORIES OF THE INTERNATIONAL COMMITTEE FOR RADIONUCLIDE METROLOGY α-, β-, AND γ-RAY SPECTROMETRY GROUP

D. D. Hoppes and F.J. Schima
National Bureau of Standards

I. Introduction

Members of the Alpha-, Beta-, and Gamma-Ray Spectrometry Group (SG) of the International Committee for Radionuclide Metrology (ICRM) agreed in 1979 to collect the nuclear data from any measurements in their laboratories that were pertinent to the calibration of the efficiency of germanium spectrometry systems. This report is composed of the contributions from 14 laboratories, as listed in part II. The contributions follow in part III. If a self-contained contribution was received, it has been incorporated without editing. Less formal communications, or references to published articles, are discussed in short comments by the compilers. Part IV is a compilation of a selected portion of the data, arranged by radionuclide.

The following suggestions were made regarding the data. Only pertinent values obtained or published after 1968 were to be submitted. Any published data were to be reconsidered in the light of subsequent knowledge, and re-evaluated where required. Sufficient detail was to be presented, or referenced, for an evaluator to appreciate the origin and probable validity of uncertainty statements. Uncertainties were to be estimated realistically, with those which could not be determined from a statistical analysis to be defined and combined in such a way that the total uncertainty would correspond, in significance, to the standard deviation of the mean. The methods whereby this considerable challenge was to be met were felt to be of interest in themselves.

The data consist of half lives ($T_{1/2}$), photon (gamma- or x-ray) probabilities per decay (P_γ or P_X), and relative photon-emission probabilities (P_R). The last suffice when a radionuclide with multiple gamma rays is used to generate a relative efficiency curve, or when a source with a known rate of gamma-ray emission at a certain energy is used as an x-ray standard. P_γ or P_X relates photon-emission rate to activity, and $T_{1/2}$ is required when a source of known emission rate is to be used after significant decay.

The question of which radionuclides are useful for calibration depends in part on the intended use of the spectrometer system.

If an efficiency vs energy relation is to be as independent as possible of past spectrometric results, the usual requirement is for the radionuclides used to have a transition or transitions with almost complete branching and little internal conversion. For a few nuclides, members have better established probabilities by measuring competing branches or conversion electrons. For many nuclides, better half lives are reported. Listings of these "primary calibration radionuclides," and remarks about their selection, appear in some contributions and references. In the region below 100 keV, the requirements for decay-scheme-derived probabilities are seldom met, although methods such as careful photon-emission-rate measurements with defined-geometry detectors, or theoretical efficiency cal-

culations, can still give efficiencies independent of past measurements (of fluorescent yields, for example). Even so, measured values for P_γ or P_X have added significance in this region.

If past spectrometric results are acceptable, almost any source with an accurate activity calibration becomes useful if radiation probabilities are known for suitable transitions. Thus the efficiency calibration of a laboratory spectrometer system can be linked to national standards even with a short-lived nuclide calibrated primarily for another purpose. Finally, the summary table contains several radionuclides with measured relative probabilities for photons of a range of energies. These can be used to better define, or check, the shape of an efficiency curve.

One purpose foreseen for the summary table was a determination of the agreement of data from different laboratories, perhaps relative to the estimated accuracy. For this reason, and to limit the size of the compilation, it was suggested that only radionuclides for which two or more SG laboratories submitted data were to be included. In many cases, the data were of different types, but all data satisfying the original requirement were included, and other radionuclides were added when requested by a laboratory.

No evaluation is made in this report, although it should serve as the basis for evaluations. Only data from ICRM SG members have been included, and only values for radiations with probabilities greater than 5 percent of the most probable have been listed in the summary table, with a few exceptions. It obviously does not include all radionulcides suitable for efficiency calibrations, even in a narrow sense, for some, such as ^{94}Nb, require no better measurements of the type reported here to be useful.

The uncertainties given in the summary table in general are believed to be total uncertainties corresponding, in significance, to one standard deviation of the mean, although this is not clear in a few instances. In some cases, labeled with asterisks, the value corresponds to about three times this value. The computer program that generated the table does not print significant final zeros, but their absence is apparent when the accompanying uncertainty is considered.

II. List of contributors

Contributor	Correspondent	Label
1. Atomic Energy of Canada, Ltd. Chalk River, Ontario K0J 1J0 Canada	A.R. Rutledge	AECL
2. Bureau International des Poids et Mesures Pavillon de Breteuil Sevres, France	A. Rytz	BIPM
3. Central Bureau of Nuclear Measurements Steenweg op Retie 2400 Geel, Belgium	W. Bambynek	CBNM

Contributor	Correspondent	Label
4. Georgia Institute of Technology Department of Chemistry Atlanta, GA 30332, U.S.A.	R.W. Fink	GITSC
5. Hiroshima University Department of Physics Hiroshima, Japan Nagoya University Department of Nuclear Engineering Nagoya, Japan Rikko University Department of Physics Tokyo, Japan Electrotechnical Laboratory, Tanashi Tokyo, Japan	Y. Yoshizawa	HNRE
6. International Atomic Energy Agency P.O. Box 100 A-1400 Vienna, Austria	K. Schaerf	IAEA
7. Institut D'Electrochimie et Radiochimie Ecole Polytechnique Federal CHB-Ecublens CH-1015 Lausanne, Switzerland	M. Decombaz	IER
8. Idaho National Engineering Laboratory EG&G Idaho, Inc. Idaho Falls, ID 83415, U.S.A.	R. Helmer	INEL
9. Lawrence Livermore Laboratory University of California Livermore, CA 94550, U.S.A.	R. A. Meyer	LLL
10. Laboratoire de Metrologie des Rayonnements Ionisants Boite Postale No. 2 F-91190 Gif-sur-Yvette, France	J. Legrand	LMRI
11. National Bureau of Standards C112 Radiation Physics Washington, DC 20234, U.S.A.	D. Hoppes	NBS
12. National Physical Laboratory Division of Radiation Science Teddington Middlesex TW111 OLW United Kingdom	P. Christmas	NPL

Contributor	Correspondent	Label
13. Physikalisch-Technische Bundesanstalt Bundesallee 100 D-3300 Braunschweig, FRG	K. Debertin	PTB
14. University of Guelph Department of Physics Guelph, Ontario N1G 2W1 Canada	J.L. Campbell	UGDP

III. Contributions

These follow in the same order as listed in part II, and vary in length from full articles to a remark about references.

ATOMIC ENERGY OF CANADA LIMITED

DECAY DATA FOR RADIONUCLIDES USED FOR THE CALIBRATION OF X- AND γ-RAY SPECTROMETERS

by

A.R. Rutledge, L.V. Smith and J.S. Merritt

ABSTRACT

Half-life values and γ-ray emission probabilities are summarized from results determined by the Radioisotope Standardization Group over the past decade or so. Half-life values are given for thirty-three radionuclides: these are ^{7}Be, ^{18}F, ^{22}Na, ^{24}Na, ^{42}K, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{56}Mn, ^{60}Co, ^{64}Cu, ^{65}Ni, ^{82}Br, ^{85}Sr, ^{95}Nb, $^{99}Tc^{m}$, ^{109}Pd, $^{113}In^{m}$, ^{113}Sn, $^{115}In^{m}$, ^{133}Xe, ^{133}Ba, ^{134}Cs, $^{134}Cs^{m}$, $^{137}Ba^{m}$, ^{137}Cs, ^{139}Ce, ^{141}Ce, ^{152}Eu, ^{169}Yb, ^{198}Au, ^{203}Hg, and ^{233}Pa. Gamma-ray emission probabilities are given for the eleven radionuclides ^{7}Be, ^{42}K, ^{65}Ni, ^{75}Se, ^{85}Kr, $^{99}Tc^{m}$, $^{113}In^{m}$, $^{115}In^{m}$, ^{137}Cs, ^{139}Ce, and ^{141}Ce. Counting equipment included the $4\pi\gamma$ ionization chamber, the $4\pi\beta$-γ coincidence system, and a Ge(Li) counter. Each method of measurement is discussed. A statistical uncertainty of one standard deviation has been used throughout and detailed information is given about the assessment of other uncertainties. The impurities found or suspected in twenty-one of the reported samples of radionuclides are discussed in an appendix.

Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada K0J 1J0
March 1980

1. INTRODUCTION

The α-, β-, and γ-ray Spectrometry Working Group (SWG) of the International Committee for Radionuclide Metrology (ICRM) has requested information about measurements of γ-ray emission probabilities and half-lives for radionuclides that are issued as standards for calibration purposes. Rather detailed information was requested, especially about the assessment of uncertainties in the final values. The SWG plans to examine critically the collected data to draw attention to discrepancies, and to encourage further and more accurate measurements to resolve these discrepancies. Ultimately this should allow γ-ray spectrometers to be calibrated more accurately.

This report is the contribution from the Radioisotope Standardization Group of Atomic Energy of Canada Limited (AECL) to the SWG, and it summarizes and reviews such measurements made in this laboratory during the past decade or more.

2. GENERAL REMARKS AND LISTS OF DATA

The attempt by the AECL Radioisotope Standardization Group (RSG) to summarize its data in a consistent manner has been complicated by the fact that while the results of some measurements have been fully documented others have appeared only as short paragraphs in Physics Division Progress Reports. In the past the RSG has generally used a confidence interval of 3σ for the statistical uncertainty and estimates of other sources of uncertainty usually were added linearly. To conform with the request of the SWG for consistent statements about accuracy at a confidence level of 68%, in order to facilitate recognition of discrepancies and a uniform evaluation of the data[1,2], considerable research and recalculation were required. As a result, in most cases the uncertainties in the values tabulated in this report differ from those in the referenced publications or reports.

The radionuclides for which half-life data are submitted are listed in Table I. Column 2 gives the number of half-lives over which observations have been made, followed by the number of observations in brackets. The

Table I

Radionuclides Issued as Standards for which

Half-Life Data are Submitted to SWG of ICRM

Radionuclide	No. of Half-Lives followed (No. of Points)	Counting Equipment[a]	Completion Status	Half-Life	Reference[b]
^{7}Be	9.3(43)	I.C.	Yes	53.284 ± 0.004 d[c]	4 (PRP)
^{18}F	6 to 20 (~30)	4πPC	Yes	109.73[d] ± 0.04 min	5 (PRP)
^{18}F	10 to 11 (25)	I.C.	Yes	109.71[d] ± 0.02 min	5 (PRP)
^{22}Na	3.9 (92)	I.C.	No	950.30[d] ± 0.27 d	6 (PRP)
^{24}Na	10 (33)	4πPC	Yes	14.965 ± 0.010 h	7 (PRP)
^{24}Na	3 to 8	4πPC	Yes	14.959 ± 0.010 h	8
^{24}Na	10 to 14 (397)	I.C.	Yes	14.965 ± 0.001 h	none
^{42}K	~10	4πPC	Yes	12.358 ± 0.007 h	9
^{46}Sc	12.4 (41)	I.C.	Yes	83.752 ± 0.015 d	10 (PRP)
^{51}Cr	13.6 (40)	I.C.	Yes	27.704 ± 0.003 d	4 (PRP)
^{54}Mn	11 (83)	I.C.	Yes	312.21 ± 0.03 d	11 (PRP)
^{56}Mn	3.2 (32)	I.C.	Yes	2.5764± 0.0008 h	12 (PRP)
^{60}Co	0.8	4πPC-γ	No	1923.78 ± 0.94 d	13 (PRP)
^{60}Co	0.5 to 3.5	I.C.	No	1924.33[d] ± 1.36 d	13 (PRP)
^{64}Cu	~10 (32)	I.C.	Yes	12.701 ± 0.003 h[c]	14 (PRP)
^{65}Ni	6 to 9	4πPC	Yes	2.520 ± 0.001 h	15

Table I (Continued)

Radionuclide	No. of Half-Lives followed (No. of Points)	Counting Equipment[a]	Completion Status	Half-Life	Reference[b]
^{82}Br	~10	4πPC	Yes	35.344 ± 0.016 h	9
^{85}Sr	~15 (26)	I.C.	Yes	64.845 ± 0.009 d	16 (PRP)
^{95}Nb	12 (37)	I.C.	Yes	34.98[d] ± 0.02 d	4 (PRP)
$^{99}Tc^{m}$	15 (89)	I.C.	Yes	6.008 ± 0.004 h[c]	17 (PRP)
^{109}Pd	5.3 (36)	4πPC	Yes	13.402 ± 0.006 h	none
$^{113}In^{m}$	4 to 5 (19)	4πPC	Yes	99.49 ± 0.06 min	18 (PRP)
^{113}Sn	~ 9 (29)	I.C.	Yes	115.12 ± 0.13 d	16 (PRP)
$^{115}In^{m}$	5 to 11 (10)	I.C.	Yes	4.49 ± 0.01 h	19 (PRP)
^{133}Xe	14 (57)	I.C.	Yes	5.243 ± 0.001 d	20 (PRP)
^{133}Ba	0.17 (22)	I.C.	No	3785.17[d] ± 27.17 d	6 (PRP)
^{134}Cs	1.36 (34)	I.C.	No	753.78[d] ± 0.30 d	6 (PRP)
$^{134}Cs^{m}$	8.5 (22)	4πPC	Yes	2.914 ± 0.002 h	21 (PRP)
$^{137}Ba^{m}$	10 to 20	4πPC	Yes	2.554 ± 0.002 min	22
^{137}Cs	0.06 (22)	I.C.	No	10677.5[d] ± 140.3 d	6 (PRP)
^{139}Ce	12.7 (50)	I.C.	Yes	137.65 ± 0.03 d	23 (PRP)
^{141}Ce	9.0 (9)	I.C.	Yes	32.50 ± 0.03 d	none
^{152}Eu	0.31 (50)	I.C.	No	4892.3[d] ± 8.2 d	6 (PRP)
^{169}Yb	13.3 (32)	I.C.	Yes	32.015 ± 0.009 d	24 (PRP)

Table I (Continued)

Radionuclide	No. of Half-Lives followed (No. of Points)	Counting Equipment[a]	Completion Status	Half-Life	Reference[b]
^{198}Au	10 to 14 (252)	I.C.	Yes	2.6935[d] ± 0.0004 d	25 (PRP)
^{203}Hg	9 (13)	I.C.	Yes	46.60 ± 0.01 d	21 (PRP)
^{233}Pa	11 (112)	I.C.	Yes	26.967 ± 0.002 d	26 (PRP)

a) 4πPC indicates 4π gas flow proportional counter; I.C. indicates ionization chamber; 4πPC-γ indicates $4\pi\beta$-γ coincidence system.

b) 'none' indicates work done in this laboratory but never published; PRP indicates Physics Division Progress Report.

c) Form of source for ^{7}Be was dilute HCl solution; for ^{64}Cu was metal, and solutions of HNO_3, H_2SO_4, and NH_3; for $^{99}Tc^{m}$ was $NaTcO_4$ in solution.

d) These values have been updated since the reference given.

counting equipment used is listed next. Then the completion status is given: 'No' indicates that the experiment is ongoing, 'Yes' indicates the converse. Most of the entries indicated as ongoing are for rather long half-lives ($\geq$2 a); it is planned to continue these measurements for several more years and to update the values at appropriate intervals.

The half-life values are given in the fifth column. The stated uncertainties contain statistical and systematic components; Table IV gives a breakdown of the contribution from various sources of uncertainties to this overall uncertainty. For most of the measurements, the decay of the radionuclide was followed for one or more samples prepared from the same batch of the radionuclide; the statistical uncertainty used here is one standard deviation in the least squares fit to the counting data. In other cases half-life values from more than one preparation or supply of the nuclide were obtained. These are identifiable where Table I, column 2, shows a range in the number of half-lives followed. For these cases the external error in the weighted mean value is used as the statistical uncertainty.

Details about our estimates of sources of systematic uncertainty are given in sections 3 and 4 of this report. Column 5 of Table I lists the overall uncertainties for each nuclide. Where there is only one known source of systematic uncertainty its estimate is added to the statistical uncertainty to get the value shown in the table. Where more than one source of a systematic nature is estimated, the individual estimates are combined in quadrature and then added to the statistical uncertainty. Because the number of known sources of systematic uncertainty is very small, other published methods of combining statistical and systematic uncertainties[2,3] seem less appropriate here; they would tend to give smaller overall uncertainties.

In the reference column the letters PRP indicate that the only available account is in an AECL Physics Division Progress Report.

Table II lists the radionuclides for which we have determined gamma-ray emission probabilities (P_γ). The energy of the gamma ray and the γ-counting equipment are also listed. P_γ is given in percent

Table II

Radionuclides Issued as Standards for which P_γ Data are Submitted to SWG of ICRM

Radionuclide	E_γ(keV)	γ-counting equipment	P_γ(%)	Reference
^{7}Be	477	IC	10.32 ± 0.04	27, 28 (PRP)
^{42}K	1530	IC	19.1 ± 0.6	29 (PRP)
^{65}Ni	1482	IC	23.5 ± 0.4	15
^{75}Se	400.5	Ge(Li)	12.5 ± 0.3	30 (PRP)
^{85}Kr	510	scintillation spectrometer	0.46 ± 0.03	31
$^{99}Tc^{m}$	140 and 142	4πPC-γ	88.75 ± 0.14	32 (PRP)
$^{113}In^{m}$	392	IC	64.9 ± 0.2	18 (PRP)
$^{115}In^{m}$	336	IC	45.9 ± 0.3	19 (PRP)
^{137}Cs	662	IC	84.7 ± 0.6	33
^{139}Ce	165	4πPC-γ	79.95 ± 0.06	34
^{141}Ce	145.44	IC	48.5 ± 0.4	35

and the uncertainties are stated on the same basis as for Table I. Again, PRP in the Reference column indicates that the only available account is in an AECL Physics Division Progress Report.

3. HALF-LIFE MEASUREMENTS WITH A $4\pi\gamma$ IONIZATION CHAMBER

A $4\pi\gamma$ ionization chamber (IC) is the instrument that has been used for most half-life measurements in this laboratory. Decay data are taken relative to a ^{226}Ra reference source in order to correct for short-term fluctuations in the IC response. The decay usually is followed for about ten half-lives. In computing the data, corrections are made for ^{226}Ra decay using a half-life value of 1600 ± 7 years[36].

The ionization chamber is a TPA MkII[37,38] reentrant model filled with twenty atmospheres of argon. A diagram of the chamber[39] and a discussion about the use of ionization chambers for high-precision measurements have been given in recent review articles[39,40].

Table IV gives information about the contribution from various sources of uncertainty toward the overall uncertainty given in Table I.

The experimental setup, described in an earlier report[41], allows the charge built up on an integrating capacitor mounted across a vibrating reed electrometer to be read out with a digital voltmeter. The standard deviation for a single observation is typically ±0.02 to ±0.04% for conditions of source strength and counting interval that are representative during the first few half-lives of a half-life measurement.

Systematic error from long-term instability of the response of the ionization chamber has been investigated and found trivial. The same ionization chamber was used in an earlier study[41], which showed no evidence of gas leakage during the 10-year period prior to 1967; our calibration data since that time confirm this finding and indicate that any decrease in efficiency has been <0.1%. An example is the set of response factors shown in Table III for ^{198}Au calibrations versus a ^{226}Ra reference source. The ^{198}Au activity was determined independently by the $4\pi\beta$-γ coincidence method. The statistical uncertainty since 1969 has been ≈0.03%, but earlier measurements were less precise.

Table III

Ionization Chamber Response Factor
for ^{198}Au over a Period of Time

Date	IC Response Factor
1978 - May	3.1940
1977 - Jan	3.1950
1974 - May	3.1947
1969 - Sept	3.1924
1966 - Sept	3.196
1966 - July	3.192
1965	3.188
1963	3.194

The source was a sample of solution sealed in an ampoule. For most of the radionuclides studied these were glass ampoules, but for hydrofluoric acid solutions (e.g. ^{95}Nb and ^{233}Pa) polyethylene ampoules were used. The carrier solution is selected for stability and usually is the same as that used for standards of radionuclides[42]. No evidence of solution instability has been observed and therefore no contribution to systematic error from it has been included. Non-reproducibility of the source position in the chamber contributes to the statistical uncertainty in the half-life measurements. Tests with ^{60}Co have revealed that this effect is $\leq 0.01\%$[41] and arises largely from anisotropy in the chamber response[41]. The effect is greater for lower energy γ rays and correlates with the somewhat larger statistical uncertainties in the half-life values of nuclides that emit only low energy γ rays.

The ^{226}Ra reference sources were obtained from Amersham Corporation between 1964 and 1967. They are doubly encapsulated in iridium-platinum alloy. In 1972 the purity was investigated by γ-ray spectrometry[14] to assess the content of 6-year ^{228}Ra. None was detected and a limit of <0.01% was estimated at that time. Therefore, no correction was made for ^{228}Ra impurity when computing any of the half-lives reported here, but the possibility of its presence contributes slightly to the systematic uncertainty in some of the half-life values, as shown in Table IV. The accuracy of the ^{226}Ra half-life (1600 ± 7 a) is sufficient to allow us to neglect the effect of its uncertainty at this time, but if the decay of some of the longer-lived samples is followed for many more years, this might become significant. For example, it would contribute ≈ ±0.02 d to the uncertainty in the ^{60}Co half-life value.

Saturation of the ionization chamber is another source of error that has been investigated[40]. Tests with a series of ^{60}Co sources of various activities have been done to demonstrate the source strength at which saturation of the ion-current level gives a noticeable loss. Source strengths have been selected to stay below this level and thus avoid the difficulty.

Other systematic uncertainties in the measurements arise from radioactive impurities in the source samples. For some radionuclides chemical separations were performed prior to commencement of the measurement period, and these are indicated by CP in the first column of Table IV. The presence of impurities was investigated by two methods. One method was the identification of impurities by γ-ray spectrometry. If an impurity was found, corrections were made to the decay data. The difference between half-life values computed with and without these corrections was used to deduce the systematic uncertainty caused by impurities. The other method used to test for impurities was to divide the decay data into two or more sections, compute the half-life for each section separately, and examine the results for a significant difference. The magnitude of the difference found, if any, gave an indication of systematic uncertainty. Details about the actual impurities found or suspected in specific radionuclides are given in Appendix 1.

Table IV

Uncertainties in Half-Life Values Determined with the $4\pi\gamma$ Ionization Chamber

Radionuclide	Uncertainty in Half-Life Value from (a) Statistical (1 σ)		(b) Purity of ^{226}Ra Reference Source	(c) Impurities in Sample
^{7}Be CP*	0.004	d	nil	nil
^{18}F CP	0.013	min	nil	< 0.01 min
^{22}Na CP	0.12	d	0.1 d	0.11 d
^{24}Na CP	0.0005	h	nil	nil
^{46}Sc	0.011	d	0.004 d	nil
^{51}Cr CP	0.003	d	nil	nil
^{54}Mn CP	0.017	d	0.01 d	nil
^{56}Mn	0.0004	h	nil	≤ 0.0004 h
^{60}Co CP	0.77	d	0.2 d	0.56 d
^{64}Cu	0.001	h	nil	0.002 h
^{85}Sr	0.007	d	0.002 d	0.0005 d
^{95}Nb CP	0.002	d	nil	0.018 d
$^{99}Tc^{m}$	0.0007	h	nil	≤ 0.003 h
^{113}Sn	0.032	d	0.005 d	0.10 d
$^{115}In^{m}$ CP	0.005	h	nil	0.005 h
^{133}Xe SI*	0.0007	d	nil	0.0003 d
^{133}Ba CP	27.1	d	0.1 d	nil
^{134}Cs CP	0.26	d	0.04 d	nil

Table IV (Continued)

Radionuclide	Uncertainty in Half-Life Value from (a) Statistical (1 σ)	(b) Purity of ^{226}Ra Reference Source	(c) Impurities in Sample
^{137}Cs CP	140.2 d	0.1 d	nil
^{139}Ce	0.024 d	0.005 d	nil
^{141}Ce	0.02 d	nil	0.01 d
^{152}Eu	7.2 d	0.1 d	1.0 d
^{169}Yb	0.007 d	nil	0.002 d
^{198}Au	0.0002 d	nil	0.0002 d
^{203}Hg	0.005 d	nil	0.002 d
^{233}Pa	0.002 d	nil	nil

*CP indicates chemically purified; SI indicates separated isotope was irradiated to produce the radionuclide.

4. HALF-LIFE MEASUREMENTS WITH A 4π PROPORTIONAL COUNTER

A 4π proportional counter was used for most other half-life measurements reported here. This instrument is less suitable than an ionization chamber because it is subject to many more sources of systematic uncertainty. Chief among these are: 1) the dead time of the counting system; 2) instability of the radioactive source over a prolonged period of time; and 3) change in the voltage plateau.

Table V shows the contribution from individual sources of uncertainty toward the overall uncertainty given in Table I.

The dead time of the counting system was measured with the two-source method or the source-pulser method, both of which have been discussed by Taylor in a recent review[43]. Typically, the dead time was 2 μs with a standard deviation of ± 0.12 μs for a single observation. For the half-lives reported here the dead-time correction to the first data point was ≤3%. To study the magnitude of uncertainty in the half-

life value from an erroneous dead-time value, the data from a run were corrected for a dead-time value different by one standard deviation; the half-life was recomputed, and the difference in the half-life value was taken as the systematic uncertainty contributed by dead time. This approach gives an uncertainty estimate that is much lower than the maximum conceivable limit of error, and seems consistent with the 68% confidence level adopted here.

It is well-known that the thin sources required for 4π counting are susceptible to small gradual changes which affect the overall 4π counting efficiency. One such change is in the source material itself. An example is the sorption of water vapour, which frequently is encountered with halides of rare earths, alkaline earths and alkali metals, and depending upon circumstances, can change the self-absorption by ± 1% over a period of several months.

Another type of change can occur in the metallic coating of the film used as the source mount. A decrease in the electrical conductivity of the film may alter the voltage plateau and hence the counting rates observed at the selected counting voltages. For a typical plateau, with a slope of $\approx$ 0.2% per 100 V, an effect of $\geq$ 0.1% has been observed for sources of long-lived nuclides over a period of a few months. It was impracticable to make quantitative observations of this effect for the actual sources used in the half-life determinations reported here because the counting statistics were inadequate after the decay of several half-lives. Our only estimate of the magnitude of this source of uncertainty is based upon our experience with longer-lived nuclides. The effect is trivial for short-lived nuclides.

Another source of systematic uncertainty has been considered and found to be small. It is the effect from change in the counter response that is not associated with the source material or source mount. We have called this "instability of the counter" in Table V. It arises from changes in the gain of the detector, such as those associated with source

Table V

% Uncertainty from Various Sources in Half-life Values
Determined with a 4π Proportional Counter

Radionuclide	Statistical	Impurities	Dead-time	Instability of Source	Instability of Counter
^{18}F CP[a]	0.01 min	0.003 min	0.03 min	negligible	<0.01 min
^{24}Na CP	0.003 h	nil	0.007 h	0.001 h	0.001 h
^{42}K CP	0.003 h	nil	0.004 h	0.001 h	0.001 h
^{60}Co[b] CP	0.56 d	nil	0.38 d[b]	N/A[b]	N/A[b]
^{65}Ni SI[a]	0.0004 h	0.0001 h	0.0004 h	negligible	0.0003 h
^{82}Br CP	0.004 h	nil	0.009 h	0.006 h	0.004 h
^{109}Pd SI	0.0019 h	nil	0.004 h	0.001 h	0.0007 h
$^{113}In^{m}$ CP	0.02 min	0.002 min	0.04 min	negligible	0.005 min
$^{134}Cs^{m}$	0.0003 h	0.001 h	0.001 h	0.0003 h	0.0002 h
$^{137}Ba^{m}$ CP	0.001 min	0.001 min	0.001 min	negligible	0.0002 min

a) CP indicates chemically purified; SI indicates separated isotope was irradiated to produce the radionuclide.

b) By 4πβ-γ coincidence method which compensates for instabilities in the source and 4π proportional counter, and for which the methods of assessment of uncertainties in timing corrections have been described[44].

rate and the accumulation of a deposit on the counter wires over a period of time; these changes alter the voltage-plateau characteristics. Although our normal practice in recording an individual half-life datum is to average three observations taken at different voltages on the plateau, a small shift in either the slope or the position of the plateau might not be noticed and would bias the half-life value. In our judgment the limit of this shift gives ≈ 0.2% in the relative counting rate over the activity range and period usually followed. Assuming that one-third of this limit is consistent with a confidence interval of one, and taking into account the number of half-lives over which the decay was followed, the estimates listed in the last column of Table V were deduced.

5. MEASUREMENT OF GAMMA-RAY EMISSION PROBABILITIES (P_γ)

Most of the P_γ values listed in Table II were direct observations of the ratio of γ-ray emission rate to activity. The counting methods and instruments used were essentially the same as discussed in earlier sections of this report. The accuracy, when applied to individual P_γ measurements, is outlined in sections 6 and 7.

Determination of internal conversion data allowed P_γ values to be deduced for other radionuclides, namely $^{99}Tc^m$, ^{139}Ce, $^{113}In^m$ and $^{115}In^m$. The data for $^{99}Tc^m$ and ^{139}Ce were determined with a method patterned on that published by Taylor for ^{203}Hg[45]. The effect of variation in efficiency of the 4π(PC) upon 4πPC-γ coincidence results is analyzed to derive the fraction of the γ-ray transitions that are internally converted. The usual techniques for efficiency variation (variation of self- and film-absorption) were used here instead of the suspended foils described by Taylor[45]. Observations of the ratio, electron emission rate to γ-ray emission rate, gave internal conversion coefficients for $^{113}In^m$ and $^{115}In^m$.

6. UNCERTAINTIES IN GAMMA-RAY MEASUREMENTS FOR P_γ VALUES

Gamma-ray emission rates for ^{7}Be, ^{42}K, ^{65}Ni, $^{113}In^{m}$, $^{115}In^{m}$, ^{137}Cs and ^{141}Ce were determined with the calibrated $4\pi\gamma$ ionization chamber (see section 3). Response versus energy curves, relative to the response of the same ^{226}Ra reference sources described in section 3, were determined for three sample holders made from (1) 0.05-mm thick aluminum, (2) 0.4-mm cadmium, and (3) 1.2-mm cadmium inside 0.12-mm tantalum. The $4\pi\beta$-γ coincidence method was used to calibrate samples of suitable radionuclides. For data taken in recent years, the uncertainty in an individual calibration point (the combined uncertainty in the coincidence counting and ion-chamber measurements) was typically ± 0.3%[44]. These data were for 140-keV $^{99}Tc^{m}$ γ rays, 165-keV ^{139}Ce, 279-keV ^{203}Hg, 411-keV ^{198}Au, annihilation radiation from ^{18}F, 514-keV ^{85}Sr, 766-keV ^{95}Nb, 835-keV ^{54}Mn, 889- and 1120-keV ^{46}Sc, and 1173- and 1332-keV ^{60}Co. The calibration data for the energy region 279 to 1332 keV were fitted to a second-order polynomial, and for the entire energy range, to a third-order polynomial. To deduce the uncertainties in the fitted calibration curves for the three sample holders, response data were compared for test γ-ray energies, and the standard deviation among the three results was taken as the uncertainty. Uncertainties in the calibration are listed in Table VI. They are greatest for the low energy region and for energies above 1.33 MeV. For example, the uncertainties in instrument calibration in the cases of ^{42}K and ^{65}Ni are larger because the response curves had to be extrapolated beyond the highest energy calibration point. A further contribution to the uncertainty for ^{42}K is that at the time of this P_γ measurement, high-precision instrumentation and stable ^{226}Ra references were not yet available.

Gamma-ray emission rates for ^{75}Se and ^{85}Kr were obtained by gamma-ray spectrometry with Ge(Li) and NaI(Tℓ) detectors respectively. For the 401-keV ^{75}Se γ ray, the most relevant energy calibration points were ^{198}Au at 411 keV and ^{69}Zn at 439 keV; the ^{198}Au data were obtained from a $4\pi\beta$-γ coincidence standardization and the ^{69}Zn from the calibrated ion chamber. ^{22}Na standardized by $4\pi\beta$-γ coincidence counting was used to calibrate the NaI(Tℓ) detector in the energy region of ^{85}Kr; most of the uncertainty shown for this calibration comes from uncertainty in the source geometry used to simulate the Kr gas sample[31].

Table VI

Breakdown of Uncertainty (%) in P_γ Values

Radionuclide	Statistical	Impurities	γ-counting Calibration Curve	Other*
^{7}Be	0.07	nil	0.16	0.18, 0.2
^{42}K	0.2	nil	2.5	0.5
^{65}Ni	<0.1	nil	1.0	1.3, 0.2
^{75}Se	0.4	nil	1.0	1.0, 1.0
^{85}Kr	2.4	nil	2.5	0.3, 0.3, 1.5
^{137}Cs	0.15	0.01	0.5	0.083
^{141}Ce	0.05	0.1	1.6	0.1, 0.2

* See text, page 21 - 22.

7. UNCERTAINTIES IN ACTIVITY MEASUREMENTS FOR P_γ VALUES

The $4\pi(PC)$-γ coincidence method was used to determine the activity of ^{7}Be[27], ^{65}Ni[15], ^{75}Se[30], ^{137}Cs[33] and ^{141}Ce[35]; ^{42}K[29] and ^{85}Kr[31] activities were determined by 4π proportional counting and internal gas counting, respectively. For ^{7}Be, the difference between results from two different γ-channel gates was 0.18%, and uncertainty from spurious pulses was estimated as ± 0.2%. These are given in the last column of Table VI.

For ^{42}K, the other uncertainty listed is the uncertainty in self-absorption and source-mount absorption corrections.

The systematic uncertainty in $4\pi\beta$-γ coincidence counting ^{65}Ni was estimated as ± 0.2%. The other major source of uncertainty arises from the correction to the ion chamber data for the response of other ^{65}Ni γ rays, for which published values for relative gamma intensities[46] were used.

The determination of the activity of ^{75}Se by $4\pi\beta$-γ coincidence counting was complicated by uncertainties in the decay scheme. The uncertainty in the correction for the decay to $^{75}As^{m}$ was taken to be ± 1.0%. In addition, the complexity of the decay scheme necessitated higher-order polynomial fits to the efficiency data. Uncertainty here was judged to contribute another ± 1.0%, by examining the differences among results from two different γ-channel gates and second- and third-order fits.

For ^{85}Kr, the systematic uncertainties in internal gas counting were from wall effect (± 0.3%), uncertainty in counter volume (± 0.3%) and slope of the differential voltage plateau (± 1.5%). The slope was 1% per 100 V for a 300 V long plateau, and the average counting rate along the plateau was used as the result.

Sources of systematic uncertainty in an accurate measurement of the activity of ^{137}Cs determined by the 4π(PC)-γ efficiency-tracing method with ^{134}Cs as tracer have been reported in detail[33]. They are from dead-time and resolving-time corrections (± 0.022%), decay-scheme corrections (± 0.067%), sensitivity of the 4π(PC) to γ rays (± 0.024%), ^{134}Cs impurity (0.010%), and ^{134}Cs decay corrections (± 0.034%). Their combination in quadrature gives ± 0.083%.

The activity measurement of ^{141}Ce was done with less attention to minute details but has also been reported[35]. Here the main sources of systematic uncertainty were from dead-time and resolving-time corrections (± 0.1%), efficiency-dependent correction (± 0.2%), and impurities of ^{46}Sc and ^{139}Ce (± 0.1%).

UNCERTAINTIES IN P_{γ} VALUES FOR $^{99}Tc^{m}$, ^{139}Ce, $^{113}In^{m}$ and $^{115}In^{m}$

We have not been able to break down the overall uncertainty value given for $^{99}Tc^{m}$ [32] into its components. It was stated that the uncertainty consisted principally of allowances for various sources of possible systematic error. The final result was the mean value from five runs,

which came from three different preparations of $^{99}Tc^{m}$; thus it seems unlikely that impurities contributed significantly to the overall uncertainty.

For ^{139}Ce, other measurements[47] have been made from time to time since the first determination in 1962[34], and these have been in good agreement. The statistical uncertainty, though not always the same, has been unimportant compared with other sources of uncertainty. Typically these were from non-detection of conversion electrons in the 4π(PC) (± 0.1%), uncertainty in the correction for the sensitivity of the 4π(PC) to γ rays (± 0.1%), uncertainty in other instrumental corrections for dead time and resolving time (± 0.15%), and uncertainty in extrapolation of the efficiency function (± 0.2%). They are listed in Table VII.

Table VII

Breakdown of Uncertainty (%) in α_T* Values

Radionuclide	Statistical	Impurities	Other†
^{139}Ce	0.09	nil	0.1, 0.1, 0.15, 0.2
$^{113}In^{m}$	0.08	nil	0.15, 0.1, 0.4, 0.1, 0.1
$^{115}In^{m}$	0.23	.03	0.15, 0.1, 1.6, 0.6, 0.1

* $P_\gamma = 1/(1+\alpha_T)$, where α_T is total internal conversion coefficient.

† See text, page 23 - 24.

The electron emission rate from sources of $^{113}In^{m}$ was determined by 4π(PC) counting. Uncertainties in it were from the slope of the plateau (± 0.15%), and from the correction for sensitivity of the 4π(PC) to γ rays, $\varepsilon_{\beta,\gamma}$ (± 0.1%). Systematic uncertainty in the correction for dead-time was considered negligible because results for different counting rates were consistent. The γ-ray emission rate was determined for other samples of $^{113}In^{m}$ with the 4π ionization chamber, by using the three sample

holders. The uncertainty in calibration of the ionization chamber was taken as the standard deviation in the results from the three holders ($\pm$ 0.4%). The uncertainty in the γ-ray energy was estimated to affect the results by $\pm$ 0.1%. Corrections for Bremsstrahlung contributed another $\pm$ 0.1% uncertainty.

Similar measurements were made to get electron and γ-ray emission rates for $^{115}In^{m}$. The result of the experiment was a set of conversion-coefficient data. The same uncertainties were assigned for the 4π(PC) counting ($\pm$ 0.15% for plateau and $\pm$ 0.1% for $\varepsilon_{\beta,\gamma}$). A correction was necessary for the contribution to the 4π(PC) rate from $^{115}In^{m}$ β rays. At the time of the measurement this was estimated as $6 \pm 1\%$ but it seems likely this was in error. A recent evaluation gives $3.7 \pm 0.8\%$ [48], and its uncertainty contributes $\pm$ 1.6% to α_T. (This branching ratio gives $\alpha_T = 1.096$.) However, it can be shown that P_γ is unaffected by the β-branching ratio. The experimental data revealed that the 4π(PC) counting rate, $N_{4\pi}$, was equal to 1.1768 times the γ-ray emission rate, N_γ. Thus we have

$$N_{4\pi} = 1.1768\ N_\gamma$$

But $$N_{4\pi} = N_\beta + N_e + N_\gamma \varepsilon_{4\pi,\gamma}$$

and $$N_o = N_{4\pi} + N_\gamma$$

where N_β is the counting rate from the β-branch,
N_e is the counting rate from conversion electrons, and
$\varepsilon_{4\pi,\gamma}$ is the very small efficiency of the 4π(PC) counter for 336-keV γ rays ($\approx$0.1%). Since

$$P_\gamma = N_\gamma / N_o$$

it is unaffected by the relative contributions from β particles and conversion electrons to the 4π counting rate.

The uncertainty in calibration of the ionization chamber for $^{115}In^{m}$ γ rays, by the same criterion as for $^{113}In^{m}$, was deduced to be $\pm$ 0.6%. Bremsstrahlung was estimated as $\pm$ 0.1% and uncertainty in the γ-ray energy was considered negligible.

9. ACKNOWLEDGEMENTS

This summary includes experimental data accumulated in this laboratory over a long period of time by the authors and many other workers. In particular, valuable contributions were made by J.G.V. Taylor; others who contributed were P.J. Campion, S.C. Misra, B.A. Risto, E.A. Ouelette, G. Frketich and F.H. Gibson. Their careful records and reports made this summary possible.

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APPENDIX 1

IMPURITIES FOUND OR SUSPECTED IN SAMPLES OF RADIONUCLIDES

^{18}F - Chemical separation removed ^{3}H and traces of ^{24}Na, ^{38}Cl and ^{198}Au. The only residual activity was ^{187}W which was detected in all 7 preparations. The impurity varied between 0.002 and 0.015% at the start of a run. Its effect on the half-life value from the 4π(PC) results was 0.015 min but was negligible for the ionization chamber results.

^{24}Na - Chemical separation effectively removed ^{42}K.

^{42}K - Chemical separation effectively removed ^{24}Na.

^{56}Mn - Possibly a small impurity of 2.5-h ^{65}Ni. This would have a negligible effect on the result because the half-lives are nearly equal.

^{64}Cu - Gamma-ray spectrometry detected no impurities. ^{56}Mn is the most suspected impurity; 0.2% ^{56}Mn would cause an error of 0.004 h in the ^{64}Cu half-life.

^{65}Ni - An impurity of 0.03% ^{24}Na was typical at the start of a run.

^{85}Sr - Impurities of ^{57}Co (0.61%), ^{65}Zn (0.12%) and ^{133}Ba (0.24%) were estimated at the end of the measurement period. Corrections for these amounted to 3.7×10^{-4} % at the beginning and 0.9% at the end of the measurement period. If the impurities are not taken into account, the half-life value would be in error by 0.001 day.

^{95}Nb - An impurity of ^{95}Zr was detected. The correction for it was 0.1% at the start and 10% at the end of the period followed. If the ^{95}Nb half-life is computed without making a correction for the presence of ^{95}Zr, the result is longer by 0.09 d. It is assumed that the accuracy of the correction is ± 20% of this 0.09-d difference.

$^{99}Tc^{m}$ - For the sample used for the half-life measurement, an impurity of ^{99}Mo was detected. This was 0.1% at the beginning and 90% at the end of the measurement period.
Different samples were used for the α_T measurement. Specific information about their purity is not available.

$^{113}In^{m}$ - Impurities of ^{113}Sn were present in most samples, and the amounts varied between 0.001 and 0.003% at the start of the measurement period.

^{113}Sn - Impurities of ^{125}Sb, ^{60}Co and $^{114}In^{m}$ were detected, with ^{125}Sb predominant. The total correction at the start of the run was 0.76% and at the end it was 50%.

$^{115}In^{m}$ - $^{115}In^{m}$ samples were prepared by neutron irradiation of ^{114}Cd, followed by a 1-day waiting period, before chemical separation. The 1-day waiting period reduces the content of ^{117}In impurity. No long-lived impurities were detected, and it is estimated that short-lived impurities were $\leq$ 0.005% at the start of a run.

^{133}Xe - An impurity of $^{131}Xe^{m}$ was detected. This was 0.009% at the start and 2% at the end of the run. If the correction for this impurity is not made, the half-life value would be longer by 0.0006 day.

$^{134}Cs^{m}$ - Impurities of ^{24}Na and ^{134}Cs were detected; these were $\simeq$ 0.5% at the start of a run.

^{137}Cs - An impurity of 0.03 ± 0.01 % ^{134}Cs was present.

$^{137}Ba^{m}$ - An impurity of ^{137}Cs was present (0.003 % at the start).

^{141}Ce - Impurities of ^{139}Ce, ^{152}Eu and ^{154}Eu were present in the sample used for the half-life measurement. The correction for these was 0.04% at the beginning and 0.23% at the end of the measurement period.
Impurities of ^{139}Ce (0.11%) and ^{46}Sc (0.01%) were present in the sample used for P_{γ} determination.

^{152}Eu - An impurity of ^{154}Eu ($\approx$ 0.5%) was detected.

^{169}Yb - An impurity of ^{170}Tm was detected. This was 0.01% at the start of the run and 7.3% at the end. If the correction is neglected, the half-life value would be 0.010 day longer.

^{198}Au - It was calculated that the irradiation which produced this material should have produced 0.02% ^{199}Au. The effect of this on the ^{198}Au half-life value is 0.0001 day. Two separate irradiations gave values that differed by 0.0004 day.

^{203}Hg - Impurities of ^{60}Co and $^{110}Ag^{m}$ were detected. These were < 0.01% at the beginning and 3.6% at the end of the run.

Bureau International des Poids & Mesures
Sevres, France
A. Rytz

The half lives reported by BIPM consist of the following:

a) Published measurements

A. Rytz, J.W. Muller and C. Veyradier, Mesures de periodes radioactives, Comite International des Poids et Mesures, Proces-Verbaux 2e serie, 62e session, 41, 68 (1973)

^{54}Mn	$T_{1/2}$ = (312.19 ± 0.13) d	38 mesures, duree	2.22 $T_{1/2}$
^{60}Co	$T_{1/2}$ = (46195 ± 24) h	24 " "	1.11 $T_{1/2}$

ibid. 2e serie, 63e session, 42, 64 (1974)

^{54}Mn	$T_{1/2}$ = (312.15 ± 0.23) d (random 0.12, systematic 0.2)	3 $T_{1/2}$

b) Unpublished result

14 electrolytical deposits (Feb. 1974) of ^{60}Co were measured four times a year by 4pi beta(PC)-gamma counting. The results showed a considerable dependence on the coincidence formula used, due to incomplete compensation for losses at high rates with the Campion formulation.

Date of last measurement used	$T_{1/2}$, Campion formula	$T_{1/2}$, Cox-Isham formula
Jan 1976	46 170 h	
Nov 1976	46 129	
Feb 1977	46 124	
Oct/Nov 1977	46 132 (11)	46 213 (8)
Jul 1978		46 212 (6)
Oct 1978 (0.88 $T_{1/2}$)		46 212 (6) = (1925.5 ± 0.3) days best value

CENTRAL BUREAU OF NUCLEAR MEASUREMENTS

DECAY DATA MEASURED AT CBNM SINCE 1968

compiled by W. BAMBYNEK

The following list contains half-lives, γ-rays and KX-ray emission probabilities measured at CBNM since 1968. Only radiations with a probability greater than 5% per decay are included. The uncertainty statements have the following meaning :

$1\,\sigma$ corresponds to $\dfrac{st(f,\sigma)}{\sqrt{n}} + \dfrac{1}{3}\,\Sigma\,\delta$

$3\,\sigma$ corresponds to $\dfrac{st(f,3\sigma)}{\sqrt{n}} + \Sigma\,\delta$

where s = standard deviation of the single result
$t(f,\sigma)$ = student-t deviate for the number of degrees of freedom f and the chosen confidence level σ
n = number of independent results
δ_i = (residual) component systematic uncertainty which is an estimated limit of the uncertainty that remains after the correction of the results for the systematic effect.

^{57}Co $T_{1/2}$ = 271.90 $\pm$ 0.09 days $1\,\sigma$
R. Vaninbroukx, G. Grosse, W. Zehner
Int.J.Appl.Radiat.Isotopes, in press

^{58}Co $T_{1/2}$ = 70.81 $\pm$ 0.10 days $3\,\sigma$

^{60}Co $T_{1/2}$ = 5.283 $\pm$ 0.008 years $3\,\sigma$
both see :
R. Vaninbroukx, G. Grosse
Int.J. Appl. Radiat.Isotopes 27, 727 (1976)

^{65}Zn $T_{1.2}$ = 244.0 ± 0.2 days 1 σ

P_γ (1115) = 0.5075 ± 0.0010 1 σ

E. De Roost, E. Funck, A. Spernol, R. Vaninbroukx
Z.Physik 250, 395 (1972)

$^{93}Nb^m$ $T_{1/2}$ = 16.0 ± 0.8 years 1 σ

D. Reher, R. Vaninbroukx
CEC - JRC, CBNM, Nuclear Measurements, Programme Progress Report, January - June 1981

P_{KX} = 0.116 ± 0.004 1 σ

W. Bambynek, D. Reher, R. Vaninbroukx
Proc.Int.Conf. on Neutron Physics and Nuclear Data for Reactor and Other Applied Purposes
Harwell, Sept. 1978 (OECD Nucl. Energy Agency, Paris 1978), p.778

^{95}Zr $T_{1/2}$ = 64.05 ± 0.06 days 3 σ

^{95}Nb $T_{1/2}$ = 34.97 ± 0.03 days 3 σ

both see :
H.H. Hansen, G. Grosse, D. Mouchel, R. Vaninbroukx
Z.Physik A 278, 317 (1976)

^{103}Ru $T_{1/2}$ = 39.260 ± 0.020 days 1 σ

R. Vaninbroukx, G. Grosse, W. Zehner
Int.J.Appl.Radiat.Isotopes, in press

$^{103}Rh^m$ $T_{1/2}$ = 56.114 ± 0.020 min. 1 σ

R. Vaninbroukx, G. Grosse, W. Zehner
Int.J.Appl.Radiat.Isotopes, in press

P_{KX} = 0.0843 ± 0.0013 1 σ

R. Vaninbroukx, W. Zehner
Int.J.Appl.Radiat.Isotopes, in press

^{103}Pd $T_{1/2}$ = 16.991 ± 0.019 days 1 σ

R. Vaninbroukx, G. Grosse, W. Zehner

Int.J.Appl.Radiat.Isotopes, in press

^{109}Cd $T_{1/2}$ = 461.90 ± 0.30 days 1 σ

R. Vaninbroukx, G. Grosse, W. Zehner

Int.J.Appl.Radiat.Isotopes, in press

$^{113}In^{m}$ $T_{1/2}$ = 99.47 ± 0.07 min. 1 σ

H.H. Hansen, E. De Roost, D. Mouchel, R. Vaninbroukx

Int.J.Appl.Radiat.Isotopes 22, 1 (1971)

$^{115}In^{m}$ $T_{1/2}$ = 4.486 ± 0.004 hours 1 σ

$P_{\gamma}(336)$ = 0.459 ± 0.001 1 σ

H.H. Hansen, E. De Roost, W. van der Eijk, R. Vaninbroukx

Z.Physik 269, 155 (1974)

^{137}Cs $P_{\gamma}(662)$= 0.851 ± 0.004 1 σ

P_{KX}/P_{γ} = 0.0813 ± 0.0010 1 σ

H.H. Hansen, G. Lowenthal, A. Spernol, W. van der Eijk,

R. Vaninbroukx

Z.Physik 215, 25 (1969)

^{139}Ce $T_{1/2}$ = 137.66 ± 0.13 days 3 σ

R. Vaninbroukx, G. Grosse

Int.J.Appl.Radiat. Isotopes 27, 727 (1976)

^{141}Ce $T_{1/2}$ = 32.50 ± 0.04 days 3 σ

R. Vaninbroukx, G. Grosse

Int.J.Appl.Radiat.Isotopes 27, 727 (1976)

$P_{\gamma}(145)$= 0.482 ± 0.003 1 σ

P_{KX} = 0.168 ± 0.002 1 σ

H.H. Hansen, E. Celen, G. Grosse, D. Mouchel, A.Nylandsted Larsen

Z.Physik A 290, 113 (1979)

^{196}Au $T_{1/2}$ = 6.13 ± 0.02 days 1 σ

R. Vaninbroukx

Progress Report on Nuclear Data Research in the European Community, 1973 NEANDC(E)161"U", page 219 (1974)

^{204}Tl $T_{1/2}$ = 3.774 ± 0.005 years 1 σ

G. Bortels

Int.J.Appl.Radiat. Isotopes 20, 612 (1969)

^{231}Th P_γ (25.65) = 0.145 ± 0.003 1 σ

P_γ (84.16) = 0.066 ± 0.003 1 σ

R. Vaninbroukx, B. Denecke

Proceedings of the 5th Symposium on X- and Gamma-Ray Sources and Applications, Ann Arbor, June 10-12, 1981

Nucl.Instr.Methods, in press

^{233}U $T_{1/2}$ = (1.5925 ± 0.0040)10^5 years 3 σ

R. Vaninbroukx, P. De Bièvre, Y. Le Duigou, A. Spernol, W. van der Eijk, V. Verdingh

Phys. Rev. C 13, 315 (1976)

^{234}U $T_{1/2}$ = (2.446 ± 0.007)10^5 years 3 σ

P. De Bièvre, K.F. Lauer, Y. Le Duigou, H. Moret, G. Müschenborn, J. Spaepen, A. Spernol, R. Vaninbroukx, V. Verdingh

in M.L. Hurrell (ed.) Chemical Nuclear Data

(The British Nuclear Energy Soc., London, 1971) p. 221

^{235}U P_γ (143.8) = 0.109 ± 0.002 1 σ

P_γ (163.4) = 0.050 ± 0.001 1 σ

P_γ (185.7) = 0.575 ± 0.009 1 σ

P_γ (205.3) = 0.050 ± 0.002 1 σ

R. Vaninbroukx, B. Denecke

Proceedings of the 5th Symposium on X- and Gamma-Ray Sources and Applications, Ann Arbor, June 10-12, 1981

Nucl. Instr.Methods, in press

^{238}Pu $P_{LX} = 0.1141 \pm 0.0034$ 1σ

R. Vaninbroukx

INDC(NDS)-105/N (1979) p. 45

^{239}Pu $T_{1/2} = (2.4100 \pm 0.0030)10^{4}$ years 1σ

R. Vaninbroukx

INDC(NDS)-105/N (1979), p. 45

^{241}Pu $T_{1/2} = 14.60 \pm 0.10$ years 1σ

by ^{241}Am ingrowth

14.30 ± 0.14 years 1σ

by mass spectrometry

$T_{1/2}\ (\alpha) = (6.04 \pm 0.05)10^{5}$ years 1σ

R. Vaninbroukx

in: Neutron Physics and Nuclear Data for Reactor and Other Applied Purposes, Harwell, Sept. 1978 (OECD Nuclear Energy Agency, Paris, 1978) p. 235

Georgia Institute of Technology
School of Chemistry
Atlanta, Georgia, USA
R.W. Fink

Several reprints were supplied concerning the measurement of the ratio of x-ray components for diferent atomic numbers. These data, while pertinent to the calibration of spectrometers at low energy, were considered as best reserved for separate consideration by the SG at a later time. However, an article by W.D. Schmidt-Ott and R.W. Fink published in Z. Physik 249, 286 (1972) gives P_R data for ^{133}Ba. Professor Fink notes that the ICRM intercomparison results for that radionuclide should also be of interest for the present compilation.

PRECISION MEASUREMENTS OF GAMMA-RAY INTENSITIES

^{52}Mn, ^{56}Co, ^{88}Y, ^{90}Nb, ^{110m}Ag, ^{124}Sb, ^{133}Ba ^{134}Cs, ^{152}Eu, ^{154}Eu, ^{192}Ir, ^{198}Au and ^{207}Bi

Yasukazu Yoshizawa, Yosei Iwata
Department of Physics, Faculty of Science
Hiroshima University, Hiroshima, Japan
Toshio Katoh
Department of Nuclear Engineering, Faculty of Engineering
Nagoya University, Nagoya, Japan
Jian-Zhi Ruan, Toshiyuki Kojima
Department of Physics, Faculty of Science
Rikkyo University, Tokyo, Japan
and
Yasushi Kawada
Electrotechnical Laboratory, Tsukuba, Ibaragi, Japan

Abstract

Relative intensities of gamma rays from thirteen nuclides were measured with Ge(Li) detectors in the region from 280 to 2750 keV. The detectors were calibrated with standard sources specially prepared and cascade gamma-ray sources. The relative intensities were determined within accuracies of about 0.5 %. Intensities per decays were obtained from the relative intensities and internal conversion coefficients for most of the nuclides.

Precision measurements of gamma-ray intensities have been requested for the non-destructive nuclear fuel investigation. Recently Debertin et al. [1~5], Gehrke et al. [6] and Meyer [7] have performed precision measurements of relative intensities. Purpose of our experiments is to determine relative gamma-ray intensities of various nuclides with errors less than 1 % in the energy region 280~2750 keV. Standard sources were prepared at Electrotechnical Laboratory in Tokyo, and gamma-ray measurements were performed at Hiroshima University and Nagoya University.

Calibration sources. Standard sources were made from eight nuclides ^{22}Na, ^{46}Sc, ^{54}Mn, ^{60}Co, ^{85}Sr, ^{88}Y, ^{134}Cs and ^{203}Hg, and cascade gamma-ray sources were from four nuclides ^{24}Na, ^{52}Mn, ^{90}Nb and ^{108m}Ag. These calibration sources are listed in Table 1. Ten standard sources were made for each nuclide, and cascade gamma-ray sources of 1~4 were also made. All the samples of about 1 μCi were mounted on plastic capsules. The standard sources were made from solution (20~30 μCi/g), and density of solution was determined by means of the $4\pi\beta$-γ or 4πX-γ coincidence method. Four parts of solution were diluted by 3~4 times and about 10 samples were made from each diluted solution. These samples were measured with the coincidence system of a box type 4π counter and two 3"x3" NaI(Tl) detectors at Electrotechnical Laboratory.

Evaluated values of intensities per decays for the calibration sources are listed in Table 1. These values were obtained from decay schemes, internal conversion coefficients and relative intensities of weak gamma rays [8, 9]. Most of these gamma rays are more than 99 % per decay, and others are more than 80 %.

Gamma-ray measurements. In Hiroshima and also in Nagoya, measurements were performed with Ge(Li) spectrometers. The distance from the detector case to the source was always 20 cm. The detector was shielded by lead in Nagoya, and most of the measurements were done without shield in Hiroshima.

Following points were taken care of for measurements:

a) Absorption effect. Absorption of the plastic cover of the source capsule is about 0.8 % for 279 keV gamma rays and covers of the detectors are thicker. But the same capsules were used for gamma-ray sources and the measurements were done under the same condition.

b) Source position effect. In our efficiency measurements four sources

(three for one case) were used at the same time. Sources were placed at 3 cm (Hiroshima) or 2 cm (Nagoya) from the detector axis on a plastic plate which was at 20 cm from the surface of the detector case. Really counting rates were different for source positions on the plate. Since the source positions were changed by cyclic order, this effect was canceled in our measurements.

c) Source to detector distance. Accuracy of the distance is within 0.2 mm, and ambiguity of the average position of source material in the capsule is also within 0.2 mm. Therefore, the error of the counting rate originated from the ambiguity of the distance is within 0.2 %.

d) Dead time and counting loss. To compensate this effect, four sources were measured at the same time. Two or three common gamma rays were measured for different energy range. Integrated peak counts were normalized by integrated peak counts of these common gamma rays. This effect is negligible (<0.3 %).

The detector efficiencies were measured by using 12 kinds of the calibration sources in Hiroshima and by 9 kinds of ones in Nagoya. For each measurement four sources (three for some cases) were placed at four source positions. Spectra were taken three times in Hiroshima and once in Nagoya in the same condition. The sources were changed by cyclic order for four positions and five standard sources were used for each nuclide. Therefore, measurements of one kind of spectrum were 60 times in Hiroshima and 20 times in Nagoya. Total integrated peak counts were about 6×10^6 in Hiroshima and 2×10^6 in Nagoya.

Relative gamma-ray intensities of ^{88}Y and ^{207}Bi were measured in Hiroshima and Nagoya, and others were in Hiroshima. Gamma-ray spectra were analyzed by PDP 11/05 in Hiroshima and spectra taken in Nagoya were by a computer FACOM 230-25 at Rikkyo University. Data analyses were performed as follows:

a) Background subtraction. First, several gamma-ray peaks with low background were measured and ratios of tail heights to the peak height were determined. Background subtraction was done by a straight line or a quadratic curve and the shape of the response function was reproduced.

b) Subtraction of close-lying peak. Weaker gamma-ray peak was subtracted by using the shape of a stronger close-lying gamma-ray peak.

c) Integration of peak area. After background subtraction, channel counts higher than 1/50 of the peak center counts were integrated. The peak center counts were determined by Gaussian fitting.

d) Sum effect. Though the source to detector distance was 20 cm, the sum effect was not negligibly small. To correct this effect, the spectra of single

gamma rays of ^{54}Mn, ^{85}Sr and ^{203}Hg were measured and total efficiencies were obtained. The sum effect of cascade gamma rays was corrected for the cross over gamma rays. In addition, the sum effect with X rays was tested. For ^{108m}Ag the sum peak with the X rays was not observed at the source to detector distance of 20 cm, but the sum peak was observed at about 1 cm. For ^{133}Ba the sum peak with the X rays was observed at 20 cm. Therefore the correction is necessary to heavier elements.

Efficiency curves. Ratios of efficiencies in Hiroshima to those in Nagoya are almost constant except ^{203}Hg. Many efficiency curves were examined. However these curves are not satisfactory for precision measurement. Curves given by exponential functions were also examined. The final efficiency curves were determined with the errors of less than 0.5 %.

Experimental results. Experimental results of relative intensity measurements for ^{88}Y and ^{207}Bi in Hiroshima agree with those in Nagoya within experimental errors. The average values are obtained from the weighted mean, where the weights are given by the number of measurements. In addition, relative intensities of ^{52}Mn, ^{56}Co, ^{90}Nb, ^{110m}Ag, ^{124}Sb, ^{133}Ba, ^{134}Cs, ^{152}Eu, ^{154}Eu and ^{192}Ir were measured in Hiroshima. All experimental results are listed in Table 2.

Intensity balances between feeding transitions and outgoing transitions were calculated for five levels, in order to examine reliability of our measurements. The largest deviation is 0.6 % and the average is 0.32 %. Therefore our errors are reasonable. Our results are compared with previous measurements. Deviations are seen at 1038 keV and 2599 keV in ^{56}Co, at 1038 keV in ^{134}Cs and at 411 keV and 1086 keV in ^{152}Eu. However, our results agree with the most of values of Debertin et al. and Gehrke et al. within their experimental errors.

Gamma-ray intensities per decays are evaluated from our results of relative intensities and internal conversion coefficients by using the well established decay schemes. These values are shown in Table 2. In conclusion we succeeded in determining relative intensities with errors of about 0.5% for strong gamma rays. Most of our results shown here will be published [10~12].

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TABLE 1

Evaluated values of calibration gamma rays.

Nuclide	Half-life	Gamma-ray energy (keV)	Intensity per decay (%)	Remarks [a]
^{24}Na	14.987±0.020 h	2754.0	99.881 ±0.008	c
		1368.6	99.994 ±0.003	
^{90}Nb	14.6 h	2319.1	81.81 ±0.08	c
		1129.1	94.22 ±0.09	
^{88}Y	106.61 ±0.21 d	1836.1	99.24 ±0.07	s
^{52}Mn	5.67 d	1434.3	99.9871±0.0014	c
		935.5	94.89 ±0.03	
^{60}Co	5.272±0.002 y	1332.5	99.9816±0.0015	s
		1173.2	99.89 ±0.02	
^{22}Na	2.603±0.004 y	1274.5	99.94 ±0.02	s
^{46}Sc	84.34 ±0.13 d	1120.5	99.9871±0.0012	s
		889.3	99.9836±0.0016	
^{54}Mn	312.16 ±0.11 d	834.8	99.9746±0.0025	s
^{134}Cs	2.061±0.005 y	795.8	85.51 ±0.05	s
		604.7	97.64 ±0.06	
^{108m}Ag	127 ±21 y	722.9	99.7 ±0.4 [b]	c
		614.3	100.00 ±0.03 [b]	
		434.0	99.48 ±0.09 [b]	
^{85}Sr	64.68 ±0.24 d	514.0	98.4 ±0.4	s
^{203}Hg	46.60 ±0.02 d	279.2	81.48 ±0.08	s

a) Symbols c and s indicate cascade gamma-ray sources and standard sources, respectively.

b) Relative intensity.

TABLE 2

Relative intensities and intensities per decays of gamma rays.

Nuclide	Gamma ray		
	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
^{52}Mn	346.0	1.032 ±0.026	1.032 ±0.026
	398.1	0.088 ±0.011	0.088 ±0.011
	399.6	0.170 ±0.017	0.170 ±0.017
	502.1	0.218 ±0.026	0.218 ±0.026
	600.1	0.387 ±0.026	0.387 ±0.026
	647.5	0.43 ±0.03	0.43 ±0.03
	744.2	90.8 ±0.3	90.35 ±0.07
	848.2	3.39 ±0.03	3.39 ±0.03
	935.5	95.0 ±0.3	94.89 ±0.03
	1246.2	4.32 ±0.09	4.32 ±0.09
	1247.8	0.37 ±0.09	0.37 ±0.09
	1333.6	5.07 ±0.03	5.07 ±0.04
	1434.1	100.0 ±0.3	99.9871±0.0014
	1645.8	0.056 ±0.004	0.056 ±0.004
	1981.1	0.036 ±0.003	0.036 ±0.004
^{56}Co	486.5	0.061 ±0.010	0.061 ±0.010
	733.6	0.193 ±0.012	0.193 ±0.012
	787.8	0.305 ±0.013	0.305 ±0.013
	846.8	100.0 ±0.3	99.920 ±0.007
	896.6	0.095 ±0.018	0.095 ±0.018
	977.4	1.435 ±0.016	1.434 ±0.016
	996.9	0.129 ±0.014	0.129 ±0.014
	1037.8	14.16 ±0.05	14.15 ±0.07
	1089.1	0.05 ±0.03	0.05 ±0.03
	1140.3	0.131 ±0.021	0.131 ±0.021
	1160.0	0.095 ±0.014	0.095 ±0.014
	1175.1	2.241 ±0.012	2.239 ±0.014
	1198.8	0.051 ±0.009	0.051 ±0.009
	1238.3	66.06 ±0.21	66.0 ±0.3
	1272.0	0.025 ±0.008	0.025 ±0.008
	1335.5	0.130 ±0.006	0.130 ±0.006
	1360.2	4.265 ±0.017	4.262 ±0.022
	1442.7	0.172 ±0.007	0.172 ±0.007
	1462.3	0.084 ±0.006	0.084 ±0.006
	1640.4	0.070 ±0.011	0.070 ±0.011

Nuclide	Gamma ray		
	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
	1771.4	15.49 ±0.05	15.48 ±0.07
	1810.7	0.657 ±0.023	0.656 ±0.023
	1963.8	0.707 ±0.011	0.706 ±0.011
	2015.4	3.026 ±0.014	3.024 ±0.017
	2034.9	7.766 ±0.028	7.76 ±0.04
	2113.3	0.363 ±0.007	0.363 ±0.007
	2213.0	0.389 ±0.008	0.389 ±0.008
	2276.1	0.124 ±0.007	0.124 ±0.007
	2373.5	0.083 ±0.011	0.083 ±0.011
	2523.8	0.068 ±0.011	0.068 ±0.011
	2598.6	16.96 ±0.06	16.95 ±0.08
	2657.4	0.021 ±0.006	0.021 ±0.006
^{88}Y	898.0	94.4 ±0.3	93.7 ±0.4
	1836.1	100.0 ±0.3	99.24 ±0.07
^{90}Nb	329.1	0.12 ±0.07	0.12 ±0.06
	371.3	2.14 ±0.04	2.02 ±0.04
	518.6	0.59 ±0.09	0.56 ±0.09
	561.6	0.124 ±0.024	0.117 ±0.023
	757.9	0.069 ±0.024	0.065 ±0.023
	827.7	1.30 ±0.06	1.22 ±0.06
	890.6	2.05 ±0.06	1.93 ±0.05
	1051.5	0.25 ±0.03	0.23 ±0.03
	1129.2	100.0 ±0.3	94.22 ±0.09
	1270.4	1.253 ±0.020	1.181 ±0.019
	1470.5	0.50 ±0.03	0.471 ±0.029
	1575.0	0.531 ±0.025	0.499 ±0.024
	1611.8	2.54 ±0.03	2.40 ±0.03
	1658.1	0.302 ±0.023	0.294 ±0.022
	1716.3	0.561 ±0.025	0.528 ±0.023
	1843.3	0.73 ±0.03	0.69 ±0.03
	1913.2	1.41 ±0.03	1.33 ±0.03
	2056.3	0.13 ±0.05	0.12 ±0.04
	2186.2	19.19 ±0.08	18.11 ±0.08
	2222.3	0.67 ±0.03	0.630 ±0.029
	2319.0	86.68 ±0.28	81.82 ±0.08
	2741.0	0.0102±0.0026	0.0096±0.0025
	2747.8	0.0081±0.0026	0.0076±0.0025
^{110m}Ag	365.4	0.091 ±0.019	0.086 ±0.018
	387.1	0.08 ±0.04	0.07 ±0.03
	396.9	0.06 ±0.03	0.06 ±0.03
	446.8	3.955 ±0.028	3.739 ±0.027
	620.4	2.965 ±0.019	2.803 ±0.019

Nuclide	Gamma ray		
	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
	626.3	0.228 ±0.014	0.216 ±0.013
	657.8	100.0 ±0.4	94.54 ±0.20
	676.6 }	11.09 ±0.08	10.48 ±0.09
	677.6 }		
	687.0	6.80 ±0.06	6.43 ±0.06
	706.7 }	17.66 ±0.10	16.70 ±0.12
	708.3 }		
	744.3	5.000 ±0.027	4.73 ±0.03
	763.9	23.55 ±0.09	22.26 ±0.13
	818.0	7.76 ±0.04	7.33 ±0.05
	884.7	76.76 ±0.26	72.6 ±0.4
	937.5	36.31 ±0.12	34.33 ±0.20
	997.2	0.142 ±0.005	0.134 ±0.005
	1085.4	0.066 ±0.012	0.062 ±0.012
	1117.5	0.041 ±0.006	0.039 ±0.005
	1125.7	0.038 ±0.008	0.036 ±0.007
	1163.2 }	0.079 ±0.012	0.075 ±0.011
	1164.9 }		
	1251.0	0.024 ±0.007	0.023 ±0.007
	1300.0	0.025 ±0.008	0.024 ±0.008
	1334.4	0.149 ±0.006	0.141 ±0.005
	1384.3	25.66 ±0.08	24.25 ±0.14
	1421.0	0.039 ±0.003	0.037 ±0.003
	1475.8	4.222 ±0.017	3.992 ±0.024
	1505.0	13.78 ±0.05	13.03 ±0.07
	1562.3	1.087 ±0.007	1.028 ±0.008
	1592.6	0.0221±0.0013	0.0209±0.0012
	1629.6	0.0061±0.0011	0.0058±0.0010
	1775.4	0.0067±0.0011	0.0063±0.0010
	1783.4	0.0103±0.0011	0.0097±0.0010
	1903.5	0.0158±0.0015	0.0149±0.0014
^{124}Sb	370.4	0.051 ±0.009	0.050 ±0.009
	400.0	0.129 ±0.016	0.127 ±0.015
	444.0	0.205 ±0.010	0.201 ±0.009
	468.6	0.058 ±0.008	0.057 ±0.008
	525.5	0.117 ±0.012	0.115 ±0.012
	602.7	100.0 ±0.4	97.83 ±0.05
	632.4	0.114 ±0.006	0.111 ±0.006
	645.8	7.61 ±0.03	7.44 ±0.04
	662.5	0.016 ±0.005	0.015 ±0.005
	709.3	1.399 ±0.011	1.368 ±0.012

Nuclide	Gamma ray		
	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
	713.82	2.338 ±0.012	2.288 ±0.015
	722.8	11.02 ±0.04	10.78 ±0.06
	735.9	0.133 ±0.009	0.130 ±0.008
	790.8	0.758 ±0.009	0.741 ±0.009
	816.8	0.079 ±0.006	0.077 ±0.006
	856.9	0.029 ±0.007	0.029 ±0.007
	899.8	0.016 ±0.009	0.016 ±0.009
	968.3	1.919 ±0.013	1.877 ±0.014
	976.4	0.088 ±0.008	0.086 ±0.008
	1045.2	1.864 ±0.017	1.824 ±0.018
	1086.3	0.038 ±0.009	0.037 ±0.009
	1263.1	0.046 ±0.015	0.045 ±0.014
	1301.2	0.041 ±0.015	0.040 ±0.015
	1325.5	1.584 ±0.022	1.549 ±0.022
	1355.2	1.042 ±0.027	1.019 ±0.027
	1368.2	2.67 ±0.03	2.61 ±0.03
	1376.1	0.501 ±0.020	0.490 ±0.020
	1385.2	0.061 ±0.026	0.060 ±0.025
	1436.7	1.225 ±0.024	1.198 ±0.024
	1445.3	0.358 ±0.017	0.351 ±0.017
	1489.0	0.679 ±0.019	0.664 ±0.018
	1526.3	0.410 ±0.024	0.401 ±0.024
	1579.9	0.433 ±0.012	0.424 ±0.012
	1622.4	0.035 ±0.012	0.034 ±0.012
	1691.0	48.58 ±0.16	47.52 ±0.23
	1720.3	0.097 ±0.007	0.095 ±0.007
	1918.7	0.052 ±0.004	0.051 ±0.004
	2015.0	0.0093±0.0026	0.0091±0.0025
	2039.3	0.0589±0.0029	0.0576±0.0028
	2078.5	0.0163±0.0025	0.0159±0.0024
	2091.0	5.589 ±0.022	5.47 ±0.03
	2099.0	0.045 ±0.006	0.044 ±0.006
	2108.0	0.0438±0.0027	0.0428±0.0026
	2182.6	0.0398±0.0019	0.0389±0.0019
	2283.2	0.0041±0.0013	0.0040±0.0013
	2293.7	0.031 ±0.010	0.030 ±0.010
	2693.9	0.0027±0.0019	0.0026±0.0019
^{133}Ba	276.4	11.53 ±0.06	7.15 ±0.03
	302.8	29.48 ±0.14	18.28 ±0.08
	356.0	100.0 ±0.4	62.00 ±0.14
	383.8	14.39 ±0.06	8.92 ±0.04

Nuclide	Gamma ray		
	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
^{134}Cs	563.1	8.57 ±0.03	8.37 ±0.05
	569.2	15.78 ±0.06	15.40 ±0.08
	604.7	100.0 ±0.4	97.64 ±0.06
	795.8	87.5 ±0.3	85.52 ±0.05
	801.8	8.89 ±0.03	8.68 ±0.04
	1038.4	1.008 ±0.005	0.984 ±0.006
	1167.7	1.827 ±0.008	1.783 ±0.010
	1365.0	3.074 ±0.013	3.001 ±0.017
^{152}Eu	295.9	2.14 ±0.04	
	329.4	0.711 ±0.014	
	344.3	127.9 ±0.6	
	367.8	4.16 ±0.04	
	411.1	10.90 ±0.05	
	443.9	15.06 ±0.06	
	488.7	2.031 ±0.015	
	503.5	0.768 ±0.018	
	564.0	2.43 ±0.04	
	566.6	0.64 ±0.06	
	586.3	2.19 ±0.08	
	656.5	0.71 ±0.05	
	674.6	0.94 ±0.05	
	678.6	2.28 ±0.05	
	688.6	4.20 ±0.04	
	719.3	1.67 ±0.03	
	764.8	0.95 ±0.05	
	778.8	62.16 ±0.22	
	810.4	1.56 ±0.04	
	841.5	0.837 ±0.023	
	867.3	20.33 ±0.10	
	901.2	0.40 ±0.05	
	919.3	2.08 ±0.06	
	926.2	1.38 ±0.06	
	930.5	0.37 ±0.06	
	963.3 } 964.0 }	70.14 ±0.23	
	1005.1	3.078 ±0.024	
	1085.8	48.15 ±0.16	
	1089.7	8.35 ±0.04	

Nuclide	Gamma ray		
	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
	1108.9	1.00 ±0.05	
	1112.0	64.67 ±0.21	
	1212.0	6.85 ±0.05	
	1249.9	0.875 ±0.024	
	1292.7	0.46 ±0.03	
	1299.2	7.80 ±0.05	
	1408.0	100.0 ±0.3	
	1457.6	2.391 ±0.029	
	1528.1	1.346 ±0.013	
^{154}Eu	401.2	0.49 ±0.04	
	444.5	1.64 ±0.03	
	478.3	0.626 ±0.027	
	557.6	0.758 ±0.024	
	582.0	2.61 ±0.03	
	591.7	14.35 ±0.06	
	625.2	0.927 ±0.021	
	676.5	0.47 ±0.05	
	692.4	5.182 ±0.025	
	723.2	58.19 ±0.21	
	756.8	13.18 ±0.07	
	815.5	1.51 ±0.05	
	845.4	1.687 ±0.021	
	850.7	0.692 ±0.023	
	873.1	35.18 ±0.12	
	892.8	1.497 ±0.026	
	904.1	2.62 ±0.03	
	996.2	30.09 ±0.12	
	1004.7	52.04 ±0.19	
	1128.5	0.90 ±0.04	
	1140.7	0.671 ±0.014	
	1241.4	0.38 ±0.05	
	1246.2	2.49 ±0.04	
	1274.4	100.0 ±0.3	
	1494.2	2.058 ±0.016	
	1596.7	5.247 ±0.026	
^{192}Ir	283.3	0.303 ±0.022	0.251 ±0.018
	296.0	34.62 ±0.17	28.70 ±0.28
	308.5	35.84 ±0.18	29.71 ±0.29
	316.5	100.0 ±0.5	82.9 ±0.6
	374.5	0.861 ±0.008	0.714 ±0.009

Nuclide	Gamma ray		
	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
	416.5	0.800 ±0.010	0.661 ±0.010
	420.5	0.078 ±0.009	0.065 ±0.007
	468.1	57.50 ±0.23	47.7 ±0.4
	484.6	3.810 ±0.018	3.16 ±0.03
	489.1	0.525 ±0.009	0.435 ±0.008
	588.6	5.398 ±0.021	4.48 ±0.04
	593.4	0.052 ±0.003	0.0432±0.0026
	604.4	9.75 ±0.04	8.08 ±0.07
	612.5	6.336 ±0.025	5.25 ±0.05
	884.5	0.3420±0.0024	0.284 ±0.003
	1061.5	0.0631±0.0011	0.0523±0.0010
	1089.9	0.0010±0.0005	0.0008±0.0004
	1378.0	0.0016±0.0005	0.0013±0.0004
^{198}Au	411.8	100.0 ±0.4	95.56 ±0.08
	675.9	0.841 ±0.003	0.804 ±0.005
	1087.7	0.1664±0.0021	0.1591±0.0021
^{207}Bi	569.7	100.0 ±0.4	97.74 ±0.03
	897.3	0.122 ±0.013	0.119 ±0.012
	1063.6	75.79 ±0.25	74.0 ±0.3
	1442.2	0.132 ±0.005	0.129 ±0.005
	1770.2	7.026 ±0.029	6.87 ±0.04

International Atomic Energy Agency
Laboratory Seibersdorf
Vienna, Austria
H. Houtermans, O. Milosevic and F. Reichel

The values given in the summary table have been extracted from the article in Int. J. appl Radiat. Isotopes, 31 153 (1980). The overall uncertainties are the "arithmetic sum of the statistical error (c.l. 68%) and the systematic errors, which are estimated for the same confidence level".

Institute d'Electrochimie et de Radiochimie
Ecole Polytechnique Federale
Lausanne, Switzerland
Marc Decombaz and J.-J. Gostely

A half life of (137.8 ± 0.2) d was measured for ^{139}Ce in connection with an international intercomparison arranged by the Bureau International des Poids et Mesures, and reported in Rapport BIPM - 77/4. The activity of three sources was measured by the 4 pi(PC)-gamma coincidence method, and followed for 2.5 months. The uncertainty has the significance of the standard deviation of the mean.

Idaho National Engineering Laboratory
EG&G, Idaho, Inc.
Idaho Falls, Idaho, USA
R.J. Gehrke, R.G.Helmer and R.C. Greenwood

The authors report that the data given in Nuclear Instruments and Methods 147, 405 (1977) remain valid as given. This article gives a description of their equipment, methods, corrections and analysis of uncertainties. The significance of the uncertainties is the same as requested here.

Lawrence Livermore Laboratory
University of California
Livermore, California, USA
R. A. Meyer

The data included in the summary table have been taken from Lawrence Livermore Laboratory report M-100, Multigamma-Ray Calibration Sources, December 1, 1978. The uncertainties are taken to be comparable in their meaning to that requested for the compilation.

NUCLEAR DATA FOR PHOTON SPECTROMETERS CALIBRATION

F. LAGOUTINE, J. MOREL, J. LEGRAND
LABORATOIRE DE METROLOGIE DES RAYONNEMENTS IONISANTS (FRANCE)

This document presents, on the one hand, the nuclear constants characteristic of several radionuclides measured at Laboratoire de Métrologie des Rayonnements Ionisants since the year 1970 and, on the other hand, X or γ references used for the efficiency calibration of photon spectrometers.

Concerning the first part of this document, LMRI contributed to the study of decay schemas by the following measurements :

Half lives

^{7}Be - ^{24}Na - ^{33}P - ^{51}Cr - ^{56}Co - ^{56}Mn - ^{57}Co - ^{58}Co - ^{55}Fe - ^{65}Zn - ^{67}Cu - ^{67}Ga - ^{75}Se - ^{85}Sr - ^{88}Y - ^{89}Y - ^{90}Sr - ^{99m}Tc - ^{103}Ru - ^{109}Cd - ^{111}In - ^{113m}In - ^{123}I - ^{125m}Te - ^{131}Cs - ^{131}I - ^{134}Cs - ^{137m}Ba - ^{139}Ce - ^{152}Eu - ^{152m}Eu - ^{169}Yb - ^{176m}Lu - ^{177}Lu - ^{192}Ir - ^{201}Tl - ^{252}Cf.

X or γ-rays

^{60}Co - ^{59}Fe - ^{54}Cu - ^{93m}Nb - ^{133}Ba - ^{141}Ce - ^{152}Eu - ^{176m}Lu - ^{192}Ir - ^{239}Pu - ^{241}Am

Internal conversion

^{90}Sr - ^{90}Y - ^{93m}Nb - ^{95}Nb - ^{99m}Tc - ^{109}Cd - ^{113m}In - ^{125m}Te - ^{129m}Xe ^{135m}Ba - ^{137m}Ba (^{137}Cs) ^{139}Ce - ^{141}Ce

Other constants

^{64}Cu - (β^-, β^+ emission) - ^{99}Tc (β^- emission) - ^{103}Rh (X_K emission) - Cr (ω_K)

The following rule was generally adopted for evaluating the total uncertainty of measured constants at LMRI :
The uncertainty is the result of the sum of the statistical uncertainties, evaluated at 99.7 % confidence level and combined quadratically, and of the systematic ones themselves, summed linearly.

Concerning the second part of this document, dealing with X or γ references used in γ spectrometry, most of the data mentioned (especially γ emission intensities) come from Table des Radionucléides (LMRI).

LABORATOIRE DE METROLOGIE DES
RAYONNEMENTS IONISANTS

AOÛT 1980

PARAMETRES DE SCHEMA DE DESINTEGRATION

MESURES AU LMRI DEPUIS 1970

^{7}Be période

T 1/2	incertitude	unité	référence
53,17	0,07	jour	IJARI, 26 (1975), 131

^{24}Na période

T 1/2	incertitude	unité	référence
14,956	0,008	heure	publication en cours

^{33}P période

T 1/2	incertitude	unité	référence
25,56	0,07	jour	IJARI, 23 (1972), 219

^{51}Cr période

T 1/2	incertitude	unité	référence
27,72	0,07	jour	IJARI, 26 (1975), 131

^{56}Co période

T 1/2	incertitude	unité	référence
77,12	0,20	jour	IJARI, 29 (1978), 269

^{56}Mn période

T 1/2	incertitude	unité	référence
2,5785	0,0006	heure	NIM, 112 (1973), 323

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^{24}Cr rendement de fluorescence

ω_k	incertitude	référence
0,290	0,003	Z.Phys. A 284 (1978), 389

---

^{57}Co période

T 1/2	incertitude	unité	référence
271,23	0,63	jour	IJARI, 23 (1972), 219

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^{58}Co période

T 1/2	incertitude	unité	référence
70,78	0,13	jour	IJARI, 26 (1975), 131

---

^{60}Co probabilité d'émission P_γ

P_γ (2158keV)	incertitude	référence
$0,5 \times 10^{-5}$	$0,2 \times 10^{-5}$	IJARI, 23 (1972), 225

---

^{55}Fe période

T 1/2	incertitude	unité	référence
2,68	0,02	an	publication en cours

^{59}Fe probabilité d'émission P_γ

E_γ	P_γ	incertitude	référence
142	0,0098	0,0004	Nucl. Phys.
192,2	0,0295	0,0008	A 142, (1970), 63
334,7	0,0024	0,0004	
381	0,00023	0,00005	
1099	0,555	0,017	
1292	0,441	0,012	
1481	0,0009	0,0002	

^{64}Cu probabilité d'émission β^-

P_{β^-}	incertitude	référence
0,180	0,005	N.T. LMRI 76/17

rapport β^-/β^+, γ/β^+

β^-/β^+	incertitude	
1,99	0,10	"

γ/β^+		
0,0260	0,0011	"

énergie γ

E γ	incertitude	unité	"
1345,88	0,12	keV	

---

^{65}Zn période

T 1/2	incertitude	unité	référence
243,75	0,35	jour	IJARI, 26 (1975), 131

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^{67}Cu période

T 1/2	incertitude	unité	référence
61,83	0,21	heure	IJARI, 23 (1972), 219

---

^{67}Ga période

T 1/2	incertitude	unité	référence
78,33	0,10	heure	IJARI, 29 (1978), 269

^{75}Se période

T 1/2	incertitude	unité	référence
118,45	0,25	jour	IJARI, 26 (1975), 131

^{85}Sr période

T 1/2	incertitude	unité	référence
64,68	0,23	jour	IJARI, 23 (1972)

^{88}Y période

T 1/2	incertitude	unité	référence
106,6	0,4	jour	IJARI, 26 (1975), 131

^{89}Sr période

T 1/2	incertitude	unité	référence
50,75	0,25	jour	IJARI, 23 (1972), 219

^{90}Sr période

T 1/2	incertitude	unité	référence
28,15	0,10	ans	IJARI, 29 (1978), 269

Probabilités d'émission d'électrons de conversion

P_{e^-}	incertitude	référence
$1,2 \times 10^{-4}$	$0,6 \times 10^{-4}$	CONF-720404 (1972)

probabilité d'émission de paires internes

P_{e^+}	incertitude	
$3,9 \times 10^{-5}$	$0,4 \times 10^{-5}$	"

rapport K/LMN

K/LMN	incertitude	
3,2	0,7	"

probabilité d'ionisation interne

$\bar{P}_k$	incertitude	
$3,6 \times 10^{-4}$	$0,4 \times 10^{-4}$	"

---

^{90}Y probabilité d'ionisation interne

$\bar{P}_k$	incertitude	
$6,0 \times 10^{-4}$	$0,6 \times 10^{-4}$	"

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^{93m}Nb énergie γ

E_γ	incertitude	unité	référence
30,77	0,02	keV	C.R. Acad. Sci. Paris E. 284 (1977)

rapport des émissions $\gamma\, X_K$

γ/X_k	incertitude	
$8,0 \times 10^{-5}$	$1,0 \times 10^{-5}$	"

rapport de coefficients de conversion interne

K/LM ...	incertitude	référence
0,173	0,007	Thèse-Doctorat ès Sciences Orsay n° 2166 (1979)

^{95}Nb coefficient de conversion interne α_K

αK	incertitude	référence
$1,18 \times 10^{-3}$	$0,05 \times 10^{-3}$	CONF-720404 (1972)

rapport K/L

K/L	incertitude
8,7	0,7

---

^{99m}Tc période

T 1/2	incertitude	unité	référence
6,031	0,012	heure	IJARI, 21 (1970), 139

coefficient de conversion interne αt

αt	incertitude	référence
0,118	0,003	Rapport CEA-R-4427 (1973)

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^{99}Tc probabilité d'émission β^- de 202 keV

P_{β^-}	incertitude	référence
$1,6 \times 10^{-5}$		Phys.Rev. 8C (1973), 366

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^{103}Rh période

T 1/2	incertitude	unité	référence
56,112	0,028	minutes	IJARI, 29 (1978), 269

probabilité d'émission X_K

P (X_K)	incertitude	référence
0,0753	0,0034	N.T. LMRI 76/13

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^{109}Cd Coefficient de conversion interne αt pour la transition γ de 88 keV

αt	incertitude	référence
25,4	0,5	Rapport CEA-R-4427 /1973/

T 1/2	incertitude	unite	
463,1	0,8	jour	Publication en cours

^{111}In période

T 1/2	incertitude	unité	référence
2,802	0,003	jour	IJARI, 29 (1978), 269

---

^{113m}In période

T 1/2	incertitude	unité	référence
1,658	0,004	heure	IJARI, 21 (1970), 139

Coefficients de conversion interne

αt	incertitude	référence
0,559	0,014	IJARI, 21 (1970), 139
αk		
0,441	0,013	"

---

^{123}I période

T 1/2	incertitude	unité	référence
13,214	0,034	heure	publication en cours

---

^{125m}Te période

T 1/2	incertitude	unité	référence
57,40	0,15	jour	IJARI, 29 (1978), 269

Coefficients de conversion interne

αt	incertitude	référence
14,25	0,64	Thèse-Doctorat ès Sciences Orsay n° 2166 (1979)
αk		
11,90	0,31	"

Rapports de coefficients de conversion interne

$L_1/L_2/L_3$	référence
$1/0,082 \pm 0,004/0,019 \pm 0,003$	Thèse Doctorat ès Sciences Orsay n° 2166 (1979)

$M_1/M_2/M_3$	
$1/0,092 \pm 0,005/0,044 \pm 0,003$	"

---

^{129m}Xe coefficient de conversion interne pour la transition γ de 39,58 keV

αk	incertitude	référence
10,72	0,26	Thèse Doctorat ès Sciences Orsay n° 2166 (1979)

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^{131}Cs période

T 1/2	incertitude	unité	référence
9,66	0,06	jour	IJARI, 26 (1975), 131

---

^{131}I période

T 1/2	incertitude	unité	référence
8,020	0,003	jour	IJARI, 29 (1978), 269

---

^{133}Ba Energie γ

Eγ	incertitude	unité	référence
53,156	0,008	keV	LMRI/80/776/EM/
79,624	0,018	"	
80,998	0,007	"	
160,616	0,010	"	
223,224	0,012	"	
276,395	0,012	"	
302,850	0,008	"	
356,006	0,010	"	
383,845	0,010	"	

Probabilité d'émission γ

E_γ	P_γ	incertitude	référence
K_α	0,997	0,030	LMRI/80/776/EM
K_β	0,229	0,008	
53,2	0,0224	0,0006	
79,624	0,0257	0,0012	
81,0	0,345	0,008	
160,616	$0,0064_3$	0,0002	
223,224	$0,0043_6$	0,00015	
276	0,0716	0,0015	
302,845	0,1827	0,0035	
356,006	0,619	0,010	
383,845	0,0891	0,0019	

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^{134}Cs période

T 1/2	incertitude	unité	référence
2,058	0,012	an	IJARI, 23 (1972), 219

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^{135m}Ba Coefficient de conversion interne pour la transition de 268 keV du ^{135}Ba

α_t	incertitude	référence
5,42	0,11	Rapport CEA-R-4427

$^{137}Cs + ^{137m}Ba$ période ^{137m}Ba

T 1/2	incertitude	unité	référence
2,5545	0,0021	minute	Rapport CEA-R-4428 (1973)

Conversion interne pour la transition de 662 keV du ^{137}Ba

α_k	incertitude	référence
0,0901	0,0011	Rapport CEA-R-4428 (1973)
α_t		
0,1105	0,0010	"
K/LM		
4,39	0,07	"

^{139}Ce conversion interne pour la transition de 166 keV du ^{139}La

α_k	incertitude	référence
0,2111	0,0026	Rapport CEA-R-4427 (1973)
α_t		
0,2446	0,0012	"
K/L		
7,80	0,35	"
K/LM		
6,30	0,30	"
L/M		
4,30	0,40	"

période

T 1/2	incertitude	unité	référence
137,59	0,12	jour	IJARI, 29 (1978), 269

---

^{141}Ce probabilité d'émission γ

P_γ	incertitude	référence
0,4844	0,0042	IJARI, 26 (1975), 179

α_k Coefficient de conversion interne

	incertitude	
0,359	0,016	"

---

^{152}Eu période

T 1/2	incertitude	unité	référence
13,10	0,15	an	IJARI, 29 (1978), 269

énergie γ

E_γ	incertitude	unité	référence
121,78	0,02	KeV	Rapport CEA-R-4656 (1975)
148,3	0,7		
207,4	0,7		
210,0	0,7		
212,3	0,2		
237,0	0,7		
239,1			
244,69	0,02		
251,76	0,08		
271,00	0,06		
275,4	0,1		
285,7	0,7		
295,94	0,03		
315,28	0,07		
317,0	0,7		
324,80	0,09		
329,44	0,06		
339,6			
344,28	0,02		
351,7	0,7		
367,76	0,03		
411,12	0,02		
416,04	0,07		
443,98	0,02		
444,00	0,10		
482,5	0,1		
488,68	0,03		
493,6	0,1		
496,4	0,7		
503,47	0,05		
520,23	0,07		
523,0	0,7		

E γ (suite)	incertitude	unité	référence
526,9	0,7	keV	Rapport CEA-R-4656 (1975)
534,33	0,14		
556,6	0,5		
564,02	0,04		
566,36	0,08		
586,26	0,03		
616,1	0,7		
644,5	0,7		
656,47	0,08		
665,0	0,7		
671,5	0,7		
674,63	0,06		
675,0	0,3		
678,60	0,04		
686,4			
688,69	0,08		
712,85	0,06		
719,36	0,04		
719,3			
728,5	0,7		
764,9	0,1		
768,9	0,1		
778,90	0,03		
794,6	0,7		
810,47	0,06		
839,4			
841,65	0,06		
867,38	0,03		
901,05	0,1		
919,34	0,04		
926,29	0,06		
930,54	0,05		
958,4			
963,43	0,08		
964,05	0,03		
974,7	0,7		

E_γ (suite)	incertitude	unité	référence
990,2	0,2	keV	Rapport CEA-R-4656 (1975)
1005,15	0,05		
1085,83	0,03		
1089,72	0,04		
1109,2			
1112,08	0,04		
1171,02	0,07		
1205,4	0,7		
1212,94	0,04		
1249,88	0,07		
1261,3	0,2		
1292,86	0,07		
1299,13	0,04		
1315,7	0,7		
1348,2	0,3		
1364,0	0,2		
1389,8	0,7		
1408,03	0,03		
1457,62	0,04		
1528,10	0,05		
1605,5	0,2		
1608,7	0,2		
1647,1	0,2		
1768,9	0,2		

Intensité absolue des photons γ

E_γ	I_γ (%)	incertitude	référence rapport CEA-R-4656 (1975)
121,78	28,2	0,5	
148,3	$\sim$ 0,01		
207,4	$\leqslant$ 0,005		
210,0	$\leqslant$ 0,005		
212,3	$\sim$ 0,01		
237,0	$\sim$ 0,01		
239,1			
244,69	7,38	0,13	
251,76	0,04	0,02	
271,00	0,080	0,011	
275,4	0,038	0,009	
285,7	$\leqslant$ 0,005		
295,94	0,423	0,013	
315,28	0,038	0,008	
317,0	$\sim$ 0,01		
324,80	0,066	0,014	
329,44	0,104	0,012	
339,6			
344,28	26,4	0,4	
351,7	0,009	0,006	
367,76	0,84	0,03	
411,12	2,21	0,04	
416,04	0,090	0,017	
443,98 / 444,00	3,076	0,05	
482,5	0,013	0,006	
488,68	0,400	0,023	
493,6	0,033	0,015	
496,4	$\sim$ 0,005		
503,47	0,150	0,013	
520,23	0,049	0,016	
523,0	$\sim$ 0,005		
526,9	$\sim$ 0,005		
534,33	0,041	0,015	
556,6	$\sim$ 0,01		
564,02	0,486	0,021	

566,36	0,127	0,013
586,26	0,454	0,023
616,1	~ 0,01	
644,5	~ 0,005	
656,47	0,135	0,016
665,0	~ 0,005	
671,5	0,013	0,007
674,63 675,0	0,175	0,023
678,60	0,459	0,020
686,4 688,69	0,849	0,025
712,85	0,094	0,022
719,36 719,3	0,322	0,018
728,5	~ 0,005	
764,9	0,143	0,019
768,9	0,072	0,024
778,90	13,00	0,22
794,6	0,026	0,013
810,47	0,321	0,024
839,4 841,65	0,173	0,019
867,38	4,16	0,06
901,05	0,100	0,031
919,34	0,410	0,022
926,29	0,253	0,021
930,54	0,070	0,024
958,4		
963,43 964,05	14,48	0,23
974,7	0,011	0,003
990,2	0,020	0,009
1005,15	0,59	0,03

	I_γ	incertitude	référence rapport CEA-R-4656
1085,83	10,14	0,16	
1089,72	1,70	0,09	
1109,2 / 1112,08	13,55	0,20	
1171,00	0,034	0,012	
1205,4	~ 0,01		
1212,94	1,39	0,03	
1249,88	0,179	0,015	
1261,3	0,034	0,017	
1292,86	0,113	0,023	
1299,13	1,63	0,03	
1315,7	0,003	0,002	
1348,2	0,019	0,006	
1364,0	0,026	0,006	
1389,8	~0,005		
1408,03	20,70	0,29	
1457,62	0,488	0,015	
1528,10	0,266	0,015	
1605,5	0,007	0,002	
1608,7	0,005	0,001	
1647,1	0,006	0,002	
1768,9	0,009	0,002	

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^{152m}Eu période

T1/2	incertitude	unité	référence
9,274	0,009	heure	publication en cours

^{169}Yb période

T1/2	incertitude	unité	référence
31,97	0,05	jour	IJARI, 26 (1975), 131

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^{176m}Lu période

T1/2	incertitude	unité	référence
3,635	0,012	heure	publication en cours

énergie γ

E_γ	incertitude	unité	référence
		keV	N.T. LMRI 77 43/MJ
88,36	± 0,02		publication en cours
202,2	0,3		
936,25	0,20		
956,8	0,3		
1061,42	0,08		
1138,25	0,15		
1159,26	0,07		
1204,70	0,18		
1226,61	0,16		
1247,62	0,09		

probabilité d'émission γ

E_γ	P_γ	incertitude	référence NT LMRI 77 43/MJ
88,36	0,088	0,002	
202,2	$8,10^{-6}$		
936,25	$2,2 \times 10^{-6}$	$0,7 \times 10^{-6}$	
956,8	$0,4 \times 10^{-6}$	$0,2 \times 10^{-6}$	
1061,42	$7,5 \times 10^{-6}$	$1,7 \times 10^{-6}$	
1138,25	$2,3 \times 10^{-6}$	$0,6 \times 10^{-6}$	
1159,26	$13,7 \times 10^{-6}$	$3,0 \times 10^{-6}$	
1204,70	$0,9 \times 10^{-6}$	$0,3 \times 10^{-6}$	
1226,61	$1,3 \times 10^{-6}$	$0,4 \times 10^{-6}$	
1247,62	$0,20 \times 10^{-6}$	$0,16 \times 10^{-6}$	

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^{177}Lu période

T 1/2	incertitude	unité	référence
6,645	0,030	jour	publications en cours

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^{192}Ir période

T 1/2	incertitude	unité	référence
74,02	0,18	jour	IJARI 23 (1972) 219

incertitudes relatives des photons γ

E_γ	I_γ	incertitude	réf Nucl. Phys. A 142 (1970) 63
110,1	non observé		
136,32	0,22	0,08	
201,2	0,56	0,08	
205,8	4,2	0,2	
283,3	0,29	0,10	
295,94	36,5	1,0	
308,43	37,4	1,0	
316,49	100		
374,4	0,82	0,05	
416,45	0,70	0,15	
468,05	57,4	2,0	
484,5	3,5	0,2	
489,1	0,41	0,13	
588,56	5,37	0,25	
604,37	10,0	0,4	
612,3	6,4	0,2	
766,43	non observé		
884,50	0,35	0,04	
1062,2	0,062	0,020	
1378,7	non observé		

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^{239}Pu énergie des principaux photons γ

E_γ	incertitude	unité keV	référence rapport CEA à paraître
111,33	0,13		
129,29	0,02		
161,30	0,21		
171,30	0,07		
179,19	0,09		
195,65	0,05		
203,55	0,02		

225,39	0,10
243,34	0,10
255,34	0,03
263,95	0,07
297,45	0,04
311,70	0,04
316,35	0,07
320,90	0,04
323,83	0,03
332,84	0,02
336,09	0,03
341,54	0,05
345,00	0,02
375,04	0,02
380,18	0,04
382,76	0,04
392,72	0,02
399,55	0,06
413,73	0,02
422,60	0,02
426,73	0,04
451,50	0,02
481,54	0,06
598,3	0,2
618,32	0,09
639,88	0,10
645,88	0,07
703,59	0,08
717,58	0,18
756,24	0,08
769,19	0,04

probabilité d'émission des principaux photons γ

E_γ	P_γ	incertitude (%)	référence rapport CEA à paraître
129,3	$6,23\ 10^{-5}$	0,7	
143,3			
144,2	$2,96\ 10^{-6}$	4,0	
161,5	$1,21\ 10^{-6}$	5,7	
171,4	$1,05\ 10^{-6}$	6,0	
179,2	$6,45\ 10^{-7}$	7,2	
189,3	$8,30\ 10^{-7}$		
195,7	$1,02\ 10^{-6}$	6,4	
203,5	$5,57\ 10^{-6}$	4,7	
255,4	$7,94 \times 10^{-7}$	7,7	
297,5	$4,83 \times 10^{-7}$	9,5	
345,0	$5,45 \times 10^{-6}$	3,5	
375,0	$1,55 \times 10^{-5}$	3,2	
414,0	$1,48 \times 10^{-5}$	3,2	

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^{201}Tl

$T_{1/2}$	Incertitude	Unite	Référence
3,048	0,0040	jour	publication en cours

^{241}Am énergie γ

E_γ (keV)	incertitude (keV)	E_γ (keV)	incertitude (keV)	E_γ (keV)	incertitude (keV)
26,345	0,005	164,63	0,04	275,66	0,05
		165,94	0,05	291,15	0,12
33,20	0,02	169,59	0,03	292,77	0,05
43,42	0,02	175,10	0,04	^{233}Pa	
55,54	0,02	190,25	0,15	304,2	0,2
59,537	0,001	191,90	0,04	233 Pa	
				322,50	0,02
				322,37	0,02
69,75	0,05	204,01	0,16	335,40	0,02
98,94	0,02	208,02	0,02	confondu	
102,97	0,02	221,47	0,03	^{233}Pa	
		232,93	0,06	350,5	0,2
122,99	0,03	confondu		358,2	0,2
125,27	0,02	246,74	0,07	368,60	0,02
139,59	0,10	260,9	0,2	371,00	0,02
146,56	0,03	264,83	0,04	376,60	0,02
150,14	0,04	267,53	0,03	383,75	0,04
				390,62	0,05

E_γ	incertitude
keV	keV
406,45	0,08
^{233}Pa	
419,25	0,03
426,54	0,06
429,7	0,2
442,73	0,04
452,0	0,2
454,61	0,04
459,62	0,06
468,01	0,07
486,22	0,15
M.P.	
514,2	0,2
522,3	0,2
574,0	0,2
M.P.	
586,66	0,10
590,30	0,06
597,43	0,03
619,00	0,02
627,22	0,15
632,92	0,13
641,40	0,04
652,93	0,04
662,40	0,02
670,2	0,3
675,5	0,3
680,00	0,10

E_γ	incertitude
keV	keV
688,74	0,02
693,42	0,08
696,45	0,06
709,38	0,05
721,96	0,02
729,30	0,15
731,4	0,3
737,23	0,04
755,85	0,05
759,55	0,15
763,7	0,6
766,89	0,07
770,50	0,12
772,3	0,2
777,4	0,4
780,8	0,3
788,8	0,3
801,85	0,10
805,5	0,4
811,76	0,15
819,5	0,3
823,0	0,4
828,5	0,4
851,6	0,3
855,1	0,4
862,4	0,3
887,6	0,4
898,5	0,6
902,6	0,3
912,3	0,5
922,5	0,4
929,0	0,5
945,7	0,4
955,8	0,3
962,0	0,5

Probabilité d'émiss on γ

E γ	P γ	Incertitude
26,3	$2,35 \times 10^{-2}$	$0,07 \times 10^{-2}$
32,2	limite 3.10^{-5}	
33,2	$1,22 \times 10^{-3}$	$0,04 \times 10^{-3}$
43,4	$6,9 \times 10^{-4}$	$0,3 \times 10^{-4}$
55,5	$1,5 \times 10^{-4}$	$0,2 \times 10^{-4}$
59,5	0,365	0,002
67,5	limite 5.10^{-6}	
69,7	$\sim 2.10^{-6}$	
k α2 (97,1)	$1,22 \times 10^{-5}$	$0,05 \times 10^{-5}$
98,9	$2,05 \times 10^{-4}$	$0,06 \times 10^{-4}$
k α1 (101,1)	$1,96 \times 10^{-5}$	$0,07 \times 10^{-5}$
103,0	$2,02 \times 10^{-4}$	$0,06 \times 10^{-4}$
kβ3, kβ1, kβ5 (113,3-114,2 - 114,9)	$6,35 \times 10^{-6}$	$0,4 \times 10^{-6}$
kβ4, kβ2, kβX (117,3 - 117,6 - 118,4)	$2,0 \times 10^{-6}$	$0,2 \times 10^{-6}$
123,0	$1,07 \times 10^{-5}$	$0,05 \times 10^{-5}$
125,3	$4,17 \times 10^{-5}$	$0,13 \times 10^{-5}$
139,6	$5,7 \times 10^{-8}$	$0,7 \times 10^{-8}$
146,6	$4,70 \times 10^{-6}$	$0,20 \times 10^{-6}$
150,1	$7,6 \times 10^{-7}$	$0,4 \times 10^{-7}$
159,1	limite 8.10^{-9}	
164,6	$7,1 \times 10^{-7}$	$0,3 \times 10^{-7}$
165,9	$2,28 \times 10^{-7}$	$0,12 \times 10^{-7}$
169,6	$1,84 \times 10^{-6}$	$0,06 \times 10^{-6}$
175,1	$1,74 \times 10^{-7}$	$0,07 \times 10^{-7}$
190,3	$2,5 \times 10^{-8}$	$0,2 \times 10^{-8}$
191,9	$2,20 \times 10^{-7}$	$0,09 \times 10^{-7}$
194,7	limite 5.10^{-9}	
201,7	limite 5.10^{-9}	
204,0	$4,2 \times 10^{-8}$	$0,7 \times 10^{-8}$

E_γ	P_γ	Incertitude
208,0	$7,97 \times 10^{-6}$	$0,20 \times 10^{-6}$
221,5	$4,26 \times 10^{-7}$	$0,14 \times 10^{-7}$
232,9	$5,3 \times 10^{-8}$	$0,4 \times 10^{-8}$
234,4		
246,7	$3,2 \times 10^{-8}$	$0,5 \times 10^{-8}$
260,9	7×10^{-9}	2×10^{-9}
264,8	$8,8 \times 10^{-8}$	$0,4 \times 10^{-8}$
267,5	$2,40 \times 10^{-7}$	$0,08 \times 10^{-7}$
271,6	^{233}Pa	
275,7	$6,1 \times 10^{-8}$	$0,4 \times 10^{-8}$
291,1	$2,72 \times 10^{-8}$	$0,17 \times 10^{-8}$
292,8	$1,40 \times 10^{-7}$	$0,05 \times 10^{-7}$
300,2	^{233}Pa	
304,2	9×10^{-9}	2×10^{-9} (6)
311,9	^{233}Pa	
322,5	$1,470 \times 10^{-6}$	$0,05 \times 10^{-6}$
332,4	$1,479 \times 10^{-6}$	$0,05 \times 10^{-6}$
335,4	$4,75 \times 10^{-6}$	$0,15 \times 10^{-6}$
337,7		
340,4	^{233}Pa	
350,5	$1,47 \times 10^{-8}$	$0,12 \times 10^{-8}$
358,2	$\sim 6.10^{-9}$	
368,6	$2,08 \times 10^{-6}$	$0,06 \times 10^{-6}$
371,0	$4,74 \times 10^{-7}$	$0,15 \times 10^{-7}$
376,6	$1,283 \times 10^{-6}$	$0,04 \times 10^{-6}$
383,7	$2,76 \times 10^{-7}$	$0,09 \times 10^{-7}$
390,6	$5,1 \times 10^{-8}$	$0,2 \times 10^{-8}$
406,4	$1,6 \times 10^{-8}$	$0,1 \times 10^{-8}$
416,8	233 Pa	
419,3	$2,84 \times 10^{-7}$	$0,09 \times 10^{-7}$
426,5	$2,36 \times 10^{-7}$	$0,08 \times 10^{-7}$
429,7	$2,8 \times 10^{-9}$	$0,6 \times 10^{-9}$
440,1	limite 5.10^{-9}	
442,7	$3,2 \times 10^{-8}$	$0,2 \times 10^{-8}$
452,0	$2,6 \times 10^{-8}$	$0,3 \times 10^{-8}$
454,6	$8,4 \times 10^{-8}$	$0,4 \times 10^{-8}$
459,6	$2,7 \times 10^{-8}$	$0,2 \times 10^{-8}$

468,0	$2,4 \times 10^{-8}$	$0,2 \times 10^{-8}$
486,2	$1,7 \times 10^{-8}$	$0,1 \times 10^{-8}$
512,0	M.P. ± limite 1.10^{-8}	
514,2	$3,2 \times 10^{-8}$	$0,4 \times 10^{-8}$
522,3	$4,8 \times 10^{-9}$	$0,8 \times 10^{-9}$
574,0	$1,4 \times 10^{-8}$	$0,1 \times 10^{-8}$
582,6	M.P. ± limite 7.10^{-9}	
586,7	$4,7 \times 10^{-9}$	$0,8 \times 10^{-9}$
590,3	$2,1 \times 10^{-8}$	$0,2 \times 10^{-8}$
597,4	$6,7 \times 10^{-8}$	$0,3 \times 10^{-8}$
619,0	$5,72 \times 10^{-7}$	$0,19 \times 10^{-7}$
627,2	$5,8 \times 10^{-9}$	$1,0 \times 10^{-9}$
632,9	$8,9 \times 10^{-9}$	$1,1 \times 10^{-9}$
641,4	$6,2 \times 10^{-8}$	$0,2 \times 10^{-8}$
652,9	$3,53 \times 10^{-7}$	$0,12 \times 10^{-7}$
662,4	$3,50 \times 10^{-6}$	$0,11 \times 10^{-6}$
670,2	$2,1 \times 10^{-8}$	$0,3 \times 10^{-8}$
675,5	$1,16 \times 10^{-8}$	$0,07 \times 10^{-8}$
680,0	$3,6 \times 10^{-8}$	$0,2 \times 10^{-8}$
688,7	$2,84 \times 10^{-7}$	$0,09 \times 10^{-7}$
693,4	$3,4 \times 10^{-8}$	$0,2 \times 10^{-8}$
696,4	$4,9 \times 10^{-8}$	$0,3 \times 10^{-8}$
709,4	$6,2 \times 10^{-8}$	$0,2 \times 10^{-8}$
722,0	$1,87 \times 10^{-6}$	$0,06 \times 10^{-6}$
729,3	$1,04 \times 10^{-8}$	$0,06 \times 10^{-8}$
731,4	$4,5 \times 10^{-9}$	$0,7 \times 10^{-9}$
737,2	$7,6 \times 10^{-8}$	$0,3 \times 10^{-8}$
755,9	$7,0 \times 10^{-8}$	$0,3 \times 10^{-8}$
759,5	$1,87 \times 10^{-8}$	$0,09 \times 10^{-8}$
763,7	5×10^{-10}	2×10^{-10}
766,9	$5,4 \times 10^{-8}$	$0,2 \times 10^{-8}$
770,5	$5,4 \times 10^{-8}$	$0,2 \times 10^{-8}$
772,3	$9,5 \times 10^{-9}$	$1,0 \times 10^{-9}$
777,4	$1,1 \times 10^{-9}$	$0,3 \times 10^{-9}$
780,8	$3,4 \times 10^{-9}$	$0,5 \times 10^{-9}$
786,6	limite 5.10^{-10}	

788,8	3,8	$0,5 \times 10^{-9}$
801,9	1,20	$0,07 \times 10^{-8}$
805,5	$1,6 \times 10^{-9}$	$0,3 \times 10^{-9}$
811,8	$6,3 \times 10^{-9}$	$0,9 \times 10^{-9}$
819,5	$2,8 \times 10^{-9}$	$0,3 \times 10^{-9}$
823,0	$1,9 \times 10^{-9}$	$0,2 \times 10^{-9}$
828,5	$1,9 \times 10^{-9}$	$0,2 \times 10^{-9}$
851,6	$4,7 \times 10^{-9}$	$0,7 \times 10^{-9}$
855,1	$1,9 \times 10^{-9}$	$0,2 \times 10^{-9}$
859,2	* limite 5.10^{-10}	
862,4	$7,0 \times 10^{-9}$	$0,8 \times 10^{-9}$
887,6	$2,0 \times 10^{-9}$	$0,4 \times 10^{-9}$
898,5	$\sim 2 \times 10^{-10}$	
902,6	$2,5 \times 10^{-9}$	$0,3 \times 10^{-9}$
912,3	$\sim 5 \times 10^{-10}$	
922,5	$1,2 \times 10^{-9}$	$0,2 \times 10^{-9}$
929,0	$\sim 7 \times 10^{-10}$	
945,7	$\sim 8 \times 10^{-10}$	
955,8	$4,9 \times 10^{-9}$	$0,8 \times 10^{-9}$
962,0	$\sim 7 \times 10^{-10}$	

^{252}Cf	période		
$T_{1/2}$	incertitude	unité	référence
2,639	0,030	an	publication en cours

Liste des références utilisées pour l'étalonnage des spectromètres de photons

Radionucléide	Période	Energie (keV)	Probabilité d'émission X ou γ
^{7}Be	53,17 ± 0,07 jours	477,605	0,1035 ± 0,0008
^{22}Na	2,602 ± 0,001 ans	1274,542	0,9995 ± 0,0003
^{24}Na	14,960 ± 0,006 heures	1368,633	0,99994 ± 0,00002
		2754,030	0,9987 ± 0,0002
^{51}Cr	27,703 ± 0,004 jours	320,084	0,0983 ± 0,0014
^{54}Mn	312,3 ± 0,3 jours	834,843	0,99876 ± 0,00002
^{55}Fe	2,68 ± 0,02 ans E.moy	6,0(K_α,K_β)	0,277 ± 0,020
^{56}Co	77,12 ± 0,10 jours	846,764	0,99923 ± 0,00007
		1037,844	0,1409 ± 0,0006
		1238,287	0,670 ± 0,007
		1360,206	0,0426 ± 0,0002
		1771,350	0,1549 ± 0,0005
		2015,179	0,0303 ± 0,0004
		2034,759	0,0778 ± 0,0012
		2598,460	0,1695 ± 0,0006
		3009,596	0,0106 ± 0,0005
		3201,954	0,0318 ± 0,0008
		3253,417	0,0764 ± 0,0020
		3272,998	0,018 ± 0,001
		3451,154	0,0093 ± 0,0003
		3548,18	0,0019 ± 0,0001
^{57}Co	271,4 ± 0,3 jours E.moy	6,5(K_α,K_β)	0,565 ± 0,020
		14,4127	0,091 ± 0,002
		122,0614	0,8568 ± 0,0013
		136,4743	0,1067 ± 0,0013
^{60}Co	5,271 ± 0,002 ans	1173,238	0,9989 ± 0,0002
		1332,502	0,999830 ± 0,000006

Radionucléide	Période	Energie (keV)	Probabilité d'émission X ou γ
^{65}Zn	243,9 ± 0,2 jours	E.moy 8,1(K_α,K_β)	0,387 ± 0,009
		1115,546	0,5075 ± 0,0010
^{85}Sr	64,85 ± 0,02 jours	E.moy 13,6(K_α,K_β)	0,591 ± 0,008
		514,009	0,9929 ± 0,0004
^{88}Y	106,62 ± 0,03 jours	898,042	0,934 ± 0,007
		1836,063	0,9934 ± 0,0007
^{95}Nb	35,05 ± 0,10 Jours	765,800	0,9980 ± 0,0002
^{103}Ru - ^{103m}Rh	39,265 ± 0,010 jours	497,080	0,895 ± 0,006
		610,33	0,0564 ± 0,0018
^{106}Ru - ^{106}Rh	372,6 ± 1,0 jours	511,860	0,205 ± 0,005
^{109}Cd	463,1 ± 0,8 jours	E.moy 23,3($K_\alpha K_\beta$)	1,00 ± 0,04
		88,034	0,365 ± 0,006
^{111}In	2,802 ± 0,003 jours	E.moy 23,8(Kα,K_β	0,824 ± 0,038
		171,3	0,909 ± 0,006
		245,40	0,942 ± 0,003
^{113}Sn - ^{113m}In	115,10 ± 0,17 jours	E.moy 24,7(K_α,K_β)	0,968 ± 0,013
		391,688	0,6489 ± 0,0017
^{123}I	13,22 ± 0,04 heures	E.moy 28,0(K_α,K_β)	0,868 ± 0,030
		158,96	0,834 ± 0,005
^{125}I	59,89 ± 0,15 jours	E.moy 27,4 (K_α)	1,146 ± 0,041
		35,492	0,0667 ± 0,0013
^{131}Cs	9,69 ± 0,01 jours	E.moy 30,4(K_α,K_β)	0,749 ± 0,022
^{133}Ba	10,6 ± 0,2 ans	E.moy 30,85 (K_α)	0,982 ± 0,040
		E.moy 35,1 (K_β)	0,218 ± 0,009
		53,156	0,0220 ± 0,0006
		79,623	0,0264 ± 0,0012
		80,998	0,343 ± 0,006
		223,234	0,00447 ± 0,00020
		276,397	0,0712 ± 0,0007
		302,845	0,183 ± 0,002
		356,006	0,621 ± 0,007
		383,845	0,0892 ± 0,0009
^{137}Cs - ^{137m}Ba	30,18 ± 0,05 ans	E.moy 32,9(K_α K_β)	0,069 ± 0,004

Radionucléide	Période	Energie (keV)	Probabilité d'émission X ou γ
		661,660	0,854 ± 0,008
^{139}Ce	137,64 ± 0,05 jours	E.moy 34,2(K_α,K_β)	0,798 ± 0,026
		165,857	0,799 ± 0,001
^{141}Ce	32,50 ± 0,04 jours	E.moy 37,1 (K_α,K_β)	0,166 ± 0,010
		145,444	0,488 ± 0,004
^{152}Eu	13,4 ± 0,1 ans	121,782	0,282 ± 0,005
		244,699	0,0742 ± 0,0015
		251,76	
		295,939	0,00423 ± 0,00013
		344,281	0,264 ± 0,004
		367,788	0,0084 ± 0,0003
		411,115	0,0230 ± 0,0006
		416,04	
		443,99	0,03076 ± 0,00050
		564,021	0,00,613 ± 0,00034
		566,36	
		688,678	0,00849 ± 0,00025
		778,903	0,1300 ± 0,0022
		867,388	0,0416 ± 0,0006
		963,48	0,1446 ± 0,0023
		964,131	
		1085,914	0,1184 ± 0,0025
		1089,700	
		1112,116	0,1355 ± 0,0020
		1212,950	0,0139 ± 0,0003
		1292,86	0,01743 ± 0,00053
		1299,124	
		1408,011	0,2070 ± 0,0023
^{159}Dy	144,4 ± 0,6 jours	E.moy 45,5(K_α,K_β)	0,946 ± 0,040
^{203}Hg	46,585 ± 0,008 jours	E.moy 76,2(K_α,K_β)	0,130 ± 0,004
		279,197	0,814 ± 0,002
^{241}Am	432,6 ± 0,6 ans	13,9 (L X)	0,132 ± 0,003
		26,344	0,0235 ± 0,0007
		59,537	0,365 ± 0,002

Nuclear Data for X- or Gamma-Ray Spectrometer Efficiency Calibrations

D.D. Hoppes, J.M.R. Hutchinson, F.J. Schima, and M.P. Unterweger
National Bureau of Standards, Washington, DC, U.S.A.

Abstract

Half-lives measured with reference ionization chambers are reported for ^{22}Na, ^{24}Na, ^{46}Sc, ^{51}Cr, ^{54}Mn, ^{57}Co, ^{58}Co, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{67}Ga, ^{75}Se, ^{85}Sr, ^{88}Y, ^{99}Mo, ^{99m}Tc (two chemical forms), ^{109}Cd, ^{110m}Ag, ^{111}In, ^{113}Sn, ^{123}I, ^{125}I, ^{125}Sb, ^{127}Xe, ^{131}I, ^{131m}Xe, ^{133}Xe, ^{133}Ba, ^{134}Cs, ^{137}Cs, ^{139}Ce, ^{140}Ba, ^{140}La, ^{141}Ce, ^{144}Ce, ^{152}Eu, ^{153}Gd, ^{154}Eu, ^{155}Eu, ^{169}Yb, ^{181}W, ^{192}Ir, ^{195}Au, ^{198}Au, ^{201}Tl, ^{203}Hg, ^{203}Pb, ^{207}Bi, and ^{228}Tl. Gamma-ray probabilities per decay measured with calibrated germanium spectrometry systems are given for ^{88}Y, ^{99}Mo, ^{125}Sb, ^{131}I, ^{154}Eu, and ^{228}Th. The gamma-ray to K-x-ray emission-rate ratio for ^{109}Cd and the gamma-ray probabliity per decay for ^{241}Am as measured with NaI(Tl) systems of known efficiency are given.

1. Introduction

Instruments used in the preparation of radioactivity standard reference materials are also useful for measuring some of the data required for accurate efficiency calibrations of x- or gamma-ray spectrometry systems. Three types of such data are discussed in this contribution: half-lives measured by observation of the activity over a period of time, gamma-ray probabilities per decay measured with germanium spectrometers, and x- or gamma-ray probabilities measured with defined-geometry systems.

The ionization chambers which serve as a repository for the calibrations of gamma-ray-emitting radionuclides at the National Bureau of Standards (NBS) have been routinely used to follow the decay of most such radionuclides used in the production of Standard Reference Materials or in the calibration of local laboratory counting systems. Deviation of the measured half-lives from tabulated values indicates that a significant additional uncertainty must be attached to standards after appreciable decay.

The ionization chambers used are not sensitive to low-energy radiations and other instruments must be used for checking half-lives in such cases. For example, a half-life of 1009.0 ± 1.7 days was measured for ^{55}Fe, with proportional and Si(Li) detectors.

Calibrated germanium spectrometer systems are used for impurity searches, the calibration of submitted samples containing more than one gamma-ray-emitting radionuclide, and for a final check of all photon-emitting standards. They also are used for confirming or revising gamma-ray probabilities per decay by direct measurement with samples of known activity.

Photon counting systems for which efficiencies are defined by geometrical limits are used to directly measure x- or gamma-ray emission rates of standards of low-energy photons. With suitable precautions to minimize scattering and source absorption, the measurement of sources of known activity gives probabilities per decay with an accuracy greater than that which can be calculated from available decay scheme data.

Results from the three types of measurement will be discussed in the order given above. In all cases the component uncertainties have been calculated or estimated at a level corresponding to the standard deviation of the mean for repetitive measurements, and have been combined quadratically to give an overall uncertainty.

2. Half-life measurements

Well-type ionization chambers, filled with 20 atmospheres of argon, are used for the half-life measurements. The majority of the measurements were made with a 2.5-cm-diameter well chamber in use since 1967. Measurements with newer 2.5- and 5-cm-diameter well chambers are included in the results for ^{46}Sc, ^{75}Se, ^{125}I, ^{127}Xe, ^{169}Yb, and ^{181}W. All decay data are taken relative to ^{228}Ra reference sources, assuming a half-life of 1600 ± 7 years. A typical data point has a standard error (standard deviation of the mean) of 0.01 to 0.06 percent, derived from 10 sample and 20 reference source readings.

The calibration factors for various radionuclides on the older chamber have been checked periodically by direct activity determinations, and no indications of change, within the measurement uncertainties, have been found. All sources are of an activity well below the level where saturation effects have been observed. The radium reference sources were prepared from material old enough for long-lived daughters to be in equilibrium; checks with germanium spectrometers showed no evidence of ^{228}Ra, which would have perturbed the reference decay calculations.

In some cases, impurities are a significant source of systematic uncertainty. All sources have been investigated with germanium spectrometer systems, and the decay data have been corrected for any impurities found. If, for a given radionuclide, only the material from one separation has been used in determining the half-life, an estimate of the uncertainty due to the impurity effects has been added in quadrature to the uncertainty derived from repeated counts.

In most cases, the half-life reported is the weighted average of the results from different batches of the radionuclide, prepared and measured at various times over 14 years. The uncertainty is the "external error" in the weighted mean value. The weights used are the reciprocal squares of the standard errors in the fitting of the data to an exponential function (or sum of exponentials, if impurities are present), multiplied by the goodness of fit, if greater than 1. The data are fitted by χ^2 - minimization and the goodness of fit is defined as the square root of χ^2 divided by the number of degrees of freedom. Using a technique suggested by Stevenson[1] to estimate possible variations among replicate samples not due to the expected distribution variations, but to other noncommon variations (i.e., inexact impurity estimates, chemical instabilities, density changes), we add the following uncertainty (if greater than zero) in quadrature:

$$\sigma_1^2 = \frac{\left[\sum_{i=1}^{k} \frac{1}{var(x_i)}\right]\left[\sum_{i=1}^{k} \frac{x_i^2}{var(x_i)}\right] - \left[\sum_{i=1}^{k} \frac{x_i}{var(x_i)}\right]^2 - (k-1)\sum_{i=1}^{k} \frac{1}{var(x_i)}}{\left[\sum_{i=1}^{k} \frac{1}{var(x_i)}\right]^2 - \sum_{i=1}^{k} \frac{1}{\left[var(x_i)\right]^2}},$$

where k is the number of results averaged.

When following a long-lived radionuclide, at high precision and with a large number of data points, the uncertainties estimated from the fitted data appear to be underestimated when the time span is small compared to the half-life. In other words, the fitted values, as points are added, fluctuate more than the individual fitting uncertainties would indicate. For example, for a source of ^{207}Bi the fitted value is 32.9 $\pm$ 0.1 years after being followed 0.152 half-lives (n=57) and 32.25 $\pm$ 0.06 after 0.28 half-lives (n=87). This observation would seem to indicate that the uncertainties quoted for the half-lives of long-lived radionuclides may often be seriously underestimated.

Table I lists the radionuclides for which the half-lives have been determined. In most cases, as indicated in Column II by a range for the number of half-lives followed, a number of sources from different preparations and different ^{226}Ra reference sources have been used to follow the decay of the radionuclide. The half-life values are given in Column III. The stated uncertainties are the sum, in quadrature, of the statistical and systematic uncertainties. Column IV gives the "external error" in the weighted mean value. Column V shows the remaining uncertainty calculated from the Stevenson equation given above. Column VI shows the uncertainty due to the effect of impurities when only one batch of material has been measured. Column VII gives a possible uncertainty due to the relatively short fraction of a half-life that a radionuclide has been followed. This last uncertainty is not included in the overall uncertainty in column III, but is shown as a warning that the apparent uncertainty may be optimistic.

3. Gamma-ray probabilities per decay measured with germanium spectrometers

Other duties have prevented re-examination of much of the germanium-spectrometer-system data taken before 1979. Results which should be modified are not included. This includes all data for energies below 120 keV.

The general features of the systems and analysis have been published [2,3]. Efficiency calibrations of the two systems described in Table 2 use only gamma-ray-emission rates which can be inferred from decay-scheme data without significant use of past spectrometric results.

All germanium detectors that we have studied, including those in Table 2, have shown important efficiency changes with time. Variations observed for detector 2 during a 2 - year period are shown in figure 1. The observed change in the counting rate of several gamma rays from a source of ^{152}Eu has been used to correct for the efficiency changes at different energies. A half-life of 13.5 $\pm$ 0.2 years was assumed.

Table 3 gives the component and total uncertainties estimated for the calibration efficiencies. The estimates, other than the standard deviation of the mean, are based on the propagation of given uncertainties (P_γ, activity, half-life) or the influence of variation of parameters (pile-up, peak analysis, efficiency changes, geometry). Most calibrations are based on at least three sources of different activity, measured over a 3-year period and corrected for observed efficiency changes. Fractional losses due to pile-up, as measured by losses from a constant-frequency-pulser peak, are in general less than 3 percent, and have been shown to be a linear function of total count rate. Geometry variations considered include positioning, source diameter, and source absorption. Many of these component uncertainties are thus included to some extent in the measured standard deviation of the mean. Although the overall uncertainty is given to two figures, in general only one is significant.

The efficiencies have been corrected for losses from the simultaneous detection of cascade radiations. Angular dependences were taken into account. The maximum correction was 0.31 percent, and the uncertainty in the correction is taken as being negligble.

Although the efficiency points are numerous, the rapid and essentially unpredictable dependence of the efficiency on energy makes necessary a reliable interpolation function in order to apply the results. We divide the measured points for each detector into three overlapping energy regions, and fit the natural logarithm of the efficiency against a polynomial in the energy for each energy region. The results are shown in Tables 4a and 4b. The deviations from the fitted functions are in reasonable agreement with the uncertainties assigned. There are small, but significant, departures from the calculated dependence in some regions; corrections to the fitted curve have been made for a few of the measured gamma rays.

The data analysis used for the measurement of unknown gamma-ray-emission rates is similar to that used for the detector calibrations, with interpolated efficiency values at a selected energy corrected for the observed change in that energy region at the time of measurement. Again sources of different activity are measured repeatedly, and uncertainties assigned from observed variation in values with changed parameters.

The gamma-ray probablilities measured for selected gamma rays from the decay of ^{88}Y, ^{99}Mo, ^{125}Sb, ^{131}I, ^{154}Eu, and ^{228}Th are given in Table 5. The uncertainties are also given in Table 5. Activities were measured with thin sources in a pressurized proportional counter, in coincidence or anticoincidence with external NaI(Tl) spectrometers, for the first five radionuclides. Efficiency extrapolation techniques were used to derive activities essentially independent of decay-scheme data. ^{125}Sb sources were measured soon after the chemical separation of the ^{125m}Te daughter (60 day half-life). The ^{228}Th activity was measured with alpha-particle counters of known efficiency; comparison of the apparent efficiency for the 2614.5-keV gamma ray in the subsequent ^{208}Tl decay with that measured with sources of known retention of radon led to a correction of about 1.5 percent for radon loss in the sources used in the gamma-ray measurements.

3. Measurements with defined-geometry systems

The 59.5-keV gamma-ray probablility in the the decay of ^{241}Am was measured as 0.3582 $\pm$ 0.0014 with a specially constructed NaI(Tl) detector with a very thin-walled well, for the gamma-ray measurement, and the NBS 0.8π α-particle detector for the activity measurement. The gamma-ray measurement was carried out in essentially 4π geometry and total corrections of approximately 5 percent were made for iodine K-x-ray escape, wall absorption, escape through the well ends, and other smaller effects.

The ratio of emitted K x rays (22 to 25 keV) divided by emitted 88-kev gamma rays in the decay of ^{109}Cd has been determined to be 27.34 $\pm$0.27.

The x-ray measurement was performed with the defined-solid-angle low-energy-photon detector described in Hutchinson et al[4], where the techniques used to minimize scattering are discussed. A platinum diaphragm with an accurately known aperature

was used to define the subtended solid angle of the K x rays from the source into the NaI(Tl) crystal. Cadmium-109 sources were measured at known distances from the diaphragm, and calculated solid-angle and other correction were applied to the measured count rates to obtain the emission rates. Results for sources mounted on three shelves at source-to-detector distances of 2, 4, and 8 inches agreed to within 0.2 percent. Total corrections for other than solid angle amounted to about 1 percent.

The ^{109}Cd 88-keV gamma rays were measured with a "pin-well" detector previously described[5]. A dried source contained in a "bag" made from thin polyester film was inserted into the thin-walled well. Corrections totalling less than 2 percent were applied to the counting rate from loss through the end of the well, absorption in the well wall, and accidentally summed pulses falling into the 88-keV region.

4. References

1) P. C. Stevenson, "Processing of Counting Data", NAS-NS 3109, 98, 1965.

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5) J. M. R. Hutchinson and S. B. Garfinkel, IJARI 22, 405, 1971.

TABLE 1

Half-Lives Measured With Ionization Chambers

Radio-nuclide	Number of half lives followed	Half life(1)	Statistical Uncertainty	Uncertainty from EQN (1)	Uncertainty due to Impurities	Uncertainty due to measurement time
^{22}Na	4.6-5.2	(2.6057 ± 0.0003) y	0.0002	0.0003		
^{24}Na	1-7.5	(14.951 ± 0.003) h	0.0009	0.0031		
^{46}Sc	1.6-4.3	(83.79 ± 0.06) d	0.02	0.06		
^{51}Cr	2-8	(27.73 ± 0.01) d	0.005	0.010		
^{54}Mn	2-7	(312.02 ± 0.04) d	0.04	0.0		
^{57}Co	3.6-6	(271.9 ± 0.2) d	0.06	0.13	0.14	
^{58}Co	9	(70.75 ± 0.07) d	0.05	0.0	0.05	
^{59}Fe	4-9	(44.507 ± 0.007) d	0.005	0.005		
^{60}Co	1-2.4	(5.282 ± 0.007) y	0.003	0.006		
^{65}Zn	3.2	(244.2 ± 0.1) d	0.1	0.0		
^{67}Ga	2-8	(3.261 ± 0.001) d	0.0005	0.0013		
^{75}Se	1-6	(119.80 ± 0.07) d	0.02	0.07		
^{85}Sr	1-4.8	(64.851 ± 0.006) d	0.004	0.005		
^{88}Y	1-4.6	(106.64 ± 0.05) d	0.02	0.04		
^{99}Mo	3-9.5	(65.924 ± 0.006) h	0.003	0.005		
^{99m}Tc (2)	2-12	(6.0072 ± 0.0009) h	0.00016	0.00086		
^{99m}Tc (3)	1-8	(6.017 ± 0.002) h	0.0004	0.0015		
^{109}Cd	3.4-5.3	(463.2 ± 0.6) d	0.3	0.5		
^{110m}Ag	9.5	(249.93 ± 0.06) d	0.023	0.0	0.05	
^{111}In	1.5-9.3	(2.8048 ± 0.0005) d	0.0002	0.0005		
^{113}Sn	2.3-11	(115.06 ± 0.07) d	0.02	0.07		
^{123}I	9-12.7	(13.219 ± 0.007) h	0.005	0.0	0.005	
^{125}I	1-3	(59.47 ± 0.21) d	0.04	0.05	0.2	
^{125}Sb	0.1-0.2	(2.75 ± 0.02) y	0.02	0.0		0.06
^{127}Xe	1-6	(36.34 ± 0.01) d	0.008	0.01		
^{131}I	1-11	(8.020 ± 0.002) d	0.0005	0.002		
^{131m}Xe	1.8	(11.93 ± 0.02) d	0.01	0.02		
^{133}Xe (4)	3-7	(5.245 ± 0.006) d	0.003	0.0	0.003	
^{133}Ba	0.2-0.3	(10.48 ± 0.03) y	0.02	0.02		0.07
^{134}Cs	1-1.7	(2.0649 ± 0.0004) y	0.0004	0.0		
^{137}Cs	.26-.43	(30.68 ± 0.02) y	0.02	0.0		0.04
^{139}Ce	1.5-6.4	(137.74 ± 0.08) d	0.03	0.08		
^{140}Ba	2-4.4	(12.753 ± 0.002) d	0.0009	0.002		
^{140}La	4.2	(1.6783 ± 0.0007) d	0.0003	0.0003	0.0005	
^{141}Ce	6	(32.52 ± 0.03) d	0.007	0.0	0.03	
^{144}Ce	3-7.5	(284.9 ± 0.5) d	0.22	0.4		
^{152}Eu	.1-.4	(13.57 ± 0.11) y	0.05	0.10		0.24
^{153}Gd	5.9-6.0	(239.63 ± 0.04) d	0.03	0.03		
^{154}Eu	0.14	(8.49 ± 0.11) y	0.11	0.0	0.008	0.35
^{155}Eu	0.2-0.4	(4.73 ± 0.02) y	0.01	0.02	0.01	0.04
^{169}Yb	2-9	(32.02 ± 0.01) d	0.004	0.013		
^{181}W	1-3	(121.1 ± 0.6) d	0.2	0.5		
^{192}Ir	2.4	(73.81 ± 0.07) d	0.02	0.0	0.07	
^{195}Au	4.5-7.4	(186.09 ± 0.04) d	0.02	0.03		
^{198}Au	4.5-7.5	(2.695 ± 0.002) d	0.0002	0.0	0.002	
^{201}Tl	2.6-11	(3.0447 ± 0.0009) d	0.0003	0.0008		
^{203}Hg	1.7-6.6	(46.62 ± 0.03) d	0.007	0.026		
^{203}Pb	1.8-2.8	(51.92 ± 0.04) h	0.013	0.034		
^{207}Bi	0.3	(32.23 ± 0.04) y	0.04	0.0		0.9
^{228}Th	1-5	(698.1 ± 0.5) d	0.17	0.48		

(1) 1 year = 365.2422 days
(2) Saline solution
(3) 3 N HCl solution
(4) Uncertainties added linearly.
Phys. Rev. C10 2631 (1974)
(5) Not included in overall uncertainty

Table 2

Description of Germanium Detectors

Detector #	1	2
Type	coaxial Ge(Li)	wraparound coaxial Ge(Li)
Approximate Volume (cm^3)	30	60
Resolution in keV, at 122 keV at 1332 keV	0.90 1.72	0.80 1.77
Source distance (cm)	25	26.2
Location method	vertical plastic spacer	two telescopes referenced to a horizontal removable fixture.
Cryostat window	0.5mm Al	0.5mm Al

Table 3

Details of Efficiency Calibration, Detector 2

Energy, keV	Radio-nuclide	P_γ, %	Number of determina-tions	Typical Uncertainty Components, %								Overall Uncertainty %
				Std. dev. of the mean	Pile up compensa-tion	Peak Analysis	Efficiency change	Activity	P_γ	$T_{1/2}$	Geometry	
88.04	^{109}Cd	--	4	0.17	.05	.05	0.2	--	0.6	.02	0.1	0.67
122.06	^{57}Co	85.59 (19)	5	0.14	0.1	0.2	0.2	0.5	0.22	0.15	0.08	0.68
140.48	^{99m}Tc	88.97 (24)	4	0.08	0.2	0.2	0.1	0.5	0.27	0.6	0.1	0.89
165.85	^{139}Ce	79.94 (13)	6	0.03	0.1	0.05	0.1	0.12	0.16	0.04	0.08	0.27
171.28	^{111}In	90.93 (22)	7	0.12	0.2	0.05	0.1	0.17	0.24	0.01	0.08	0.38
245.39	^{111}In	94.17 (11)	7	0.09	0.2	0.05	0.1	0.17	0.12	0.01	0.08	0.33
279.19	^{203}Hg	81.5 (8)	4	0.05	0.05	0.05	0.2	0.8	0.98	0.01	0.1	1.29
364.48	^{131}I	81.6 (2)	5	0.05	0.2	0.05	0.1	0.24	0.25	0.1	0.1	0.44
411.80	^{198}Au	95.47 (8)	5	0.14	0.3	0.2	0.2	0.61	0.08	0.02	0.1	0.76
433.93	^{108m}Ag	*99.06 (12)	6	0.08	0.1	0.3	0.2	0.40	0.02	0.02	0.2	0.59
569.68	^{207}Bi	97.8 (5)	5	0.21	0.2	0.1	0.2	0.42	0.1	0.04	0.08	0.57
604.70	^{134}Cs	97.6 (1)	4	0.09	0.05	0.1	0.1	0.25	0.1	0.03	0.08	0.33
614.37	^{108m}Ag	*99.64 (18)	6	0.07	0.1	0.05	0.2	0.40	0.02	0.02	0.2	0.51
661.64	^{137}Cs	85.3 (3)	4	0.19	0.05	0.05	0.2	0.35	0.40	0.05	0.08	0.61
702.63	^{94}Nb	99.82 (10)	5	0.20	0.05	0.1	0.1	0.5	0.03	0.00	0.2	0.59
722.95	^{108m}Ag	*99.77 (10)	6	0.06	0.1	0.05	0.2	0.40	0.01	0.02	0.2	0.51
834.83	^{54}Mn	99.98 (1)	5	0.12	0.05	0.05	0.2	0.21	0.00	0.01	0.08	0.33
871.10	^{94}Nb	99.90 (3)	5	0.17	0.05	0.05	0.1	0.5	0.03	0.00	0.2	0.58
889.25	^{46}Sc	99.98 (0)	7	0.02	0.2	0.1	0.2	0.2	0.00	0.01	0.1	0.37
1120.51	^{46}Sc	99.99 (0)	7	0.08	0.2	0.1	0.2	0.2	0.00	0.01	0.1	0.38
1173.21	^{60}Co	99.90 (2)	7	0.18	0.1	0.2	0.2	0.47	0.02	0.28	0.08	0.65
1274.54	^{22}Na	99.94 (2)	2	0.1	0.1	0.05	0.2	0.56	0.02	0.1	0.1	0.63
1332.47	^{60}Co	99.98 (0)	7	0.13	0.1	0.05	0.2	0.47	0.00	0.28	0.08	0.61
1368.53	^{24}Na	100.00 (0)	8	0.08	0.2	0.1	0.1	0.3	0.01	0.1	0.1	0.42
1596.49	^{140}La	95.40 (8)	8	0.09	0.1	0.1	0.2	0.5	0.08	0.02	0.08	0.58
1836.04	^{88}Y	99.35 (3)	7	0.09	0.2	0.05	0.1	0.10	0.03	0.02	0.08	0.28
2318.90	^{90}Nb	*86.83 (11)	6	0.41	--	0.05	0.2	0.5	0.2	--	--	0.71
2614.60	^{228}Th	*36.04 (6)	3	0.12	0.05	0.05	0.2	0.6	0.17	0.06	0.2	0.70
2754.09	^{24}Na	99.86 (1)	8	0.10	0.1	0.05	0.2	0.5	0.01	0.1	0.1	0.58

* For ^{108m}Ag, the probability is per direct electron capture, rather than total, decay.
For ^{90}Nb, measurements were relative to the probability of the 1129-keV gamma ray.
For ^{228}Th, the probability is per decay of that radionuclide, but the gamma ray is in the decay of ^{208}Tl, in equilibrium.

TABLE 4A

FITTING RESULTS FOR DETECTOR 1.
LOG(EFF) = A(-3)/E*E*E + A(-2)/E*E + A(-1)/E
+ A(0) + A(1)*E

GOODNESS OF FIT = 0.979151E 0

A(-3) = 0.285717E 7+,- 320813.
A(-2) = -87150.9 +,- 7949.46
A(-1) = 869.717 +,- 67.8377
A(0) = -10.0116 +,- 0.236949
A(1) = -0.159864E -3+,- 0.281965E -3

PT #	ENERGY	OBS EFF	CALC EFF	% RESIDUAL
1	88.037	0.000743700000	0.000743718312	-0.0025
2	122.063	0.000758000000	0.000758453439	-0.0598
3	140.479	0.000728000000	0.000725576594	0.3340
4	165.853	0.000652400000	0.000651509324	0.1367
5	171.280	0.000629800000	0.000634096232	-0.6775
6	245.390	0.000427900000	0.000426228273	0.3922
7	279.188	0.000358300000	0.000360558481	-0.6264
8	364.480	0.000253500000	0.000253361270	0.0548
9	411.795	0.000214700000	0.000216390151	-0.7811
10	433.927	0.000203460000	0.000202545751	0.4514

GOODNESS OF FIT = 0.101513E 1

A(-2) = -87597.7 +,- 6632.18
A(-1) = 881.622 +,- 24.0020
A(0) = -9.90949 +,- 0.254646E -1
A(1) = -0.378480E -3+,- 0.771621E -5

PT #	ENERGY	OBS EFF	CALC EFF	% RESIDUAL
1	411.795	0.000214700000	0.000215835852	-0.5263
2	433.927	0.000203460000	0.000202005835	0.7199
3	569.685	0.000143800000	0.000143747019	0.0369
4	604.699	0.000132800000	0.000133693089	-0.6680
5	614.370	0.000131600000	0.000131160142	0.3354
6	661.645	0.000119800000	0.000120057871	-0.2148
7	702.627	0.000112430000	0.000111877632	0.4937
8	722.950	0.000108510000	0.000108231990	0.2569
9	834.825	0.000091490000	0.000091874415	-0.4184
10	871.099	0.000088130000	0.000087616352	0.5862
11	889.250	0.000085630000	0.000085635871	-0.0068
12	1120.510	0.000066830000	0.000066617432	0.3191
13	1173.208	0.000063930000	0.000063421730	0.8014
14	1274.540	0.000058110000	0.000058057098	0.0911
15	1332.470	0.000055750000	0.000055368766	0.6885
16	1368.530	0.000054200000	0.000053812161	0.7207
17	1596.490	0.000045610000	0.000045587740	0.0488
18	1836.040	0.000038950000	0.000039068159	-0.3024
19	2318.900	0.000029750000	0.000029733196	0.0565
20	2614.600	0.000025600000	0.000025554828	0.1768
21	2754.090	0.000024020000	0.000023860373	0.6690

TABLE 48

FITTING RESULTS FOR DETECTOR 2.
LOG(EFF) = A(-3)/E*E*E + A(-2)/E*E + A(-1)/E
+ A(0) + A(1)*E

GOODNESS OF FIT = 0.990432E 0

A(-3) = 0.211960E 7+,- 330160.
A(-2) = -66457.3 +,- 8133.78
A(-1) = 669.481 +,- 68.7024
A(0) = -8.84039 +,- 0.237333
A(1) = -0.532320E -3+,- 0.281387E -3

PT #	ENERGY	OBS EFF	CALC EFF	% RESIDUAL
1	88.037	0.001169400000	0.001169853516	-0.0388
2	122.063	0.001214500000	0.001211874944	0.2166
3	140.479	0.001171500000	0.001167969138	0.3023
4	165.853	0.001066400000	0.001066393095	0.0006
5	171.280	0.001038200000	0.001042259975	-0.3895
6	245.390	0.000747000000	0.000744363634	0.3542
7	279.188	0.000640800000	0.000645004121	-0.6518
8	364.480	0.000471400000	0.000474106043	-0.5708
9	411.795	0.000413100000	0.000411631512	0.3567
10	433.927	0.000389700000	0.000387590545	0.5442

GOODNESS OF FIT = 0.710940E 0

A(-2) = -10105.3 +,- 52385.7
A(-1) = 442.650 +,- 267.800
A(0) = -8.54350 +,- 0.438915
A(1) = -0.634197E -3+,- 0.231151E -3

PT #	ENERGY	OBS EFF	CALC EFF	% RESIDUAL
1	411.795	0.000413100000	0.000414132425	-0.2493
2	433.927	0.000389700000	0.000388871141	0.2131
3	569.685	0.000286700000	0.000286170486	0.1850
4	604.699	0.000267600000	0.000268511099	-0.3393
5	614.370	0.000264200000	0.000264039634	0.0607
6	661.645	0.000245200000	0.000244282893	0.3754
7	702.627	0.000230100000	0.000229505979	0.2588
8	722.950	0.000223100000	0.000222842469	0.1156
9	834.827	0.000191730000	0.000192153519	-0.2204
10	871.099	0.000185140000	0.000183900530	0.6740
11	889.250	0.000179760000	0.000180016704	-0.1426

GOODNESS OF FIT = 0.605105E 0

A(-2) = -165323. +,- 44431.6
A(-1) = 976.674 +,- 99.2687
A(0) = -9.21731 +,- 0.682483E -1
A(1) = -0.329015E -3+,- 0.144856E -4

PT #	ENERGY	OBS EFF	CALC EFF	% RESIDUAL
1	834.827	0.000191730000	0.000191756498	-0.0138
2	871.099	0.000185140000	0.000183997367	0.6210
3	889.250	0.000179760000	0.000180344235	-0.3240
4	1120.510	0.000143580000	0.000143953887	-0.2597
5	1173.208	0.000137880000	0.000137629602	0.1819
6	1274.540	0.000127080000	0.000126897483	0.1438
7	1332.470	0.000121610000	0.000121469265	0.1159
8	1368.530	0.000118820000	0.000118312064	0.4293
9	1596.490	0.000101250000	0.000101476668	-0.2234
10	1836.040	0.000087950000	0.000087971888	-0.0249
11	2614.600	0.000059550000	0.000059579866	-0.0501
12	2754.090	0.000056010000	0.000055974237	0.0638

Table 5

Radionuclide	Energy (keV)	Photon probability per decay, %	Uncertainty in last digit
^{88}Y			
	898.0	94.3	4
^{99}Mo			
	140.5	90.3	10
	181.1	6.00	5
	739.4	12.06	9
	777.8	4.25	3
^{125}Sb*			
	176.4	6.68	4
	427.9	28.78	18
	600.6	17.18	10
	606.7	4.88	3
	635.9	10.91	7
	671.4	1.80	2
^{131}I			
	284.3	6.21	4
	637.0	7.11	4
	722.9	1.78	1
^{154}Eu			
	123.1	40.8	3
	248.0	6.91	4
	591.7	4.95	3
	723.3	20.08	12
	873.2	12.19	9
	1004.8	18.08	11
	1274.4	34.84	17
^{228}Th			
	277.4	2.34	4
	300.1	3.28	3
	583.2	30.7	3
	727.3	6.67	6
	860.5	4.55	4

* These values are based on preliminary activity measurements which are currently being checked, hence only relative values are quoted in the summary table.

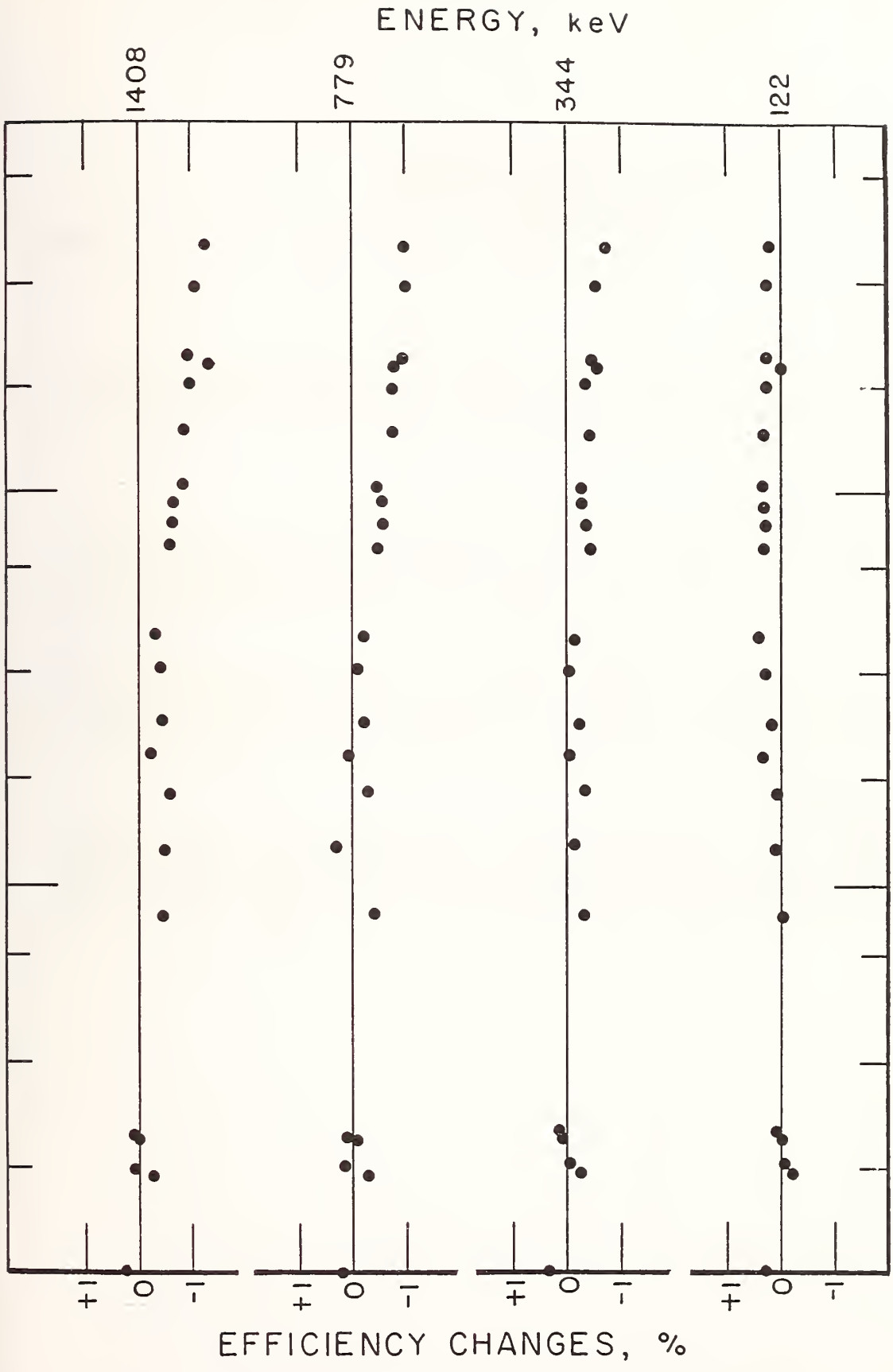

Figure 1. Efficiency changes of detector 2 with time.

National Physical Laboratory
Division of Radiation Science
Teddington, Middlesex TW111 OLW
United Kingdom

Peter Christmas

Half-Lives

Many half-life values shown in the summary table have been checked in use since the original measurements (referenced in the table), and no discrepancies have been observed. Eight previously unpublished values, all with uncertainties at the "one sigma" level, are included.

Electron Measurements

The iron-free, double-focussing beta-ray spectrometer at NPL has been used by P. Christmas and P. Cross to measure P_γ (662) following the decay of ^{137}Cs. A value of (84.56 ± 0.09) percent was published in Metrologia 14, 157 (1978), but a further, and continuing, investigation of the influence of beta-ray spectral shapes suggests that this value may be revised.

The authors have used the same instrument for relative conversion-electron measurements in the decay of ^{180m}Hf [Nucl. Instrum. Methods 174, 571 (1980)]. The measured ratios are used, together with theoretical conversion coefficents, to derive the relative gamma-ray probabilities shown in the summary table.

$P_x(K)$ Measurement

Measurements of K x-ray emission rates in an internal-source pressurized proportional counter, combined with activity measurements by 4 (A,x)- gamma-ray coincidence counting, gave a value of (58.66 ± 0.41) percent for $P_x(K)$ in the decay of ^{85}Sr, as reported by D.J. Thomas in Z. Physik A289, 51 (1978).

Decay data of radionuclides used for the calibration of germanium detectors

by

K. Debertin, U. Schötzig and K. F. Walz
Physikalisch-Technische Bundesanstalt
Braunschweig, Fed. Rep. of Germany

December 1979

Contribution to ICRM action 10/79

Summary:

Results for gamma-ray emission probabilities of 12 radionuclides and for half-lives of 18 radionuclides are summarized. Most of the data were obtained within the last five years. The selected radionuclides are suitable for the efficiency calibration of Ge(Li) and high purity germanium detectors.

Part I: Photon emission probabilities

I.1. Introduction

Photon emission probabilities of many radionuclides have been determined over the last five years in the Physikalisch-Technische Bundesanstalt by means of three accurately calibrated germanium spectrometers. The nuclides considered in the past can be divided into three groups:

1. fission product nuclides;
2. nuclides of interest in nuclear medicine;
3. nuclides which are used for the efficiency calibration of germanium spectrometers

In Part I of this paper we summarize the results obtained for 12 nuclides of the third group.When calibrating a spectrometer we differentiate between "primary" and "secondary" calibration lines. The term "primary" is used here

1. if the activity of the source has been determined fundamentally by accurate absolute measurements, like 4π-γ-coincidence counting and
2. if the determination of the photon emission probability is not or not solely based on measurements with germanium detectors and if p is known with good accuracy.

Examples for primary calibration lines are given in Table 2.

Other calibration lines which do not fulfil both conditions given above are called "secondary".

An efficiency calibration with primary lines of many calibration sources may be very time-consuming. Moreover, it may be difficult to obtain or produce the sources which in part are short-lived. It has therefore become common practice to use only one or a few calibration sources of long-lived nuclides emitting photons of several energies in the region of interest. In that case most lines are secondary lines. Gamma-ray emission probabilities of such nuclides are determined by means of germanium detectors which were calibrated by using primary lines. All lines for which experimental results for p are given in this report are secondary

calibration lines.

We do not give much detail on the experimental set-up, the efficiency calibration and the evaluation of our measurements, because this is contained in other publications quoted later on. We also do not discuss our results for the gamma-ray emission probabilities and we do not compare them with those of other authors. This report is just a summary of our work, most of which has been published in individual reports and papers.

I.2. Experimental set-up

Specifications of the detectors used in our three spectrometers G1, G2 and G3 are given in Table 1. For measurements with G3 at energies below 122 keV lead or tantalum collimators (3 or 2 mm thick, 10 mm hole) are inserted near the source and detector.

Table 1
Detector specifications

Spectrometer	G1	G2	G3
Type	Ge(Li) true coaxial	Ge(Li) coaxial, one end open	HPGe planar
Supplier	Canberra	Canberra	PGT
Date of delivery	June 1969	Oct.1973	Oct.1973
High voltage	- 1400 V	+ 2900 V	- 1500 V
Volume	30 cm^3	70 cm^3	area 200 mm^2 depth 5 mm
FWHM	2.9 keV at 1.33 MeV	2.2 keV at 1.33 MeV	208 eV at 5.9 keV 520 eV at 122 keV
Source to detector distance	16.5 cm	16.5 cm	6.2 cm
Used energy range	122 - 2754 keV	122 - 2754 keV	5 - 412 keV

After amplification in the preamplifier (CI 1408 C, CI 970, PGT P012/B), amplifier (CI 1413, CI 2010), and biased amplifier, (CI 1467) the pulses are fed into a 4096 channel pulse height analyzer (ND 2400, Northern 720, CI 8180). Data are printed out on

paper or magnetic tape and evaluated by our central CGK computer TR 440. Pulses of a periodic 50 Hz pulse generator (BNC BH-1 or PB-4 triggered by PTB 7401) are added at the input of the preamplifier.

I.3. Peak evaluation, corrections

The number of counts in the gamma-ray and pulser peaks of the spectra are determined by our computer program GELI.[4]) Losses due to dead-time and pile-up effects are corrected by using the pulser method[2,6,8,16]). Coincidence summing corrections are calculated by the program KORSUM[4,11]). The program GELIMI averages results of several runs within a measuring series, combines the output information of GELI and KORSUM, and calculates either the peak efficiency of the spectrometer system from the emission rate of the calibration sources or the gamma-ray emission probability from the efficiency and the source activity A.

I.4. Efficiency calibration

The efficiency ε at an energy E_i is obtained from

$$\varepsilon(E_i) = \frac{N(E_i) \cdot C(E_i)}{R(E_i)}$$

with

$N(E_i)$	number of counts in the peak corresponding to the energy E_i
$C(E_i)$	factor accounting for all necessary corrections
$R(E_i) = A \cdot p(E_i)$	emission rate of calibration source
A	activity of the source
$p(E_i)$	emission probability for photons of energy E_i

Primary photon lines used for the calibration of our detectors are listed in Table 2. The efficiency curves are given in several publications[6,9,10,15,18]). Interpolation between the calibration points is performed either manually or by fitting an analytical function. Table 3 gives estimates of the relative uncertainties (68 % confidence level) reached for our spectrometers. The figures have to be considered as pessimistic estimates, the uncertainties may even be smaller in the neighbourhood of calibration points.

Table 2

Primary calibration lines

Most of the data are taken from a contribution of M.J. Martin to NCRP Report No. 58[30])

Nuclide	Half-life	Energy in keV	Emission probability
^{22}Na	950.4 d	1274.542	0.99940(20)
^{24}Na	15.00 h	1368.633	1.
		2754.030	0.99863(5)
^{46}Sc	83.80 d	889.277	1.
		1120.545	1.
^{51}Cr	27.705 d	4.95 (K_α)	0.1970(45)
^{54}Mn	312.5 d	5.41 (K_α)	0.2213(45)
		834.843	0.999760(2)
^{57}Co	272 d	14.4147	0.0954(13)
		122.0614	0.8559(19)
^{58}Co	70.78 d	6.40 (K_α)	0.2318(45)
		810.775	0.99450(10)
^{60}Co	5.272 a	1173.237	0.99900(20)
		1332.501	1.
^{65}Zn	243.97 d	8.04 (K_α)	0.3410(58)
^{85}Sr	64.85 d	13.37 (K_α)	0.5010(81)
		514.009	0.980(10)
^{88}Y	106.64 d	14.14 (K_α)	0.515(16)
		1836.064	0.9944(2)
^{95}Nb	35.0 d	765.800	0.9980(4)
$^{99}Tc^m$	6.006 h	140.509	0.8896(24)
^{111}In	2.802 d	23.11 (K_α)	0.678(18)
		171.28	0.9093(22)
		245.39	0.9417(11)
^{125}I	60.14 d	27.38 (K_α)	1.140(29)
^{131}I	8.02 d	364.480	0.816(6)
^{134}Cs	2.062 a	604.699	0.976(1)
		795.845	0.853(9)
^{137}Cs	30.0 a	32.06 (K_α)	0.0548(11)
		661.660	0.8456(3)
^{139}Ce	137.65 d	33.30 (K_α)	0.657(16)
		165.857	0.800(2)
^{140}La	40.272 h	1596.49	0.9540(8)
$^{180}Hf^m$	5.5 h	215.251	0.8170
		332.307	0.9447
^{198}Au	2.696 d	411.8044	0.9547(8)
^{203}Hg	46.59 d	72.1 (K_α)	0.1011(19)
		279.1967	0.813(2)
^{207}Bi	32.49 a	74.2 (K_α)	0.588(15)
^{241}Am	432.0 a	59.537	0.360(3)

Table 3

Estimates of the uncertainty of the efficiency calibration

Spectrometer	Energy region in keV	Uncertainty in %
G3	5 - 20	1.5
	20 - 70	1.0
	70 - 110	1.5
	110 - 180	0.7
	180 - 411	1.0
G1, G2	122 - 250	1.0
	250 - 550	0.7
	550 - 1400	0.5
	1400 - 1900	0.7
	1900 - 2754	1.5

I.5 Results for photon emission probabilities

Photon emission probabilities per decay were obtained according to

$$p(E) = \frac{N(E) \cdot C(E)}{A \cdot \varepsilon(E)}$$

(cf. section I.4). For all nuclides except ^{152}Eu and ^{226}Ra activities were determined by $4\pi(\beta-\gamma)$ or $4\pi X-\gamma$ coincidence counting. Details can be found in reference 9 for ^{133}Ba and in reference 15 for ^{75}Se and ^{182}Ta. For $^{110}Ag^{m}$, ^{152}Eu and ^{182}Ta $4\pi\gamma$-counting with a NaI(Tl) detector system was applied[15,17]). In the case of ^{226}Ra emission probabilities per decay were derived from a source with known radium mass. The results for the emission probabilities are summarized in Table 4. Quoted uncertainties correspond to one standard deviation and include systematic uncertainties.[19])

Table 4

Results for photon emission probabilitites p. Energies E are taken from reference 30.
A reference with an * contains preliminary results.

Nuclide	E in keV	p	Reference
$^{51}_{57}Cr$	320.076	0.0985(9)	15
^{57}Co	136.476	0.1058(8)	15
$^{65}_{75}Zn$	1115.546	0.5039(26)	7
^{75}Se	66.050	0.0114(2)	23*, 15
	96.733	0.0348(9)	
	121.115	0.173(3)	
	136.000	0.590(8)	
	198.596	0.0147(3)	
	264.651	0.591(8)	
	279.528	0.252(4)	
	303.910	0.0134(2)	
	400.646	0.1156(15)	
$^{88}_{110}Y$	898.020	0.946(5)	7
$^{110}Ag^m$	657.749	0.9465(16)	6
	706.670	0.1656(13)	
	763.928	0.2243(18)	
	884.667	0.734(18)	
	937.478	0.346(4)	
	1384.270	0.2470(22)	
	1505.001	0.1316(13)	
^{133}Ba	30.85 (K_α)	0.971(16)	21, 26
	35.1 (K_β)	0.232(5)	
	53.155	0.0220(4)	
	79.621	0.0261(7)	
	80.997	0.340(8)	
	160.605	0.00646(10)	
	223.25	0.0045(1)	
	276.397	0.0710(10)	
	302.851	0.1833(22)	
	356.005	0.623(7)	
	383.851	0.0892(9)	
^{134}Cs	475.35	0.0151(3)	23
	563.227	0.0834(12)	
	569.315	0.1538(22)	
	604.699	0.976(1)	
	795.845	0.853(9)	
	801.932	0.0864(12)	
	1038.57	0.00998(13)	
	1167.94	0.01800(20)	
	1365.15	0.0302(3)	
^{141}Ce	145.440	0.489(4)	15
^{152}Eu	39.9 (K_α)	0.591(12)	14
	45.7 (K_β)	0.149(3)	
	121.7824	0.2855(37)	21*, 5, 27
	244.6989	0.0744(11)	
	344.275	0.2652(29)	

Table 4 continued

Nuclide	E in keV	p	Reference
^{152}Eu	411.115	0.0224(4)	
	443.983	0.0312(5)	
	778.910	0.1291(14)	
	964.131	0.1466(15)	
	1085.914	0.1009(13)	
	1112.116	0.1353(19)	
	1408.011	0.2085(19)	
^{182}Ta	31.7370	0.00892(21)	23*, 15, 26
	42.7143	0.00266(8)	
	58.8 ($K\alpha$)	0.2802(52)	
	65.7217		
	67.2 ($K\beta_1$)	0.571(13)	
	67.7495		
	69.1 ($K\beta_2$)		
	84.6805	0.0263(10)	
	100.1064	0.1423(42)	
	113.6670	0.0187(6)	
	116.4149	0.00445(15)	
	152.4281	0.0695(9)	
	156.3817	0.0263(5)	
	179.3904	0.0309(4)	
	198.3477	0.0144(2)	
	222.101	0.0750(10)	
	229.316	0.0364(5)	
	264.071	0.0362(6)	
	1121.28	0.3530(32)	
	1189.04	0.1644(15)	
	1221.418	0.2717(25)	
	1230.97	0.1158(11)	
	1257.47	0.0150(2)	
	1289.17	0.0136(2)	
^{226}Ra	185.99	0.0351(6)	24*
	241.91	0.0712(11)	
	295.17	0.1815(22)	
	351.90	0.351(4)	
	609.32	0.446(5)	
	768.36	0.0475(7)	
	934.05	0.0307(4)	
	1120.28	0.147(2)	
	1238.11	0.0578(7)	
	1509.19	0.0208(5)	
	1764.51	0.1506(26)	
	2118.54	0.0117(3)	
	2204.12	0.0498(12)	
	2293.36	0.00301(9)	
	2447.71	0.0155(4)	

Part II: Half-lives

Half-lives are measured by following the radioactive decay with two ionization chambers (open air and high pressure argon chamber). All sources were checked for γ-ray emitting impurities. Their contributions to the ionization current were subtracted for each measuring point. Details on the measurements and the data evaluation are given in references 1, 13 and 15. In some cases a Ge(Li)-spectrometer was used[3]). Table 5 summarizes the results obtained for calibration nuclides.

Table 5

Half-lives

A reference with an * contains preliminary results

Nuclide	Half-life	Reference
^{51}Cr	27.705(12) d	20*, 28
^{57}Co	271.5(5) d	24
^{60}Co	5.272(2) a	1
^{65}Zn	243.97(8) d	20*, 28
^{75}Se	119.76(5) d	22*, 15
^{85}Sr	64.865(8) d	
^{88}Y	106.64(8) d	28
$^{110}Ag^{m}$	249.78(4) d	20*, 28
^{111}In	2.8045(8) d	25
^{131}I	8.021(1) d	25
^{133}Ba	10.74(5) a	1, 20*, 9
^{137}Cs	29.901(45) a	1
^{140}La	40.272(7) h	28
^{141}Ce	32.51(6) d	3
^{152}Eu	4931(15) d	15*
^{154}Eu	8.57(7) a	25
^{182}Ta	114.43(4) d	22*, 15
^{241}Am	432.0(2) a	29

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22) PTB-Jahresbericht 1975, 3.6.12 (p. 239) and 3.6.16 (p. 242)

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Decay data of radionuclides used for the calibration of germanium detectors

Supplement to the PTB-contribution to ICRM-SP action 10/79

July 1980

Table 5

Nuclide	Half-life	Reference
^{59}Fe	44.529 (7) d	28
^{67}Ga	3.2594 (12) d	13
^{95}Zr	64.10 (4) d	28
^{103}Ru	39.276 (9) d	22, 28
^{133}Ba	10.53 (6) a	*
^{140}Ba	12.746 (10) d	24
^{144}Ce	285.08 (18) d	28

Decay data of radionuclides used for the calibration of germanium detectors

Supplement to the PTB-contribution to ICRM-SP action 10/79

July 1980

Table 4

Nuclide	E in keV	P		Reference
^{95}Zr	724.2	0.440	(5)	31
	756.7	0.543	(5)	
^{99}Mo	140.5	0.905	(5)	25
	181.1	0.0603	(7)	
	366.4	0.0122	(2)	
	739.5	0.1231	(9)	
	777.9	0.0433	(4)	
^{103}Ru	496.9	0.909	(7)	21*
	610.2	0.0565	(7)	
^{125}Sb	176.4	0.0695	(12)	
	427.9	0.305	(5)	
	463.4	0.1071	(17)	
	600.6	0.180	(3)	
	606.7	0.0512	(8)	
	635.9	0.1147	(15)	
	671.4	0.1842	(24)	
^{131}I	284.3	0.0620	(6)	24
	364.5	0.816	(6)	
	637.0	0.0712	(6)	
	722.9	0.0178	(2)	
^{140}Ba	162.6	0.0621	(8)	32
	537.3	0.2439	(22)	
^{140}La	328.8	0.2074	(18)	32
	487.0	0.4594	(38)	
	815.8	0.2364	(17)	
	867.9	0.0559	(5)	
	925.2	0.0705	(8)	
	1596.5	0.9540	(8)	
^{144}Ce	133.5	0.1109	(16)	31
^{144}Pr	696.5	0.01342	(14)	31
	1489.1	0.00279	(3)	
	2185.6	0.00700	(10)	

Decay data of radionuclides used for the calibration of germanium detectors

ICRM-SP Action 10/79

Corrections to computer entries referring to PTB data

^{75}Se	Photon probability per decay All data except for 400.5 keV are lacking
^{133}Ba	Photon probability per decay; 79 and 81 keV data are lacking
^{133}Ba	Half-life Replace our value by the new value given in the supplementary table
^{134}Cs	Photon probability per decay Data for high energy lines should be given although the probability is less than 5 %.
^{182}Ta	Photon probability per decay Reference to be replaced by reference 15 The energy selection criteria should be the same for relative and absolute probabilities (e.g. 198.4 keV)

Supplementary references

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University of Guelph
Department of Physics
Guelph, Ontario, Canada
J.L. Campbell and L.A. Mc Nelles

In Nucl. Instr. Meth. 98, 433 (1972), the authors give the results of 4π CsI(Tl) measurements of the emission rate of K x rays relative to gamma rays in the decay of ^{109}Cd, ^{139}Ce and ^{141}Ce. These values are believed still to be valid as given. The uncertainties given there are taken to have the significance suggested for this compilation.

IV. Table of Selected Calibration Data

The process for selecting the data from those supplied by ICRM-SG members is outlined in part I. The laboratory corresponding to each label is given in part II.

Final zeros after a decimal point are suppressed by the computer program used to group the data even if the zeros are significant (as indicated by the accompanying uncertainty). An asterisk signifies that the uncertainty is at the 3 sigma or 99% confidence level. Other uncertainties are to be taken as total uncertainties equivalent, in significance, to one standard deviation of the mean.

BE 7

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	53.284	D	.004	AECL-3668;50(1970)
LMRI	53.17	D	.07*	IJARI-26;131(1975)
NPL	53.16	D	.01	NPL PREV. UNPUBL.

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
477 KEV			
AECL	10.32	.04	CAN J PHYS 40;926(1962) & AECL-3512;29(1969)

F 18

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	109.73	M	.04	AECL-4708;20(1974)
AECL	109.71	M	.02	AECL-4708;20(1974)
NPL	109.68	M	.17	NPL PREV. UNPUBL.

NA 22

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	950.3	D	.27	AECL-6788;45(1980)
IAEA	950.34	D	.13	IJARI-31;153(1980)
NBS	2.6057	Y	.0003	NBS PREV. UNPUBL.

NA 24

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	14.965	H	.01	AECL-3912;43(1971)
AECL	14.959	H	.01	CAN J PHYS 36;983(1958)
AECL	14.965	H	.001	AECL PREV. UNPUBL.
IAEA	14.959	H	.0012	IJARI-31;153(1980)
LMRI	14.956	H	.008*	(IN PRESS)
NBS	14.951	H	.003	NBS PREV. UNPUBL.

K 42

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	12.358	H	.007	CAN J PHYS 40;1044(1962)

K 42 (CONTINUED)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
1530 KEV			
AECL	19.1	.6	AECL-1142;25(1960)

SC 46

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	83.752	D	.015	AECL-6788;45(1980)
IAEA	83.819	D	.006	IJARI-31;153(1980)
NBS	83.79	D	.06	NBS PREV. UNPULB.

CR 51

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	27.704	D	.003	AECL-3668;50(1970)
IAEA	27.69	D	.005	IJARI-31;153(1980)
LMRI	27.72	D	.07*	IJARI-26;131(1975)
NBS	27.73	D	.01	NBS PREV. UNPULB.
NPL	27.71	D	.01	NPL PREV. UNPULB.
PTB	27.705	D	.012	INT.REP. PTB RADIOACT. GROUP;MARCH 1976

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
320.1 KEV			
PTB	9.85	.09	NIM-169;43(1980)

MN 52

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
744.2 KEV			
HNRE	90.35	.07	NIM-175;525(1980)
848.2 KEV			
HNRE	3.39	.03	NIM-175;525(1980)
935.5 KEV			
HNRE	94.89	.03	NIM-175;525(1980)
1246.2 KEV			
HNRE	4.32	.09	NIM-175;525(1980)
1333.6 KEV			
HNRE	5.07	.04	NIM-175;525(1980)
1434.1 KEV			
HNRE	99.9871	.0014	NIM-175;525(1980)

MN 52 (CONTINUED)
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RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
744.233 KEV			
LLL	90	.8	M-100;LAWRENCE LIVERMORE LAB;(1978)
935.544 KEV			
LLL	94.5	.9	M-100;LAWRENCE LIVERMORE LAB;(1978)
1333.65 KEV			
LLL	5.07	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
1434.09 KEV			
LLL	100	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)

MN 54
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	312.21	D	.03	AECL-6530;44(1979)
NBS	312.02	D	.04	NBS PREV. UNPUBL.
BIPM	312.19	D	.13	PROC.CIPM-41;68(1973)
BIPM	312.15	D	.23	PROC.CIPM-42;64(1974)

FE 55
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	1000.4	D	1.3	IJARI-31;153(1980)
LMRI	2.68	Y	.02*	(IN PRESS)
NBS	1009.0	D	1.7	NBS PREV. UNPUBL.

MN 56
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	2.5764	H	.0008	AECL-3333;32(1969)
LMRI	2.5785	H	.0006*	NIM-112;323(1973)
NPL	2.578	H	.008	IJARI-19;823(1968)

CO 56
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
LMRI	77.12	D	.20*	IJARI-29;269(1978)

CO 56 (CONTINUED)
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PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
846.8 KEV			
HNRE	99.92	.007	NIM-174;109(1980)
1037.8 KEV			
HNRE	14.15	.07	NIM-174;109(1980)
1238.3 KEV			
HNRE	66	.3	NIM-174;109(1980)
1360.2 KEV			
HNRE	4.262	.022	NIM-174;109(1980)
1771.4 KEV			
HNRE	15.48	.07	NIM-174;109(1980)
2015.4 KEV			
HNRE	3.024	.017	NIM-174;109(1980)
2034.9 KEV			
HNRE	7.76	.04	NIM-174;109(1980)
2598.6 KEV			
HNRE	16.95	.08	NIM-174;109(1980)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
846.8 KEV			
INEL	100	1	NIM-147;405(1977)
LLL	100	0	M-100;LAWRENCE LIVERMORE LAB;(1978)
1037.8 KEV			
INEL	14.04	.14	NIM-147;405(1977)
LLL	14	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
1175.1 KEV			
INEL	2.28	.02	NIM-147;405(1977)
LLL	2.28	.02	M-100;LAWRENCE LIVERMORE LAB;(1978)
1238.3 KEV			
INEL	66.4	.7	NIM-147;405(1977)
LLL	67.6	.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
1360.2 KEV			
INEL	4.24	.04	NIM-147;405(1977)
LLL	4.33	.04	M-100;LAWRENCE LIVERMORE LAB;(1978)
1771 KEV			
INEL	15.65	.16	NIM-147;405(1977)
LLL	15.7	.15	M-100;LAWRENCE LIVERMORE LAB;(1978)
2015.2 KEV			
INEL	3.09	.05	NIM-147;405(1977)
LLL	3.08	.03	M-100;LAWRENCE LIVERMORE LAB;(1978)
2034.7 KEV			
INEL	7.95	.12	NIM-147;405(1977)
LLL	7.89	.07	M-100;LAWRENCE LIVERMORE LAB;(1978)
2598.4 KEV			
INEL	17.34	.26	NIM-147;405(1977)
LLL	16.9	.15	M-100;LAWRENCE LIVERMORE LAB;(1978)
3201.9 KEV			
INEL	3.18	.1	NIM-147;405(1977)
LLL	3.04	.03	M-100;LAWRENCE LIVERMORE LAB;(1978)
3253.4 KEV			
INEL	7.79	.24	NIM-147;405(1977)
LLL	7.41	.065	M-100;LAWRENCE LIVERMORE LAB;(1978)

CO 57

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
CBNM	271.90	D	.09	IJARI(IN PRESS)
IAEA	271.77	D	.05	IJARI-31;153(1980)
LMRI	271.23	D	.63*	IJARI-23;219(1972)
NBS	271.9	D	.2	NBS PREV. UNPUBL.
PTB	271.5	D	.5	PTB-ANNUAL(1977);177

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
136.5 KEV			
PTB	10.58	.08	U.SCHOTZIG ET AL NIM(IN PRESS)

CO 58

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
CBNM	70.81	D	.1*	IJARI-27;727(1980)
IAEA	70.916	D	.015	IJARI-31;153(1980)
LMRI	70.78	D	.13*	IJARI-26;131(1975)
NBS	70.75	D	.07	NBS PREV. UNPUBL.
NPL	70.83	D	.02	NPL PREV. UNPUBL.

FE 59

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	44.496	D	.007	IJARI-31;153(1980)
NBS	44.507	D	.007	NBS PREV. UNPUBL.
PTB	44.529	D	.007	PTB;INT. REP. MAR 1976

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
1099 KEV			
LMRI	55.5	1.7*	NP A-142;63(1970)
1292 KEV			
LMRI	44.1	1.2*	NP A-142;63(1970)

CO 60

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	1923.78	D	.94	AECL-6788;46(1980)
AECL	1924.33	D	1.36	AECL-6788;46(1980)
CBNM	5.283	Y	.008*	IJARI-27;727(1976)
IAEA	1925.2	D	.4	IJARI-31;153(1980)
NBS	5.282	Y	.007	NBS PREV. UNPUBL.
PTB	5.272	Y	.002	Z.NATURF-25A;921(1970)
BIPM	46195	H	24	PROC.CIPM-41;68(1973)
BIPM	1925.5	D	.3	BIPM PREV. UNPUBL.

ZN 65
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
CBNM	244	D	.2	Z.PHYSIK-250;395(1972)
LMRI	243.75	D	.21*	IJARI-26;131(1975)
NBS	244.2	D	.1	NBS PREV. UNPUBL.
PTB	243.97	D	.08	INT.REP.PTB RADIOACT. GROUP MAR 1976

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
1115 KEV			
CBNM	50.75	.1	Z.HYSIK-250;395(1972)
PTB	50.39	.26	PTB-MITTEILUNGEN-87;22(1977)

GA 67
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	3.2607	D	.0008	IJARI-31;153(1980)
LMRI	78.33	H	.10*	IJARI-29;269(1978)
NBS	3.2606	D	.001	NBS PREV. UNPUBL.
NPL	3.261	D	.006	IJARI-23;279(1972)
PTB	3.2594	D	.0012	IJARI-30;551(1979)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
91.237 KEV			
LLL	3	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
93.291 KEV			
LLL	36.6	1.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
184.569 KEV			
LLL	21.7	.9	M-100;LAWRENCE LIVERMORE LAB;(1978)
208.97 KEV			
LLL	2.4	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
300.23 KEV			
LLL	16.6	.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
393.539 KEV			
LLL	4.5	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)

SE 75
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	119.779	D	.004	IJARI-31;153(1980)
LMRI	118.45	D	.25*	IJARI-26;131(1975)
NBS	119.80	D	.07	NBS PREV. UNPUBL.
PTB	119.76	D	.05	NIM-169;43(1980)

SE 75 (CONTINUED)
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PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
96.7 KEV			
PTB	3.48	.09	NIM-169;43(1980)
121.1 KEV			
PTB	17.3	.3	NIM-169;43(1980)
136.0 KEV			
PTB	59.0	.8	NIM-169;43(1980)
264.7 KEV			
PTB	59.1	.8	NIM-169;43(1980)
279.5 KEV			
PTB	25.2	.4	NIM-169;43(1980)
400.5 KEV			
AECL	12.5	.3	AECL-3666;46(1970)
PTB	11.56	.15	NIM-169;43(1980)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
96.7 KEV			
INEL	5.9	.3	NIM-147;405(1977)
LLL	5.72	.21	M-100;LAWRENCE LIVERMORE LAB;(1978)
121.1 KEV			
INEL	29.8	.9	NIM-147;405(1977)
LLL	29.8	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
136 KEV			
INEL	102	3	NIM-147;405(1977)
LLL	100	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
264.7 KEV			
INEL	100	3.	NIM-147;405(1977)
LLL	100	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)
279.5 KEV			
INEL	42.4	1.3	NIM-147;405(1977)
LLL	42.2	.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
400.5 KEV			
INEL	19.1	.3	NIM-147;405(1977)
LLL	19.5	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)

BR 82
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	35.344	H	.016	CAN.J.P.-40;1044(1962)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
554.3 KEV			
INEL	84.7	.8	NIM-147;405(1977)
LLL	84.8	1.6	M-100;LAWRENCE LIVERMORE LAB;(1978)
619.1 KEV			
INEL	52	.5	NIM-147;405(1977)
LLL	51.6	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)
776.5 KEV			
INEL	100	1	NIM-147;405(1977)
LLL	100	0	M-100;LAWRENCE LIVERMORE LAB;(1978)
827.8 KEV			
INEL	28.77	.29	NIM-147;405(1977)
LLL	28.7	.7	M-100;LAWRENCE LIVERMORE LAB;(1978)
1044 KEV			
INEL	32.55	.33	NIM-147;405(1977)
LLL	32.8	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)
1317.4 KEV			
INEL	31.74	.32	NIM-147;405(1977)
LLL	32.2	.6	M-100;LAWRENCE LIVERMORE LAB;(1978)
1474.9 KEV			
INEL	19.53	.2	NIM-147;405(1977)
LLL	19.9	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)

KR 85
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PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
514 KEV			
AECL	.46	.03	NUCLEONICS-19;97(1961)

SR 85
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	64.845	D	.009	AECL-5315;37(1976)
IAEA	64.856	D	.007	IJARI-31;153(1980)
NBS	64.851	D	.006	NBS PREV. UNPUBL.
NPL	64.84	D	.013	Z.PHYSIK-A-289;51(1978)
PTB	64.865	D	.008	PTB;PREV. UNPUBL.

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
13.38 KEV			
NPL	58.66	.41	K X-RAY;Z.PHYSIK-A-289;51(1978)

Y 88
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	106.612	D	.014	IJARI-31;153(1980)
LMRI	106.6	D	.4*	IJARI-26;131(1975)
NBS	106.64	D	.05	NBS PREV. UNPUBL.
PTB	106.64	D	.08	PTB INT. REP. MAR 1976

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
898 KEV			
HNRE	93.7	.4	NIM-174;109(1980)
NBS	94.3	.3	NBS PREV. UNPUBL.
PTB	94.6	.5	PTB-MITTEILUNGEN-87;22(1977)

NB 90
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PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
141.2 KEV			
HNRE	70.1	1.7	NIM-175;525(1980)
1129.2 KEV			
HNRE	94.22	.09	NIM-175;525(1980)
2186.2 KEV			
HNRE	18.11	.08	NIM-175;525(1980)
2319 KEV			
HNRE	81.82	.08	NIM-175;525(1980)

NB 90 (CONTINUED)
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RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
132.7 KEV			
LLL	5.04	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
141.2 KEV			
LLL	81.4	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
1129.2 KEV			
LLL	113	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)
2186.2 KEV			
LLL	21.9	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
2319 KEV			
LLL	100	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)

ZR 95
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
CBNM	64.05	D	.06*	Z.HYSIK A-276;317(1976)
IAEA	64.03	D	.006	IJARI-31;153(1980)
PTB	64.10	D	.04	PTB INT. REP. MAR 1976

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
724.2 KEV			
LLL	43.7	.8	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	44.0	.5	ANN. NUCL. ENERGY-2;37(1974)
756.7 KEV			
LLL	55.4	1.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	54.3	.5	ANN. NUCL. ENERGY-2;37(1974)

NB 95
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	34.98	D	.02	AECL-3668;50(1970)
CBNM	34.97	D	.03*	Z.PHYSIK-A-278;317(1976)
IAEA	34.979	D	.009	IJARI-31;153(1980)

MO 99
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	65.945	H	.003	IJARI-31;153(1980)
NBS	65.924	H	.006	NBS PREV. UNPUBL.
NPL	65.903	H	.001	NPL PREV. UNPUBL.

MO 99 (CONTINUED)
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PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
140.4 KEV			
LLL	90.6	1.8	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	90.3	1.0	NBS PREV. UNPUBL.
PTB	90.5	.5	PTB-ANN.REP.(1978)
181.1 KEV			
LLL	6.04	.12	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	6.00	.05	NBS PREV. UNPUBL.
PTB	6.03	.07	PTB-ANN.REP.(1978)
739.5 KEV			
LLL	12	.33	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	12.06	.09	NBS PREV. UNPUBL.
PTB	12.31	.09	PTB-ANN.REP.(1978)
777.9 KEV			
LLL	4.24	.09	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	4.25	.03	NBS PREV. UNPUBL.
PTB	4.33	.04	PTB-ANN.REP.(1978)

TC 99M
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	6.008	H	.004	AECL-6083;38(1978)
IAEA	6.006	H	.002	IJARI-31;153(1980)
LMRI	6.031	H	.012*	IJARI-21;139(1970)
NBS	6.0072	H	.0009	SALINE;NBS PREV. UNPUBL.
NBS	6.017	H	.002	ACID;NBS PREV. UNPUBL.
NPL	6.0067	H	.0038	NATURE-210;614(1966)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
140 KEV			
AECL	88.75	.14	AECL-3157;30(1968)

RU103
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
CBNM	39.26	D	.02	IJARI(IN PRESS)
IAEA	39.254	D	.008	IJARI-31;153(1980)
PTB	39.276	D	.009	PTB-INT.REP. MAR 1976

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
497 KEV			
LLL	100	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)
610.2 KEV			
LLL	6.3	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
497 KEV			
PTB	90.9	.7	PTB-ANN.REP.(1974)
610.2 KEV			
PTB	5.65	.07	PTB-ANN.REP.(1974)

CD109

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
CBNM	461.9	D	.3	IJARI(IN PRESS)
LMRI	463.1	D	.8*	(IN PRESS)
NBS	463.2	D	.6	NBS PREV. UNPUBL.

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
22.5 KEV			
NBS	2734	27	NBS PREV. UNPUBL.
UGDP	2560	90	NIM-98; 433 (1972)
88 KEV			
NBS	100	0	NBS PREV. UNPUBL.
UGDP	100	0	NIM-98; 433 (1972)

AG110M

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	249.74	D	.05	IJARI-31;153(1980)
NBS	249.93	D	.06	NBS PREV. UNPUBL.
PTB	249.78	D	.04	PTB-INT.REP. MAR 1976

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
657.8 KEV			
HNRE	94.54	.2	NIM-174;109(1980)
PTB	94.65	.16	USAEC REP. CONF-760539;59;NTIS;1976
677.1 KEV			
HNRE	10.48	.09	NIM-174;109(1980)
687 KEV			
HNRE	6.43	.06	NIM-174;109(1980)
707.5 KEV			
HNRE	16.7	.12	NIM-174;109(1980)
PTB	16.56	.13	USAEC REP. CONF-760539;59;NTIS;1976
744.3 KEV			
HNRE	4.73	.03	NIM-174;109(1980)
763.9 KEV			
HNRE	22.26	.13	NIM-174;109(1980)
PTB	22.43	.18	USAEC REP. CONF-760539;59;NTIS;1976
818 KEV			
HNRE	7.33	.05	NIM-174;109(1980)
884.7 KEV			
HNRE	72.6	.4	NIM-174;109(1980)
PTB	73.4	1.8	USAEC REP. CONF-760539;59;NTIS;1976
937.5 KEV			
HNRE	34.33	.2	NIM-174;109(1980)
PTB	34.6	.4	USAEC REP. CONF-760539;59;NTIS;1976
1384.3 KEV			
HNRE	24.25	.14	NIM-174;109(1980)
PTB	24.7	.22	USAEC REP. CONF-760539;59;NTIS;1976
1505 KEV			
HNRE	13.03	.07	NIM-174;109(1980)
PTB	13.16	.13	USAEC REP. CONF-760539;59;NTIS;1976

AG110M (CONTINUED)
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RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
657.7 KEV			
INEL	100	1	NIM-147;405(1977)
LLL	100	0	M-100;LAWRENCE LIVERMORE LAB;(1978)
677.6 KEV			
INEL	11.31	.11	NIM-147;405(1977)
LLL	11.2	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
687 KEV			
INEL	6.85	.07	NIM-147;405(1977)
LLL	6.83	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
706.7 KEV			
INEL	17.67	.18	NIM-147;405(1977)
LLL	17.28	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
744.3 KEV			
INEL	4.92	.05	NIM-147;405(1977)
LLL	4.93	.08	M-100;LAWRENCE LIVERMORE LAB;(1978)
763.9 KEV			
INEL	23.6	.24	NIM-147;405(1977)
LLL	23.6	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
818 KEV			
INEL	7.73	.08	NIM-147;405(1977)
LLL	7.71	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
884.7 KEV			
INEL	76.9	.8	NIM-147;405(1977)
LLL	77.1	1	M-100;LAWRENCE LIVERMORE LAB;(1978)
937.5 KEV			
INEL	36.22	.36	NIM-147;405(1977)
LLL	36.3	.6	M-100;LAWRENCE LIVERMORE LAB;(1978)
1384.3 KEV			
INEL	25.7	.26	IM-147;405(1977)
LLL	26.1	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)
1505 KEV			
INEL	13.84	.14	NIM-147;405(1977)
LLL	14.01	.19	M-100;LAWRENCE LIVERMORE LAB;(1978)

IN111
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	2.8071	D	.0015	IJARI-31;153(1980)
LMRI	2.802	D	.003*	IJARI-29;269(1978)
NBS	2.8048	D	.0005	NBS PREV. UNPUBL.
PTB	2.8045	D	.0008	PTB-ANN.REP (1978)

IN113M
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	99.49	M	.06	AECL-2256;23(1965)
CBNM	99.47	M	.07	IJARI-22;1(1971)
LMRI	1.658	H	.004*	IJARI-21;139(1970)
NBS	99.21	M	.13*	IJARI-26;314(1975)
NPL	1.658	H	.002*	IJARI-21;678(1970)

IN113M (CONTINUED)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
392 KEV			
AECL	64.9	.2	AECL-2256;23(1965)
NPL	64.9	.3*	IJARI-21;678(1970)

SN113

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	115.12	D	.13	AECL-5315;37(1976)
IAEA	115.09	D	.04	IJARI-31;153(1980)
NBS	115.06	D	.07	NBS PREV. UNPUBL.

I 123

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
LMRI	13.21	H	.03*	(IN PRESS)
NPL	13.222	H	.003	NPL PREV. UNPUBL.

SB125

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	1007.3	D	.3	IJARI-31;153(1980)
NBS	2.75	Y	.02	NBS PREV. UNPUBL.

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
176.4 KEV			
LLL	6.79	.02	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	6.95	.12	PTB PREV. UNPUBL.
427.9 KEV			
LLL	29.4	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	30.5	.5	PTB PREV. UNPUBL.
463.4 KEV			
LLL	10.45	.15	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	10.71	.17	PTB PREV. UNPUBL.
600.6 KEV			
LLL	17.78	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	18.0	.3	PTB PREV. UNPUBL.
606.7 KEV			
LLL	5.02	.07	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	5.12	.08	PTB PREV. UNPUBL.
635.9 KEV			
LLL	11.32	.18	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	11.47	.15	PTB PREV. UNPUBL.
671.4 KEV			
LLL	1.8	.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	1.842	.024	PTB PREV. UNPUBL.

SB125 (CONTINUED)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
176.4 KEV			
INEL	23.9	.7	NIM-147;405(1977)
NBS	23.2	.1	NBS PREV. UNPUBL.
380.4 KEV			
INEL	5.1	.05	NIM-147;405(1977)
427.9 KEV			
INEL	100	1	NIM-147;405(1977)
NBS	100.0	.6	NBS PREV. UNPUBL.
463.4 KEV			
INEL	35.26	.37	NIM-147;405(1977)
600.6 KEV			
INEL	60.6	.6	NIM-147;405(1977)
NBS	59.7	.4	NBS PREV. UNPUBL.
606.7 KEV			
INEL	17.12	.17	NIM-147;405(1977)
NBS	17.0	.1	NBS PREV. UNPUBL.
635.9 KEV			
INEL	38.6	.4	NIM-147;405(1977)
NBS	38.1	.2	NBS PREV. UNPUBL.
671.4 KEV			
INEL	6.18	.06	NIM-147;405(1977)
NBS	6.3	.1	NBS PREV. UNPUBL.

I 125

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	59.156	D	.02	IJARI-31;153(1980)
NBS	59.47	D	.21	NBS PREV. UNPUBL.

I 131

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	8.0213	D	.0009	IJARI-31;153(1980)
LMRI	8.020	D	.003*	IJARI-29;269(1978)
NBS	8.020	D	.002	NBS PREV. UNPUBL.
PTB	8.021	D	.001	PTB-ANN.REP. (1978)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
284.3 KEV			
LLL	6.01	.06	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	6.21	.04	NBS PREV. UNPUBL.
PTB	6.20	.06	PTB-ANN.REP. 1977
364.5 KEV			
LLL	80.6	1.6	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	81.6	.6	PTB-ANN.REP. 1977
637 KEV			
LLL	7.21	.09	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	7.11	.04	NBS PREV. UNPUBL.
PTB	7.12	.06	PTB-ANN.REP. 1977

XE133

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	5.243	D	.001	AECL-5032;34(1975)
NBS	5.245	D	.006*	PRC-10;2631(1974)
NPL	5.25	D	.013*	IJARI-26;485(1975)

BA133
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	3785.17	D	27.17	AECL-6788;45(1980)
IAEA	3848	D	1.1	IJARI-31;153(1980)
NBS	10.48	Y	.03	NBS PREV. UNPUBL.
PTB	10.53	Y	.06	PRELIMINARY VALUE IN IJARI-28;503(1977)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
30.85 KEV			
LMRI	99.7	3.0*	K-ALPHA X-RAY;LMRI/80/776/EM
PTB	97.1	1.6	K-ALPHA X-RAY;PTB-ANN. REP. 1 /9
35.1 KEV			
LMRI	22.9	.8*	K-BETA X-RAY;LMRI/80/776/EM
PTB	23.2	.5	K-BETA X-RAY;PTB-ANN. REP. 1979
79.6			
LMRI	2.57	.12*	LMRI/80/776/EM
PTB	2.61	.07	PTB-ANN.REP. 1979
81.0			
LMRI	34.5	.8*	LMRI/80/776/EM
PTB	34.0	.8	PTB-ANN.REP. 1979
276.4 KEV			
HNRE	7.15	.03	Y. YOSHIZAWA PRI. COMM.(1980)
LMRI	7.16	.15*	LMRI/80/776/EM
PTB	7.1	.1	PTB-ANN.REP. 1979
302.9 KEV			
HNRE	18.28	.08	Y. YOSHIZAWA PRI. COMM.(1980)
LMRI	18.27	.35*	LMRI/80/776/EM
PTB	18.33	.22	PTB-ANN.REP. 1979
356 KEV			
HNRE	62	.14	Y. YOSHIZAWA PRI. COMM.(1980)
LMRI	61.9	1.0*	LMRI/80/776/EM
PTB	62.3	.7	PTB-ANN.REP. 1979
383.9 KEV			
HNRE	8.92	.04	Y. YOSHIZAWA PRI. COMM.(1980)
LMRI	8.91	.19*	LMRI/80/776/EM
PTB	8.92	.09	PTB-ANN.REP. 1979

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
81 KEV			
INEL	49.2	2.6	NIM-147;405(1977)
LLL	51.2	.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
GITSC	52.6	1	Z. PHYSIK-249; 286 (1972)
276.4 KEV			
INEL	11.7	.4	NIM-147;405(1977)
LLL	11.3	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
GITSC	11.4	.3	Z. PHYSIK-249; 286 (1972)
302.9 KEV			
INEL	29.76	.3	NIM-147;405(1977)
LLL	29.2	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
GITSC	30.2	.6	Z. PHYSIK-249; 286 (1972)
356 KEV			
INEL	100	1	NIM-147;405(1977)
LLL	100	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
GITSC	100	0	Z. PHYSIK-249; 286 (1972)
383.9 KEV			
INEL	14.36	.14	NIM-147;405(1977)
LLL	14.5	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
GITSC	14.4	.3	Z. PHYSIK-249; 286 (1972)

CS134

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	753.78	D	.3	AECL-6788;45(1980)
IAEA	754.5	D	.07	IJARI-31;153(1980)
LMRI	2.058	Y	.012*	IJARI-23;219(1972)
NBS	2.0649	Y	.0004	NBS PREV. UNPUBL.

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
563.1 KEV			
HNRE	8.37	.05	NIM-174;109(1980)
LLL	8.38	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	8.34	.12	PTB-ANN.REP. 1976
569.2 KEV			
HNRE	15.4	.08	NIM-174;109(1980)
LLL	15.4	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	15.38	.22	PTB-ANN.REP. 1976
604.7 KEV			
HNRE	97.64	.06	NIM-174;109(1980)
LLL	97.6	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	97.6	.1	PTB-ANN.REP. 1976
795.8 KEV			
HNRE	85.52	.05	NIM-174;109(1980)
LLL	85.4	.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	85.3	.9	PTB-ANN.REP. 1976
801.8 KEV			
HNRE	8.68	.04	NIM-174;109(1980)
LLL	8.73	.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	8.64	.12	PTB-ANN.REP. 1976
1167.9			
HNRE	1.783	.010	NIM-174;109(1980)
LLL	1.81	.03	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	1.80	.20	PTB-ANN.REP. 1976
1365.2			
HNRE	3.001	.017	NIM-174;109(1980)
LLL	3.04	.04	M-100;LAWRENCE LIVERMORE LAB;(1978)
PTB	3.02	.02	PTB-ANN.REP. 1976

CS137

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	10677.5	D	140.3	AECL-6788;##(1980)
IAEA	11009	D	11	IJARI-31;153(1980)
NBS	30.68	Y	.02	NBS PREV. UNPUBL.
PTB	29.901	Y	.045	Z. NATURF-25A;921(1970)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
662 KEV			
AECL	84.7	.6	AECL-6203;(1978)
CBNM	85.1	.4	Z.HYSIK-215;25(1969)
NPL	84.56	.08	METROLOGIA-14;157(1978)

CS137 (CONTINUED)
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RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
661.6 KEV			
CBNM	100	0	REFERENCE LINE
32.1 KEV			
CBNM	8.13	.1	Z.HYSIK-215;25(1969)

CE139
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	137.65	D	.03	AECL-5546;32(1976)
CBNM	137.66	D	.13*	IJARI-27;727(1976)
IER	137.8	D	.2	RAPPORT BIPM-77/4
LMRI	137.59	D	.12*	IJARI-29;269(1978)
NBS	137.74	D	.08	NBS UNPUBLISHED

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
165 KEV			
AECL	79.95	.06	BAPS-7;352(1962)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
34 KEV			
UGDP	101	2.5	NIM-98; 433 (1972)
165.8 KEV			
UGDP	100	0	NIM-98; 433 (1972)

BA140-LA140
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
NBS	12.753	D	.002	NBS UNPUBLISHED
PTB	12.746	D	.010	PTB-ANN. REP. 1977

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
162.5 KEV			
PTB	6.21	.08	NUCL. SCI. ENG. 64,784(1977)
537.3 KEV			
PTB	24.39	.22	NUCL. SCI. ENG. 64,784(1977)

BA140-LA140 (CONTINUED)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
162.5 KEV			
INEL	5.83	.18	NIM-147;405(1977)
328.8 KEV			
INEL	21.46	.22	NIM-147;405(1977)
487 KEV			
INEL	47.7	.5	NIM-147;405(1977)
537.3 KEV			
INEL	22.07	.23	NIM-147;405(1977)
751.7 KEV			
INEL	4.65	.05	NIM-147;405(1977)
815.8 KEV			
INEL	24.85	.25	NIM-147;405(1977)
867.8 KEV			
INEL	5.9	.06	NIM-147;405(1977)
925.2 KEV			
INEL	7.42	.08	NIM-147;405(1977)
1596.2 KEV			
INEL	100	1	NIM-147;405(1977)

LA140

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	40.28	H	.006	IJARI-31;153(1980)
PTB	40.272	H	.007	PTB-INT.REP. MAR 1976
NBS	1.6783	D	.0007	NBS PREV. UNPUBL.

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
328.8 KEV			
PTB	20.74	.18	NUCL. SCI. ENG. 64,784(1977)
487 KEV			
PTB	45.94	.38	NUCL. SCI. ENG. 64,784(1977)
815.8 KEV			
PTB	23.64	.17	NUCL. SCI. ENG. 64,784(1977)
867.8 KEV			
PTB	5.59	.05	NUCL. SCI. ENG. 64,784(1977)
925.2 KEV			
PTB	7.05	.08	NUCL. SCI. ENG. 64,784(1977)
1596.2 KEV			
PTB	95.40	.08	NUCL. SCI. ENG. 64,784(1977)

CE141

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	32.5	D	.03	AECL PREV. UNPUBL.
CBNM	32.5	D	.04*	IJARI-27;727(1976)
NBS	32.52	D	.03	NBS PREV. UNPUBL.
PTB	32.51	D	.06	Z. NATURF-26A;596(1971)

CE141 (CONTINUED)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
145.44 KEV			
AECL	48.5	.4	AECL-5909(ICRM-LS-1)(1977)
CBNM	48.2	.3	Z.PHYSIK-A-290;113(1979)
LMRI	48.44	.42*	IJARI-26;179(1975)
PTB	48.9	.4	NIM-169;43(1980)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
35.8 KEV			
UGDP	33.4	.9	NIM-98; 433 (1972)
145 KEV			
UGDP	100	0	NIM-98; 433 (1972)

CE144

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	285.8	D	.1	IJARI-31;153(1980)
NBS	284.9	D	.5	NBS PREV. UNPUBL.
PTB	285.08	D	.18	PTB-INT.REP. MAR 1976

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
133.5 KEV			
PTB	11.09	.16	ANN. NUCL. ENERGY 2,37(1974)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
80.1 KEV			
INEL	112	6	NIM-147;405(1977)
133.5 KEV			
INEL	836	25	NIM-147;405(1977)
696.5 KEV			
INEL	100	1	NIM-147;405(1977)
1489.1 KEV			
INEL	20.27	.21	NIM-147;405(1977)
2185.6 KEV			
INEL	52.3	.7	NIM-147;405(1977)

EU152

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	4892.3	D	8.2	AECL-6788;45(1980)
LMRI	13.10	Y	.15*	IJARI-29;269(1978)
NBS	13.57	Y	.11	NBS PREV. UNPUBL.
PTB	4931	D	15	NIM-169;43(1980)

EU152 (CONTINUED)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
39.9 KEV			
PTB	59.1	1.2	K-ALPHA X-RAY;NIM-165;279(1979)
45.7 KEV			
PTB	14.9	.3	K-BETA X-RAY;NIM-165;279(1979)
121.8 KEV			
LMRI	28.2	.5*	CEA-R-4656(1975)
PTB	28.55	.37	NIM-158;479(1979)
244.7 KEV			
LMRI	7.38	.13*	CEA-R-4656(1975)
PTB	7.44	.11	NIM-158;479(1979)
344.3 KEV			
PTB	26.52	.29	NIM-158;479(1979)
411.12 KEV			
LMRI	2.21	.04*	CEA-R-4656(1975)
PTB	2.24	.04	NIM-158;479(1979)
444.0 KEV			
LMRI	3.076	.05*	CEA-R-4656(1975)
PTB	3.12	.05	NIM-158;479(1979)
778.9 KEV			
LMRI	13.00	.22*	CEA-R-4656(1975)
PTB	12.91	.14	NIM-158;479(1979)
964.0 KEV			
LMRI	14.48	.23*	CEA-R-4656(1975)
PTB	14.66	.15	NIM-158;479(1979)
1085.9 KEV			
LMRI	10.14	.16*	CEA-R-4656(1975)
PTB	10.09	.13	NIM-158;479(1979)
1112.1 KEV			
LMRI	13.55	.20*	CEA-R-4656(1975)
PTB	13.53	.19	NIM-158;479(1979)
1408.0 KEV			
LMRI	20.70	.29*	CEA-R-4656(1975)
PTB	20.85	.19	NIM-158;479(1979)

EU152 (CONTINUED)
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RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
121.8 KEV			
INEL	141.	4.	NIM-147;405(1977)
LLL	136.2	1.6	M-100;LAWERENCE LIVERMORE LAB;(1978)
244.7 KEV			
INEL	36.6	1.1	NIM-147;405(1977)
LLL	35.9	.6	M-100;LAWERENCE LIVERM[illegible];(1978)
344.3 KEV			
HNRE	127.9	.6	NIM-174;133(1980)
INEL	127.2	1.3	NIM-147;405(1977)
LLL	127.5	.9	M-100;LAWRENCE LIVERMORE
411.1 KEV			
HNRE	10.9	.05	NIM-174;133(1980)
INEL	10.71	.11	NIM-147;405(1977)
LLL	10.7	.1	M-100;LAWRENCE LIVERMORE LAB;(1[illegible]8)
443.9 KEV			
HNRE	15.06	.06	NIM-174;133(1980)
INEL	15	.15	NIM-147;405(1977)
LLL	14.8	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
778.8 KEV			
HNRE	62.16	.22	NIM-174;133(1980)
INEL	62.6	.6	NIM-147;405(1977)
LLL	61.9	.8	M-100;LAWRENCE LIVERMORE LAB;(1978)
867.3 KEV			
HNRE	20.33	.1	NIM-174;133(1980)
INEL	20.54	.21	NIM-147;405(1977)
LLL	19.9	.4	M-100;LAWRENCE LIVERMORE LAB;(1978)
963.65 KEV			
HNRE	70.14	.23	NIM-174;133(1980)
INEL	70.4	.7	NIM-147;405(1977)
LLL	69.2	.9	M-100;LAWRENCE LIVERMORE LAB;(1978)
1085.8 KEV			
HNRE	48.15	.16	NIM-174;133(1980)
INEL	48.7	.5	NIM-147;405(1977)
LLL	47.5	.7	M-100;LAWRENCE LIVERMORE LAB;(1978)
1089.7 KEV			
HNRE	8.35	.04	NIM-174;133(1980)
INEL	8.26	.09	NIM-147;405(1977)
LLL	8.2	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
1112 KEV			
HNRE	64.67	.21	NIM-174;133(1980)
INEL	65	.7	NIM-147;405(1977)
LLL	64.9	.09	M-100;LAWRENCE LIVERMORE LAB;(1978)
1212 KEV			
HNRE	6.85	.05	NIM-174;133(1980)
INEL	6.67	.07	NIM-147;405(1977)
LLL	6.7	.08	M-100;LAWRENCE LIVERMORE LAB;(1978)
1299.2 KEV			
HNRE	7.8	.05	NIM-174;133(1980)
INEL	7.76	.08	NIM-147;405(1977)
LLL	7.8	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
1408 KEV			
HNRE	100	.3	NIM-174;133(1980)
INEL	100	1	NIM-147;405(1977)
LLL	100	.03	M-100;LAWRENCE LIVERMORE LAB;(1978)

EU154
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
NBS	8.49	Y	.11	NBS PREV. UNPUBL.
PTB	8.57	Y	.07	PTB-ANNUAL REPORT;189(1978)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
123.1 KEV			
LLL	40.5	.7	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	40.8	.3	NBS PREV. UNPUBL.
248.0 KEV			
LLL	7	.11	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	6.91	.04	NBS PREV. UNPUBL.
591.7 KEV			
LLL	5.02	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	4.95	.03	NBS PREV. UNPUBL.
692.4 KEV			
LLL	1.81	.03	M-100;LAWRENCE LIVERMORE LAB;(1978)
723.3 KEV			
LLL	20.3	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	20.08	.12	NBS PREV. UNPUBL.
756.9 KEV			
LLL	4.61	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
873.2 KEV			
LLL	12.3	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	12.19	.09	NBS PREV. UNPUBL.
996.3 KEV			
LLL	10.7	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	10.59	.08	NBS PREV. UNPUBL.
1004.8 KEV			
LLL	18.4	.2	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	18.08	.11	NBS PREV. UNPUBL.
1274.4 KEV			
LLL	35.5	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	34.84	.17	NBS PREV. UNPUBL.
1596.5 KEV			
LLL	1.82	.03	M-100;LAWRENCE LIVERMORE LAB;(1978)
NBS	1.785	.014	NBS PREV. UNPUBL.

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
591.7 KEV			
HNRE	14.35	.06	NIM-174;133(1980)
692.4 KEV			
HNRE	5.182	.025	NIM-174;133(1980)
723.3 KEV			
HNRE	58.19	.21	NIM-174;133(1980)
756.9 KEV			
HNRE	13.18	.07	NIM-174;133(1980)
873.2 KEV			
HNRE	35.18	.12	NIM-174;133(1980)
904.1 KEV			
HNRE	2.62	.03	NIM-174;133(1980)
996.3 KEV			
HNRE	30.09	.12	NIM-174;133(1980)
1004.8 KEV			
HNRE	52.04	.19	NIM-174;133(1980)
1274.4 KEV			
HNRE	100	.3	NIM-174;133(1980)
1596.5 KEV			
HNRE	5.247	.026	NIM-174;133(1980)

EU155
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
NBS	4.73	Y	.02	NBS PREV. UNPUBL.

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
45.295 KEV			
LLL	6.3	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
60.022 KEV			
LLL	5.39	.06	M-100;LAWRENCE LIVERMORE LAB;(1978)
86.554 KEV			
LLL	149.6	3	M-100;LAWRENCE LIVERMORE LAB;(1978)
105.338 KEV			
LLL	100	2	M-100;LAWRENCE LIVERMORE LAB;(1978)

HO166M
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RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
80.6 KEV			
INEL	21.4	1.1	NIM-147;405(1977)
184.4 KEV			
INEL	128	4	NIM-147;405(1977)
280.5 KEV			
INEL	51.5	1.6	NIM-147;405(1977)
300.7 KEV			
INEL	6.36	.2	NIM-147;405(1977)
410.9 KEV			
INEL	19.55	.2	NIM-147;405(1977)
529.8 KEV			
INEL	16.36	.16	NIM-147;405(1977)
571 KEV			
INEL	9.53	.1	NIM-147;405(1977)
670.5 KEV			
INEL	9.43	.1	NIM-147;405(1977)
711.7 KEV			
INEL	95.3	1	NIM-147;405(1977)
752.3 KEV			
INEL	21.21	.21	NIM-147;405(1977)
810.3 KEV			
INEL	100	1	NIM-147;405(1977)
830.6 KEV			
INEL	16.97	.17	NIM-147;405(1977)

YB169

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	32.015	D	.009	AECL-5032;35(1975)
IAEA	32.022	D	.008	IJARI-31;153(1980)
LMRI	31.97	D	.05*	IJARI-26;131(1975)
NBS	32.02	D	.01	NBS PREV. UNPUBL.
NPL	32.040	D	.004	NPL PREV. UNPUBL.

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
63.1 KEV			
INEL	116	6	NIM-147;405(1977)
93.7 KEV			
INEL	7.1	.4	NIM-147;405(1977)
109.8 KEV			
INEL	48.5	1.5	NIM-147;405(1977)
118.1 KEV			
INEL	5.31	.16	NIM-147;405(1977)
130.5 KEV			
INEL	32	1	NIM-147;405(1977)
177.2 KEV			
INEL	62.2	1.9	NIM-147;405(1977)
198 KEV			
INEL	100	3	NIM-147;405(1977)
307.7 KEV			
INEL	27.5	.8	NIM-147;405(1977)

HF180M

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	5.519	H	.004	IJARI-31;153(1980)

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
93.3 KEV			
NPL	21.94	.1	NIM-174;571(1980)
215.3 KEV			
NPL	100	0	NIM-174;571(1980)
332.3 KEV			
NPL	117.46	.74	NIM-174;571(1980)
443.2 KEV			
NPL	100.72	.69	NIM-174;571(1980)

TA182

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
PTB	114.43	D	.04	NIM-169;43(1980)

TA182 (CONTINUED)
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PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
58.8 KEV			
PTB	28.02	.52	K-ALPHA X-RAY;NIM-169;43(1980)
67.8 KEV			
PTB	57.1	1.3	UNRESOLVED GAMMA AND K-BETA X-RAYS NIM-169;43(1980)
84.7 KEV			
PTB	2.63	.1	NIM-169;43(1980)
100.1 KEV			
PTB	14.23	.42	NIM-169;43(1980)
113.7 KEV			
PTB	1.87	.06	NIM-169;43(1980)
152.4 KEV			
PTB	6.95	.09	NIM-169;43(1980)
156.4 KEV			
PTB	2.63	.05	NIM-169;43(1980)
179.4 KEV			
PTB	3.09	.04	NIM-169;43(1980)
198.4 KEV			
PTB	1.44	.02	NIM-169;43(1980)
222.1 KEV			
PTB	7.5	.1	NIM-169;43(1980)
229.3 KEV			
PTB	3.64	.05	NIM-169;43(1980)
264.1 KEV			
PTB	3.62	.06	NIM-169;43(1980)
1121.3 KEV			
PTB	35.3	.32	NIM-169;43(1980)
1189 KEV			
PTB	16.44	.15	NIM-169;43(1980)
1221.4 KEV			
PTB	27.17	.25	NIM-169;43(1980)
1231 KEV			
PTB	11.58	.11	NIM-169;43(1980)

TA182 (CONTINUED)
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RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
67.8 KEV			
INEL	122	6	NIM-147;405(1977)
LLL	131	10	M-100;LAWRENCE LIVERMORE LAB;(1978)
84.7 KEV			
INEL	7.8	.4	NIM-147;405(1977)
LLL	7.19	.14	M-100;LAWRENCE LIVERMORE LAB;(1978)
100.1 KEV			
INEL	40.8	1.2	NIM-147;405(1977)
LLL	40.4	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)
113.7 KEV			
INEL	5.43	.17	NIM-147;405(1977)
LLL	5.34	.05	M-100;LAWRENCE LIVERMORE LAB;(1978)
152.4 KEV			
INEL	20.5	.6	NIM-147;405(1977)
LLL	19.95	.18	M-100;LAWRENCE LIVERMORE LAB;(1978)
156.4 KEV			
INEL	7.77	.23	NIM-147;405(1977)
LLL	7.59	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
179.4 KEV			
INEL	9.1	.28	NIM-147;405(1977)
LLL	8.82	.1	M-100;LAWRENCE LIVERMORE LAB;(1978)
198.4 KEV			
INEL	4.31	.13	NIM-147;405(1977)
LLL	4.19	.09	M-100;LAWRENCE LIVERMORE LAB;(1978)
222.1 KEV			
INEL	21.9	.7	NIM-147;405(1977)
LLL	21.6	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
229.3 KEV			
INEL	10.6	.3	NIM-147;405(1977)
LLL	10.39	.18	M-100;LAWRENCE LIVERMORE LAB;(1978)
264.1 KEV			
INEL	10.5	.3	NIM-147;405(1977)
LLL	10.26	.18	M-100;LAWRENCE LIVERMORE LAB;(1978)
1121.3 KEV			
INEL	100	1	NIM-147;405(1977)
LLL	100	.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
1157.4 KEV			
INEL	2.85	.04	NIM-147;405(1977)
1189 KEV			
INEL	46.5	.5	NIM-147;405(1977)
LLL	47.1	.8	M-100;LAWRENCE LIVERMORE LAB;(1978)
1221.4 KEV			
INEL	77.8	.8	NIM-147;405(1977)
LLL	77.8	1.3	M-100;LAWRENCE LIVERMORE LAB;(1978)
1231 KEV			
INEL	32.96	.33	NIM-147;405(1977)
LLL	33.1	.5	M-100;LAWRENCE LIVERMORE LAB;(1978)
1257.4 KEV			
INEL	4.26	.04	NIM-147;405(1977)
LLL	4.36	.08	M-100;LAWRENCE LIVERMORE LAB;(1978)

IR192
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	73.831	D	.008	IJARI-31;153(1980)
LMRI	74.02	D	.18*	IJARI-23;219(1972)
NBS	73.81	D	.07	NBS PREV. UNPUB.

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
296 KEV			
LMRI	36.5	1.0*	NPA-142;63(1970)
INEL	34.64	.35	NP-A204;26(1973)
308.5 KEV			
LMRI	37.4	1.0*	NPA-142;63(1970)
INEL	35.77	.36	NP-A204;26(1973)
316.5 KEV			
LMRI	100.	0	NPA-142;63(1970)
INEL	100.	0	NP-A204;26(1973)
468.1 KEV			
LMRI	57.4	2.0*	NPA-142;63(1970)
INEL	58.	.9	NP-A204;26(1973)
588.6 KEV			
LMRI	5.37	.25*	NPA-142;63(1970)
INEL	5.52	.10	NP-A204;26(1973)
604.4 KEV			
LMRI	10.0	.4*	NPA-142;63(1970)
INEL	10.04	.26	NP-A204;26(1973)
612.5 KEV			
LMRI	6.4	.2*	NPA-142;63(1970)
INEL	6.55	.13	NP-A204;26(1973)

AU198
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	2.6935	D	.0004	AECL-5802;43(1977)
NBS	2.695	D	.002	NBS PREV. UNPUB.
NPL	2.695	D	.007	IJARI-19;823(1968)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
411.8 KEV			
HNRE	95.56	.08	NIM-175;525(1980)

HG203
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HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
AECL	46.6	D	.01	AECL-4205;21(1972)
IAEA	46.582	D	.002	IJARI-31;153(1980)
NBS	46.62	D	.03	NBS PREV. UNPUB.

PB203

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
IAEA	51.88	H	.02	IJARI-31;153(1980)
NBS	51.92	H	.04	NBS PREV. UNPUBL.
NPL	51.873	H	.009	NPL PREV. UNPUBL.

BI207

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
NBS	32.23	Y	.0	NBS PREV. UNPUBL.

PHOTON PROBABILITY PER DECAY

569.7 KEV			
HNRE	97.74	.03	NIM-174;109(1980)
1063.6 KEV			
HNRE	74	.3	NIM-174;109(1980)
1770.2 KEV			
HNRE	6.87	.04	NIM-174;109(1980)

RA226

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
186.0 KEV			
PTB	3.51	.6	PTB ANN. REP. 1977
241.9 KEV			
PTB	7.12	.11	PTB ANN. REP. 1977
295.2 KEV			
PTB	18.15	.22	PTB ANN. REP. 1977
351.9 KEV			
PTB	35.1	.4	PTB ANN. REP. 1977
609.3 KEV			
PTB	44.6	.5	PTB ANN. REP. 1977
768.4 KEV			
PTB	4.75	.07	PTB ANN. REP. 1977
934.05 KEV			
PTB	3.07	.04	PTB ANN. REP. 1977
1120.3 KEV			
PTB	14.7	.2	PTB ANN. REP. 1977
1238.1 KEV			
PTB	5.78	.07	PTB ANN. REP. 1977
1764.5 KEV			
PTB	15.06	.26	PTB ANN. REP. 1977
2204.1 KEV			
PTB	4.98	.12	PTB ANN. REP. 1977

TH228

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
NBS	698.1	D	.5	NBS PREV. UNPUBL.

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
583.2			
NBS	30.7	.3	NBS PREV. UNPUBL.
727.3			
NBS	6.67	.06	NBS PREV. UNPUBL.
860.5			
NBS	4.55	.04	NBS PREV. UNPUBL.

RELATIVE PHOTON PROBABILITY

LABORATORY	P(%)	UNCERTAINTY	REF.
583.2 KEV			
INEL	100	1	NIM-147;405(1977)
860.5 KEV			
INEL	14.79	.15	NIM-147;405(1977)
2614.5 KEV			
INEL	118.5	1.6	NIM-147;405(1977)

AM241

HALF LIFE

LABORATORY	T1/2	UNIT	UNCERTAINTY VALUE	REF.
PTB	432	Y	.2	IJARI-26;589(1975)

PHOTON PROBABILITY PER DECAY

LABORATORY	P(%)	UNCERTAINTY	REF.
26.3			
LMRI	2.35	.07*	LMRI PREV. UNPUBL.
59.5			
LMRI	36.5	.2*	LMRI PREV. UNPUBL.
NBS	35.82	.14	NBS PREV. UNPUBL.

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Members of the Alpha-, Beta-, and Gamma-Ray Spectrometry Group of the International Committee for Radionuclide Metrology agreed in 1979 to collect the nuclear data from any measurements in their laboratories that were pertinent to the calibration of the efficiency of germanium spectrometer systems. This report is composed of the contributions from 14 laboratories, as listed in part II. If a self-contained contribution was received, it has been incorporated without editing. Less formal communications, or references to published articles, are discussed in short comments prepared by the compilers. Part IV is a compilation of a selected portion of the data, arranged by radionuclide.

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compilation; efficiency data; half lives; measurement uncertainties; photon probabilities per decay; relative photon-emission probabilities

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