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X-ray and gamma-ray standards for detector calibration

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FOREWORD

A major objective of the IAEA nuclear data programme is to promote the improvement of the quality of nuclear data used in science and technology. For many years various groups around the world have engaged in the compilation and evaluation of decay data for radionuclides. Generally these evaluators have operated independently and arrived at different values for the same quantity. Such disagreements in the recommended data are particularly critical when attempting to define the decay characteristics of radionuclides used as standards in the calibration of detector efficiencies to a high degree of accuracy. Under such circumstances these differences can be propagated into the subsequent measurements of decay data for other radionuclides.

The IAEA established a Co-ordinated Research Programme (CRP) on the Measurements and Evaluation of X- and Gamma-Ray Standards for Detector Efficiency Calibration in 1986 with the aim of alleviating the generation of such discrepancies. Within the framework of this CRP, representatives of nine research groups from six Member States and one international organization performed a number of precise measurements and systematic in-depth evaluations of the required decay data. They have also contributed to the development of evaluation methodology and measurement techniques, and stimulated a number of such studies at laboratories not directly involved in the IAEA project.

The results of the work of the CRP, which was finished in 1990, are presented in this report. Recommended values of half-lives and photon emission probabilities are given for a carefully selected set of radionuclides that are suitable for detector efficiency calibration (X-rays from 5 to 90 keV and gamma-rays from 30 to about 3000 keV). Detector efficiency calibration for higher gamma-ray energies (up to 14 MeV) is also considered. The evaluation procedures used to obtain the recommended values and their estimated uncertainties are reported, and a summary of the remaining discrepancies is given.

Part 1 of this report lists the CRP participants and gives a summary of the data status and evaluation procedures. The results of the work undertaken by the CRP are presented in Parts 2 and 3 of this report. Part 2 takes the form of tabulations with specific reference to the measurements and evaluations performed by the CRP participants and the data they recommend; these tables consist of half-life values, and X-ray and gamma-ray transition energies and emission probabilities for 36 radionuclides used routinely in the efficiency calibration of gamma-ray detectors. A complete set of recommended decay data for these standards nuclides is given in Part 3. It is expected that these recommended values will be recognized as international reference standards.

All of the CRP participants wish to acknowledge the assistance of A. Lorenz and H.D. Lemmel of the IAEA Nuclear Data Section, for coordinating the CRP during its working period, and for preparing this document. The IAEA is also grateful to the French Commissariat à l'Energie Atomique, the Centro Studi Nucleari of the Italian ENEA and the German Physikalisch-Technische Bundesanstalt for hosting the meetings which led to the successful conclusion of this project.

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Part 1

DATA STATUS AND ASSESSMENT

1. INTRODUCTION

The question of gamma-ray detector efficiency calibration arose during a previous IAEA Co-ordinated Research Programme (1978-1985) on Transactinium Nuclide Decay Data [1] when the importance of international reference standards for detector calibration became apparent. Although a provisional compilation of calibration data was agreed upon for that work [2], it was recommended that an internationally accepted file of X- and gamma-ray decay data should be prepared for nuclides used to calibrate detector efficiencies. Such a proposal was supported at the IAEA Advisory Group Meeting at Uppsala on Transactinium Nuclear Data, May 1984 [3], and by the International Nuclear Data Committee (INDC) which recommended the establishment of a meeting of experts associated with the International Committee for Radionuclide Metrology (ICRM). As a result, an IAEA consultants' meeting was held at the Centre d'Etudes Nucléaires de Grenoble on 30 and 31 May 1985 to discuss the quality of the relevant data and define a suitable programme to resolve various issues [4]. As a consequence of these discussions, a Co-ordinated Research Programme (CRP) on the Measurement and Evaluation of X- and Gamma-ray Standards for Detector Efficiency Calibration was established in 1986 by the IAEA Nuclear Data Section. Participants in the programme were specialists in gamma-ray spectrometry and in related areas of standards and data evaluation. Their objective was to produce a recommended set of decay parameters for selected radionuclides judged as the most important for the calibration of equipment used to detect and quantify X- and gamma-ray emissions. CRP meetings were held in Rome (1987 [5]) and Braunschweig (1989 [6]) to monitor progress, promote needed measurements, determine evaluation methodology, and agree upon the final recommended half-lives and X- and gamma-ray emission probabilities as presented in this report.

Various factors, such as source preparation and source-detector geometry, may affect the quality of measurements made with intrinsic germanium and other gamma-ray spectrometers. However, the accuracy of such measurements depends invariably upon the accuracy of the efficiency versus energy calibration curve, and hence upon the accuracy of the decay data for the radionuclides from which calibration standard sources are prepared. Both half-lives and X- and gamma-ray emission probabilities need to be known to good accuracy.

The participants in this IAEA CRP on X- and Gamma-ray Standards for Detector Calibration were given the task to establish a data file that would be internationally accepted so as to improve the worldwide uniformity of subsequent measurements of photon emission probabilities. Thus, the CRP has defined an evaluation methodology which should provide consistent and high quality results. Furthermore, it is expected that gamma-ray spectroscopists will be willing to accept the standard values presented in this report and use the recommended data in their work.

2. COMPOSITION OF THE CO-ORDINATED RESEARCH PROGRAMME

After the initial meeting at Grenoble in 1985, nine groups experienced in decay data measurements and evaluations agreed to participate in the work of the CRP under the auspices of the IAEA Nuclear Data Section. Representatives of these groups met at ENEA Headquarters in Rome from 11 to 13 June 1987 [5], and at PTB, Braunschweig from 31 May to 2 June 1989 [6]. Representatives from the following laboratories participated formally in this CRP by performing the required measurements and evaluations:

CEC-JRC, Central Bureau for Nuclear Measurements (CBNM), Geel, Belgium (represented by W. Bambynek),

Faculty of Science, Hiroshima University, Hiroshima-Shi, Japan (represented by Y. Yoshizawa),

Idaho National Engineering Laboratory (INEL), Idaho Falls, Idaho, USA (represented by R.G. Helmer),

Laboratoire de Métrologie des Rayonnements Ionisants (LMRI), *) Gif-sur-Yvette, France (represented by N. Coursol),

National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, USA (represented by F.J. Schima),

National Office of Measures (OMH), Budapest, Hungary (represented by T. Barta and R. Jedlovszky),

National Physical Laboratory (NPL), Teddington, Middlesex, United Kingdom (represented by P. Christmas),

Physikalisch Technische Bundesanstalt (PTB), Braunschweig, Germany (represented by K. Debertin),

AEA Technology, Winfrith Technology Centre, Dorchester, Dorset, United Kingdom (represented by A.L. Nichols).

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*) now: Laboratoire Primaire des Rayonnements Ionisants (LPRI)

The programme was co-ordinated by A. Lorenz and H.D. Lemmel of the IAEA Nuclear Data Section.

In addition, other laboratories in Japan, Europe and the USA were engaged in measurements relevant to the objectives of the CRP and contributed to this effort. Valuable contributions were also provided by multinational intercomparison projects organised by the International Committee for Radionuclide Metrology (ICRM) and the Bureau International des Poids et Mesures (BIPM).

3. OBJECTIVES OF THE CO-ORDINATED RESEARCH PROGRAMME

The objectives of the CRP were identified with the following steps:

a) selection of appropriate calibration nuclides,
b) assessment of the status of the existing data,
c) identification of data discrepancies and limitations,
d) stimulation of measurements to meet the data needs, and
e) evaluation and recommendation of improved calibration data.

Every effort was made to cover as wide a range of photon energy as possible. X-ray and low-energy gamma-ray emitting radionuclides were included to cover the energy range from 5 to 100 keV, e.g., ^{55}Fe, ^{93m}Nb, ^{109}Cd and ^{111}In. Other considerations for the selection of radionuclides included:

commonly used and readily available nuclides,
nuclides used and offered as standards by national laboratories,
multi-line nuclides for rapid calibrations,
definition of a set of single-line nuclides to avoid the need for coincidence summing corrections, and
choice of nuclides with accurately known emission probabilities.

Emission probability data for selected photons were evaluated and expressed as absolute probabilities of the emission per decay.

A recommended list of 36 nuclides evolved from meetings of the IAEA CRP (Table 1). After assessing the status of the existing data, the participants agreed to measure and/or evaluate data which were either discrepant or of inadequate accuracy. The laboratories contributing to this effort are listed in the columns marked "CRP activities" of Table 1.

TABLE 1. CALIBRATION STANDARDS: DECAY PARAMETERS AND CRP ACTIVITIES

The laboratories that contributed to the IAEA Co-ordinated Research Programme on the Measurement and Evaluation of X- and Gamma-Ray Standards for Detector Efficiency Calibration are referred to by their abbreviations:

AEA - UK Atomic Energy Authority, Winfrith Technology Centre, UK;
CBNM - CEC-JRC Central Bureau of Nuclear Measurements, Geel, Belgium;
Hiroshima University, Hiroshima, Japan;
INEL - Idaho National Engineering Laboratory, Idaho Falls, USA;
LMRI - CEA Laboratoire de Métrologie des Rayonnements Ionisants, Saclay, France;
NIST - US National Institute of Standards and Technology, Washington DC, USA;
NPL - National Physical Laboratory, Teddington, UK;
OMH - National Office of Measures, Budapest, Hungary;
PTB - Physikalisch-Technische Bundesanstalt, Braunschweig, Germany.

Data types:

$T_{1/2}$ half-life
P_X X-ray emission probability
P_γ gamma-ray emission probability
α_t total internal conversion coefficient

Footnotes:

+ Uncertainties for X- and gamma-ray emission probabilities and internal conversion coefficients apply to the major transitions only, corresponding to 1σ confidence level.
* Measurement programme has been co-ordinated by ICRM.
# Measurement programme is being co-ordinated as BIPM intercomparison.

Radio-nuclide	Data Type	Uncertainty Achieved(%)+	CRP activities		Comments
			Measurements	Evaluations	
^{22}Na	$T_{1/2}$	0.1	NIST	NPL/PTB	
	P_γ	0.015	-	NIST	
^{24}Na	$T_{1/2}$	0.03	-	NPL/PTB	
	P_γ	0.0015-0.005	-	NIST	
^{46}Sc	$T_{1/2}$	0.05	-	NPL/PTB	
	P_γ	0.0016	-	Hiroshima Univ.	
^{51}Cr	$T_{1/2}$	0.03	-	NPL/PTB	
	P_X	1.3	-	CBNM	
	P_γ	0.5	OMH	AEA	
^{54}Mn	$T_{1/2}$	0.13	NIST/NPL	NPL/PTB	
	P_X	3.1	-	CBNM	
	P_γ	0.0024	-	Hiroshima Univ.	
^{55}Fe	$T_{1/2}$	0.8	PTB	NPL/PTB	
	P_X	3.5	-	CBNM	

TABLE 1. (cont.)

Radio-nuclide	Data Type	Uncertainty Achieved(%)$^{+}$	CRP activities: Measurements	CRP activities: Evaluations	Comments
^{56}Co	$T_{1/2}$	0.3	PTB/NPL	NPL/PTB	
	P_γ	0.007-0.4	-	Hiroshima Univ.	
^{57}Co	$T_{1/2}$	0.03	NIST/NPL	NPL/PTB	P_γ for 14.4 keV transition particularly uncertain
	P_X	0.7	-	CBNM	
	P_γ	0.2-1.5	PTB	OMH	
^{58}Co	$T_{1/2}$	0.1	NPL	NPL/PTB	
	P_X	3.8	-	CBNM	
	P_γ	0.01	-	OMH	
	α_t	3	-	LMRI	
^{60}Co	$T_{1/2}$	0.03	NIST/NPL	NPL/PTB	
	P_γ	0.006-0.02	-	NIST	
^{65}Zn	$T_{1/2}$	0.11	NPL	NPL/PTB	Few direct measurements of P_γ for 1115 keV transition
	P_X	2.3	-	CBNM	
	P_γ	0.5	NPL/PTB	AEA	
^{75}Se	$T_{1/2}$	0.2	NIST/NPL	NPL/PTB	Significant uncertainty in P_γ arises from quantifying direct population of ^{75}As ground state
	P_X	7.1	-	CBNM	
	P_γ *	0.3-1.2	LMRI/NIST/OMH/PTB	AEA	
	α_t	1-7	-	LMRI	
^{85}Sr	$T_{1/2}$	0.006	-	NPL/PTB	P_γ for 514 keV transition depends on a theoretical estimate of the branch to the ground state
	P_X	1.4	-	CBNM	
	P_γ	0.4	-	Hiroshima Univ.	
	α_t	12	-	Hiroshima Univ.	
^{88}Y	$T_{1/2}$	0.02	-	NPL/PTB	
	P_X	1.3	-	CBNM	
	P_γ	0.03-0.3	PTB	LMRI	
	α_t	1	-	LMRI	
^{93m}Nb	$T_{1/2}$	0.85	-	PTB/NPL	
	P_X	3.2	-	CBNM	
^{94}Nb	$T_{1/2}$	12	-	PTB/NPL	
	P_γ	0.05	-	INEL	
	α_t	1	-	LMRI	

TABLE 1. (cont.)

Radio-nuclide	Data Type	Uncertainty Achieved(%)$^+$	CRP activities: Measurements	CRP activities: Evaluations	Comments
^{95}Nb	$T_{1/2}$	0.02	-	PTB/NPL	
	P_γ	0.03	-	INEL	
	α_t	1-3	-	LMRI	
^{109}Cd	$T_{1/2}$	0.15	NIST	PTB/NPL	
	P_x	2.0	-	CBNM	
	P_γ #	0.6	PTB	LMRI	
	α_t	2	-	LMRI	
^{111}In	$T_{1/2}$	0.02	-	PTB/NPL	
	P_x	2.4	-	CBNM	
	P_γ #	0.1	-	Hiroshima Univ.	
	α_t	1.2	-	Hiroshima Univ.	
^{113}Sn	$T_{1/2}$	0.03	-	PTB/NPL	
	P_x	0.6	-	CBNM	
	P_γ #	0.2	-	INEL	
^{125}Sb	$T_{1/2}$	0.06	-	PTB/NPL	
	P_γ	1	INEL	LMRI	
^{125}I	$T_{1/2}$	0.02	NIST/NPL/PTB/CBNM	PTB/NPL	
	P_x	2.2	-	CBNM	
	P_γ #	1.2	PTB	LMRI	
	α_t	1.5	-	LMRI	
^{134}Cs	$T_{1/2}$	0.03	-	PTB/NPL	
	P_γ	0.06-1.3	-	Hiroshima Univ.	
^{137}Cs	$T_{1/2}$	0.4	NIST	PTB/NPL	
	P_x	2.9	-	CBNM	
	P_γ	0.24	-	LMRI	
	α_t	0.7	-	LMRI	
^{133}Ba	$T_{1/2}$	0.4	-	PTB/NPL	Resolution of 79 and 81 keV gamma transitions poses problems
	P_x	1.3	-	CBNM	
	P_γ *	0.3-0.8	OMH/PTB	OMH	
	α_t	5.5-7	-	LMRI	
^{139}Ce	$T_{1/2}$	0.02	-	PTB/NPL	
	P_x	2.8	-	CBNM	
	P_γ	0.08	-	LMRI	
	α_t	0.4	-	LMRI	

TABLE 1. (cont.)

Radio-nuclide	Data Type	Uncertainty Achieved(%)+	CRP activities		Comments
			Measurements	Evaluations	
^{152}Eu	$T_{1/2}$	0.2	NIST/NPL	PTB/NPL	
	P_x	1.6	-	CBNM	
	P_γ *	0.5	-	INEL	
^{154}Eu	$T_{1/2}$	0.09	-	PTB/NPL	
	P_x	2.3	-	CBNM	
	P_γ	1.1-1.7	INEL/NIST/NPL	Hiroshima Univ.	
^{155}Eu	$T_{1/2}$	2.8	PTB	PTB/NPL	
^{198}Au	$T_{1/2}$	0.03	-	PTB/NPL	
	P_x	7.1	-	CBNM	
	P_γ	0.5	-	AEA	
^{203}Hg	$T_{1/2}$	0.03	-	PTB/NPL	
	P_x	3.1	-	CBNM	
	P_γ	0.1	-	INEL	
^{207}Bi	$T_{1/2}$	6	-	PTB/NPL	Additional P_γ measurements are underway to resolve discrepant data
	P_x	5.2	-	CBNM	
	P_γ	0.03-0.6	INEL/NIST/PTB	Hiroshima Univ.	
	α_t	1.4	-	Hiroshima Univ.	
^{228}Th (and daughters)	$T_{1/2}$	0.9	-	NPL/PTB	
	P_γ	0.2-3.3	-	LMRI	
^{239}Np	$T_{1/2}$	0.17	-	PTB/NPL	
	P_γ	1.5	-	LMRI	
^{241}Am	$T_{1/2}$	0.15	-	PTB/NPL	
	P_x	2.0	-	CBNM	
	P_γ	1-4	PTB	CBNM	
^{243}Am	$T_{1/2}$	0.3	-	NPL/PTB	
	P_γ	1.5-1.9	-	AEA/LMRI	
	α_t	2	-	LMRI	

4. DATA EVALUATION

It was decided that all available data were to be considered in the initial assessments; data were evaluated from the open literature and laboratory reports published over a considerable period of time. The eventual omission of individual values had to be justified on the basis of their quality or other specific grounds.

Following the initial assessment of the existing half-life and gamma-ray emission probability data, members of the CRP concluded:

- There were certain half-lives and emission probabilities for which further measurements were desirable. Some specific cases are noted below and others are implied by the CRP-related measurements, as listed in Table 1.

- Greater consistency was needed between the various evaluators. This was true for both the half-lives, all of which were evaluated by two groups (at NPL and PTB) only, and the gamma-ray emission probabilities which were evaluated by six groups.

An evaluation procedure was developed for the half-life data, which was also used, when appropriate, for the gamma-ray emission probabilities. This methodology is outlined below and is described in detail in Ref. [7].

The recommended value consisted of the weighted average of the published values in which the weights were taken to be the inverse of the squares of the overall uncertainties. A set of data was self-consistent if the reduced-χ^2 value was approximately 1.0 or less. When the data in a set were inconsistent and there were three or more values, the method of limitation of the relative weight proposed by Zijp [8] was recommended. The sum of the individual weights was computed; if any one weight contributed over 50% of the total, the corresponding uncertainty was increased so that the contribution of the value to the sum of the weights would be less than 50%. The weighted average was then recalculated and used if the reduced-χ^2 value for this average was < 2. If the reduced-χ^2 was > 2, the weighted or unweighted mean was chosen according to whether or not the 1σ uncertainty on each mean value included the other term. The basis for the latter choice is that it may be unreasonable to use the weighted average if the data do not comprise a consistent set.

With these guidelines in hand, the evaluations were carried out as discussed in the next sections.

It was not considered necessary to carry out evaluations of the X- and gamma-ray energies, because the photon energies are only required to the nearest 1 or 0.1 keV. However, for completeness it was decided to include the best available energy values, many of which have been precisely measured and evaluated [9]. Most of the energy values quoted in this report were taken from Ref. [9]; original references were cited when the data were not available from this source.

Internal conversion coefficients are often used in the evaluation of gamma-ray emission probabilities, either directly in the determination of a particular emission probability or in testing the consistency of the decay scheme. Theoretical internal conversion coefficients were normally taken from Rösel et al. [10]; when necessary these data were obtained by interpolation using a computer program written at LMRI [11].

4.1 Half-lives

After the preliminary evaluation of the half-lives had been carried out by the participants from NPL and PTB, it was judged advantageous to undertake additional high quality half-life measurements for a number of radionuclides. Such a decision was made on the basis of either one or both of the following criteria: (1) the computed uncertainty for the weighted average was undesirably large and/or (2) the existing values were inconsistent (e.g. reduced-χ^2 of over 10 for the average). Furthermore, it was decided that the uncertainty was undesirably large if the value contributed an uncertainty in the decay correction of more than 0.1% after a decay period of up to the shorter of five half-lives or 15 years. The CRP divided the radionuclides that needed additional half-life measurements into three groups of priority 1, 2, and 3 on the basis of the first criterion. For priority 1 nuclides, the uncertainties were too large by a factor of 10 or more; for priority 2, the uncertainties were too large by a factor of between 4 and 10; for priority 3, the uncertainties were too large by factors of 3.3 to 4.

The categorized half-lives were:

priority 1 - ^{55}Fe, ^{56}Co, ^{125}I and ^{155}Eu
priority 2 - ^{54}Mn, ^{75}Se, and ^{109}Cd
priority 3 - ^{22}Na, ^{58}Co, ^{65}Zn and ^{133}Ba.

As noted in Table 1, many of these half-lives were subsequently measured by the CRP participants.

All recommended half-lives in this report are based on the re-evaluation of these quantities, incorporating both old and newly measured values and the methodology outlined above. The exclusion of measured values and modifications to the uncertainties are noted for each case.

4.2 X-ray emission probabilities

X-ray emissions originate from the creation of inner-shell vacancies and the subsequent reorganization of the unstable atomic shells. Orbital electron capture by the nucleus and internal conversion of gamma-rays can produce these inner-shell vacancies during radioactive decay.

For any particular decay scheme, the emission probability of K X-rays is given by

$$P_{KX} = \{ \sum_i P_{EC}(E_i)\, P_K(E_i) + \sum_i b_i \left(\frac{\alpha_K}{1+\alpha_t}\right)_i \} \omega_K$$

where $P_{EC}(E_i)$ and $P_K(E_i)$ are the relative transition probabilities to the energy level E_i by total electron capture and K-electron capture, respectively; α_K and α_t are the K-shell and the total internal conversion coefficients, respectively; b_i is the transition probability of the i^{th} gamma-ray transition, and ω_K is the K-shell fluorescence yield. A similar equation can be used to calculate the L X-ray emission probabilities. However, these values depend on the mode of vacancy production in the three L subshells, which is different for internal conversion and electron capture by the nucleus. Furthermore, the interpretation of L X-ray data may be complicated by the transfer of the primary vacancies between the L subshells due to Coster-Kronig transitions [12].

The chosen radionuclides can be subdivided into primary and secondary X-ray standards; the former have been either measured directly without using an efficiency-calibrated detector or can be reliably derived by other means. The relevant data were evaluated so that K_{α}, K_{β} and the total K X-ray emission probabilities could be calculated for all Z; in addition, subdivisions into $K_{\alpha 1}$, $K_{\alpha 2}$, $K_{\beta' 1}$, and $K_{\beta' 2}$ were made for a few nuclides with $Z > 65$ and for a limited number of emission probabilities for nuclides with $Z \geq 82$. The following data sources were used:

(a) Electron-capture probabilities were calculated from the electron wave functions of Mann and Waber [13]; exchange and overlap corrections were made as given by Bahcall [14] and Vatai [15] and as recalculated by Chen [16] for $Z > 54$; and corrections by Suslov [17] and Martin and Blichert-Toft [18] were made for $Z > 54$. The method of calculation and the input data have been described by Bambynek et al. [16].

(b) Fluorescence yields were deduced from the evaluation of Bambynek [19].

(c) Internal conversion data were obtained from compilations of experimental values by Hansen [20,21], and from evaluations of some selected transitions made by Hansen [22] and Lagoutine et al. [23].

(d) Relative X-ray emission rates (K_{β}/K_{α}, $K_{\alpha 2}/K_{\alpha 1}$, $K_{\beta}/K_{\alpha 1}$, $K_{\beta' 1}/K_{\alpha 1}$) were taken from Salem et al. [24], allowing for the contribution of radiative Auger satellites to these ratios [25].

The resulting X-ray data were critically evaluated against measured X- or gamma-ray emission probabilities, and minor adjustments were made, if necessary. The X-ray energies were not evaluated but taken from Browne and Firestone [26]. Uncertainties were estimated according to the recommendations of BIPM [27].

It should be noted that the X-ray peaks differ in shape from gamma-ray peaks when measured with semiconductor detectors, due to the larger natural line widths of X-rays. This can result in calibration errors of several percent when using the same procedure to analyse X-ray and gamma-ray data [28].

TABLE 2. Inconsistencies and measurements of emission probabilities

Radionuclide	Decay Parameter	CRP Measurements
^{51}Cr	P_{γ}	OMH
^{57}Co	P_{γ} (14.4 keV)	PTB
^{65}Zn	P_{γ}	NPL/PTB
^{75}Se	P_{γ} *	LMRI/NIST/OMH/PTB
^{109}Cd	P_{γ} #	PTB
^{111}In	α	-
^{125}Sb	P_{γ}	INEL
^{125}I	P_{γ} #	PTB
^{133}Ba	P_{γ} (79 and 81 keV doublet) *	OMH/PTB
^{154}Eu	P_{γ}	INEL/NIST/NPL
^{207}Bi	P_{γ}	INEL/NIST/PTB
^{241}Am	P_{γ} (26.3 and 59.5 keV), P_{Lx}	PTB

* Measurement programme has been co-ordinated by ICRM
\# Measurement programme is being co-ordinated as BIPM intercomparison

4.3 Gamma-ray emission probabilities

After the initial evaluation of the gamma-ray emission probabilities, the need for more measurements was deemed necessary to resolve inconsistencies in the decay data of specific radionuclides (see Table 2). The CRP laboratories that carried out these measurements are listed in Tables 1 and 2.

The final recommended data cover the energy range from 14 to 3548 keV for gamma-rays and 4.95 to 87 keV for X-rays. Although data above 3.6 MeV were not evaluated by this CRP, the methods and sources that can be used to determine a detector efficiency for high-energy photons are given in Section 5.

A wide variety of methods can be used to obtain evaluated gamma-ray emission probabilities. For example, the emission probabilities of ^{60}Co were calculated from the decay scheme using various parameters (notably the internal conversion coefficients), rather than direct gamma-ray measurements. The gamma-ray emission probabilities of other radionuclides were derived primarily from gamma-ray measurements, as for example in the case of ^{152}Eu where 35 sets of spectral data were included in the evaluation. These large numbers of ^{152}Eu emission rate measurements originated as a result of an earlier intercomparison performed under the auspices of the International Committee for Radionuclide Metrology (ICRM). A similar intercomparison has been organized for ^{75}Se by the OMH within the framework of the ICRM.

5. DETECTOR EFFICIENCY CALIBRATION AT HIGH ENERGIES

The radioactive sources discussed in the preceding sections permit the precise determination of the efficiency of a germanium detector up to about 2.7 MeV with either a ^{24}Na or ^{228}Th source, or to 3.6 MeV with a ^{56}Co source. A brief description is given in this section of some sources of radiation that can be used to extend the efficiency calibration to above 10 MeV. Except for one radioactive nuclide (^{66}Ga), these sources of radiation are based on nuclear reactions. While other reactions could be used, only thermal neutron capture and the (p,γ) reaction are considered here.

Although each type of calibration source may involve special considerations or limitations, there are some general problems that can be noted. One experimental problem is that of the source-detector geometry. If an efficiency curve is determined from spectra of one type of reaction and used for spectra from another type of reaction or radioactive decay, care must be taken to maintain the same source-detector geometry (i.e., source distance, size and gamma-ray attenuation must be the same, or the appropriate corrections have to be made). This may be a very difficult problem if a reaction has a low cross-section requiring a large or thick target.

5.1 High-energy gamma-rays

Some general comments are required concerning the high-energy gamma-ray data. These data are generally taken from a single reference and have not been subjected to the detailed evaluation of the other data in this report. Furthermore, the data are of somewhat uneven quality. Some of the measurements have been made recently and were done with metrology goals in mind; other measurements were made earlier with less well defined efficiency calibrations. The latter problem is illustrated by the early work on ^{56}Co where the efficiency curves above 2 MeV were simply extrapolated from the lower energy data.

5.2 ^{66}Ga

^{66}Ga is the only radionuclide that has been used in the energy region above 3600 keV. This radionuclide has a half-life of 9.5 hours and can be produced by ^{63}Cu(α,n), ^{66}Zn(p,n) and ^{64}Zn(α,2n)^{66}Ge(EC)

TABLE 3. Gamma-ray emission probabilities from the decay of ^{66}Ga (9.5 hour) for those gamma-rays with probabilities over 0.01 (Refs [26] and [29])

E_γ (keV)	P_γ [a]
833.6	0.0603(12)
1039.4	0.379
1333.2	0.01232(25)
1918.8	0.0214(4)
2189.9	0.0571(11)
2422.9	0.0196(4)
2752.3	0.232(8)
3229.2	0.0148(11)
3381.4	0.0140(11)
3791.6	0.0102(11)
4086.5	0.0114(19)
4295.7	0.035(7)
4807.0	0.015(4)

[a] The uncertainties are those for the probabilities relative to that for the 1039-keV gamma-ray. A normalization uncertainty of 3.2% should be added (in quadrature) to obtain the overall uncertainty in the emission probabilities.

reactions. The gamma-rays with emission probabilities > 0.01 are listed in Table 3, including six lines from 3.2 to 4.8 MeV. However, two limitations are immediately apparent: the half-life of 9.5 hours means that this radionuclide can only be used by spectroscopists with access to an appropriate production facility, and the uncertainties in the emission probabilities above 3 MeV range from 7% to 27% which does not result in a precise efficiency calibration. Since a source of unknown activity would be used, the relative efficiencies would be measured and normalized to efficiencies determined previously at lower energies, for example at 1039 or 2752 keV. Despite the high decay energy of 5.2 MeV, the multiplicity of the gamma-ray cascades is not high. Considering that the decay scheme consists only of the gamma-rays listed in Table 3, 6% of the decays produce three gamma-rays in cascade, 32% produce only two cascade gamma-rays, 10% produce only one gamma-ray, and 50% do not produce any gamma-rays at all. This means that any coincidence summing corrections will be similar to those of simple sources (e.g., ^{60}Co) with cascades of two gamma-rays (assuming the X-rays from the electron-capture process do not reach the detector). Anyone using this nuclide for efficiency calibration should recognize that

TABLE 4. Gamma-ray emission probabilities per neutron capture (P_γ) for prompt gamma-rays from the $^{14}N(n,\gamma)^{15}N$ reaction from Kennett et al. [30]

E_γ(keV)	P_γ
1678.174(55)	0.0723(18)
1884.879(21)	0.1866(25)
2520.418(15)	0.0579(7)
3532.013(13)	0.0924(9)
3677.772(17)	0.1489(15)
4508.783(14)	0.1654(17)
5269.169(12)	0.3003(20)
5297.817(15)	0.2131(18)
5533.379(13)	0.1975(21)
5562.062(17)	0.1065(12)
6322.337(14)	0.1867(14)
7298.914(33)	0.0973(9)
8310.143(29)	0.0422(5)
9149.222(47)	0.0162(2)
10829.087(46)	0.1365(21)

Note: Recently, A.H. Wapstra [Nucl. Instr. Methods A292 (1990) 671] has given an alternate set of gamma-ray energies based on the average of three sets of measurements and a revised value of the neutron binding energy.

the high-energy values may have a systematic bias similar to that for the emission probabilities of ^{56}Co.

5.3 Thermal neutron capture reactions

It is possible to derive an efficiency calibration using gamma-rays from the thermal neutron capture reaction on selected target materials. Of the many thermal neutron capture reactions that could be used, only a few are mentioned here. As noted earlier, care is needed to maintain the source-detector geometry between measurements, especially if the efficiency curve from the (n,γ) reaction is to be used for radioactive sources. The two sources may be hard to match if the neutron beam does not irradiate the target uniformly.

The $^{14}N(n,\gamma)^{15}N$ reaction is of particular interest [30]. As shown in Table 4, there are twelve gamma-ray emission probabilities (per neutron capture) ranging from 3 to 11 MeV that have uncertainties of ~1%. This

TABLE 5. Gamma-ray emission probabilities per thermal neutron capture (P_γ) for prompt gamma-rays from $^{35}Cl(n,\gamma)^{36}Cl$ reaction, Spits and Kopecky [31]

E_γ [a]	P_γ [b]
516.73(8)	0.227 (9,20)
786.26(5)	0.096 (5,9)
788.40(5)	0.150 (3,12)
1164.72(5)	0.257 (8,22)
1600.82(6)	0.0343 (17,32)
1950.93(6)	0.187 (4,15)
1959.13(6)	0.121 (4,10)
2863.94(16)	0.060 (2,5)
3061.71(16)	0.035 (2,3)
5715.20(22)	0.0514 (6,42)
6110.82(22)	0.197 (2,16)
6619.42(23)	0.0810 (10,66)
6627.50(23)	0.0464 (10,38)
6977.56(24)	0.0223 (9,20)
7413.7(2)	0.1000 (10.81)
7790.05(25)	0.0861 (8,69)
8578.21(26)	0.0294 (6,24)

a Calculated from level energy differences given in Ref. [31] and uncertainties include 20 ppm systematic contribution.

b Normalized as given in Ref. [31]; the two uncertainties are the statistical contribution and the total which includes an 8% systematic contribution.

accuracy was achieved in part because the level scheme is quite simple (for capture gamma-ray decay) and the authors could use intensity balances at each level to constrain the deduced emission probabilities. The results of earlier measurements for this reaction are also given in Ref. [30].

The $^{35}Cl(n,\gamma)^{36}Cl$ reaction may also be useful, with seventeen strong gamma-rays (>0.020 photons per thermal neutron capture) ranging from 0.516 to 8.58 MeV of which eight are above 5 MeV. The accuracy of the reported emission probabilities is not as good as the $^{14}N(n,\gamma)^{15}N$ data for several reasons, including a more complex scheme which precludes the confident use of intensity balances to constrain the values. The results of Spits and Kopecky [31] are given in Table 5 for these strong lines. Since the systematic uncertainty of 8% quoted by these authors is large compared to many of the statistical uncertainties (which are as low as 1%), both

TABLE 6. Thermal neutron capture reactions with subsequent emission of gamma-rays in cascade with energies E_1 and E_2 and emission probabilities P_1 and P_2

Reaction	E_1	E_2	P_1/P_2	References
$^{35}Cl(n,\gamma)^{36}Cl$	5.716	2.864	0.86(7) [a]	[31]
	6.111	1.951	1.05(9) [a]	
	6.111	0.517	0.87(7) [a]	
	6.620	1.959	0.67(6) [a]	
	6.978	1.601	0.65(6) [a]	
	7.791	0.788	0.57(5) [a]	
$^{48}Ti(n,\gamma)^{49}Ti$	4.882	1.499	0.92(3)	[32]
	6.419	0.342	1.23(2)	
	6.761	1.382	0.54(2)	
$^{52}Cr(n,\gamma)^{53}Cr$	5.618	2.231	1.00	[33]
$^{53}Cr(n,\gamma)^{54}Cr$	6.645	2.239	0.95	[34]
	7.100	1.785	1.07	
	8.884	0.835	0.60	

[a] This uncertainty includes the statistical uncertainties as given in Table 5 and 8% for the systematic uncertainty.

statistical and total uncertainties are given. The user must decide which uncertainty would be most applicable.

The gamma-ray emission probabilities are independent of each other for all of the radionuclides discussed in this section. However, for many reactions the level schemes are such that the ratio of the emission probabilities of two gamma-rays in cascade can be determined much more accurately than the relative probabilities for the whole spectrum of gamma-rays. Ideally the ratio of the emission probabilities should be 1.00, which would arise when the two gamma-rays populate and depopulate a common level, no other gamma-rays populate or depopulate this level, and there is no significant internal conversion or internal pair production for either gamma-ray. These ratios are useful for the calibration of a detector efficiency if one of the gamma-rays occurs in an energy region for which the efficiency is already known, so that the efficiency can be computed at the second energy.

Some ratios of gamma-ray emission probabilities are given in Table 6 (taken from Ref. [28]). This table includes the ratios deduced from the $^{35}Cl(n,\gamma)^{36}Cl$ data given in the previous table. The adoption of these

TABLE 7. Proton capture reactions with subsequent emission of gamma-rays in cascade at energies $E_{\gamma 1}$ and $E_{\gamma 2}$ with emission probabilities P_1 and P_2. The proton-resonance energy is E_p

Reaction	E_p (MeV)	$E_{\gamma 1}$ (MeV)	$E_{\gamma 2}$ (MeV)	P_1/P_2	References
$^{11}B(p,\gamma)^{12}C$	0.675	12.14	4.44	1.000	[35]
	1.388	12.79	4.44	1.000	
	2.626	13.92	4.44	1.000	
$^{14}N(p,\gamma)^{15}O$	0.278	5.183	2.374	1.00	[36]
		6.176	1.381	1.00	
		6.793	0.764	1.00	
$^{23}Na(p,\gamma)^{24}Mg$	1.318	11.588	1.368	0.963(3)	[35]
	1.416	8.929	2.754	0.985(3)	
$^{24}Al(p,\gamma)^{28}Si$	0.767	7.706	2.837	0.981(2)	[35]
	0.992	10.76	1.780	0.806(10)	
	1.317	6.58	4.50	1.017(7)	

reactions depends on the availability of a neutron source, and the usefulness of any particular reaction depends on the reaction cross section, a suitable sample, and the lack of any interference from background lines (including the production of the same reaction outside the target).

5.4 Proton capture reactions

Proton capture reactions can be used to provide gamma-rays to calibrate germanium detectors. Although there are some experimental difficulties, these reactions have the advantage that simple gamma-ray spectra are often produced when the proton energy is chosen to coincide with a resonance. Some useful proton resonances and the related gamma-ray emission probability ratios are listed in Table 7. The ratios from the $^{23}Na(p,\gamma)^{24}Mg$ and $^{27}Al(p,\gamma)^{28}Si$ reactions may be particularly useful with uncertainties $< 1\%$. These measurements have been made specifically to provide efficiency calibration lines [35].

Certain experimental effects should be taken into account in these reactions: the width of the resonance, the energy spread of the beam, and the target thickness should all be such that they do not degrade the detector resolution and alter the apparent efficiency. Since the emitted gamma-rays have anisotropic angular distributions with respect to the beam direction, the observed counting rate must be corrected for this variation, and can normally be achieved simply by undertaking the measurements at 55° or 125° relative to the beam where $P_2(\cos \theta) = 0.0$; this method assumes that the P_1, P_3 and P_4 terms are negligible. However, there are reactions where this is not sufficient, for example the $^{11}B(p,\gamma)$ reaction in which the $P_1(\cos \theta)$ terms do not vanish.

Many other potentially useful resonances may be identified from the review articles of Endt and van der Leun [37] and Ajzenberg-Selove [38].

5.5 Alpha-particle reactions

Croft [39] has recently drawn attention to the widespread use of (α,n) sources made from intimate mixtures of long lived alpha emitting actinides and low Z target materials such as beryllium. An example is $^{241}Am/^{9}Be(\alpha,n)$, which emits not only neutrons but also gamma-rays with an energy of 4438 keV. Croft has determined the ratio of gamma-ray to neutron output for a commercially available $^{241}Am/Be$ source, enabling the derivation of the gamma-ray emission from the neutron output as determined by the $MnSO_4$-bath method; the claimed accuracy is ± 2.6%.

6. REMAINING DISCREPANCIES

6.1 Half-lives

On the basis of the criterion adopted in Section 4.1 above, namely that the data be considered discrepant if the value of $\chi^2/(n-1)$ is larger than 10, the half-lives of the following nuclides are considered discrepant: ^{22}Na, ^{24}Na, ^{54}Mn, ^{55}Fe, ^{56}Co, ^{75}Se, ^{133}Ba, ^{137}Cs and ^{155}Eu.

With regard to the need of future measurements, the following guidelines are recommended:

A given half-life value T should be regarded as adequate if the uncertainty does not exceed dT where

$$dT/T = 0.00144\ T/T_1$$

T_1 is the maximum source-in-use period for the given nuclide, taken as 15 years or five half-lives, whichever is the shorter. On this basis the uncertainty in a calibration using the nuclide in question will not exceed 0.1%.

Adopting this procedure, ^{24}Na can be omitted from the list of nuclides given above.

6.2 X-ray emission probabilities

It was concluded that inconsistencies exist in the results for the K X-ray emission probabilities for the following radionuclides:

^{51}Cr, ^{55}Fe, ^{57}Co, ^{58}Co, ^{75}Se, ^{133}Ba, and ^{207}Bi.

No reliable experimental values are available for:

^{111}In, ^{113}Sn, ^{154}Eu, and ^{198}Au.

6.3 Gamma-ray emission probabilities

Inconsistencies in the decay data of the following nuclides have been found during the course of this evaluation exercise: ^{51}Cr, ^{57}Co, ^{65}Zn,

^{75}Se, ^{133}Ba ^{198}Au and ^{243}Am. Recommendations to improve the status of these data are given below.

Chromium-51

The gamma-ray emission probability data fall into two distinct groupings at approximately 0.098 and 0.102; a weighted mean of 0.0986(5) was adopted in the current evaluation. Further measurements would be desirable to confirm the adoption of a mean value in this way.

Cobalt-57

The internal conversion data for the 14.4 keV gamma-ray are inconsistent and increase the uncertainty of the emission probability.

Zinc-65

There have been relatively few direct measurements of the absolute gamma-ray emission probability of the 1115.546 keV transition of ^{65}Zn. Further confirmatory measurements would be welcome.

Selenium-75

An intercomparison exercise has been conducted to determine the relative gamma-ray emission probabilities of ^{75}Se with good accuracy. Provisional data from thirteen laboratories are available from this study and have been used in the evaluation. These data include estimates of absolute as well as relative gamma-ray emission probabilities. However, plans are underway for the Bureau International des Poids et Mesures (BIPM) to organise a series of activity measurements in 1990s to derive more accurate absolute gamma-ray emission probabilities from these data. A re-evaluation is recommended after this multi-laboratory exercise has been fully completed.

Barium-133

There is no consistent set of internal conversion data, and the resolution of the 79 and 81 keV gamma-rays is a problem.

Antimony-125

The uncertainties of the evaluated relative emission probabilities are lower than those of the recommended absolute emission probabilities. These last values were deduced from the evaluated relative emission probability using P_γ as 0.297(3) for the 427 keV reference line. Further direct measurements are recommended to confirm and increase the confidence in the calculated value for the reference line.

Iodine-125

There is only one direct measurement of the absolute emission probability of the 35.49 keV transition of ^{125}I. A measurement programme is being co-ordinated as a BIPM intercomparison, and a re-evaluation is recommended after this work has been completed.

Cerium-139

The absolute emission probability of the 165.8 keV transition was inferred from the estimated electron capture branching ratio to the ground level of ^{139}La (from the log ft values) and by using the adopted total internal conversion coefficient evaluated from data published between 1962 and 1977. Additional measurements are required, particularly studies of the absolute emission probability.

Gold-198

Specific data had to be adopted in order to derive the desired absolute gamma-ray emission probability for the 411.8044 keV transition. The gamma-ray emission probability data are sparse, and the evaluation relies heavily on the relative emission probability data of one laboratory. Additional confirmatory measurements are required, particularly studies of the absolute emission probabilities.

Americium-243

There has only been one comprehensive study of the alpha-particle decay of ^{243}Am, in which the uncertainties of the measured emission probabilities were not quantified. Furthermore, all gamma-ray measurements have focussed only on the six major gamma-ray emissions (31.13, 43.53, 74.66, 86.6, 117.72 and 142.2 keV transitions).

Alpha-particle measurements are required to confirm and improve the available data. Such studies are being undertaken by Bortels (CBNM, Geel), and their publication would merit a further assessment of the decay scheme for Am-243. Efforts are also required to improve the quality of the gamma-ray data that depopulate the nuclear levels of ^{239}Np above 240 keV.

7. CONCLUSIONS

A set of recommended half-life and emission probability data has been prepared by the IAEA Co-ordinated Research Programme on the Measurement and Evalution of X- and Gamma-ray Standards for Detector Efficiency Calibration. The results from this work represent a significant improvement in the quality of specific decay parameters required for the efficiency calibration of X- and gamma-ray detectors. Data inadequacies were highlighted, several of the identified inconsistencies remain unresolved, and further efforts are required to address these uncertainties.

The accomplishments of the CRP include:

- assessment of the existing relevant data during 1986/87,

- coordination of measurements within the existing programme and extensive cooperation among the participating research groups,

- performance of a large number of measurements stimulated by the CRP, and

- preparation of a report which consolidates most of the data needed for gamma-ray detector efficiency calibration.

It is hoped that the resulting data will be internationally accepted, as a significant contribution to the improved quality of gamma-ray spectrometry in its many and varied applications. In particular, the data are recommended with confidence for use in future decay data studies of other radionuclides.

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Part 2

DATA MEASURED AND EVALUATED

This part of the report contains the results of measurements performed by members of the CRP. These data and other relevant experimental results have been evaluated to produce the recommended values for detector efficiency calibration. Half-lives, X-ray emission probabilities and gamma-ray emission probabilities are listed separately for each radionuclide considered by the CRP. Source references are also given for these evaluations.

I. HALF-LIFE

Recommended value: 950.8 ± 0.9 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
951.71 ± 0.11	Hoppes et al (1982) [1]
950.25 ± 0.11	Rutledge and Merritt (1980) [2]
950.34 ± 0.13	Houtermans et al (1980) [3]
950.8 ± 0.9[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.

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II. *Gamma-Ray Emission Probability*

Evaluation by F. J. Schima (NIST, Gaithersburg USA)

A. Recommended Values

E_γ(keV)[a]	P_γ[b]
1274.542(7)	0.99935(15)

[a]From Ref [1].

[b]Determined from the measurements of the unique 2nd forbidden positron branch to the allowed positron branch ratio, Ref. [2], the electron capture to positron ratio, Ref. [3], for the allowed positron decay and the total internal conversion coefficient, for an E2 transition, Ref. [4]. Uncertainty is dominated by the error in the unique 2nd forbidden to allowed positron branch ratio, and the possibility of internal pair conversion coefficient estimated at 2.0E-5 Ref [5].

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I. HALF-LIFE

Recommended value: 0.62356 ± 0.00017 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
0.62323 ± 0.00012	Walz et al (1983) [1]
0.62317 ± 0.00011	Lagoutine and Legrand (1982) [2]
0.62296 ± 0.00013	Hoppes et al (1982) [3]
0.62354 ± 0.00042	Rutledge and Merritt (1980) [4]
0.62329 ± 0.00042	Rutledge and Merritt (1980) [4]
0.62354 ± 0.00004	Rutledge and Merritt (1980) [4]
0.62350 ± 0.00063	Muckenheim et al (1980) [5]
0.62329 ± 0.00005	Houtermans et al (1980) [6]
0.62542 ± 0.00117	Davis et al (1978) [7]
0.62875 ± 0.00250[b]	Genz et al (1976) [8]
0.62383 ± 0.00056	Chakraborty (1974) [9]
0.62368 ± 0.00073	Chakraborty (1974) [9]
0.62230 ± 0.00092	Chakraborty (1974) [9]
0.62267 ± 0.00072	Chakraborty (1974) [9]
0.62626 ± 0.00117	Chakraborty (1974) [9]
0.62575 ± 0.00110	Chakraborty (1974) [9]
0.62625 ± 0.00012	Emery et al (1972) [10]
0.63167 ± 0.00208[b]	Kemeny (1969) [11]
0.62500 ± 0.00028	Lagoutine et al (1968) [12]
0.62356 ± 0.00017	Weighted mean

Notes to Table

[b] These values have been omitted in the calculation of the weighted mean on the basis of statistical considerations.

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II. Gamma-Ray Emission Probabilities

Evaluation by F. J. Schima (NIST, Gaithersburg USA), April 1989

A. Recommended Values

E_γ(keV)[a]	P_γ
1368.633(6)	0.999936(15)[b]
2754.030(14)	0.99855(5)[c]

[a]From Ref. [1].

[b]Based on the sum of emission probabilities of the 4238.9 keV γ ray + 1368.633 keV γ ray + 1368.633 keV total internal conversion electron + 1368.633 keV internal pair conversion = 1.000.

[c]Based on the sum of emission probabilities of the 2754.030 keV γ ray + 2754.030 keV internal conversion electron + 2754.030 keV internal pair conversion = 0.999310 the evaluated beta decay probability to the 4122.633 keV level.

B. Other Data

Gamma-ray emission probability data

Energy (keV)	Artamonova(60) Ref. [2]	Monahan(62) Ref. [3][a]	VanKlinken(68) Ref. [4][a]	Lebowitz(70) Ref. [5][a]	Raman(72) Ref. [6]	Evaluated Value
996.1[b]	-	-	-	-	-	0.14(3)E-4[c]
1368.633	-	-	-	-	0.999992	0.999936(15)[d]
2754.030	-	1.00	1.00	1.00	0.99908	0.99855(5)[e]
2870.3	-	-	-	-	-	2.4(3)E-6[f]
3867.37[g]	9.(2)E-4	7.5(2)E-4	6.3(6)E-4	4.89(25)E-4	6.1(5)E-4	6.45(14)E-4[i]
4238.9[h]	80.(30)E-6	15.(5)E-6	-	-	8.4(10)E-6	9.(1)E-6[i]

[a]Gamma-ray emission probability measurements relative to the 2754.030 gamma ray.

[b]This weak gamma-ray is not reported in ^{24}Na decay data, however its presence is indicated by other measurements. This energy is determined from the difference of other measured level and gamma-ray energies.

[c]This gamma ray has not been reported in the decay of Na24. However, the emission probability is inferred from the 4238.9 keV gamma-ray probability and the depopulation ratio measurements of the 4238.9 keV level, in the Na23(p,γ)Mg24 reaction, Ref. [7].

[d]Evaluation made on the basis of Iγ 4238.9 + Iγ 1368.633 + Ice 1368.633 + Ipc 1368.633 = 1.000.

[e]Evaluation made on the basis of Iγ 2754.030 + Ice 2754.030 + Ipc 2754.030 = 0.999310, the evaluated beta decay probability to the 4122.633 keV level.

[f]This gamma ray also has not been reported in the decay of Na24. The emission probability is inferred from the 3867.37 keV gamma-ray probability and the depopulation ratio measurements of the 5236. keV level, in the Na23(p,γ) reaction, Ref. [8].

[g]From weighted mean energy measurements of Refs [4], [5], and [6].

[h]Energy value from Ref. [6].

[i]From weighted mean of all measurements assuming that the emission probability of the 2754.03 keV transition is 1.0.

Beta Decay Branches

Eβ max keV	Grant(50) Ref. [9][a]	Turner(51) Ref. [10]	Evaluated Value
275.65(32)	-	-	6.60(15)E-4[b]
1389.05(29)[c]	1.0E+5	1.0E+5	0.999310(16)
4143.08(29)	<10.	3.	3.0(6)E-5[d]

[a]Ref. [9], gives an upper limit on 4143.08 keV beta decay probability. This value is not used in the evaluation.

[b]No direct measurement reported of this beta branch. Probability is inferred from the gamma-ray emission probability measurements.

[c]End-point energy of this intense branch, is from the weigthed average of the three most recent measurements; Refs [11], [12], and [13].

[d]Value based on the result of Turner(51), Ref. [10]. The error is estimated by the evaluater from the details of the measurement in that work.

Total Internal Conversion Coefficient

Energy (keV)	Siegbahn(49) Ref. [14]	Theoretical Band(76), Ref. [15]	Evaluated Value[a]
1368.633	-	1.019E-5	1.019E-5
2754.030	3.E-6	2.770E-6	2.770E-6

[a]Due to the paucity of internal conversion coefficient measurements, the theoretical values of Ref. [15], are adopted.

Internal Pair Conversion Coefficient

Energy	Slatis(51) Ref. [16]	Bloom(52) Ref. [17]	Theorectical Jaeger(35) Ref. [18]	Evaluated Value[a]
1386.633	3.0E-5	6.(1)E-5	5.5E-5	4.5(15)E-5
2754.030	8.0E-4	7.1(2)E-4	6.3E-4	7.6(5)E-4

[a]*Evaluated values obtained from the average of the two sets of measurements.*

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I. HALF-LIFE

Recommended value: 83.79 ± 0.04 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
83.730 ± 0.117	Walz et al (1983) [1]
83.790 ± 0.060	Hoppes et al (1982) [2]
83.790 ± 0.060	Olomo and MacMahon (1980) [3]
83.819 ± 0.006[c]	Houtermans et al (1980) [4]
83.752 ± 0.015	Rutledge et al (1980) [5]
84.340 ± 0.130[b]	Cressey (1974) [6]
84.300 ± 0.400[b]	Walker and Easterday (1967) [7]
83.79 ± 0.04[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[b] These values have been omitted from the calculation of the weighted mean on the basis of statistical considerations.
[c] The uncertainty was increased to 0.015 to ensure that this value did not contribute a weighting of greater than 50%.

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II. GAMMA RAY EMISSION PROBABILITIES

Evaluated by Y. Yoshizawa and Y. Iwata (Hiroshima University)

A. Recommended values

E_γ(keV)	P_γ
889.277 ± 0.003	0.999844 ± 0.000016
1120.545 ± 0.004	0.999874 ± 0.000011

C. Comparison with other measurements

Gamma ray data

E_γ (keV)	Fujishiro et al (1980) [1]	Iwata et al. (1980) [2]	Calculated values [a]
	P_γ	P_γ	P_γ
2009.8	$(1.3\pm1.0)\times10^{-7}$		
90-1116		$< 6\times10^{-4}$	
1124-1800		$< 6\times10^{-5}$	
889.2			0.999844 ± 0.000016
1120.5			0.999874 ± 0.000011

Note to Table

a Gamma ray emission probabilities are calculated by using the theoretical total internal conversion coefficients, the pair formation coefficient and the beta ray branching ratio.

Theoretical internal conversion coefficients

E_γ (keV)	Transition type	Total ICC[a]	Pair formation coef.
889.3	E2	1.56×10^{-4}	
1120.5	E2	0.89×10^{-4}	4×10^{-7}

Note to Table

a Theoretical total internal conversion coefficients taken from F. Rósel et al, Atomic Data and Nuclear Data Tables 21 (1978) 91 by the extrapolation method ($\propto Z^3$).

Beta decay branching ratio

		Keister (1954) [3]	Wolfson (1956)[a] [4]
E_β (keV)	Transition	P_β	P_β
1475	4+ → 1st 2+	$(9.6\pm0.1)\times10^{-4}$	$(3.6\pm0.7)\times10^{-5}$

Note to Table

a This value is adopted for evaluation, because of two other available measurements (≤0.06 and <0.05) [5], [6].

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I. HALF-LIFE

Recommended value: 27.706 ± 0.007 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
27.710 ± 0.030	Walz et al (1983) [1]
27.730 ± 0.010	Hoppes et al (1982) [2]
27.690 ± 0.005	Houtermans et al (1980) [3]
27.704 ± 0.003[c]	Rutledge et al (1980) [4]
27.720 ± 0.027	Lagoutine et al (1975) [5]
27.703 ± 0.008	Tse et al (1974) [6]
27.750 ± 0.009	Visser et al (1973) [7]
27.760 ± 0.150	Emery et al (1972) [8]
28.100 ± 1.700[b]	Araminowicz and Dresler (1973) [9]
27.800 ± 0.510[b]	Bormann et al (1968) [10]
27.706 ± 0.007	Weighted mean

Notes to Table

[b] These values have been omitted from the calculation of the weighted mean on the basis of statistical considerations.
[c] The uncertainty was increased to 0.004 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
V K_{α}	4.95	0.201 ± 0.003
V K_{β}	5.43	0.027 ± 0.001
V KX	4.95 - 5.43	0.228 ± 0.003

B. CRP measurements

None.

C. Other measurements

	E (keV)	Taylor and Merrit (1963) [1]	Mukerji et al. (1967) [2]
V KX	4.95 - 5.43	0.227 3	0.196 16

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III GAMMA-RAY EMISSION PROBABILITY

Evaluated by A L Nichols (AEA Technology, Winfrith, UK), August 1989.

A Recommended Value

E_{γ} (keV)	P_{γ}
320.0842 ± 0.0009	0.0986 ± 0.0005

B CRP Measurement

E_{γ} (keV)	P_{γ} Barta et al (1989) Ref 1
320.084	0.0986(9)

C **Comparison with other measurements**

E_γ (keV)	CRP Measurement	Other Measurements				
	Barta et al (1989) Ref 1	Merritt and Taylor (1963) Ref 2	Legrand (1965) Ref 3	Dhingra et al (1965) Ref 4	Ribordy and Huber (1970) Ref 5	Schotzig et al (1980) Ref 6
320 084	0 0986(9)	0.0972(15)	0.097(2) 0 098(2)	0.1020(63)	0 102(10)[a]	0.0985(9)

Other Measurements	Evaluated Value
Fisher and Hershberger (1984) Ref 7	
0 1030(19)[a]	0.0986(5)

[a] Authors prefer to express their data in terms of the EC branching fraction to the 320.084 keV level of V-51; however, study of their measurement techniques indicates that these data are effectively P_γ and that the small internal conversion coefficient has been ignored.

Internal Conversion Coefficients

E_γ (keV)	Transition Type	ICC	Ribordy and Huber (1970) Ref 5	Carter and Hamilton (1970) Ref 8	Willett and Emery (1973) Ref 9	evaluated, Hansen (1985) Ref 10	Evaluated Value
320.084	M1+E2	K	0 00146(13)	0.00156(8)	0.001527(43)	0.00154(3)	0.00153(4)
		total	-	-	0.00169(5)	0.00169(5)	0.00169(5)

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I. HALF-LIFE

Recommended value: 312.3 ± 0.4 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
312.02 ± 0.04	Hoppes et al (1982) [1]
312.21 ± 0.03[c]	Rutledge et al (1980) [2]
312.60 ± 0.80	Cressey (1974) [3]
312.99 ± 0.05	Zimmer and Dahl (1968) [4]
312.20 ± 0.30	Lagoutine et al (1968) [5]
312.20 ± 0.90	Boulanger (1969) [6]
315.40 ± 0.03[b]	Visser et al (1973) [7]
312.00 ± 5.00	Hammer (1968) [8]
312.3 ± 0 4[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.

[b] This value has been omitted from the calculation of the weighted mean on the basis of statistical considerations.

[c] The uncertainty was increased to 0.04 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Cr K_α	5.41	0.226 ± 0.007
Cr K_β	5.95	0.030 ± 0.001
Cr KX	5.41 - 5.95	0.256 ± 0.008

B CRP measurements

None.

C. Other measurements

	E (keV)	Taylor and Merrit (1963) [1]	Leistner (1965) [2]
Cr KX	5.41 - 5.95	0.257 4	0.243 12

	E (keV)	Bambynek (1967) [3]	Petel and Houtermans (1967) [4]
Cr KX	5.41 - 5.95	0.2514 17	0.2490 53

	E (keV)	Hammer (1968) [5]	Konstantinov et al. (1973) [6]
Cr KX	5.41 - 5.95	0.2492 17	0.244 3

	E (keV)	Mukerji and Lee Chin (1973) [7]	Magnier et al. (1978) [8]
Cr KX	5.41 - 5.95	0.247 9	0.2593 14

	E (keV)	Cohen (1980) [9]	
Cr KX	5.41 - 5.95	0.251 7	

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III. GAMMA RAY EMISSION PROBABILITIES

Evaluated by Y. Yoshizawa and Y. Iwata (Hiroshima University)

A. Recommended values

E_γ (keV)	P_γ
834.843 ± 0.006	0.999758 ± 0.000024

B. CRP measurements

None

C. Comparison with other measurements

Theoretical internal conversion coefficient

E_γ (keV)	Transition type	Theoretical [a]	Experimental Hamilton et al. (1966) [1]	Calculated P_γ [b]
834.8	E2	2.37×10^{-4}	$(2.51 \pm 0.11) \times 10^{-4}$	0.999758±0.000024

Notes to table

a Theoretical total internal conversion coefficient taken from ref. [2] by the extrapolation method ($\propto Z^3$).

b Gamma ray emission probability calculated by using the theoretical total conversion coefficient and the estimated electron capture branching ration $(5 \pm 5) \times 10^{-6}$ to the ground state.

Estimation of beta decay branching ratio

Q (keV)[a]	Transition	Berenyi et al. (1968) [3]		Estimated [b]
		$\beta+$	log ft	ε
1377.1	3+ → 0+	$< 8 \times 10^{-7}$	> 12.0	$< 1 \times 10^{-5}$

Notes to table

a Beta decay Q-values taken from ref. [4].

b Electron capture branching ratio estimated by using log ft>12.0 and Q_β, because this transition is the unique second forbidden transition and log ft>12.0 is reasonable.

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I. HALF-LIFE

Recommended value: 999 ± 8 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
977.9 ± 2.3	Lagoutine et al (1978) [1]
1000.4 ± 1.3[c]	Houtermans et al (1980) [2]
1009.0 ± 1.7	Hoppes et al (1982) [3]
999 ± 8	Weighted mean

Notes to Table

[c] The uncertainty was increased to 1.4 to ensure that this value did not contribute a weighting of greater than 50%.

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[1] LAGOUTINE,F.,LEGRAND,J.,BAC,C.
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NBS Special Publication 626 (1982) 85

II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Mn K_α	5.89	0.249 ± 0.009
Mn K_β	6.49	0.034 ± 0.001
Mn KX	5.89 - 6.49	0.283 ± 0.010

B. CRP measurements

	E (keV)	Konstantinov et al. (1989) [1][a]
Mn KX	5.89 - 6.49	0.273 3

Note to table B:
[a] Calculated from the quoted $\omega_K = 0.312 \pm 0.003$ with $P_K = 0.881 \pm 0.004$ of Pengra et al [2] as used by the authors to calculate the fluorescence yield.

C. Other measurements

	E (keV)	Belyatsky et al. (1980) [3][a]	Smith (1982) [4]
Mn KX	5.89 - 6.49	0.275 3	0.382 2

Note to table C:
[a] Calculated from the quoted value $\omega_K = 0.312 \pm 0.003$ with $P_K = 0.881 \pm 0.004$ of Pengra et al. [2] as used by the authors to calculate the fluorescence yield.

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I. HALF-LIFE

Recommended value: 77.31 ± 0.19 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
77.08 ± 0.08	Lesko et al (1989) [1]
77.28 ± 0.04[c]	Schrader (1989) [2]
77.120 ± 0.067	Lagoutine et al (1978) [3]
77.12 ± 0.10	Anderson (1977) [4]
78.4 ± 0.5	Cressey (1974) [5]
78.76 ± 0.12	Emery et al (1972) [6]
77.31 ± 0.19	Weighted mean

Notes to Table

[c] The uncertainty was increased to 0.05 to ensure that this value did not contribute a weighting of greater than 50%.

REFERENCES

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Nucl.Sci.Eng. 48 (1972) 319

II. GAMMA RAY EMISSION PROBABILITIES

Evaluated by Y. Yoshizawa and H. Inoue (Hiroshima University)

A. Recommended value

E_γ(keV)	P_γ
846.764 ± 0.006	0.99933 ± 0.00007
1037.844 ± 0.004	0.1413 ± 0.0005
1175.099 ± 0.008	0.02239 ± 0.00011
1238.287 ± 0.006	0.6607 ± 0.0019
1360.206 ± 0.006	0.04256 ± 0.00015
1771.350 ± 0.015	0.1549 ± 0.0005
2015.179 ± 0.011	0.03029 ± 0.00013
2034.759 ± 0.011	0.07771 ± 0.00027
2598.460 ± 0.010	0.1696 ± 0.0006
3201.954 ± 0.014	0.0313 ± 0.0009
3253.417 ± 0.014	0.0762 ± 0.0024
3272.998 ± 0.014	0.0178 ± 0.0006
3451.154 ± 0.013	0.0093 ± 0.0004
3548.27 ± 0.10	0.00178 ± 0.00009

Note to Table A:

a. Gamma-ray energies from ref. [9] except for the value at the bottom of the table which is from ref. [2]

B. CRP Measurement

None

C. Measurements

Relative intensities

Energy (keV)	Camp Meredith (1971)[1]	Hofmann (1974)[2]	Katou (1975)[3]	McCallum Coote (1975)[4]	Gehrke et al. (1977)[5]	Hautala et al. (1978)[6]	Stewart Shaban (1980)[7]	Yoshizawa et al. (1980)[8]	Evaluated values[b]
263.3	.021 4	.020 6					.022 4		
410.9	.025 5	.025 9					.031 4		
486.5	.041 7	.07 2					.069 7	.061 10	0.061 10
674.7		.03 1					.038 7		
733.6	.193 3	.165 8	.219 7			.143 13	.195 14	.193 12	0.195 11
787.8	.308 8	.29 3	.311 12	.33 3		.34 3	.320 7	.305 13	0.305 12
846.8	100.0	100.0	100.0[a]	100.0	100.0 10	100.0	100.0	100.0 3	100.00 28
896.6	.071 4	.062 6	.089 11			.077 10	.063 6	.095 18	0.095 17
977.4	1.448 14	1.37 4	1.386 15	1.45 7	1.426 15	1.38 4	1.41 2	1.435 16	1.431 14
996.9	.112 6	.17 5				.170 14	.092 14	.129 14	0.129 14
1037.8	14.240 140	14.24 14	13.922 116	13.34 25	14.04 14	13.5 2	14.11 19	14.16 5	14.136 45
1089.1	.048 9	.07 2				.06 2	.050 7	.05 3	0.050 30
1140.3	.142 9	.13 2	.107 3			.117 13	.125 6	.131 21	0.129 20
1160.0	.100 9	.078 7	.095 6			.080 10	.074 8	.095 14	0.095 13
1175.1	2.300 25	2.25 11	2.180 24	2.12 12	2.28 2	2.11 10	2.300 32	2.241 12	2.240 11
1198.8	.050 7	.028 9				.044 8	.04 1	.051 9	0.051 9
1238.3	67.640 680	67.640 680	66.366 742	68.60 40	66.4 7	65.1 4	68.47 87	66.06 21	66.11 19
1272.0	.019 1	.022 3				.035 4	.038 6	.025 8	0.025 8
1335.5	.123 3	.120 12	.120 3			.12 2	.128 6	.130 6	0.129 6
1360.2	4.340 45	4.35 12	4.189 52	4.27 4	4.24 4	4.24 15	4.32 6	4.265 17	4.258 15
1442.7	.200 8	.177 9	.172 4			.195 10	.173 7	.172 7	0.172 7
1462.3	.077 1	.065 12	.078 3				.091 13	.084 6	0.084 6
1640.4	.065 9	.063 6	.062 3			.050 10	.062 7	.070 11	0.069 10
1771.4	15.780 160	15.780 160	15.369 241	15.72 20	15.65 16	15.26 15	15.50 40	15.49 5	15.494 47
1810.7	.641 8	.63 3	.665 23		.650 7	.59 3	.629 13	.657 23	0.657 20
1963.7	.721 15	.71 3	.667 21	.70 3	.724 8	.70 2	.719 15	.707 11	0.706 10
2015.2	3.095 31	3.095 31	3.025 72	2.98 5	3.09 5	2.97 3	3.182 66	3.026 14	3.031 13
2034.8	7.950 80	7.950 80	7.694 146	7.77 20	7.95 12	7.64 6	8.14 17	7.766 28	7.775 27
2113.1	.387 4	.37 2	.375 17	.38 1	.387 8	.34 2	.375 14	.363 7	0.366 6
2212.9	.377 10	.36 2	.387 18		.406 9	.39 2	.42 2	.389 8	0.390 7
2276.1	.106 5	.128 8	.146 7			.15 2	.117 9	.124 7	0.126 7
2373.5	.055 12	.059 12				.050 6	.097 12	.083 11	0.083 11
2523.8	.060 5	.044 10				.084 9	.079 11	.068 11	0.068 11
2598.5	16.850 170	16.850 170	16.642 220	17.51 20	17.34 26	17.19 15	17.40 38	16.96 6	16.967 57
2657.4		.016 5				.029 4		.021 6	0.021 6
3009.6	1.010 11	.98 9	.922 29	.99 5	1.06 3	1.05 3	.84 4		0.995 21
3202.0	3.030 30	3.030 30	3.067 157	3.36 5	3.18 10	3.24 3	3.03 7		3.127 91
3253.4	7.390 75	7.390 75	7.447 432	8.12 9	7.79 24	7.97 11	7.60 15		7.63 24
3273.0	1.755 18	1.755 18	1.697 103	1.81 4	1.85 6	1.84 3	1.815 36		1.778 58
3369.6	.011 2	.008 2				.010 1	.011 2		
3451.2	.875 9	.89 4	.936 84	.96 2	.93 3	.95 2	.90 2		0.933 43
3548.1	.178 3	.178 9	.164 18	.20 1	.190 6	.196 5	.196 6		0.178 9
3600.8	.015 1	.016 2			.0165 7	.012 3	.015 2		0.0165 7
3611.7	.0065 10	.008 2			.0085 4	.005 2	.010 2		0.0085 4

Notes to table C:

a Uncertainty of 1.0 % is assumed for evaluation.

b Three measurements by Katou [3], Gehrke et al. [5] and Yoshizawa et al. [8] are adopted for the weighted average. The emission probability $P_{\beta}(847)$ of the 847 keV transition is derived from the evaluated values of the relative intensities of the 847, 2657 and 3601 keV gamma rays and the internal conversion coefficient of 2.99×10^{-4} for the 847 keV transition.

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I. HALF-LIFE

Recommended value: 271.79 ± 0.09 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
271.84 ± 0.04[c]	Walz et al (1983) [1]
271.90 ± 0.20	Hoppes et al (1982) [2]
271.90 ± 0.09	Vaninbroukx et al (1981) [3]
271.77 ± 0.05	Houtermans et al (1980) [4]
271.23 ± 0.21	Lagoutine et al (1972) [5]
269.80 ± 0.40	Emery et al (1972) [6]
271.79 ± 0.09	Weighted mean

Notes to Table

[c] The uncertainty was increased to 0.05 to ensure that this value did not contribute a weighting of greater than 50%.

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Nucl.Sci.Eng. 48 (1972) 319

II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Fe K_α	6.40	0.510 ± 0.007
Fe K_β	7.06	0.069 ± 0.001
Fe KX	6.40 - 7.06	0.579 ± 0.008

B. CRP measurements

None

C. Other measurements

	E (keV)	Rubinson and Gopinathan (1968) [1][a]	Mukerji and Lee Chin (1973) [2][a]
Fe KX	6.40 - 7.06	0.569 8	0.584 17

Note to table C:

[a] Internal conversion accounted for with α_K and α values from Hansen [3].

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III. EMISSION PROBABILITIES OF SELECTED GAMMA-RAYS

Evaluated by T. Barta et al. (OMH, Budapest, Hungary)

A. Recommended Values

E_γ (keV) [a]	P_γ [b]
14.4127 ± 0.0004	0.0916 ± 0.0015 [c]
122.0614 ± 0.0003	0.8560 ± 0.0017 [d]
136.4743 ± 0.0005	0.1068 ± 0.0008 [d]

Notes to Table A

a E_γ at 122 and 136 keV from ref. [1], E_γ at 14 keV computed from the other two values.

b Calculated from α values given in the next table and taking into account the balance in the decay scheme. The uncertainties are from the uncertainties of α-s and of relative gamma-ray emission probabilities.

c Experimental measurement from ref. [2].

d On the basis of measured relative emission probabilities and the well clarified decay scheme the P_γ could have been stated with suitable precision for detector calibration purposes.

Table of internal-conversion data by H.H. Hansen (1985) [3]

	E_γ(keV)	Multipolarity	α
$\gamma 1$	14.4127 ± 0.0004	M1 + E2	8.18(11) [a]
$\gamma 2$	122.0614 ± 0.0003	M1 + E2	0.0240(14)
$\gamma 3$	136.4743 ± 0.0005	E2	0.137(15)

Note for table

a It had not been taken into account because inconsistent data are existing. The recommended $P_{\gamma 1}$ is supported by 8.61(25) of α calculated by N. Coursol [4].

B. CRP measurements

E_γ(keV)	P_γ Debertin (1989) [2]
14.41	0.0916(15)

C. Comparison with other measurements

P_{γ} values from other sources

	CRP measurement		Other measurements[a]				
E_{γ}(keV)	Debertin [2]	Schotzig [5]	Kistner[b] [6]	Mathiesen[b] [6]	Konijn[b] [6]	Heath [7]	Grutter [8]
14.41	0.0916(15)	-	0.0957(46)[c]	0.0961(40)[c]	0.0972(52)	0.0953(42)[c]	0.0957(41)[c]
122.06	-	-	0.8563(106)	0.8603(50)	0.8520(74)	0.8527(86)	0.8565(72)
136.47	-	0.1058(21)[a]	0.1070(83)	0.1032(15)	0.1108(44)	0.1100(60)	0.1066(42)

Notes for table

a Calculated from relative emission probabilities and the confidence level 99.0%
b Reference [6] quotes the measurements by Kistner, Mathiesen and Konijn as separate results.
c Calculated from ICC

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I. HALF-LIFE

Recommended value: 70.86 ± 0.07 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
70.750 ± 0.070	Hoppes et al (1982) [1]
70.916 ± 0.015[c]	Houtermans et al (1980) [2]
70.810 ± 0.033	Vaninbroukx and Grosse (1977) [3]
70.780 ± 0.043	Lagoutine et al (1975) [4]
71.100 ± 0.200	Werner and Santry (1972) [5]
70.800 ± 0.900	Crisler et al (1972) [6]
70.400 ± 1.000	Crisler et al (1972) [6]
71.540 ± 0.750	Decowski et al (1968) [7]
71.830 ± 6.120	Araminowicz and Dresler (1973) [8]
70.86 ± 0.07[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[c] The uncertainty was increased to 0.025 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Fe K_{α}	6.40	0.235 ± 0.003
Fe K_{β}	7.06	0.032 ± 0.001
Fe KX	6.40 - 7.06	0.267 ± 0.003

B. CRP measurements

None

C. Other measurements

	E (keV)	Bambynek et al. (1968) [1]
Fe KX	6.40 - 7.06	0.2596 10

REFERENCE

[1] BAMBYNEK, W., DE ROOST, E., FUNCK, E., Proceedings of the Conference on Electron Capture and Higher Order Processes in Nuclear Decays, Debrecen, Hungary, July 15-18, 1968 (D. Berényi, Ed.),Eotvos Lóránd Physical Society, Budapest, (1968) 253.

III. EMISSION PROBABILITIES OF SELECTED GAMMA-RAYS

Evaluated by T. Barta et al. (OMH, Budapest, Hungary)

A. Recommended Values

E_{γ} (keV) [1]	P_{γ} [a]
810.775 ± 0.009	0.9945 ± 0.0001

Notes to table A

a Value computed using $(3.4\pm0.1)\cdot10^{-4}$ for $\alpha_{\gamma1}$ [2] and $0.829\cdot10^{-4}$ for $\alpha_{\gamma3}$ [3] taking into account the balance in the decay scheme. The uncertainty is from the uncertainty of α and uncertainties of relative gamma-ray emission probabilities.

Table of internal-conversion data computed by N. Coursol of LMRI

	E_{γ}(keV)	Multipolarity	α	α_K
$\gamma1$	810.775 ± 0.009	E2	0.00034(1)	0.00030(1)
$\gamma2$	863.959 ± 0.009	M1+E2	0.00026(4)	0.00023(4)
$\gamma3$	1674.730 ± 0.010	E2	0.000083 [a]	0.000076 [a]

Note to table

a Theoretical from ref.[3].

B. CRP measurements

None

C. Comparison with other measurements

E_γ(keV)	Hill[a]	Dolan[a]	Bambynek[a]	Ritter[a] [4][b]	Dyer	Denecke	Legrand
	P_γ[c]	P_γ[c]	P_γ[c]	P_γ[c]	P_γ[c]	P_γ[c]	P_γ[c]
511.003	—	—	—	—	—	—	—
810.775	100	100	100	100	100	100	100
863.959	0.77(4)	0.64	0.645(15)	0.81(3)	0.70(2)	0.69(2)	0.69(2)
1674.730	0.68(5)	0.46	0.506(15)	0.57(3)	0.49(3)	0.527(15)	0.525(13)

continue

E_γ(keV)	Gunnink et al. [5][a]	Heath, R. L. [6]	Grutter, A. [7]	Recommended[d]	
	P_γ	P_γ[c]	P_γ[c]	P_γ[c]	P_γ
511.003	29.2	32.5(3)	—	—	—
810.775	99.50	100(3)	100	100	0.9945(1)
863.959	—	0.74(4)	0.682(17)	0.697	0.0069(3)
1674.730	—	0.54(4)	0.511(15)	0.520	0.00519(10)

Notes for table

a omitted from the evaluation
b reference [4] quotes the measurements by Hill, Dolan, Bambynek, Ritter, Dyer, Denecke and Legrand as separate results.
c relative gamma-ray probabilities
d weighted mean values of [4], [6] and [7]

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I. HALF-LIFE

Recommended value: 1925.5 ± 0.5 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
1925.0 ± 0.5	Rutledge et al (1983) [1]
1929.2 ± 2.6	Hoppes et al (1982) [2]
1925.2 ± 0.4	Houtermans et al (1980) [3]
1929.6 ± 1.0	Vaninbroukx and Grosse (1977) [4]
1925.5 ± 0.4	Walz and Weiss (1970) [5]
1924.8 ± 2.4	Lagoutine et al (1968) [6]
1913.9 ± 76.7	Harbottle et al (1973) [7]
1925.5 ± 0.5	Weighted mean

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II. Gamma-Ray Emission Probabilities

Evaluation by F. J. Schima (NIST, Gaithersburg USA)

A. Recommended Values

E_γ(keV)[a]	P_γ
1173.238(4)	0.99857(22)[b]
1332.502(5)	0.99983(6)[c]

[a]From Ref. [1].

[b]Based on the sum of the emission probabilities for the 1173.238 keV γ ray + 1173.238 keV internal conversion electron + 1173.238 keV internal pair conversion + 346.93 keV γ ray + 346.93 keV internal conversion electron = emission probability of the 317.88 keV β branch. The emission probability of the 2505.74 keV γ ray, Ref. [2] and [3] was neglected.

[c]Based on the sum of the emission probabilities for the 2158.77 keV γ ray + 1332.502 keV γ ray + 1332.502 keV internal conversion electron + 1332.502 keV internal pair = 1.000. The emission probabilities of the 2158.77 keV internal conversion electron, the 2158.77 keV internal pair conversion and the 2505.74 keV γ ray, Ref. [2] and [3], were neglected.

B. Other Data

Beta Branching Fractions

E_β max(keV)	Keister(54) Ref. [9]	Wolfson(56) Ref. [10][a]	Camp(61) Ref. [11]	Hansen(68) Ref. [12]	Evaluated Value[b]
317.88(10)[c]	0.9985(1)	-	-	0.9974(5)	0.99883(21)
664.89(20)	-	-	-	0.0018(3)	0.00000(2)[d]
1491.16(13)	0.0015(1)	0.00010(2)	0.0012	0.0008(2)	0.00117(20)

[a]Value reported by Ref. [10] was not used in the evaluation.

[b]Evaluation based the beta branching fractions to the 1332.502 and 2505.74 keV levels summing to 1.0 and neglecting any beta branching fraction to the 2158.77 keV level.

[c]The 317.88 endpoint energy is from Ref. [13]. This gives rise to a Q value of 2823.62(10) keV from which the higher energy beta endpoints are determined.

[d]*For evaluation, the beta branching fraction is taken as zero, but an uncertainty of 2.0E-5 is assigned from the transition intensity imbalance, in and out of the 2158.77 keV level.*

Gamma-ray emission probability data

Energy(keV)	Dixon(70) Ref. [4]	Legrand(72) Ref. [5]	Fujishiro(73) Ref. [6]	Camp(76) Ref. [7][a]	Logan(77) Ref. [8]	Evaluated Value[b]
346.93[c]	-	-	-	75.8(50)	0.69(10)E-4	7.42(44)E-5
826.28[c]	-	-	-	76.2(80)	-	7.6(8)E-5
1173.238	-	-	-	1.0E+6	-	0.99857(22)
1332.502	-	-	-	1.0E+6	-	0.999831(60)
2158.77[c]	0.7(+7,-4)E-5	0.5(2)E-5	2.0(1.3)E-5	11.1(18)	-	1.08(33)E-5

[a]Reference [7], made relative gamma ray intensity measurements, 1173.238 keV intensity as 1.0E+6 Gamma-ray probabilities for the weak transitions were inferred from this data for the evaluation.

[b]Evaluation made on the basis of Iγ 2158.77 + Iγ 1332.502 + Ice 1332.502 + Ipc 1332.502 = 1.000, and in which, the Ice 2158.77 and the Iγ 2505.74, Ref. [2] and [3], were ignored.

[c]Energy of the weak probabilities is from Ref. [7].

Total Internal Conversion Coefficients

Energy keV	Multipolarity	Theoretical Band(76), Ref. [14]	Evaluation Hansen(85), Ref. [15]	Evaluated Value
346.93	E2	59.09E-4	-	59.09E-4
826.28	45%M1 + 55%E2[a]	3.440E-4	-	3.440E-4
1173.238	E2	1.706E-4	1.68(4)E-4	1.68(4)E-4
1332.502	E2	1.272E-4	1.28(5)E-4	1.28(5)E-4

[a]Multipolarity mixture from angular correlation measurements in ^{60}Cu decay of Ref. [16].

Internal Pair Conversion Coefficient

Energy	Slatis(51) Ref. [17]	Theorectical Jaeger(35), Ref. [18]	Evaluated Value
1173.238	observed	1.5E-5	1.5E-5
1332.502	observed	3.0E-5	3.0E-5

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I. HALF-LIFE

Recommended value: 244.26 ± 0.26 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
243.90 ± 0.29	Walz et al (1983) [1]
244.20 ± 0.10	Hoppes et al (1982) [2]
243.75 ± 0.12	Lagoutine et al (1975) [3]
244.30 ± 0.40	Cressey (1974) [4]
244.52 ± 0.02[c]	Visser et al (1973) [5]
244.00 ± 0.20	De Roost et al (1972) [6]
258.00 ± 4.00[b]	Crisler et al (1972) [7]
246.00 ± 5.00[b]	Crisler et al (1972) [7]
251.00 ± 6.00[b]	Crisler et al (1972) [7]
252.00 ± 6.00[b]	Crisler et al (1972) [7]
244.26 ± 0.26[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value

[b] These values have been omitted from the calculation of the weighted mean on the basis of statistical considerations.

[c] The uncertainty was increased to 0.07 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W Bambynek (CBNM, Geel, Belgium)

A. Recommended values

	E (keV)	P_{KX}
Cu K_α	8.03 - 8 05	0 341 ± 0.006
Cu K_β	8 91	0 046 ± 0 001
Cu KX	8 03 - 8 91	0 387 ± 0.006

B. CRP measurements

None

C. *Other measurements*

	E (keV)	Taylor and Merrit (1963) [1]	Hammer (1968) [2]
Cu KX	8 03 - 8 91	0.394 6	0.3870 26

	E (keV)	Bambynek (1968) (1983) [3][a]	Mukerji and Lee Chin (1973) [4][a]
Cu KX	8 03 - 8 91	0 384 2	0 380 2

Note to table C

[a] P_{EC} = 0 9852 2 used

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III GAMMA-RAY EMISSION PROBABILITY

$^{65}_{30}$Zn

Evaluated by A L Nichols (AEA Technology, Winfrith, UK), August 1989.

A **Recommended Value**

E_γ (keV)	P_γ
1115.546 ± 0.004	0.5060 ± 0.0024

B **CRP Measurement**

E_γ (keV)	P_γ Schötzig (1990) Ref 1
1115.546	0.502(4)

C **Comparison with other measurements**

E_γ (keV)	CRP Measurement	Other Measurements					Evaluated Value
	Schötzig (1990) Ref 1	Taylor and Merrit (1963) Ref 2	Rao (1966) Ref 3	Hammer (1968) Ref 4	De Roost et al (1972) Ref 5	Poenitz and Devolpi (1973) Ref 6	
1115.546	0.502(4)	0.507(5)	0.513(15)	0.524(10)[a]	0.5075(28)[b]	0.493(8)[a]	0.5060(24)

[a] Inferred from EC branching fraction

[b] Uncertainty increased from ± 0.0010 so that the measurement does not contribute more than 50% to the sum of weights.

Internal Conversion Coefficients

E_γ (keV)	Transition Type	ICC	Hamilton et al (1966) Ref 7	evaluated, Hansen (1985) Ref 8	Evaluated Values [a]
1115.546	M1+E2	K total	0.0001664(66) 0.0001853(74)	0.000166(6) 0.000185(7)	0.000166(6) 0.000185(7)

[a] Evaluated data adopted from Hansen (1985), Ref 8.

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I. HALF-LIFE

Recommended value: 119.64 ± 0 24 d

Evaluated by M. J. Woods (NPL, Teddıngton, UK) and
K. Debertın (PTB, Braunschweıg, FRG)

Measured values

Value (in days)	Reference
119.800 ± 0.070	Hoppes et al (1982) [1]
119.760 ± 0.050	Schötzıg et al (1980) [2]
119.779 ± 0.004[c]	Houtermans et al (1980) [3]
118.450 ± 0.080	Lagoutıne et al (1975) [4]
119.64 ± 0.24	Weıghted mean

Notes to Table

[c] The uncertaınty was ıncreased to 0.037 to ensure that thıs value dıd not contrıbute a weıghtıng of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W Bambynek (CBNM, Geel, Belgıum)

A Recommended values

	E (keV)	P_{KX}
As K_α	10 51 10 54	0 493 ± 0 011
As K_β	11 72 11 95	0 075 ± 0 002
As KX	10 51 11 95	0 568 ± 0 013

B. CRP measurements

None

C. *Other measurements*

	E (keV)	Paradellıs and Hontzeas (1969, 1970) [1,2]	Chew et al (1973) [3][a]
As KX	10 51 - 11 95	0 514 21	0 580 20

	E (keV)	Rao et al (1966) [5][b]	Sıngh et al (1983) [6][c]
As K_α	10 51 10 54		0 494 3
As K_β	11 75 - 11 95		0 083 3
As KX	10 51 11 95	0 556 16	0 57 7 13

Notes to table C

[a] Internal conversıon accounted for wıth data from Lagoutıne et al [7]

[b] Corrected wıth ω_K = 0 575 3 from Bambynek [8]

[c] From measurements relatıve to the 264-keV gamma ray emıssıon rate, normalızed wıth $P_\gamma(264)$ = 0 590 2, as evaluated by A L Nıchols (thıs report)

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Evaluated by A L Nichols (AEA Technology, Winfrith, UK), September 1989.

A Recommended Values

E_γ (keV)	P_γ
96.7344 ± 0.0010	0.0341 ± 0.0004
121.1171 ± 0.0014	0.171 ± 0.001
136.0008 ± 0.0006	0.588 ± 0.003
264.6580 ± 0.0017	0.590 ± 0.002
279.5431 ± 0.0022	0.250 ± 0.001
400.6593 ± 0.0013	0.115 ± 0.001

B CRP Measurements

Relative Emission Probabilities (P_γ^{rel})

E_γ (keV)	Jedlovszky et al (1987) Ref 1	Jedlovszky (1989) Ref 2 [a]								
		1/2	2/4	3/5A	4/5B	5/7	6/8	7/9	8/10	9/12
24.4	-	0.00045(6)	0.00127(12)	-	-	-	-	-	-	-
66.0	-	0.0185(3)	0.0182(6)	0.0176(8)	0.0195(6)	-	0.0178(6)	0.0200(17)	0.0186(2)	0.0196(4)
80.9	-	-	-	-	-	-	-	-	-	-
96.7	-	0.0593(8)	0.0568(15)	0.0613(18)	0.0647(18)	-	0.0541(13)	0.0513(30)	0.0579(3)	0.0563(5)
121.1	0.292(5)	0.2923(15)	0.291(6)	0.279(6)	0.292(4)	0.293(5)	0.285(5)	0.300(10)	0.2865(11)	0.2896(14)
136.0	0.998(18)	0.999(3)	0.963(20)	0.946(21)	0.999(9)	0.999(18)	0.959(21)	0.995(31)	0.982(4)	0.999(5)
198.6	-	0.02518(13)	0.0252(7)	0.0225(8)	0.02568(21)	0.0248(5)	0.0238(4)	0.0253(7)	0.02509(16)	0.02581(12)
249.2	-	-	-	-	-	-	-	-	-	-
264.7	1.000(15)	1.000(4)	1.000(21)	1.000(22)	1.000(11)	1.000(15)	1.000(17)	1.000(26)	1.000(5)	1.000(4)
279.5	0.4266(50)	0.4253(16)	0.439(9)	0.422(9)	0.421(3)	0.426(6)	0.424(5)	0.426(11)	0.4248(23)	0.4236(14)
303.9	0.02245(25)	0.02248(9)	0.0225(5)	0.0221(6)	0.02091(14)	0.0224(4)	0.0223(4)	0.0224(6)	0.02234(15)	0.02224(8)
373.5	-	-	-	-	-	-	-	-	-	-
400.7	0.1956(25)	0.1927(11)	0.197(4)	0.191(4)	0.1941(12)	0.195(3)	0.1917(21)	0.195(5)	0.1960(10)	0.1979(6)
419.1	-	0.000206(7)	0.00024(9)	-	-	-	0.000102(32)	0.000154(10)	-	-
468.6	-	-	-	-	-	-	-	-	-	-
542.2	-	-	-	-	-	-	-	-	-	-
556.4	-	-	-	-	-	-	-	-	-	-
572.2	-	0.000602(20)	0.000625(22)	-	-	-	0.00058(4)	0.00059(3)	0.000610(18)	0.000617(14)
617.7	-	0.000072(7)	0.000067(10)	-	-	-	0.000076(6)	0.000080(6)	-	0.000063(6)
821.6	-	-	0.000016(12)	-	-	-	0.0000030(15)	0.000013(7)	-	-

Cont.

E_γ (keV)	Jedlovszky (1989) Ref 2 [a]			
	10/13	11/14	12/15	13/16
24.4	0.00045(6)	-	-	-
66.0	0.0191(2)	0.0194(3)	0.0188(1)	0.0195(2)
80.9	-	-	-	-
96.7	0.0591(5)	0.0588(6)	0.0583(2)	0.0591(5)
121.1	0.2916(23)	0.2943(22)	0.2931(10)	0.2924(20)
136.0	0.997(8)	1.004(7)	1.012(2)	0.994(10)
198.6	0.02534(23)	0.02514(20)	0.02586(10)	0.0250(3)
249.2	-	-	-	-
264.7	1.000(8)	1.000(8)	1.0000(14)	1.000(7)
279.5	0.425(3)	0.424(4)	0.4225(4)	0.4269(21)
303.9	0.02242(18)	0.02220(22)	0.02219(8)	0.02239(16)
373.5	-	-	-	-
400.7	0.1949(16)	0.1908(17)	0.19360(25)	0.1951(10)
419.1	0.000196(11)	0.000217(5)	0.000247(13)	-
468.6	-	-	-	-
542.2	-	-	-	-
556.4	-	-	-	-
572.2	0.000610(10)	0.000603(7)	0.00067(2)	0.00064(3)
617.7	0.000078(5)	0.000077(3)	0.000108(12)	-
821.6	-	-	-	-

[a] ICRM (International Committee for Radionuclide Metrology) intercomparison of relative gamma-ray emission probabilities: 13 sets of data were submitted for assessment. The various participants in this exercise included Andai et al (1990) Ref 3 and Wang Xin Lin and Wang Yuandi (1990) Ref 4.

Absolute Emission Probability of 264.7 keV Gamma Ray (P_{γ}^{abs})

E_{γ} (keV)	Jedlovszky et al (1987) Ref 1	Jedlovszky (1989) Ref 2 [a]												
		1/2	2/4	3/5A	4/5B	5/7	6/8	7/9	8/10	9/12	10/13	11/14	12/15	13/16
264.7	0.593(9)	0.594(3)	0.590(13)	0.602(14)	0.593(7)	0.596(9)	0.588(10)	0.593(16)	0.597(4)	0.588(3)	0.590(5)	0.596(5)	0.580(3)	0.588(5)

[a] Provisional data from ICRM (International Committee for Radionuclide Metrology) studies.

C **Comparison with other measurements**

Relative Emission Probabilities (P_{γ}^{rel})

E_{γ} (keV)	CRP Measurements									
	Jedlovszky et al (1987) Ref 1 [a]	Jedlovszky (1989) Ref 2 [b]								
		1/2	2/4	3/5A	4/5B	5/7	6/8	7/9	8/10	9/12
24.4	-	0.00045(6)	0.00127(12) [d]	-	-	-	-	-	-	-
66.0	-	0.0185(3)	0.0182(6)	0.0176(8)	0.0195(6)	-	0.0178(6)	0.0200(17)	0.0186(2)	0.0196(4)
80.9	-	-	-	-	-	-	-	-	-	-
96.7	-	*0.0593(8)*	*0.0568(15)*	0.0613(18)	0.0647(18)	-	0.0541(13)	0.0513(30)	0.0579(3)	0.0563(5)
121.1	0.292(5)	0.2923(15)	0.291(6)	0.279(6)	0.292(4)	0.293(5)	0.285(5)	0.300(10)	0.2865(11)	0.2896(14)
136.0	0.998(18)	0.999(3)	0.963(20)	0.946(21)	0.999(9)	0.999(18)	0.959(21)	0.995(31)	0.982(4)	0.999(5)
198.6	-	0.02518(13)	0.0252(7)	0.0225(8)	0.02568(21)	0.0248(5)	0.0238(4)	0.0253(7)	0.02509(16)	0.02581(12)
249.2	-	-	-	-	-	-	-	-	-	-
264.7	1.000(15)	1.000(4)	1.000(21)	1.000(22)	1.000(11)	1.000(15)	1.000(17)	1.000(26)	1.000(5)	1.000(4)
279.5	0.4266(50)	0.4253(16)	0.439(9)	0.422(9)	0.421(3)	0.426(6)	0.424(5)	0.426(11)	0.4248(23)	0.4236(14)
303.9	*0.02245(25)*	*0.02248(9)*	*0.0225(5)*	*0.0221(6)*	*0.02091(14)*	*0.0224(4)*	*0.0223(4)*	*0.0224(6)*	*0.02234(15)*	*0.02224(8)*
373.5	-	-	-	-	-	-	-	-	-	-
400.7	0.1956(25)	0.1927(11)	0.197(4)	0.191(4)	0.1941(12)	0.195(3)	0.1917(21)	0.195(5)	0.1960(10)	0.1979(6)
419.1	-	0.000206(7)	0.00024(9)	-	-	-	0.000102(32)	0.000154(10)	-	-
468.6	-	-	-	-	-	-	-	-	-	-
542.2	-	-	-	-	-	-	-	-	-	-
556.4	-	-	-	-	-	-	-	-	-	-
572.2	-	0.000602(20)	0.000625(22)	-	-	-	0.00058(4)	*0.00059(3)*	*0.000610(18)*	*0.000617(14)*
617.7	-	0.000072(7)	0.000067(10)	-	-	-	0.000076(6)	0.000080(6)	-	0.000063(6)
821.6	-	-	0.000016(12) [d]	-	-	-	0.0000030(15)	0.000013(7) [d]	-	-

Cont.

E_{γ} (keV)	CRP Measurements				Other Measurements					
	Jedlovszky (1989) Ref 2 [b]				Grigoriev and Zolotavin (1959) Ref 5	Rao et al (1966) Ref 6	Raeside et al (1969) Ref 7	Paradellis and Hontzeas (1969) Ref 8	Pratt (1971) Ref 9	Sutela (1973) Ref 10
	10/13	11/14	12/15 [c]	13/16						
24.4	*0.00045(6)*	-	-	-	-	≤0.00001	-	0.00044(6)	-	-
66.0	0.0191(2)	0.0194(3)	0.0188(2)	0.0195(2)	0.0153(15)	0.0164(5)	0.0140(40)	0.0172(4)	-	0.0097(6)
80.9	-	-	-	-	≤0.001	≤0.0000001	-	≤0.001	-	-
96.7	0.0591(5)	0.0588(6)	0.0583(4)	0.0591(5)	0.055(3)	0.0533(16)	0.0483(96)	0.0512(10)	-	0.047(2)
121.1	0.2916(23)	0.2943(22)	0.2931(20)	0.2924(20)	0.279(13)	0.278(8)	0.292(29)	0.2770(50)	-	0.254(12)
136.0	0.997(8)	1.004(7)	1.012(4)	0.994(10)	0.96(5)	0.949(20)	0.960(96)	0.950(18)	-	0.903(28)
198.6	0.02534(23)	0.02514(20)	0.02586(20)	0.0250(3)	0.026(2)	0.0228(5)	0.0225(23)	0.0238(7)	-	0.025(1)
249.2	-	-	-	-	-	-	-	-	-	-
264.7	1.000(9)	1.000(8)	1.000(3)	1.000(7)	1.000	1.00	1.00	1.00	1.00	1.00
279.5	0.425(3)	0.424(4)	0.4225(8)	0.4269(21)	0.410(25)	0.430(9)	0.413(41)	0.420(8)	-	0.425(15)
303.9	0.02242(18)	0.02220(22)	0.02219(16)	0.02239(16)	0.025(3)	0.0239(5)	0.0206(21)	0.0219(7)	-	0.0220(8)
373.5	-	-	-	-	≤0.005	-	-	≤0.00006	-	-
400.7	0.1949(16)	0.1908(17)	0.1936(5)	0.1951(10)	0.223(23)	0.223(5)	0.192(19)	0.204(5)	-	0.190(6)
419.1	0.000196(11)	0.000217(5)	0.000247(26)	-	-	0.000322(6)	0.00020(3)	0.00023(2)	-	0.000140(16)
468.6	-	-	-	-	-	-	-	0.000010(5) [d]	0.0000054(18)	-
542.2	-	-	-	-	-	-	-	-	-	-
556.4	-	-	-	-	-	-	-	-	-	-
572.2	0.000610(10)	0.000603(7)	0.00067(4)	0.00064(3)	0.0018(16) [d]	0.000636(13)	0.00053(8)	0.00063(2)	-	0.00054(3)
617.7	0.000078(5)	0.000077(3)	0.000108(23)	-	-	0.0000777(15)	0.000076(10)	0.000075(2)	-	0.000075(31)
821.6	-	-	-	-	-	-	-	-	0.00000216(10)	-

Cont.

E_γ (keV)	Other Measurements						P_γ^{rel} Evaluated Values
	Prasad (1977) Ref 11	Gehrke et al (1977) Ref 12	Meyer (1978) Ref 13	Schötzig et al (1980) Ref 14	Yoshizawa et al (1983) Ref 15		
					Yoshizawa	Katoh	
24.4	0.00065(8)	-	0.00046(4)	-	-	-	0.00047(3)
66.0	0.0146(20)	0.0186(9)	0.0187(1)	0.0193(4)	-	-	0.0187(2)
80.9	0.00012(4)	-	0.00019(4)	-	-	-	0.00016(4)
96.7	0.0522(20)	0.059(3)	0.0572(21)	0.0589(13)	0.0578(17)	-	0.0578(4)
121.1	0.271(40)	0.298(9)	0.298(2)	0.293(3)	0.2924(29)	0.2912(31)	0.2906(9)
136.0	0.9546(600)	1.02(3)	1.000(3)	0.998(8)	0.992(9)	0.991(13)	0.997(2)
198.6	0.0248(40)	0.0253(8)	0.0254(2)	0.0249(5)	0.0251(4)	0.0257(4)	0.0253(1)
249.2	0.0000016(4)	-	-	-	-	-	0.0000016(4)
264.7	1.00	1.00(3)	1.000(5)	1.000(8)	1.000(5)	1.000(6)	1.000(1)
279.5	0.426(8)	0.424(13)	0.422(4)	0.426(4)	0.4243(20)	0.4245(24)	0.4238(5)
303.9	0.0226(40)	0.0221(3)	0.0223(2)	0.0227(2)	0.02234(17)	0.02226(19)	0.02224(9)
373.5	0.000042(4)	-	-	-	-	-	0.000042(4)
400.7	0.188(6)	0.191(3)	0.195(3)	0.1956(16)	0.1942(13)	0.1938(12)	0.1949(5)
419.1	0.00018(4)	-	0.00018(3)	-	0.000231(21)	0.000198(25)	0.000229(15)
468.6	0.0000062(10)	-	-	-	-	-	0.0000058(13)
542.2	0.0000022(4)	-	-	-	-	-	0.0000022(4)
556.4	0.0000006(2)	-	-	-	-	-	0.0000006(2)
572.2	0.00050(4)	-	0.00060(3)	-	0.000634(29)	0.000651(31)	0.000611(5)
617.7	0.000062(8)	-	0.000077(4)	-	0.000078(21)	0.000073(19)	0.000076(1)
821.6	0.0000028(2)	-	0.0000022(2)	-	-	-	0.0000023(2)

[a] Data of Jedlovszky et al (1987) Ref 1 have been provisionally replaced by the later measurements of Andai et al (1990) Ref 3, however, these data have been retained until the ICRM (International Committee of Radionuclide Metrology)-BIPM (Bureau International des Poids et Mesures) exercise has been fully completed

[b] ICRM (International Committee for Radionuclide Metrology) intercomparison of relative gamma-ray emission probabilities 13 sets of data were submitted for assessment and these measurements have been individually evaluated Data sets were identified through an arbitrary numbering system (2, 4, 5A, 5B, 7 etc) established by Jedlovszky (1989) Ref 2 to maintain a semi-anonymous arrangement, this system has been retained in conjunction with numerical ordering Very few of these measurements have been published separately in the open literature, although specific participants in this exercise included Andai et al (1990) Ref 3 and Wang Xin Lin and Wang Yuandi (1990) Ref 4

[c] Uncertainty adjusted by a factor of 2 to prevent excessive and unrealistic weighting of this data set

[d] Data discrepant and omitted from evaluation

Absolute Emission Probability of 264.7 keV Gamma Ray (P_γ^{abs})

E_γ (keV)	CRP Measurements													
	Jedlovszky et al (1987) Ref 1 [a]	Jedlovszky (1989) Ref 2 [b]												
		1/2	2/4	3/5A	4/5B	5/7	6/8	7/9	8/10	9/12	10/13	11/14	12/15	13/16
264.7	0.593(9)	0.594(3)	0.590(13)	0 602(14)	0.593(7)	0.596(9)	0.588(10)	0.593(16)	0.597(4)	0.588(3)	0.590(5)	0.596(5)	0.580(3)	0.588(5)

Cont.

E_γ (keV)	Other Measurements			P_γ^{abs} Evaluated Value
	Schötzig et al (1980) Ref 14	Yoshizawa et al (1983) Ref 15		
		Yoshizawa	Katoh	
264.7	0.591(8)	0.580(9)	0.582(9)	0.590(2)

[a] Data of Jedlovszky et al (1987) Ref 1 have been provisionally replaced by the later measurements of Andai et al (1990) Ref 3; however, these data have been retained until the ICRM (International Committee of Radionuclide Metrology)-BIPM (Bureau International des Poids et Mesures) exercise has been fully completed

[b] Provisional data from ICRM (International Committee for Radionuclide Metrology) studies: an activity intercomparison is planned in the 1990s by BIPM (Bureau International des Poids et Mesures) to derive absolute gamma-ray emission probabilities from these measurements.

Derived Absolute Emission Probabilities (P_γ^{abs})

E_γ (keV)	Absolute Emission Probability [a]
24.4	0.00028(6)
66.0	0.0110(2)
80.9	0.00009(2)
96.7	0.0341(4)
121.1	0.171(1)
136.0	0.588(3)
198.6	0.0149(1)
249.2	0.0000009(2)
264.7	0.590(2)[b]
279.5	0.250(1)
303.9	0.0131(1)
373.5	0.000025(2)
400.7	0.115(1)
419.1	0.00014(1)
468.6	0.0000034(8)
542.2	0.0000013(2)
556.4	0.0000004(1)
572.2	0.000360(4)
617.7	0.000045(1)
821.6	0.0000014(1)

[a] Calculated from evaluated relative emission probability and normalisation factor of 0.590(2).

[b] Uncertainty adopted is the uncertainty in the evaluated absolute emission probability only.

Internal Conversion Coefficients (ICC) and Transition Type

E_γ (keV)	ICC	Grigoriev and Zolotavin (1959) Ref 5	Speidel et al (1968) Ref 16	Becker and Steffen (1969) Ref 17	Sutela (1973) Ref 10
96.7	K	0.78(5)	-	-	-
	K/L	7.5(7)	-	-	-
	L/M	5.3(8)	-	-	-
	E2(%)	100	-	-	-
121.1	K	0.037	-	-	-
	K/(L+M)	7.2(6)	-	-	-
	E1(%)	100	100	100	100
136.0	K	0.026	-	-	-
	K/L	10.1(4)	-	-	-
	L/M	5.9(7)	-	-	-
	E1(%)	100	100	100	100
264.7	K	0.0065(4)	-	-	-
	K/(L+M)	7.4(8)	-	-	-
	M1(%)	100	100	-	97.1(12)
	E2(%)	-	-	-	2.9(12)
279.5	K	0.0076(8)	0.0074(5)	-	-
	K/(L+M)	7.7(8)	-	-	-
	M1(%)	80	-	-	83(1)
	E2(%)	20	-	-	17(1)
400.7	K	0.0011	-	-	-
	K/(L+M)	8.5(17)	-	-	-
	E1(%)	100	-	-	-

Theoretical Internal Conversion Coefficients

E_γ (keV)	Transition Type	Theoretical Internal Conversion Coefficients [a]			
		α_K	α_L	α_{M+}	α_{tot}
96.7	E2	0.7739(77)	0.1064(10)	0.0180(2)	0.8983(90)
121.1	E1	0.0374(7)	0.00392(8)	0.00067(1)	0.0420(8)
136.0	E1	0.0265(5)	0.00277(6)	0.00046(1)	0.0297(6)
264.7	(M1 (E2 M1 + E2 [b] (97.1% + 2.9%)	0.00640 0.01920 0.00677	0.00068 0.00215 0.00072	0.00012 0.00038 0.00013	0.00720) 0.02173) 0.00762(50)
279.5	(M1 (E2 M1 + E2 [b] (83% + 17%)	0.00559 0.01582 0.00733	0.00059 0.00176 0.00079	0.00010 0.00031 0.00013	0.00628) 0.01789) 0.00825(40)
400.7	E1	0.00121(2)	0.000125(2)	0.000021(1)	0.00136(2)

[a] Internal conversion coefficient data derived from Rösel et al (1978) Ref 18.

[b] Mixing ratio from Sutela (1973) Ref 10.

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I. HALF-LIFE

Recommended value: 64.849 ± 0 004 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
64.850 ± 0.143	Walz et al (1983) [1]
64.851 ± 0.006	Hoppes et al (1982) [2]
64.856 ± 0.007	Houtermans et al (1980) [3]
64.845 ± 0.009	Rutledge et al (1980) [4]
64.840 ± 0.010	Thomas (1978) [5]
64.680 ± 0.077	Lagoutine et al (1972) [6]
64.930 ± 0.220	Emery et al (1972) [7]
65.000 ± 5.000	Vatai et al (1974) [8]
65.000 ± 4.860	Araminowicz and Dresler (1973) [9]
64.849 ± 0.004	Weighted mean

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W Bambynek (CBNM, Geel, Belgium)

A. Recommended values

	E (keV)	P_{KX}
Rb K_{α}	13 34 - 13 40	0 500 ± 0 003
Rb K_{β}	14 96 15 29	0 087 ± 0 002
Rb KX	13 34 15 29	0 587 ± 0 004

B. CRP measurements

None

C. Other measurements

	E (keV)	Grotheer et al (1969) [1]	Bambynek and Reher (1970) [2]
Rb KX	13 34 - 15 29	0 5959 35	0 586 4

	E (keV)	Thomas (1978) [3]
Rb KX	13 34 15 29	0 5866 47

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III. GAMMA RAY EMISSION PROBABILITIES

Evaluated by Y. Yoshizawa and H. Inoue (Hiroshima University)

A. Recommended Values

E_γ (keV) [1]	P_γ
514.0076 ± 0.0022	0.984 ± 0.004

B. CRP measurements

None

C. Measurements

Energy (keV)	Sattler (1962) [2]	Vartanov et al. (1966) [3]	Bubb et al. (1971) [4]	Vatai et al. (1974) [5]
514.0	100	100	100	100
356	0.002			< 0.001
868.5	0.017	0.010(2)	< 0.006	0.014(2)

Electron capture and internal conversion coefficient.

Item	Value	Remarks
EC to the ground state	0.008 ± 0.004	a
Internal conversion coefficient	0.008 ± 0.001	Sunyar et al. [8]
P_γ	0.984 ± 0.004	b

Note to Table

a. This value is estimated by using the average log ft value [6] of 9.47±0.17 for seven neighbouring nuclei with uncertainty of 2σ. The Q_β value was taken from the mass table Wapstra and Gove [7].

b. The emission probability of the 514 keV gamma ray is obtained from the electron capture transition to the ground state and the internal conversion coefficient of the 514 keV transition. The intensity of the 869 keV gamma ray is negligible.

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I. HALF-LIFE

Recommended value: 106.630 ± 0.025 d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
106.660 ± 0.050	Walz et al (1983) [1]
106.640 ± 0.050	Hoppes et al (1982) [2]
106.612 ± 0.014[c]	*Houtermans et al (1980) [3]*
106.600 ± 0.130	Lagoutine et al (1975) [4]
107.710 ± 1.400	Bormann et al (1976) [5]
106.630 ± 0.025	Weighted mean

Notes to Table

[c] The uncertainty was increased to 0.035 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Sr K_α	14.10 - 14.17	0.522 ± 0.006
Sr K_β	15.83 - 16.19	0.094 ± 0.002
Sr KX	14.10 - 16.19	0.616 ± 0.007

B. CRP measurements

None.

C. Other measurements

	E (keV)	Grotheer et al. (1969) [1][a]	Bambynek and Reher (1973) [2][a]
Sr KX	*14.10 - 16.19*	*0.6277 32*	*0.612 4*

Notes to table C:
[a] Corrected for $P_{\beta+}$ = 0.0020 2.

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III. EMISSION PROBABILITIES OF SELECTED GAMMA RAYS

Evaluated by N. Coursol (LMRI, Saclay, France)

A. Recommended Values

E_γ (keV) [1]	P_γ
898.042 ± 0.004	0.940 ± 0.003
1836.063 ± 0.013	0.9936 ± 0.0003

B. CRP measurements

E_γ (keV) [1]	P_γ Schötzig (1989) [2]
898.042	0.942 9

C - Comparison with other measurements

Eγ (keV)	CRP measurements: Schotzig (1989) [2]	Other measurements: Debertin et al. (1977)[3]	Yoshizawa et al. (1980)[4]	Hoppes et al. (1982)[5]	Evaluate values
898	0.942 9	0.946 5 [a,b]	0.937 4 [c]	0.943 4 [a]	0.940 3
1836			0.9924 7 [c]	0.9935 3 [c]	0.9933 3

Eγ (keV)	Peelle (1960) [6]	Sakai et al (1966) [7]	Heath (1974) [8]	Ardisson et al. (1974)[9]	Evaluate values
2734	0.00597 25 [d]	0.0063 4 [d]	0.0054 9 [d]	0.0072 7 [d]	0.0061 2

Notes to Table C

a The P_γ , have been determined directly from the decay rate of the source and Ge(Li) spectrometric techniques.

b This gamma emission probability has not been used in the calculation of the weighted mean and the derivation of the recommended value. It was withdrawn by the author and superseded by Ref.[2].

c The P_γ values have been calculated from the measured relative intensities and the experimental ICC values obtained by Allan Ref.[10] and Anton'eva et al. Ref.[11].

d These values are deduced from relative values related to 1836 keV photon- emission probability.

D - Internal Conversion Coefficient

E (keV)	Transition type	Experimental ICC total Allan (1971) [10]	Experimental ICC pair formation Anton'eva et al (1979) [11]	Theoretical total ICC Rosel et al (1978) [12] [a]
898.042	E1	$(2.8\ 3)\times10^{-4}$		3.09×10^{-4}
1836.063	E2	$(1.6\ 2)\times10^{-4}$	$(2.3\ 2)\times10^{-4}$	1.64×10^{-4}
2734.086	E3		$(4.8\ 6)\times10^{-4}$	

Note to Table D

a ICC values' from Ref. [12] interpolated by cubic spline method.

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PTB Report 87 (1977) 22

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I. HALF-LIFE

Recommended Value: 5.89 x 10^3 ± 0.05 x 10^3 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M.J. Woods (NPL, Teddington, UK)

Measured values

Values (in days)	Reference
5891.0 ± 55.0 [c]	Vaninbroukx (1983) [1]
5880.0 ± 70.0	Lloret (1981) [2]
4164.0 ± 329.0 [b]	Hegedues (1976) [3]
5890 ± 50	Weighted mean

Notes to Table

b This value has been omitted from the calculation of the weighted mean on the basis of statistical considerations.

c The uncertainty was increased to 69 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Nb K_α	16.52 - 16.62	0.0925 ± 0.0030
Nb K_β	18.62 - 19.07	0.0179 ± 0.0007
Nb KX	16.52 - 19.07	0.1104 ± 0.0035

B. CRP measurements

	E (keV)	Coursey et al. (1989) [1]
Nb KX	16.52 - 19.07	0.1112 22

C. Other measurements

	E (keV)	Bambynek et al. (1978, 1980) [2.3]	Alberts et al. (1983) [4]
Nb KX	16.52 - 19.07	0.116 4	0.107 3

	E (keV)	Vaninbroukx (1983) [5]	Gehrke et al. (1985) [6]
Nb KX	16.52 - 19.07	0.115 3	0.1104 28

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I. HALF-LIFE

Recommended value: $7.3 \times 10^{6} \pm 0.9 \times 10^{6}$ d

Evaluated by M. J. Woods (NPL, Teddington, UK) and
K. Debertin (PTB, Braunschweig, FRG)

Measured values

Value (in days)	Reference
7410000 ± 590000[c]	Schumann and Goris (1959) [1]
6600000 ± 1500000	Rollier et al (1955) [2]
8000000 ± 1900000	Douglas et al (1953) [3]
7336667 ± 833438	Weighted mean

Notes to Table

[c] The uncertainty was increased to 1180000 to ensure that this value did not contribute a weighting of greater than 50%.

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II. EMISSION PROBABILITIES OF SELECTED GAMMA RAYS

Evaluated by R.G. Helmer (INEL, Idaho Falls, Idaho, USA)

A. Recommended Values

E_γ (keV) [a]	P_γ [b]
702.645 ± 0.006	0.9979 ± 0.0005
871.119 ± 0.004	0.9986 ± 0.0005

Notes to Table A

[a] From Ref. [1] and based on data from Rev. [2].

[b] Values are computed from 0.9995(5)/(1+α) where the uncertainty is from a conservative estimate of the upper limit for the total emission probability of all weak beta branches.

Table of possible weak beta-decay branches from parent state with $I^\pi = 6^+$.

Level (keV)	I^π	Log ft lower limit [a]	P_β upper limit
0	0^+	~33	$<<10^{-12}$
871	2^+	~23	$\sim10^{-10}$
1742	0^+	~33	10^{-22}
1864	2^+	~23	$\sim10^{-12}$

Note for Table

[a] Estimated from data in Ref. [3].

Table of internal-conversion coefficients interpolated [4] from tables of Rösel et al. [5] with uncertainties of 1% assigned [4].

E_γ (keV)	Multipolarity	α
702.6	E2	0.00185(2)
871.1	E2	0.00108(1)

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I HALF-LIFE

Recommended Value 34 975 ± 0 007 d

Evaluated by K Debertin (PTB, Braunschweig, FRG) and
M J Woods (NPL, Teddington, UK)

Measured values

Values (in days)	Reference
34 980 ± 0 020	Rutledge et al (1980) [1]
34 979 ± 0 009	Houtermans et al (1980) [2]
34 970 ± 0 010	Hansen et al (1976) [3]
35 150 ± 0 030 [b]	Reynolds et al (1968) [4]
34 975 ± 0 007	Weighted mean

Notes to Table

b This value has been omitted from the calculation of the weighted mean on the basis of statistical considerations

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II Emission Probabilities of Selected Gamma Rays

Evaluated by R G Helmer (INEL, Idaho Falls, Idaho, USA)

A Recommended values

E_γ(keV)[a]	P_γ[b]
765 807 ± 0 006	0 9981±0 0003

Notes to table A

a From Ref [1]

b Value computed as [0 9997(3) 0 00011]/1 00147 where 0 9997(3) is the beta feeding of the 765 keV level and the second term is the intensity of the 561 keV gamma ray

Internal conversion coefficients interpolated [2] from the tables of Rosel et al [3]

$E_\gamma$keV)	Multi polarity	Mixing ratio		α	α_K
204 1	M1+E2	0 62(7)[a]	M1	0 0368(10)	0 0323(10)
			E2	0 0927(9)	0 0790(8)
			mixed	0 0523(8)	0 0453(7)
561 8	E2			0 00341(3)	0 00298(3)
765 8	M1+E2	0 14(5)[b]	M1	0 00147(4)	0 00129(4)
			E2	0 00148(1)	0 00130(1)
			mixed	0 00147(4)	0 00129(4)

Notes for table

a From evaluation of Ref [4] as deduced from ^{95}Tc decay
b From evaluation in Ref [5] and based on data of Ref [6]

Table of relative gamma-ray and transition emission probabilities

E_γ(keV)	Measured I_γ[b]	Measured I_K[d]	Deduced[e] I_γ	Adopted I_γ	Adopted I_t[f]
204.12(1)[a]		1.0(3)	0.028(8)	0.028(8)	0.029(9)
561.88(2)[b]	0.015(1)	0.025(5)	0.011(2)	0.013(3)	0.013(3)
765.807(6)[c]	100	100	100	100	100

Notes for table

a From Ref. [7]

b From Ref. [8]

c From Ref. [1]

d From Ref. [9]

e Calculated from I_K values given here and α_K in previous table.

f Calculated from I_γ values in previous column and α in previous table.

Table of beta-emission probabilities from ^{95}Nb parent which has $I^\pi = 9/2^+$.

Level (keV)	I^π	$\Delta I,\Delta\pi$	From systematics[a] log ft	From systematics[a] P_β	From data P_β	Adopted P_β
0	$5/2^+$	2, no	≥11.9	<0.000 06	0.000 30(5)[c]	0.000 3(3)[e]
204	$3/2^+$	3, no	≥12.8	<0.000 003	0.000 16(9)[d]	
765	$7/2^+$	1, no	5.091(5)[b]	~100.		0.999 7(3)
786	$1/2^+$	4, no	~23	~0.0		0.0
820	$3/2^+$	3, no	≥12.8	<0.000 000 01		0.0

Notes for table

a From systematics of Ref.[10], unless otherwise noted.

b From Ref. [5].

c From beta-sprectral measurements of Ref. [9].

d From intensity balance at 204-keV level as given in previous table.

e From this evaluation. The log ft systematics argue strongly against the P_β value from the data. In any case, the assigned uncertainty covers the range of the values from the data.

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I. HALF-LIFE

Recommended value: 462.6 ± 0.7 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
463.1 ± 0.3	Lagoutine and Legrand (1982) [1]
463.2 ± 0.6	Hoppes et al (1982) [2]
461.9 ± 0.3	Hansen et al (1980) [3]
450.0 ± 5.0	Reynolds et al (1968) [4]
462.6 ± 0.7[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Ag K_α	21.99 - 22.16	0.821 ± 0.009
Ag K_β	24.93 - 25.60	0.173 ± 0.003
Ag KX	21.99 - 25.60	0.994 ± 0.010

B. CRP measurements

None

C. Other measurements

	E (keV)	Campbell and McNelles (1972) [1][a]	Dragoun et al. (1976) [2][a]
Ag KX	21.99 - 25.60	0.920 3	0.980 12

	E (keV)	Hoppes and Schima (1982) [3][a]	Geidelman et al. (1988) [4]
Ag KX	21.99 - 25.60	0.992 11	1.025 30

	E (keV)	Yegorov et al. (1989) [5]
Ag K_α	21.99 - 22.16	0.836 12
Ag $K_{\beta'1}$	24.93	0.149 3
Ag $K_{\beta'2}$	25.60	0.0256 7
Ag KX	21.99 - 25.60	1.010 14

Note to table C:

[a] Deduced from measurements of the KX/γ (88) emission rates using the recommended P_γ (88) = 0.0363 2, as evaluated by N. Coursol (this report).

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III. GAMMA RAY EMISSION PROBABILITY

Evaluated by N. Coursol (LPRI, Saclay, France)

A. Recommended Value

E_γ (keV) [1]	P_γ
88.0341 ± 0.0011	0.0363 ± 0.0002

B. CRP Measurement

E_γ (keV)	Funck and Schötzig (1989) [2]
88.0341	0.0368 (7)

C - Comparison with other measurements (P_γ)

E_γ (keV)	CRP measurement: Funck and Schotzig (1989)[2]	Other measurements: Ballaux et al (1988)[3]	Other measurements: Hino and Kawada (1989)[4]	Other measurements: Chechev (1989)[5]	BIPM intercomparison[a]: Martin AECL [6]	BIPM intercomparison[a]: Gostely IER [7]
88.0	0.0368 7 [c]	0.03675 18 [d]	0.0366 5 [c]	0.0365 5 [c]	0.0367 7	0.0365 3
	0.0368 4 [b]	0.03688 24 [b]		0.0359 11 [b]		

E_γ (keV)	BIPM intercomparison[a] (cont'd): Park et al. KSRI [8]	Chauvenet LMRI [9]	Woods and Smith NPL [10]	Szorenyi et al. OMH [11]	Plch and Suran UVVVR[12]	Evaluated values
88.0	0.0370 6	0.0360 1 [d]	0.0357 10	0.0365 8	0.03594 19 [d]	0.03632 12
						0.03664 25 [e]

Notes to Table C

a Gamma-ray emission probabilities taken from Ratel Ref.[13] "Internationa comparison of activity measurements of a solution of 109Cd (March 1986)" These values were deduced from the conversion-electron and gamma-ray emission rates obtained by each laboratory named.

b Value obtained in the frame of the BIPM international comparison (note a above). This gamma-ray emission probability has not been used in the calculation of the weighted mean and the derivation of the recommended value; assumed superseded by the value immediately above it as published on the paper referred upper.

c Gamma-ray emission probability obtained using the final result of the activity of the solution of 109Cd in the BIPM international comparison and the gamma-ray emission rate measured by the laboratory.

d This uncertainty has been adjusted (increased x2) in the calculation of the weighted mean on the basis of statistical considerations, chi-square value .

e Evaluated value obtained without using the BIPM intercomparison results.

III - Internal Conversion Coefficients

E_γ (keV)	Transition type	Theoretical ICC[a] K	Theoretical ICC[a] L	Theoretical ICC[a] total	Experimental ICC[b] total
88.0341	E3	11.35	12.43	26.78	26.4 4
	M4	392.8	284.9	752.3	

Note to Table

a Theoretical total internal conversion coefficient interpolated from Rosel et al. Ref. [14] by cubic spline method.

b Experimental total internal conversion coefficient from Dragoun et al Ref. [15]

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I. HALF-LIFE

Recommended value: 2.8047 ± 0.0005 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
2.8048 ± 0.0001[c]	Rutledge et al (1986) [1]
2.8049 ± 0.0005	Walz et al (1983) [2]
2.8048 ± 0.0005	Hoppes et al (1982) [3]
2.8071 ± 0.0015	Houtermans et al (1980) [4]
2.8020 ± 0.0010	Lagoutine et al (1978) [5]
2.8300 ± 0.0100	Emery et al (1972) [6]
2.8047 ± 0.0005	Weighted mean

Notes to Table

[c] The uncertainty was increased to 0.0004 to ensure that this value did not contribute a weighting of greater than 50%.

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Nucl.Sci.Eng. 48 (1972) 319

II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Cd K_α	22.98 - 23.17	0.684 ± 0.005
Cd K_β	26.09 - 26.80	0.146 ± 0.003
Cd KX	22.98 - 26.80	0.830 ± 0.005

B. CRP measurements

None

C. Other measurements

None

III. GAMMA RAY EMISSION PROBABILITIES

Evaluated by Y. Yoshizawa and H. Inoue (Hiroshima University)

A. Recommended Values

E_γ (keV) [2]	P_γ
171.28 ± 0.03	0.9078 ± 0.0010
245.35 ± 0.04	0.9416 ± 0.0006

B. CRP Measurement

None

C. Measurements

Internal conversion coefficient

Transition Energy (keV)	Sparrman et al. (1966) [1]	Shevelev et al. (1975) [2]	Kawada Hino (1985) [3]	Average [a]
171.3	0.0998±0.0028	0.1240±0.0059	0.1018±0.0013	0.1014±0.0012
245.4	0.0618±0.0015	0.0634	0.0620±0.0007	0.0620±0.0006

Note to Table

a Weighted average of Sparrman et al. [1] and Kawada and Hino [3]. The electron capture branching ration of $\epsilon = (5\pm5)\times10^{-5}$ is given by the observed upper limit 1×10^{-4} [4]. The emission probabilities of the 171 and 245 keV gamma rays are calculated by $P_\gamma=(1-\epsilon)/(1+\alpha(171))$ and $P_\gamma=1/(1+\alpha(245))$, respectively, where $\alpha(171)$ and $\alpha(245)$ denote the internal conversion coefficients of the 171 and 245 keV transitions, respectively.

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I HALF-LIFE

Recommended value 115 09 ± 0 04 d

Evaluated by K Debertin (PTB, Braunschweig, FRG) and
M J Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
115 06 ± 0 07	Hoppes et al (1982) [1]
115 09 ± 0 04 [a]	Houtermans et al (1980) [2]
115 12 ± 0 07	Merritt and Gibson (1976) [3]
115 20 ± 0 80	Emery et al (1972) [4]
115 07 ± 0 10	Lagoutine et al (1972) [5]
115 09 ± 0 04	Weighted mean

Note that the 391-keV level in ^{113}In has a half-life of 1 6 hours, so the activity of this level is slightly larger (after it has grown in from a pure ^{113}Sn sample) than that of the ^{113}Sn parent The LMRI evaluation [6] adopts a value of 1 6580(5) hours, so

$$\frac{\text{activity (391 level)}}{\text{activity } (^{113}\text{Sn})} = \frac{T_{1/2}\ (^{113}\text{Sn})}{T_{1/2}\ (^{113}\text{Sn}) - T_{1/2}\ (\text{391 level})} = 1\ 00060$$

Note to Table

a The uncertainty was increased to 0 05 to ensure that this value did not contribute a weighting of greater than 50%

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W Bambynek (CBNM, Geel, Belgium)

A. Recommended values

	E (keV)	P_{KX}
In K_α	24 00 24 21	0 796 ± 0 006
In K_β	27 27 28 02	0 172 ± 0 003
In KX	24 00 28 02	0 968 ± 0 006

B. CRP measurements

None

C. Other measurements

None

III. EMISSION PROBABILITY OF A GAMMA-RAY

Evaluated by R.G. Helmer (INEL, Idaho Falls, Idaho, USA)

A. Recommended Value

E_γ (keV) [1]	P_γ [a]
391.702 ± 0.004	0.6489 ± 0.0013

Note for Table A

[a] Value computed from [1.000-0.000 000 06(3)]/1.541(3) where 6×10^{-8} is the emission probability of the 646-keV γ ray and 0.54(3) is the internal-conversion coefficient for the 391-keV γ ray.

The measured, evaluated and theoretical internal-conversion coefficient for the 391-keV γ ray.

α	Reference	Origin
0.542 (8)	[2]	measurement
0.528 (9)	[3]	measurement
0.541 (6)	[4]	measurement
0.559 (14)	[5]	measurement
0.544 (8)	[6]	measurement
0.540 (7)	[7]	measurement
0.540 (4)	[8]	evaluation of data from Refs. [3-7]
0.541 (3)		this evaluation of data from Refs. [2-7]
0.559 (17)	[9]	theory for M4
0.536 (16)	[9]	theory for E5

Table of relative gamma-ray emission probabilities from Ref. [10].

E_γ (keV)	Relative P_γ
255.1	2.85 (7)
382.0	<0.001
391.7	100.
638.0	0.0149 (5)
646.8	0.000 006 (3)

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I. HALF-LIFE

Recommended value: 1007.7 ± 0.6 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
1008.1 ± 0.8	Walz et al (1983) [1]
1004.0 ± 8.0	Hoppes et al (1982) [2]
1007.3 ± 0.3[c]	Houtermans et al (1980) [3]
1007.7 ± 0.6	Weighted mean

Notes to Table

[c] The uncertainty was increased to 0.8 to ensure that this value did not contribute a weighting of greater than 50%.

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NBS Special Publication 626 (1982) 85

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Int.J.Appl.Radiat.Isotopes 31 (1980) 153

II - EMISSION PROBABILITIES OF SELECTED GAMMA RAYS

Evaluated by N. Coursol (LMRI, Saclay, France)

A - Recommended values

E_γ (keV) [1]	P_γ
176.313 ± 0.001	0.0685 ± 0.0007
380.452 ± 0.008	0.01518 ± 0.00016
427.875 ± 0.006	0.297 ± 0.003
463.365 ± 0.005	0.1048 ± 0.0011
600.600 ± 0.004	0.1773 ± 0.0018
606.718 ± 0.003	0.0500 ± 0.0005
635.954 ± 0.005	0.1121 ± 0.0012

B - CRP measurements

E_γ[a] (keV)	Helmer[b] (1990) [1]
116.952 11	0.867 24
172.714 6	0.659 11
176.313 1	22.96 24
204.139 8	1.080 23
208.080 9	0.825 16
227.891 10	0.443 23
321.03 4	1.41 3
380.452 8	5.14 5
408.065 10	0.630 19
427.873 5	100.0 8
443.554 9	1.019 29
463.364 5	35.07 28
600.601 3	59.09 45
606.718 3	16.70 14
635.953 4	37.52 30
671.445 4	6.05 6

Note to Table B

a Gamma-ray energy from Ref. [1].

b Mesured photon emission rate relative to that of the 427 keV gamma-ray reference line.

C - Comparison with other measurements

Mesured P_γ relative to that of 427 keV gamma-ray reference line.

E_γ (keV)	CRP measurement	Other measurements			
	Helmer (1988/90) [1]	Nappal and Gaucher (1970) [2]	Marsol and Ardisson (1971) [3]	Gupta et al.(1973) [4]	Ardisson and Abdmeziem (1977) [5]
116	0.867 25	1.10 10 [a]	1.13 11 [a]	0.75 4 [a]	0.89 4
172	0.659 11	0.9 1	0.89 10	0.65 4 [a]	0.65 5
176	22.96 24	24.9 20	22.7 9	23.9 8	22.9 7
204	1.080 23	1.15 10	0.93 9 [a]	1.21 5 [a]	0.99 5 [a]
208	0.825 16	0.85 8	0.63 6 [a]	0.90 4 [a]	0.79 4
227	0.443 23	0.44 4	0.39 4 [a]	0.47 2 [a]	0.45 2
321	1.41 3	1.41 10	1.52 15	1.42 5	1.41 7
380	5.14 5	5.27 40	5.1 3	5.22 17	5.15 20
408	0.630 19	0.62 6	0.45 5	0.59 3	0.59 3
427	100.0 8	100	100	100	100
443	1.019 29	1.03 10	1.0 2	1.07 4	1.05 5
463	35.07 28	35.4 28	35.2 15	35.3 13	35.2 10
600	59.09 45	61.5 49	59.8 25	59.6 18	60.1 18
606	16.70 14	16.4 12	16.4 8	16.9 6	16.8 5
635	37.52 30	37.3 30	38.4 19	38.2 12	38.4 11
671	6.05 6	6.0 5	5.83 30	6.09 20	6.02 24

Note to Table C

a This value was dropped by the evaluator due to large deviation from the weighted mean and a higher than expected chi-square value.

C - Comparison with other measurements (cont'd)

Mesured P_γ relative to that of 427 keV gamma-ray reference line.

E_γ (keV)	Other measurements (cont'd)					
	Meyer and Mann (1978) [6]	Prasad (1979) [7]	Roney and Seale (1980) [8]	Debertin et al. (1980) [9]	Coursey et al. (1982) [10]	Iwata et al. (1984) [11]
116	0.867 14	0.91 5	/	0.872 24	/	0.867 25
172	0.619 10 [a]	0.74 6 [a]	1.01 12 [a]	0.66 3	/	0.69 4
176	23.10 7	22.9 6	25.45 60 [a]	22.8 3	23.02 14	22.62 21 [a]
204	1.099 14	1.12 4	1.19 22	1.09 3	/	1.08 3
208	0.803 14	0.80 4	0.96 10	0.796 22	/	0.788 21
227	0.449 14	0.42 2	0.42 7	0.452 16	/	0.433 12
321	1.395 14	1.48 6	1.46 8	1.400 23	/	1.391 24
380	5.17 3	5.18 20	5.26 10	5.04 5	5.10 4	5.12 15
408	0.622 20	0.57 4	0.66 8	0.603 22	/	0.608 21
427	100.0 7	100	100	100 1	100.0 7	100.0 7
443	1.031 24	1.06 2	1.03 8	1.023 20	/	0.989 23
463	35.5 5	35.1 8	35.45 84	35.1 4	35.18 25	35.23 14
600	60.5 7	60.4 11	59.31 125	59.0 7	59.4 4	59.54 22
606	17.07 24	16.6 5	16.25 62	16.78 20	/	16.94 7
635	38.5 6	38.7 8	37.72 100	37.6 3	37.97 23	37.87 14
671	6.12 14	6.04 16	6.02 14	6.04 5	/	6.039 24

Note to Table C

a This value was dropped by the evaluator due to large deviation from the weighted mean and a higher than expected chi-square value.

C - Comparison with other measurements (cont'd)

Mesured P_γ relative to that of 427 keV gamma-ray reference line.

E_γ (keV)	Other measurements (cont'd): Singh and Sahota (1983) [12]	Wang et al. (1986) [13]	Longaria-Gandara et al. (1989) [14]	Evaluated relative values	Calculated absolute values[d]
116	1.060 10	/	0.865 22	0.870 9	0.00258 4
172	0.86 2[a]	/	1.066 6[a]	0.66 1	0.00196 4
176	24.5 8	22.91 41	23.12 11	23.08 5	0.0685 7
204	1.14 4	/	1.112 12	1.11 1	0.00330 5
208	0.82 2	/	0.879 31	0.812 8	0.00241 4
227	0.44 2	/	0.445 21	0.441 6	0.00131 2
321	1.30 5	/	1.381 15	1.393 7	0.00414 5
380	6.02 25[a]	5.12 15	5.069 34	5.11 2	0.01518 16
408	0.61 3	/	0.653 37	0.613 8	0.00182 3
427	100	100	100	100.0 10	0.297 3[c]
443	1.12 5	/	1.017 13	1.028 8	0.00305 4
463	35.50 7[b]	35.41 93	35.41 14	35.28 8	0.1048 11
600	60.50 10[b]	60.25 67	60.92 44	59.72 16	0.1773 18
606	17.2 3	16.97 26	16.64 9	16.83 5	0.0500 5
635	39.1 2	37.47 27	37.58 14	37.74 8	0.1121 12
671	5.9 3	5.65 12[a]	6.14 4	6.06 2	0.0180 2

Notes to Table C

a This value was dropped by the evaluator due to large deviation from the weighted mean and a higher than expected chi-square value.

b This uncertainty was reestimated by the evaluator in the calculation of the weighted mean on the basis of statistical considerations, chi-square value.

c This value has been obtained from the evaluated relative emission probabilities by requiring that the sum of all transitions (beta transition, gamma rays and conversion electron emission) to the ground state and first two excited states of 125Te at 35.5 and 144.8 keV from higher levels should be 100%. The beta branching ratio to the 144.8 keV level was taken as 0.136 1; an unweighted mean of Narcisi (1959) Ref.[15] and Mann Ref.[16] values'.

d Value deduced from the evaluated relative emission probability using P_γ = 0.297 3 for the 427 keV reference line.

D - Total internal conversion coefficients

E_γ (keV)	Transition type	Theoretical total ICC[a]
116.952 11	E1	0.127
176.313 1	M1	0.143
380.452 8	E2	0.0183
408.01 4	M1+50%E2	0.0151
427.875 6	E2+40%M1	0.0134
443.497 35	E2	0.0117
463.365 5	E2	0.0102
600.600 4	E2	0.0050
606.718 3	E2	0.0048
635.954 5	M1+11%E2	0.0052
671.445 4	E2	0.0037

Note to Table D

a Values deduced from Rosel et al. Ref.[17] interpolated by cubic spline method and using the Singh et al. Ref. [12] values for the ratio multipolarities.

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I. HALF-LIFE

Recommended value: 59.43 ± 0.06 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
59.416 ± 0.010	Woods and Lucas (1989) [1]
59.38 ± 0.03	De Felice et al (1989) [2]
59.39 ± 0.02	Schrader (1989) [3]
59.40 ± 0.05	Simpson and Meyer (1988) [4]
59.56 ± 0.17	Kubo (1983) [5]
59.47 ± 0.21	Hoppes et al (1982) [6]
59.156 ± 0.020	Houtermans et al (1980) [7]
59.666 ± 0.016	Kundig and Muller (1979) [8]
60.18 ± 0.17	Emery et al (1972) [9]
59.43 ± 0.06	Weighted mean

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Nucl.Sci.Eng. 48 (1972) 319

II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Te K_α	27.20 - 27.47	1.135 ± 0.021
Te K_β	30.98 - 31.88	0.255 ± 0.006
Te KX	27.20 - 31.88	1.390 ± 0.025

B. CRP measurements

None

C. Other measurements

	E (keV)	Karttunen et al. (1969) [1][a]	Tolea et al. (1974) [2][a]
Te KX	27.20 - 31.88	1.379 27	1.393 25

	E (keV)	Plch and Zderadicka (1974) [3][a]	Konstantinov et al. (1989) [4][b]
Te KX	27.20 - 31.88	1.379 23	1.38 2

Notes to Table C:

[a] Internal conversion accounted for with values from Lagoutine et al. [5].

[b] Deduced from $P_{KX+\gamma}$ = 1.42 2 with P_γ = 0.0658 8 evaluated by N. Coursol (this report).

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III. EMISSION PROBABILITY OF A GAMMA-RAY

Evaluated by N. Coursol (LMRI, Saclay, France)

A. Recommended Value

E_γ (keV) [1]	P_γ
35.4919 ± 0.0005	0.0658 ± 0.0008

B. CRP Measurement

E_γ (keV) [1]	Debertin and Schötzig (1989) [2]
35.4919	0.0655 13

C. Comparison with other measurements

E_γ (keV)	CRP measurement	Other measurements			Evaluated value
	Debertin and Schötzig (1989) [2]	Debertin and Pessara (1968) [3]	Karttunen et al. (1969) [4]	Coursol (1980) [5]	
35.49	0.0655 13	0.0651 13[a]	0.0683 26[b]	0.0656 12[c]	0.0658 8

Notes to table C

a Gamma emission probability not used in the calculation of the weighted mean and the derivation of the recommended value. It was re-evaluated by the author and replaced by later measurements of Debertin and Schötzig (1989) Ref. [2].

b Value derived from the measured total internal conversion coefficient and the uncertainty recalculated by this evalutor.

c Value derived from the measured total internal conversion coefficient.

D. Internal conversion coefficient

E_γ(keV)	Transition type	Theoretical total ICC	Experimental total ICC	
			Karttunen et al. (1969) [4]	Coursol (1980) [5]
35.4919	M1+0.03%E2	14.28 [a]	13.65 55 [b]	14.25 22 [c]

Notes to table D

a ICC value from Rösel et al. Ref. [6] interpolated by cubic spline method.

b The original uncertainty was adjusted to take into account 2% of systematical error.

c Uncertainty re-calculated to 1 standard deviation.

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I. HALF-LIFE

Recommended value: 754.28 ± 0.22 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
754.20 ± 0.15	Hoppes et al (1982) [1]
754.50 ± 0.07[c]	Houtermans et al (1980) [2]
753.78 ± 0.30	Rutledge et al (1980) [3]
745.00 ± 11.00[b]	Bulovic and Simic (1977) [4]
753.10 ± 0.70	Dietz and Pachucki (1973) [5]
751.70 ± 1.50[b]	Lagoutine et al (1972) [6]
754.28 ± 0.22[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[b] These values have been omitted in the calculation of the weighted mean on the basis of statistical considerations.
[c] The uncertainty was increased to 0.14 to ensure that this value did not contribute a weighting of greater than 50%.

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Evaluated by Y Yoshizawa and K Shizuma (Hiroshima University)

A. Recommended values

E_γ (keV) [12]	P_γ
475.364 ± 0 003	0 0149 ± 0.0002
563 240 ± 0 004	0 0836 ± 0.0003
569 328 ± 0.003	0.1539 ± 0.0006
604.720 ± 0 003	0 9763 ± 0.0006
795.859 ± 0.005	0.854 ± 0.003
801.948 ± 0.005	0.0869 ± 0.0003
1038.610 ± 0.007	0.00990 ± 0 00005
1167 968 ± 0.005	0 01792 ± 0.00007
1365 185 ± 0.007	0 03016 ± 0.00011

B. CRP measurement

None

C. Measurements

E_γ (keV)	Brown, Ewan (1965)[1]		Bashaindy et al. (1966)[2]	Raeside et al. (1967)[3]	Nagpal et al. (1968)[4]	Abdul-Malek, Naumann (1968)[5]		Hofmann et al. (1970)[6]
	P_γ^{rel}	P_γ^{abs}	P_γ^{rel}	P_γ^{abs}	P_γ^{rel}	P_γ^{abs}	P_γ^{abs}	P_γ^{abs}
475.4	1.54 8	1.5 15	0.31 5	1.51 16	1.67 11	1.62 11	1.4 2	1.57 8
563.2	8.5 8	8.3 8	8.86 83	8.96 84	8.83 46	8.60 46	8.7 10	8.86 4
569.3	14.6 14	14.2 14	14.18 112	15.81 110	13.61 70	13.30 70	15.0 16	16.0 10
604.7	100 5	97.5	100	98.04	100 3	97.5 30	98.0	98.1 60
795.9	90 9	87.8 90	48.08 355	87.79 660	89.25 447	87.00 447	88.4 91	86.0 43
801.9	9.0 15	8.8 15	1.43 25	8.94 80	8.12 42	7.90 42	9.2 10	8.70 44
1038.6	1.06 10	1.03 15	1.55 21	1.02 8	1.06 6	1.04 6	1.1 6	0.99 6
1167.9	1.99 17	1.94 15	2.31 30	1.96 22	2.06 14	2.01 14	1.9 2	1.86 10
1365.2	3.46 30	3.37 30	4.76 52	3.25 32	3.55 19	3.47 19	3.3 3	3.23 17

E_γ (keV)	Stelson et al. (1973)[7]	Van Hise et al. (1975)[8]	Debertin et al. (1976)[9]	Meyer (1978)[10]	Yoshizawa et al. (1980)[11]	Wang (1987)[12]	Evaluated values [a]
	P_γ^{abs}	P_γ^{abs}	P_γ^{abs}	P_γ^{abs}	P_γ^{rel}	P_γ^{rel}	P_γ^{rel}
475.4	1.50 3	1.465 40	1.51 3	1.47 4		1.520 10	1.52 2
563.2	8.47 17	8.30 5	8.34 12	8.38 5	8.57 3	8.53 6	8.57 3
569.3	15.36 31	15.43 11	15.38 22	15.4 1	15.78 6	15.71 10	15.77 6
604.7	98.2 10	97.56 32	97.6 1	97.6 3	100.0 4	100.0 7	100.0 2
795.9	84.9 22	85.44 38	85.3 9	85.4 4	87.5 3	87.5 6	87.5 3
801.9	8.61 22	8.73 4	8.64 12	8.73 4	8.89 3	8.97 8	8.90 3
1038.6	1.03 2	1.00 1	0.998 13	1.00 2	1.008 5	1.016 7	1.014 5
1167.9	1.84 4	1.805 26	1.800 20	1.81 3	1.827 8	1.841 13	1.836 7
1365.2	3.11 8	3.04 4 4	3.02 3	3.04 4	3.074 13	3.109 20	3.090 11

Note to Table

a These values are obtained from the weighted average of the relative intensities since 1973 except the evaluated values of Meyer. In this calculation, the reported emission probabilities [7] [8] [9] are rewritten into relative intensities. The emission probability of the 605 keV gamma ray was calculated by the normalization of the 605 keV and the 1168 keV transitions feeding to the ground state. The theoretical internal conversion coefficients for these transitions are 0.00598 and 0.00131, respectively. The beta decay to the ground state was neglected because of the 4th forbidden transition. The conversion factor from the relative intensities to the emission probabilities is 0.9763±0.0006.

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I. HALF-LIFE

Recommended value: $1.102 \times 10^4 \pm 0.006 \times 10^4$ d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
10968 ± 5	Martin and Taylor (1989) [1]
11206 ± 8	Hoppes et al (1982) [2]
11009 ± 11	Houtermans et al (1980) [3]
10906 ± 33	Gries and Steyn (1978) [4]
11034 ± 29	Corbett (1973) [5]
11021 ± 5	Dietz and Pachucki (1973) [6]
11023 ± 37	Emery et al (1972) [7]
11191 ± 157	Harbottle (1970) [8]
10921 ± 17	Walz and Weiss (1970) [9]
11023 ± 55[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Ba K_α	31.82 - 32.19	0.0566 ± 0.0016
Ba K_β	36.36 - 37.45	0.0134 ± 0.0005
Ba KX	31.82 - 37.45	0.0700 ± 0.0020

B. CRP measurements

None

C. Other measurements

	E (keV)	Hansen et al. (1969) [1][a]	Detertin and Peßara (1983) [2]
Ba K_α	31.82 - 32.19	-	0.0560 12
Ba K_β	36.36 - 37.45	-	0.0135 5
Ba KX	31.82 - 37.45	0.0700 9	0.0695 13

	E (keV)	Mehta et al. (1987) [3][a]
Ba K_α	31.82 - 32.19	0.0582 9
Ba $K_{\beta'1}$	36.36	0.0111 2
Ba $K_{\beta'2}$	37.45	0.00320 7
Ba KX	31.82 - 37.45	0.0725 10

Note to table C:

[a] Deduced from measurements of the KX/γ emission rates using $P_\gamma = 0.851$ 2, evaluated by N. Coursol (this report) and corrected with $\omega_K = 0.900$ 1 evaluated by Bambynek [4].

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III. EMISSION PROBABILITY OF A GAMMA-RAY

Evaluated by N. Coursol (LMRI, Saclay, France)

A. Recommended Value

E_γ (keV) [1]	P_γ
661.660 ± 0.003	0.851 ± 0.002

B. CRP Measurements

None

C - Other measurements

E_γ (keV)	P_γ: Daniel and Schmitt (1962) [2]	Merritt and Taylor (1965) [3]	Hsue et al. (1966) [4]	Hansen et al. (1969) [5]	Legrand et al. (1973) [6]
661	0.843 2 [a] 0.843 5 [c]	0.857 9 [b]	0.847 5 [a]	0.851 4	0.8456 8

Goodier et al. (1975) [7]	Merritt and Gibson (1978) [8]	Gromov et al. (1978) [9]	Christmas and Cross (1978) [10]	Behrens and Christmas (1983) [11]	Evaluated value
0.851 4	0.847 7	0.843 5	0.8456 8 [d]	0.8521 7 0.8521 20 [c]	0.851 2

Notes to Table C

a Value inferred from original beta-decay branch and evaluated total internal conversion coefficient.

b Gamma emission probability not included in this evaluation; replaced by later datum published by Merritt (1978) Ref. [8].

c Uncertainties assigned by this evaluator from the original values.

d Datum not included in this evaluation: replaced by re-assessed datum from Behrens and Christmas (1983) Ref. [11].

D - Internal Conversion Coefficient

Theoretical value [a]

E_γ (keV)	Transition type	Total ICC
661.660	M4	0.1143

Experimental values

Merritt Ref.[3]	Hansen Ref.[5]	Legrand Ref.[6]	Goodier Ref.[9]	Behrens Ref.[11]	Total ICC Evaluated value
0.1100 11	0.1124 6	0.1105 4	0.1100 3	0.1083 3	0.1097 7

Note to Table

a Theoretical total internal conversion coefficient interpolated from Rosel et al. (1978) Ref. [12] by cubic spline method.

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I. HALF-LIFE

Recommended value: 3862 ± 15 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
3885.9 ± 4.3	Kits et al (1983) [1]
3842.0 ± 18.0	Walz et al (1983) [2]
3828.0 ± 11.0	Hoppes et al (1982) [3]
3850.0 ± 55.0	Hansen et al (1980) [4]
3848.0 ± 1.1[c]	Houtermans et al (1980) [5]
3785.0 ± 27.0	Rutledge et al (1980) [6]
3981.0 ± 37.0	Emery et al (19729 [7]
3894.0 ± 44.0	Reynolds et al (1968) [8]
3862 ± 15[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[c] The uncertainty was increased to 3.9 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Cs K_α	30.63 - 30.97	0.980 ± 0.014
Cs K_β	34.97 - 36.01	0.230 ± 0.005
Cs KX	30.63 - 36.01	1.210 ± 0.016

B. CRP measurements

None

C. Other measurements

	E (keV)	Gurfunkel and Notea (1967) [1][a]	Faermann et al. (1971) [2][b]
Cs $K_{\alpha 2}$	30.63	-	0.368 17
Cs $K_{\alpha 1}$	30.97	0.799 56	0.709 31
Cs $K_{\beta' 1}$	34.97	0.219 2	0.210 8
Cs $K_{\beta' 2}$	36.01	-	0.050 2
Cs KX	30.63 - 36.01	-	1.337 36

	E (keV)	Schmidt-Ott and Fink (1972) [3][a]	Schotzig et al. (1967) [4][a]
Cs $K_{\alpha 2}$	30.62	0.999 17	0.331 7
Cs $K_{\alpha 1}$	30.97	-	0.614 12
Cs K_β	34.97 - 36.01	0.232 3	0.228 6
Cs KX	30.62 - 36.01	1.231 17	1.173 15

	E (keV)	Schotzig et al. (1977) [5]	Debertin and Peßara (1983) [6]
Cs Kα	30.62 - 30.97	0.951 22	0.971 16
Cs Kβ	34.97 - 36.01	0.229 6	0.232 5
Cs KX	30.62 - 36.01	1.180 23	1.203 17

	E (keV)	Chauvenet et al. (1983) [7][c]	Chauvenet et al. (1983) [7][d]
Cs K_α	30.62 - 30.97	0.988 6	0.994 6
Cs K_β	34.97 - 36.01	0.231 1	0.232 1
Cs KX	30.62 - 36.01	1.119 6	1.226 6

	E (keV)	Yegorov et al. (1989) [8]
Cs K_α	30.63 - 30.97	0.966 20
Cs $K_{\beta' 1}$	34.97	0.186 4
Cs $K_{\beta' 2}$	36.01	0.0453 14
Cs KX	30.63 - 36.01	1.197 25

Notes to table C:

[a] Deduced from measurements of the KX/γ(356) emission rates using $P_\gamma(356) = 0.6194$ 14, evaluated by T. Barta (this report).

[b] Deduced from measurements of the KX/γ(81) emission rates using $P_\gamma(81) = 0.3411$ 28, evaluated by T. Barta (this report).

[c] Deduced from an ICRM intercomparison to measure the KX- and gamma-ray emission probabilities in the ^{133}Ba decay, arithmetic mean from eight participants.

[d] Same measurements as b, weighted mean.

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III. EMISSION PROBABILITIES OF SELECTED GAMMA-RAYS

Evaluated by T. Barta et al. (OMH, Budapest, Hungary)

A. Recommended values

E_γ (keV) [1]	P_γ [a]
80.998 ± 0.005	0.3411 ± 0.0028 [b]
276.398 ± 0.001	0.07147 ± 0.00030
302.853 ± 0.001	0.1830 ± 0.0006
356.017 ± 0.002	0.6194 ± 0.0014
383.851 ± 0.003	0.08905 ± 0.00029

Notes to table A

a Calculated from α values given in the next table and taking into account the balance in the decay scheme. The uncertainties are from the uncertainties of α-s and of relative gamma-ray emission probabilities.

b The recommended P_γ value of 81.0 keV line is supported by CRP measurements of the ratio of $P_{\gamma 2}/P_{\gamma 3}$ [2] (0.0767(28)) and [3] (0.0782(17)).

Table of internal-conversion data

	E_γ (keV)	Multipolarity	α	Ref.
γ_1	53.161 ± 0.001	M1+E2	5.8(10)	[4]
γ_2	79.623 ± 0.010	M1+E2	1.73(18)	[4]
γ_3	80.998 ± 0.005	M1+E2	1.63(9)	[4]
γ_4	160.613 ± 0.008	M1+E2	0.25(6)	[4]
γ_5	223.234 ± 0.012	M1+E2	0.084(5)	[5]
γ_6	276.398 ± 0.001	E2	0.056(4)	[5]
γ_7	302.853 ± 0.001	M1+E2	0.045(3)	[5]
γ_8	356.017 ± 0.002	E2	0.0259(18)	[5]
γ_9	383.851 ± 0.003	E2	0.034(12)	[5]

C. Comparison with other measurements

P_γ values from other sources

E_γ(keV)	CRP measurements (Chauvenet et al.(1983) [6])						
	1/2*	2/3	3/4a	4/4b	5/5	6/6a	7/6b
53.16	-	0.02198(73)	0.02185(44)	0.02192(42)	0.02421(407)	0.02072(35)	0.02171(40)
79.62	-	-	0.02601(70)	0.02594(65)	0.02467(74)	0.02837(51)	0.02888(52)
81.00	-	0.3278(89)	0.3393(71)	0.3386(71)	0.3177(92)	0.3458(62)	0.3590(65)
160.61	0.00686(54)	0.00610(19)	0.00638(14)	0.00643(11)	0.00629(8)	0.00612(11)	0.00653(12)
223.23	0.00524(30)	0.00450(14)	0.00427(20)	0.00453(13)	0.00449(9)	0.00437(8)	0.00450(8)
276.40	0.07240(188)	0.07194(122)	0.07124(64)	0.07118(64)	0.07093(121)	0.07004(119)	0.07018(119)
302.85	0.1848(48)	0.1858(35)	0.1823(15)	0.1827(15)	0.1818(35)	0.1779(30)	0.1803(31)
356.02	0.6176(154)	0.6173(142)[a]	0.6189(50)	0.6203(50)	0.6168(142)	0.5999(102)	0.6100(104)
383.85	0.08981(234)	0.08885(195)[a]	0.08894(71)	0.08938(72)	0.08766(237)	0.08718(148)	0.08745(149)

Note for table

a Improved values

* in front of the slash: present column numbering
behind the slash: ICRM numbering

P_γ values from other sources (continue)

E_γ(keV)	CRP measurements (Chauvenet et al.(1983) [6])						
	8/7a	9/7b	10/8a	11/8b	12/9	13/11	14/15
53.16	-	-	-	-	0.02307(113)	0.01800(88)	0.02190(44)
79.62	-	-	-	-	0.02728(98)	-	0.02722(63)
81.00	-	-	-	-	0.3457(104)	-	0.3471(69)
160.61	-	-	-	-	0.00656(10)	- [b]	0.00630(11)
223.23	-	-	-	-	0.00463(8)	0.00463(15)	0.00456(5)
276.40	0.06887(138)	0.06917(125)	0.07294(146)	0.07265(102)	0.07205(72)	0.07301(175)	0.07202(50)
302.85	0.1800(27)	0.1805(23)	0.1862(26)	0.1847(20)	0.1845(18)	0.1859(45)	0.1836(17)
356.02	0.6136(80)	0.6166(74)	0.6352(57)	0.6280(57)	0.6248(62)	0.6160(154)	0.6204(56)
383.85	0.08914(125)	0.08790(114)	0.09021(117)	0.09017(144)	0.08974(90)	0.08999(216)	0.08898(80)

Note for table

b Omitted from evaluation

P_γ values from other sources (continue)

E_γ(keV)	CRP measurements (Chauvenet et al.(1983) [6])						
	15/16a	16/16b	17/17a	18/17b	19/20	20/21	21/22
53.16	0.02071(104)	0.02023(101)	0.02167(50)	0.02177(50)	0.02191(28)	0.02154(28)	0.02241(27)
79.62	-	-	-	-	-	0.02475(42)	0.02570(72)
81.00	-	-	0.3407(55)	0.3421(55)	-	0.3362(40)	0.3450(41)
160.61	0.00647(20)	0.00651(20)	-	-	0.0066(1)	0.00643(32)	0.00643(7)
223.23	0.00467(14)	0.00475(15)	-	-	0.0045(1)	0.00441(22)	0.00436(5)
276.40	0.07201(230)	0.07273(225)	-	-	0.0721(6)	0.07014(105)	0.07162(79)
302.85	0.1826(46)	0.1848(26)	-	-	0.1845(15)	0.1796(27)	0.1827(18)
356.02	0.6159(129)	0.6214(87)	-	-	0.621(4)	0.6106(67)	0.6188(62)
383.85	0.08793(158)	0.08891(160)	-	-	0.0902(6)	0.08861(97)	0.08911(89)

C. Comparison with other measurements

P_γ values from other sources (continue)

E_γ(keV)	CRP meas.	Other measurements				Evaluated
	Yoshizawa[5]	ORNL [7]	Gunnink[8][a]	Heath[9][a,b]	Danilenko [10][a,b]	
53.16	-	0.0217(4)	0.0195(2)	0.030(4)	0.0360(5)	0.02161(18)
79.62	-	0.0266(8)	0.0304(2)	0.056(15)	0.0372(5)	0.02656(55)
81.00	-	0.335(5)	0.36(1)	0.52(3)	0.523(6)	0.3411(28)
160.61	0.00642(17)	0.0062(4)	0.0076(10)	0.0112(6)	0.01032(8)	0.00641(5)
223.23	0.00468(10)	0.00460(13)	-	0.0085(5)	0.00713(7)	0.00453(4)
276.40	0.07170(40)	0.0709(13)	0.075(2)	0.1169(60)	0.1151(4)	0.07147(30)
302.85	0.1831(10)	0.1840(20)	0.196(2)	0.2978(150)	0.2951(14)	0.1830(6)
356.02	0.6196(15)	0.621(7)	0.67(1)	1.00(5)	1.000(6)	0.6194(14)
383.85	0.08900(50)	0.0891(10)	0.094(1)	0.1443(80)	0.1399(10)	0.08905(29)

Notes for table

a *Omitted from evaluation*
b Relative P_γ values

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I. HALF-LIFE

Recommended value: 137.640 ± 0.023 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
137.74 ± 0.08	Hoppes et al (1982) [1]
137.65 ± 0.03	Rutledge et al (1980) [2]
137.59 ± 0.04	Lagoutine et al (1978) [3]
137.66 ± 0.05	Vaninbroukx and Grosse (1976) [4]
137.20 ± 0.40	Emery et al (1972) [5]
137.640 ± 0.023	Weighted mean

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Nucl.Sci.Eng. 48 (1972) 319

II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
La K_α	33.03 - 33.44	0.643 ± 0.018
La K_β	37.78 - 38.93	0.154 ± 0.005
La KX	33.03 - 38.93	0.797 ± 0.022

B. CRP measurements

None

C. Other measurements

	E (keV)	Campbell and McNelles (1972) [1][a]	Plch et al. (1971) [2][b]
La KX	33.03 - 38.93	0.807 20	0.795 7

	E (keV)	Debertin and Peßara (1983) [3]
La K_β	37.78 - 38.93	0.159 5

Notes to table C:

[a] Deduced from measurements of the KX/γ emission rates using P_γ = 0.7987 6, evaluated by N. Coursol (this report).

[b] Deduced from measurements of $P_K\omega_K$ and allowing for internal conversion coefficients α_K = 0.215 2 and α = 0.252 1 evaluated by N. Coursol (this report) and the fluorescence yield ω_K = 0.905 1 evaluated by W. Bambynek [4].

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III. GAMMA RAY EMISSION PROBABILITY

Evaluated by N. Coursol (LMRI, Saclay, France)

A. Recommended value

E_γ (keV) [1]	P_γ [a]
165.857 ± 0.006	0.7987 ± 0.0006

Note to table A

a The recommended gamma-ray emission probability is calculated by using the adopted total internal conversion coefficient value and the estimated electron capture branching ratio to the ground level of ^{139}La about 1E-05 from the log ft values of second forbidden transitions, i.e., $P_\gamma = 1/(1 + \alpha)$.

B. CRP measurements

None

C - Other measurements

Total internal conversion coefficient

E_γ (keV)	Experimental values					
	Taylor and Merrit (1962) [2]	Aristov and Bazhenov (1971) [3]	Plch et al. (1975) [4]	Walz et al (1975) [5]	Hansen and Mouchel (1975) [6]	Schönfel and Brus (1977) [7]
166.8	0.2514 11	0.254 6	0.251 2	0.2519 12	0.2520 50	0.2519 6

E_γ (keV)	Transition type	Theoretical values	Evaluated value	Adopted value
166.8	M1	0.267 [a]	0.2518 5 [c]	0.252 1
	E2	0.339 [a]		
	M1 + λ	0.251 [a,b]		

Note to Table C

a Theoretical total internal conversion coefficient interpolated from Rösel et al. Ref.[8] by cubic spline method.

b Calculated value taking into account the nuclear structure effect. The penetration parameter λ = 3.6 (5) employed is a weighted mean of the values 3.1 7, 3.6 18 and 4.2 8 from Plch et al. Ref.[4], Morinaga and Hisatake Ref.[9] and Rysavy et al. Ref. [10] respectively, which supports the assumption of a pure M1 multipolarity for this transition.

c This value was been evaluated from the experimental ICC values listed here.

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I. HALF-LIFE

Recommended value: 4933 ± 11 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
4943.0 ± 4.0[c]	Woods and Lucas (1986) [1]
4792.0 ± 37.0[b]	Baba et al (1983) [2]
4939.0 ± 6.0	Walz et al (1983) [3]
4956.0 ± 42.0	Hoppes et al (1982) [4]
4892.3 ± 8.2	Rutledge et al (1980) [5]
4785.0 ± 19.0[b]	Lagoutine et al (1978) [6]
4821.0 ± 110.0	Emery et al (1972) [7]
4933 ± 11[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[b] These values have been omitted in the calculation of the weighted mean on the basis of statistical considerations.
[c] The uncertainty was increased to 5.0 to ensure that this value did not contribute a weighting of greater than 50%.

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Nucl.Sci.Eng. 48 (1972) 319

II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Sm K_α	39.52 - 40.12	0.591 ± 0.012
Gd K_α	42.31 - 43.00	0.00648 ± 0.00022
Sm K_β	45.38 - 46.82	0.149 ± 0.003
Gd K_β	48.65 - 50.21	0.00176 ± 0.00018
Sm KX	39.52 - 46.82	0.740 ± 0.012
Gd KX	42.31 - 50.21	0.00824 ± 0.00028
Sm + Gd KX	39.52 - 50.21	0.748 ± 0.012

B. CRP measurements

None

C. Other measurements

	E (keV)	Notea and Elias (1970) [1][a]	Faermann et al. (1971) [2][b]
Sm K_α	39.52 - 40.12	0.492 35[c]	0.602 21
Sm K_β	45.38 - 46.82	0.122 9[c]	0.176 7
Sm KX	39.52 - 46.82	0.614 36	0.778 22

	E (keV)	Dasmahapatra (1972) [3][a]	Bylov et al. (1978) [4][d]
Sm K_α	39.52 - 40.12	0.501 16	0.594 9
Gd K_α	42.31 - 43.00	0.0068 2	0.00635 14
Sm K_β	45.38 - 46.82	0.122 8	0.143 8
Gd K_β	48.65 - 50.21	0.00167 50	0.00163 4
Sm KX	39.52 - 46.82	0.623 16	0.737 12
Gd KX	42.31 - 50.21	0.00847 20	0.00798 14
Sm + Gd KX	39.52 - 50.21	0.631 16	0.745 12

	E (keV)	Debertin and Peßara (1979, 1983) [5][e]	Sergienko et al. (1985) [6][d]
Sm K_α	39.52 - 40.12	0.591 12	0.594 9
Gd K_α	42.31 - 43.00	0.00648 22	0.00635 14
Sm K_β	45.38 - 46.82	0.149 3	0.143 8
Gd K_β	48.65 - 50.21	0.00176 18	0.00163 4
Sm KX	39.52 - 46.82	0.740 12	0.737 12
Gd KX	42.31 - 50.21	0.00824 28	0.00798 14
Sm + Gd KX	39.52 - 50.21	0.748 12	0.745 12

	E (keV)	Mehta et al. (1986) [7][f]
Sm K_α	39.52 - 40.12	0.589 9
Gd K_α	42.31 - 43.00	0.00459 11
Sm K_β	45.38 - 46.82	0.144 2
Gd K_β	48.65 - 50.21	0.00171 3
Sm KX	39.52 - 46.82	0.733 9
Gd KX	42.31 - 50.21	0.00630 12
Sm + Gd KX	39.52 - 50.21	0.739 12

Notes to table C:

[a] Deduced from measurements of the KX/γ(344) emission rates, using $P_\gamma(344)$ = 0.2657 11, evaluated by R.G. Helmer (this report).

[b] Deduced from measurements of KX/$K_{\alpha 1}$ emission rates, using $P_{K\alpha 1}$(Sm) = 0.383 12, measured by V.A. Sergienko et al. [6].

[c] Includes both Sm and Gd KX rays.

[d] Deduced from measurements of KX/γ(121) emission rates, using $P_\gamma(121)$ = 0.2837 13, evaluated by R.G. Helmer (this report).

[e] Measured with a calibrated HPGe detector.

[f] Deduced from measurements of KX/γ(1408) emission rates, using $P_\gamma(1408)$ = 0.2085 9, evaluated by R.G. Helmer (this report).

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III Emission Probabilities of Selected Gamma-Rays

Evaluated by R.G. Helmer (INEL, Idaho Falls, Idaho, USA)

A. Recommended Values

E (keV)[a]	P_γ
121.7824 ± 0.0004 [b]	0.2837 ± 0.0013
244.6989 ± 0.0010 [b]	0.0753 ± 0.0004
344.2811 ± 0.0019 [c]	0.2657 ± 0.0011
411.126 ± 0.003	0.02238 ± 0.00010
443.965 ± 0.004 [d]	0.03125 ± 0.00014 [d]
778.903 ± 0.006 [c]	0.1297 ± 0.0006
867.390 ± 0.006	0.04214 ± 0.00025
964.055 ± 0.004 [d]	0.1463 ± 0.0006
1085.842 ± 0.004	0.1013 ± 0.0005
1089.767 ± 0.014	0.01731 ± 0.00009
1112.087 ± 0.006	0.1354 ± 0.0006
1212.970 ± 0.013	0.01412 ± 0.00008
1299.152 ± 0.009	0.01626 ± 0.00011
1408.022 ± 0.004	0.2085 ± 0.0009 [e]

Notes to Table A

[a] From Ref. [1] unless otherwise noted.

[b] From Ref. [2] and based on data from Ref. [3].

[c] From Ref. [4].

[d] Multiplet as noted in Ref. [1].

[e] Determined in ICRM study [10] from ratio of measured gamma-ray emission rate and source activity. Based on the relative gamma-ray emission rates deduced here, the internal-conversion coefficients, and the decay scheme, the total intensity feeding the ground states is 100% if $P_\gamma(1408) = 0.2083(7)$, as shown in the last table of this section.

B. Comparison of measurements

In table B, which follows, relative gamma-ray emission rates are quoted from individually published papers and from an ICRM study [10]. In the latter the data are not related to individual authors, so the data sets can only be identified by the participant number. The participants are listed in Ref. [10].

TABLE B

E_c (keV)	Varnell et.al. 1969 [5]	Riedinger 1970 [6]	Barrette 1971 [7]	Morel 1975 [8]	Gehrke 1977 [9]	Meyer 1978 [4]	ICRM #1 1978 [10]	ICRM #2 1978 [10]	ICRM #4 1978 [10]	ICRM #5 1978 [10]
121	154 (5)[a]	139 (6)	128 (4)	136.2(24)	141 (4)	136.2(16)	135.0(8)[kw1]	135.7(8)	122.9(34)[b]	128.9(26)[kb]
244	38.1(12)	36.3(18)	34.6(10)	35.7(6)	36.6(11)	35.9(6)	35.45(25)[w9]	35.51(25)[lw10]	36.0(9)[b]	35.0(7)[b]
295	2.11(5)	1.95(12)	2.02(14)	2.04(6)	-	2.11(5)	-	-	-	-
344	131.7(4)[a]	130 (7)[m]	123.8(41)[m]	127.5(19)	127.2(13)	127.5(9)	128.9(6)[w16]	127.2(8)	121.9(30)[b]	123.8(19)[b]
367	4.17(12)	4.06(23)	4.00(15)	4.06(14)	4.19(4)	4.05(8)	-	-	-	-
411	10.9(2)	10.4(5)	10.4(4)	10.86(19)	10.71(11)	10.7(1)	10.46(12)[w23]	10.67(7)	9.72(24)[b]	10.04(29)[b]
444	15.2(8)	14.4(9)	13.5(5)[a]	14.86(24)	15.00(15)	14.8(2)	14.68(12)[w32]	14.84(9)	14.06(34)[b]	14.58(34)[b]
488	1.97(6)	1.91(12)	1.88(12)	1.93(11)	1.984(23)	1.95(2)	-	-	-	-
564	2.36(7)	2.41(19)	2.38(19)	2.35(10)	-	2.36(5)	-	-	-	-
586	2.27(7)	2.09(27)	2.20(14)	2.19(11)	2.24(5)	2.20(5)	-	-	-	-
678	2.25(14)	2.07(15)	2.23(14)	2.22(10)	2.296(28)	2.21(4)	-	-	-	-
688	4.00(8)	3.90(22)	3.83(20)	-	4.12(4)[w42]	4.00(8)	-	-	-	-
778	61.5(6)	60.1(30)	60.4(14)	62.8(11)	62.6(6)	62.9(8)	62.44(25)[w44]	62.63(38)	56.2(11)[b]	57.0(9)[b]
867	19.72(23)	19.33(90)	19.40(47)	20.10(29)	20.54(21)	19.9(4)	-	-	-	-
919	1.97(5)	1.89(14)	1.99(24)	1.98(11)	-	2.09(5)	-	-	-	-
964	69.4(14)	67.8(34)	66.8(17)	70.0(11)	70.4(7)	62.2(9)	69.62(42)[w54]	69.82(42)	66.0(12)[b]	65.8(11)[b]
1005	3.04(18)	3.05(31)	3.02(31)	2.85(14)	3.57(7)[a]	3.10(7)	-	-	-	-
1085	48.4(7)	47.9(28)	48.9(15)	49.0(8)	48.7(5)	47.5(7)	48.89(24)[w63]	48.61(29)	45.9(10)[b]	47.0(10)[b]
1089	8.03(28)	8.04(64)	8.17(74)	8.21(43)	8.26(9)	8.2(1)	-	-	-	-
1112	64.8(7)	63.9(32)	62.9(17)	-	65.0(7)	64.9(9)	64.28(32)[w71]	64.45(32)	62.8(11)[b]	63.5(19)[b]
1212	6.76(23)	6.59(35)	6.81(25)	6.71(14)	6.67(7)	6.70(8)	-	-	-	-
1299	7.79(59)	7.74(40)	7.95(40)	7.87(14)	7.76(8)	7.8(1)				
1408	100.0(23)	100 (5)	100.0(26)	100.0(14)	100.0(10)	100.0(3)	100.0(5)[w81]	100.0(5)	100.0(23)[b]	100.00(15)[b]
1457	2.38(12)	2.46(13)	2.38(19)	2.36(7)	2.52(9)	2.36(5)	-	-	-	-
1528	1.64(12)	1.68(9)[a]	1.24(7)	1.29(7)		1.27(3)	-	-	-	-

TABLE B (cont.)

E_c (keV)	ICRM #8 1978 [10]	ICRM #10 1978 [10]	ICRM #11 1978 [10]	ICRM #12 1978 [10]	ICRM #13 1978 [10]	ICRM #14 1978 [10]	ICRM #15 1978 [10]	ICRM #16 1978 [10]	ICRM #17 1978 [10]	ICRM #18 1978 [10]
121	136.4(5)	131.5(22)[kw2]	130.1(20)[h]	135.8(9)	135.6(28)[kc]	141.8(37)[kg]	138.0(17)[ki]	133.4(14)[k]	142.0(43)[e]	139.2(14)[kw3]
244	36.28(22)	36.2(5)[w11]	36.2(7)[h]	35.9(5)	35.6(5)[lc]	38.3(10)[g]	37.3(8)[e]	36.34(32)	36.7(11)	39.22(35)[d]
295	-	-	-	-	-	-	-	-	-	-
344	127.4(6)	123.9(16)[w17]	126.6(25)[h]	127.6(4)	127.6(22)[c]	127.3(32)[g]	127.9(28)[w18]	130.4(12)	127.1(13)	133.4(11)[a]
367	-	-	-	-	-	-	-	-	-	-
411	10.80(6)	10.27(14)[w24]	11.19(22)[h]	10.75(4)	10.69(27)[c]	10.03(26)[g]	10.53(12)[w25]	10.90(12)	10.71(11)	10.90(19)[w26]
444	14.96(7)	14.35(17)[w33]	14.58(35)[h]	15.07(6)	14.86(24)[c]	15.22(40)[g]	14.91(12)[w34]	15.33(18)	14.88(15)	15.30(20)[w35]
488	-	-	-	-	-	-	-	-	-	-
564	-	-	-	-	-	-	-	-	-	-
586	-	-	-	-	-	-	-	-	-	-
678	-	-	-	-	-	-	-	-	-	-
688	-	-	-	-	-	-	-	-	-	-
778	62.25(19)	58.84(41)[a]	59.4(6)[h]	62.12(23)	62.9(9)[c]	58.2(15)[g]	60.59(42)[w45]	62.4(12)	62.6(6)	61.8(5)[w46]
867	-	-	-	-	-	-	-	-	-	-
919	-	-	-	-	-	-	-	-	-	-
964	70.10(23)	67.90(48)[a]	67.7(7)[h]	70.41(22)	70.0(10)[c]	65.8(16)[g]	68.3(5)[w55]	69.8(9)	70.3(7)	69.9(5)[w56]
1005	-	-	-	-	-	-	-	-	-	-
1085	49.13(19)	47.43(38)[w64]	48.4(5)[h]	48.83(14)	49.6(9)[c]	47.2(12)[g]	47.97(43)[w65]	47.9(6)	48.7(5)	48.90(32)[w66]
1089	-	-	-	-	-	-	-	-	-	-
1112	65.25(27)	64.0(5)[w72]	64.6(6)[h]	65.26(20)	64.9(11)[c]	60.5(15)[g]	64.1(6)[w73]	64.7(4)	64.3(6)	66.7(6)[w74]
1212	-	-	-	-	-	-	-	-	-	-
1299	-	-	-	-	-	-	-	-	-	-
1408	100.00(29)	100.0(8)[w82]	100.0(7)	100.0(3)	100.0(20)	100.0(25)	100.0(9)	100.0(9)	100.0(10)	100.0(6)[w83]
1457	-	-	-	-	-	-	-	-	-	-
1528	-	-	-	-	-	-	-	-	-	-

TABLE B (cont.)

Ec (keV)	ICRM #20 1978 [10]	ICRM #25 1978 [10]	ICRM #26 1978 [10]	ICRM #27 1978 [10]	ICRM #28 1978 [10]	ICRM #29 1978 [10]	ICRM #30 1978 [10]	ICRM #31 1978 [10]	ICRM #32 1978 [10]	ICRM #34 1978 [10]
121	137.0(14)[w4]	131.9(14)[ka]	109.4(44)[kb]	136.4(30)[k]	132.5(27)[kw5]	134.8(27)[kw6]	136.8(41)[k]	134.1(20)[kw7]	-	138.9(43)[k]
244	35.70(39)	35.71(44)	25.9(10)[b]	34.1(12)[d]	36.3(6)[w12]	36.4(6)[w13]	37.9(12)	35.2(5)[w14]	50.6(10)[b]	40.3(9)[d]
295	-	-	-	-	-	-	-	-	-	-
344	127.2(10)	126.7(11)	122.4(48)[b]	126.2(34)	128.9(21)[w19]	128.8(18)[w20]	132.7(40)	125.4(18)[w21]	141.6(28)[b]	133.9(55)
367	-	-	-	-	-	-	-	-	-	-
411	10.72(13)[w27]	10.90(32)[w28]	9.74(49)[b]	10.62(67)	10.74(24)[w29]	10.86(15)[w30]	11.21(39)	10.42(17)[w31]	10.31(21)[b]	11.18(53)
444	14.95(18)[w36]	14.73(41)[w37]	13.09(63)[b]	14.64(89)	15.15(27)[w38]	15.22(21)[w39]	14.3(5)[e]	14.74(24)[w40]	14.24(28)[b]	16.15(73)
488	-	-	-	-	-	-	-	-	-	-
564	-	-	-	-	-	-	-	-	-	-
586	-	-	-	-	-	-	-	-	-	-
678	-	-	-	-	-	-	-	-	-	-
688	-	-	-	-	-	-	-	-	-	-
778	61.9(5)[w47]	61.1(8)[w48]	57.4(23)[b]	61.0(10)	62.0(7)[w49]	62.4(6)[w50]	61.2(19)	59.9(8)[w51]	59.2(24)[b]	64.2(20)[w52]
867	-	-	-	-	-	-	-	-	-	-
919	-	-	-	-	-	-	-	-	-	-
964	70.3(5)[w57]	70.9(9)[w58]	63.4(25)[b]	69.3(10)	68.4(8)[w59]	70.1(6)[w60]	69.8(22)	68.7(10)[w61]	67.4(34)[b]	71.2(23)
1005	-	-	-	-	-	-	-	-	-	-
1085	48.4(5)[w67]	-	47.7(19)[b]	48.5(9)	46.9(5)[e]	48.59(44)[w68]	50.7(15)	47.3(7)[w69]	54.2(33)[b]	50.0(11)[w70]
1089	-	-	-	-	-	-	-	-	-	-
1112	64.9(7)[w75]	67.2(8)[w76]	61.2(24)[b]	64.5(11)	65.5(7)[w77]	65.3(6)[w78]	64.7(20)	64.4(10)[w79]	71.2(43)[b]	66.5(15)
1212	-	-	-	-	-	-	-	-	-	-
1299	-	-	-	-	-	-	-	-	-	-
1408	100.0(6)[w84]	100.0(9)[w85]	100.0(6)[b]	100.0(15)	100.0(21)[w86]	100.0(9)[w87]	100.0(30)	100.0(4)[w88]	100.0(70)[b]	100.0(28)[w89]
1457	-	-	-	-	-	-	-	-	-	-
1528	-	-	-	-	-	-	-	-	-	-

TABLE B (cont.)

Ec (keV)	ICRM #35 1978 [10]	ICRM #36 1978 [10]	Iwata 1984 [11]	Wang 1984 [12]	Mehta 1986 [13]	Average All Data Value	Average All Data v_R^2	Average Final Data Value	Average Final Data v_R^2
121	133.1(9)[kw8]	141.6(21)[kb]	136.9(13)	134.5(38)	136.7(7)	135.6(5)	4.12	136.07(27)	0.84
244	36.14(16)[w15]	37.4(6)[b]	36.16(25)	34.8(11)	36.53(42)	36.21(27)	13.6	36.10(9)	1.06
295	-	-	2.13(4)	2.11(6)	2.22(4)	-	-	2.127(24)	1.51
344	126.4(5)[w22]	129.2(22)[b]	127.1(7)	126.3(40)[m]	126.9(9)	128.3(4)	5.30	127.44(21)	0.73
367	-	-	4.13(4)	3.96(14)	4.14(7)	-	-	4.136(23)	0.74
411	10.57(8)	10.67(19)[b]	10.84(7)	10.63(15)	10.73(10)	10.70(3)	2.38	10.735(21)	1.06
444	14.81(7)[w41]	14.85(27)[b]	15.01(11)	14.85(19)	14.81(13)	14.90(4)	2.23	14.99(3)	1.30
488	-	-	2.031(15)	2.03(13)	-	-	-	1.995(15)	1.87
564	-	-	2.43(4)	2.25(3)	-	-	-	2.33(3)	2.36
586	-	-	2.19(8)	2.10(8)	-	-	-	2.207(26)	0.47
678	-	-	2.28(5)	2.31(25)	-	-	-	2.264(20)	0.74
688			4.20(4)[w43]	3.88(15)	-	4.11(4)	2.35	4.08(4)	1.74
778	62.0(3)[w53]	62.3(10)[b]	62.16(22)	62.0(13)	62.14(46)	61.84(19)	5.39	62.19(9)	0.60
867	-	-	20.33(10)	19.95(19)	20.36(17)	-	-	20.21(9)	1.97
919	-	-	2.08(6)	-	-	-	-	2.032(28)	0.96
964	69.9(4)[w62]	70.9(11)[b]	70.14(23)	69.4(8)	71.03(40)	69.85(16)	3.10	70.17(10)	0.76
1005	-	-	3.078(24)	3.40(8)[a]		3.14(6)	8.6	3.074(22)	0.56
1085	45.2(9)[d]	48.9(7)[b]	48.15(16)	45.73(60)[a]	47.84(31)	48.48(12)	3.42	48.59(10)	1.83
1089	-	-	8.35(4)	-	8.19(10)	-	-	8.30(3)	0.73
1112	64.2(6)[w80]	65.4(10)[b]	64.67(21)	64.0(9)	65.4(8)	64.84(12)	1.81	64.96(10)	1.21
1212	-	-	6.85(5)	6.88(14)	-	-	-	6.77(3)	0.92
1299	-	-	7.80(5)	7.79(	-	-	-	7.80(4)	0.09
1408	100.0(8)[w90]	100.0(22)[b]	100.0(3)	100.0(5)	100.0(6)	100.0	-	100.00(12)	-
1457	-	-	2.391(29)	2.32(23)	-	-	-	2.390(22)	0.43
1528	-	-	1.346(13)	1.45(5)	-	1.344(26)	5.6	1.339(22)	3.86

Footnotes to Table B

[a]Line dropped by this evaluator due to large deviation from mean.

[b]All values from this participant dropped in ICRM study [10] because mean deviation of these values from mean values is ≥3.0%.

[c]All values from this participant dropped in ICRM study [10] because detector was calibrated with a ^{152}Eu source.

[d]Individual line dropped in ICRM study [10] because deviation from mean was >5%.

[e]Individual line dropped in ICRM study [10].

[f]Line dropped by this evaluator due to large uncertainty.

[g]All data from this ICRM participant dropped by this evaluator because five of the ten lines were dropped in the ICRM study [10].

[h]All data from this ICRM participant dropped by this evaluator because several detector efficiency values were adjusted in the ICRM study [10].

[i]Individual line dropped by this evaluator since the revised value from ICRM study [10] would result in a large deviation from the mean.

[j]Individual line dropped by this evaluator due to large deviation from the mean.

[k]Originally quoted as emission rate for doublet and converted to singlet value by dividing by 1.005 [10].

[l]Originally quoted as emission rate for doublet and converted to singlet value in ICRM study [10].

[m]Originally quoted as reference line without an uncertainty. Evaluator assigned uncertainty that is typical of other strong lines.

[w1] Uncertainty increased [10], final value 135.0(19).

[w2] Uncertainty increased [10], final value 131.5(43).

[w3] Uncertainty increased [10], final value 139.2(29).

[w4] Uncertainty decreased [10], final value 137.0(10).

[w5] Uncertainty increased [10], final value 132.5(29).

[w6] Uncertainty decreased [10], final value 134.8(20).

[w7] Value modified [10], final value 135.5(20).

[w8] Value modified [10], final value 134.9(12).

[w9] Uncertainty increased [10], final value 35.45(52).

[w10]Uncertainty increased [10], final value 35.51(32).

[w11]Uncertainty increased [10], final value 36.2(10).

[w12]Uncertainty increased [10], final value 36.3(7).

[w13]Uncertainty decreased [10], final value 36.4(4).

[w14]Value modified [10], final value 35.6(5).

[w15]Value modified [10], final value 36.37(20).

[w16]Uncertainty increased [10], final value 128.9(15).

[w17]Uncertainty increased [10], final value 123.9(28).

[w18]Value modified [10], final value 130.6(29).

[w19]Uncertainty increased [10], final value 128.9(24).

[w20]Uncertainty decreased [10], final value 128.8(13).

[w21]Value modified [10], final value 126.6(13).

[w22]Uncertainty increased [10], final value 126.4(9).

[w23]Uncertainty increased [10], final value 10.46(16).

[w24]Uncertainty increased [10], final value 10.27(22).

[w25]Value modified [10], final value 10.77(12).

[w26]Uncertainty increased [10], final value 10.90(23).

[w27]Uncertainty decreased [10], final value 10.72(10).

[w28]Uncertainty increased [10], final value 10.90(33).

[w29]Value modified [10], final value 10.72(26)

[w30]Uncertainty decreased [10], final value 10.86(12).

[w31]Value modified [10], final value 10.52(14).

[w32]Uncertainty increased [10], final value 14.68(21).

[w33]Uncertainty increased [10], final value 14.35(40).

[w34]Value modified [10], final value 15.25(12).

[w35]Uncertainty increased [10], final value 15.30(26).

[w36]Uncertainty decreased [10], final value 14.95(13).

[w37]Uncertainty increased [10], final value 14.73(43).

[w38]Uncertainty increased [10], final value 15.15(32).

[w39]Uncertainty decreased [10], final value 15.22(15).

[w40]Value modified [10], final value 14.89(19).

[w41]Uncertainty increased [10], final value 14.81(16).

[w42]Uncertainty increased [10], final value 4.12(6).

[w43]Uncertainty increased [10], final value 4.20(6).

[w44]Uncertainty increased [10], final value 62.44(75).

[w45]Value modified [10], final value 62.6(4).

[w46]Uncertainty increased [10], final value 61.8(12).

[w47]Uncertainty decreased [10], final value 61.9(4).

[w48]Uncertainty increased [10], final value 61.1(9).

[w49]Uncertainty increased [10], final value 62.0(10).

[w50]Uncertainty decreased [10], final value 62.4(5).

[w51]Value modified [10], final value 61.3(7)

[w52]Uncertainty increased [10], final value 64.2(21).

[w53]Uncertainty increased [10], final value 62.0(5).

[w54] Uncertainty increased [10], final value 69.62(84).

[w55]Value modified [10], final value 70.4(6).

[w56]Uncertainty increased [10], final value 69.9(10).

[w57]Uncertainty decreased [10], final value 70.3(4).

[w58] Uncertainty increased [10], final value 70.9(10).

[w59]Uncertainty increased [10], final value 68.4(11).

[w60]Uncertainty decreased [10], final value 70.1(5).

[w61]Value modified [10], final value 70.0(8).

[w62]Uncertainty increased [10], final value 69.9(5).

[w63]Uncertainty increased [10], final value 48.89(59).

[w64]Uncertainty increased [10], final value 47.4(6).

[w65]Value modified [10], final value 49.1(4).

[w66]Uncertainty increased [10], final value 48.9(5).

[w67]Uncertainty decreased [10], final value 48.4(3).

[w68]Uncertainty decreased [10], final value 48.59(30).

[w69]Value modified [10], final value 48.0(5).

[w70]Uncertainty increased [10], final value 50.0(12).

[w71]Uncertainty increased [10], final value 64.28(77).

[w72]Uncertainty increased [10], final value 64.0(8).

[w73]Value modified [10], final value 65.7(7).

[w74]Uncertainty increased [10], final value 66.7(8)

[w75]Uncertainty decreased [10], final value 64.9(5).

[w76]Uncertainty increased [10], final value 67.2(9).

[w77]Uncertainty increased [10], final value 65.5(10).

[w78]Uncertainty decreased [10], final value 65.3(5).

[w79]Value modified [10], final value 65.4(8).

[w80]Uncertainty increased [10], final value 64.2(7).

[w81]Uncertainty increased [10], final value 100.0(12).

[w82]Uncertainty increased [10], final value 100.0(15).

[w83]Uncertainty increased [10], final value 100.0(12).

[w84]Uncertainty decreased [10], final value 100.0(5).

[w85]Uncertainty increased [10], final value 100.0(12).

[w86]Uncertainty increased [10], final value 100.0(23).

[w87]Uncertainty decreased [10], final value 100 0(7).

[w88]Uncertainty increased [10], final value 100.0(10).

[w89]Uncertainty increased [10], final value 100.0(29).

[w90]Uncertainty increased [10], final value 100.0(12)

Table of data for gamma-ray transitions to the daughter ground states.

Daughter nuclide	E_γ	Relative emission rate	α	Transition rate
^{152}Gd	344.2	127.44(21)	0.0399	132.5(2)
	615.4		E0	0.046(3)
	930.5	0.35(1)		0.35(1)
	1109.1	0.88(2)		0.88(2)
	1605.6	0.036(3)		0.036(3)
^{152}Sm	121.7	136.07(27)	1.167(12)[b]	294.9(17)[b]
	810.4	1.52(2)	0.0040	1.53(2)
	964.1	0.65(2)[a]	0.0011	0.65(2)
	1085.9	48.59(10)	0.0021	48.69(10)
	1292.7	0.49(3)		0.49(3)
	1769.0	0.042(3)		0.042(3)
	Total transition rate to ^{152}Gd ground state			133.8(2)
	Total transition rate to ^{152}Sm ground state			346.3(17)[b]
	Total transition rate to both ground states			480.1(17)[b]
	P_γ (1408)		20.83(7)%[b]	

[a]Decomposition of the measured relative rate for the 964-keV peak was based on the relative rates of these two γ rays from Ref. 14.

[b]An uncertainty of 1% has been assigned to α(121). If the commonly used value of 3% is used, the uncertainties of the related quantities will increase by a factor of about 2.8.

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I. HALF-LIFE

Recommended value: 3136.8 ± 2.9 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
3138.0 ± 2.0[c]	Woods and Lucas (1986) [1]
3136.0 ± 4.0	Walz et al (1983) [2]
3101.0 ± 41.0	Hoppes et al (1982) [3]
3105.0 ± 183.0[b]	Emery et al (1972) [4]
3136.8 ± 2.9	Weighted mean

Notes to Table

[b] This value has been omitted in the calculation of the weighted mean on the basis of statistical considerations.
[c] The uncertainty was increased to 4.0 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}[a]
Gd K_α	42.31 - 43.00	0.205 ± 0.006
Gd K_β	48.65 - 50.21	0.051 ± 0.002
Gd KX	42.31 - 50.21	0.256 ± 0.006

Note to table A:
[a] Contribution of 0.02 % decay by electron capture to Sm has been neglected.

B. CRP measurements

None

C. Other measurements

None

III. GAMMA RAY EMISSION PROBABILITIES

Evaluated by Y. Yoshizawa and K. Shizuma (Hiroshima University)

A. Recommended values

E_γ (keV) [3]	P_γ
123.071 ± 0.001	0.412 ± 0.005
247.930 ± 0.001	0.0695 ± 0.0009
591.762 ± 0.005	0.0499 ± 0.0006
692.425 ± 0.004	0.0180 ± 0.0003
723.305 ± 0.005	0.202 ± 0.002
756.804 ± 0.005	0.0458 ± 0.0006
873.190 ± 0.005	0.1224 ± 0.0015
996.262 ± 0.006	0.1048 ± 0.0013
1004.725 ± 0.007	0.182 ± 0.002
1274.436 ± 0.006	0.350 ± 0.004
1494.048 ± 0.009	0.0071 ± 0.0002
1596.495 ± 0.018	0.0181 ± 0.0002

B. CRP measurements

E_γ (keV)	Iwata et al. (1984)[1]	Schima (1989)[2]	Helmer (1989)[3]	Evaluated values [a]
123.1	118.5 12	117.0 9	116.5 12	117.7 9
248.0	19.91 19	19.82 12	19.8 2	19.87 12
401.3	0.49 4		0.543 6	0.51 3
444.5	1.63 3		1.600 15	1.62 2
478.3	0.626 27		0.644 6	0.63 2
557.6	0.758 24		0.778 11	0.76 2
582.0	2.61 3		2.543 21	2.59 4
591.8	14.35 6	14.19 8	14.21 11	14.26 10
625.3	0.925 21			0.924 20
676.6	0.47 5			0.47 5
692.4	5.182 25		5.09 4	5.14 5
723.3	58.19 21	57.6 3	57.3 4	57.76 43
756.8	13.18 7		12.9 11	13.10 11
815.6	1.51 5		1.455 14	1.49 3
845.4	1.687 21		1.737 20	1.70 3
850.7	0.692 23			0.69 2
873.2	35.18 12	34.95 25	34.81 28	35.0 2
892.8	1.497 26			1.491 25
904.1	2.62 3		2.537 22	2.59 4
996.3	30.09 12	29.9 3	29.78 23	29.96 14
1004.7	52.04 19	51.9 4	51.55 40	51.88 17
1128.6	0.90 4		0.952 15	0.92 3
1140.7	0.671 14		0.671 8	0.672 10
1241.4	0.38 5			0.38 5
1246.2	2.49 4		2.449 23	2.47 3
1274.4	100.0 3	100.0 5	100.0	100.0 2
1494.0	2.058 16		1.979 16	2.032 36
1596.5	5.247 26	5.08 4	5.078 40	5.165 18

Note to Table

a These values are the weighted averages of the measurements by Ronney and Seale, Sharma et al., Iwata et al., Schima and Helmer. The emission probability of the 1274 keV gamma ray was calculated to be 0.350+0.004, assuming that the total intensity sum of the transitions to and through the first excited states is 100 %. *The average values of Meyer and Sharma et al. were adopted for* weak gamma rays (<0.1 %). The experimental value of the beta decay branch to the first excited state of ^{154}Gd was adopted. The electron capture branches to the first and the second excited states of the ^{154}Gd are estimated to be 0.02 % and 0.01 % by using the log ft values. Multipole mixing ratios are taken from the angular correlation measuremnt [4] and the internal conversion measurement [5]. Theoretical values were adopted for the internal conversion coefficient. The E0 transitions of 680 keV and the K-shell internal conversion coeffcient of the 692 keV gamma ray were measured by Yamada et al [5]. The electron emission probability of 680 keV and the total conversion coefficient were 0.034 % and 46.7x10^{-3}, respectively, from their measurement.

C. Comparison with other merasurements

Gamma ray data

E_γ (keV)	Meyer (1968)[6]	Riedinger et al. (1970)[7]	Roney,Seale (1980)[8]	Sharma et al. 1980[9]
123.1	114.1 20	116 6		115.39 226
248.0	19.7 3	20.1 10	20.51 20	19.34 37
401.3	*0.592 18*	*0.58 10*		*0.57 8*
444.5	1.58 3	1.69 15	1.53 6	1.54 3
478.3	0.606 18	0.69 15		0.63 10
557.6	0.73 3	0.74 10		0.72 10
582.0	2.51 3	2.53 23	2.86 11	2.45 5
591.8	*14.14 14*	*14.8 8*	*13.62 24*	*13.57 26*
625.3	0.879 26	0.89 12		0.84 5
676.6	0.394 12	0.43 11		0.52 10
692.4	5.10 8	4.97 30	4.86 8	4.92 10
723.3	57.2 6	60.1 31	55.40 41	55.33 106
756.8	*12.99 14*	*12.9 6*	*12.51 11*	*12.62 24*
815.6	1.44 3	1.38 18	1.45 8	1.47 10
845.4	1.66 3	1.60 22		1.58 10
850.7	0.684 19	0.60 13		0.67 8
873.2	34.6 3	34.8 17	33.6 25	34.47 70
892.8	*1.49 3*	*1.3110*	*1.38 12*	*1.43 3*
904.1	2.54 6	2.42 17	2.47 8	2.49 5
924.6	0.166 25	0.19 10		0.18 10
996.3	30.1 3	29.4 15	29.7 21	30.30 65
1004.7	51.8 6	50.6 25	50.93 32	51.4 103
1118.5	0.296 25	0.30 8		0.37 10
1128.6	0.89 3	0.79 9		0.94 8
1140.7	0.65 3	0.69 10		0.73 8
1241.4	0.366 17	0.30 7		0.40 5
1246.2	2.48 3	2.40 22	2.35 5	2.48 10
1274.4	100.0 3	100	100.0	100.0
1290.5	0.037 8			
1295.5	0.025 3			0.026 3
1408.5	0.059 8			0.082 1
1415.0	0.0113 28			0.004
1418.5	0.0208 28	0.027 16		0.039
1494.0	1.99 3	1.88 9	2.10 4	1.91 8
1531.4	0.0172 11	0.009 5		0.018 5
1537.8	0.155 6	0.15 2		0.15 1
1596.5	5.13 8	5.15 26	5.19 8	4.81 10
1667.3	0.0056(8)			
1673.6	0.0039 11			0.005 1
1716.9	0.0017 11			
1838.0	0.0023 6			

Theoretical internal conversion coefficients

E (keV)	Internal conversion coefficient $\alpha \times 10^3$ E1	E2	M1	Mixing ratio δ (E2/M1)	Adopted conversion coefficient $\alpha \times 10^3$
248.0		110			110
557.6		10.7			10.7
692.4		6.25	11.5	$7.7^{+1.3}_{-1.1}$	46.7*
815.6		4.29			4.29
873.2		3.70	6.54	$-9.5^{+0.6}_{-0.8}$	3.74*
924.4		3.33			3.33
996.3		2.79			2.78
1004.7		2.74	4.66	$-7.8^{+0.3}_{-0.2}$	2.77
1118.5	0.93				0.93
1128.6	0.91				0.91
1140.7		2.10			2.10
1241.4	0.77				0.77
1274.4	0.73				0.73
1292.5	0.72				0.72
1295.5		1.63			1.63
1408.5		1.39			1.39
1415.0		1.38			1.38
1418.5		1.38			1.38
1494.0	0.56				0.56
1531.4		1.18			1.18
1537.8		1.17			1.17
1596.5	0.50				0.50
1667.3		1.03			1.03
1673.6	0.46				0.46
1716.9		0.95			0.95
1838.0		0.92			0.92

* E0+M1+E2, experimental value.

Experimental values of beta-ray intensity to the first excited state of ^{154}Gd.

Maximum energy (keV)	Beta-ray intensity (%) Hansen et al. (1966)[10]	Ng et al. (1968)[11]	Average value
1866	9.2± 1.5	10.8± 1.2	10.0± 1.0

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I. HALF-LIFE

Recommended value: $1.77 \times 10^3 \pm 0.05 \times 10^3$ d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
1737.0 ± 23.0	Walz et al (1983) [1]
1728.0 ± 8.0	Hoppes et al (1982) [2]
1812.0 ± 4.0[c]	Emery et al (1972) [3]
1698.0 ± 74.0	Mowatt (1970) [4]
1768 ± 44[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[c] The uncertainty was increased to 8.0 to ensure that this value did not contribute a weighting of greater than 50%.

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II Gamma-ray emission probability

No gamma-ray emission probabilities were recommended for Eu-155. The half-life was included in these studies because this nuclide is widely used as a secondary gamma-ray standard in circumstances when neither the activity nor the gamma-ray emission probabilities are required.

I. HALF-LIFE

Recommended value: 2.6943 ± 0.0008 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
2.6950 ± 0.0020	Hoppes et al (1982) [1]
2.6935 ± 0.0004[c]	Rutledge et al (1980) [2]
2.6930 ± 0.0030	Debertin (1971) [3]
2.6946 ± 0.0010	Cabell and Wilkins (1970) [4]
2.6960 ± 0.0040	Costa Paiva and Martinho (1970) [5]
2.6950 ± 0.0020	Vuorinen and Kaloinen (1969) [6]
2.6950 ± 0.0070	Goodier (1968) [7]
2.6970 ± 0.0020	Lagoutine et al (1968) [8]
2.6930 ± 0.0050	Reynolds et al (1968) [9]
2.6943 ± 0.0008[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[c] The uncertainty was increased to 0.0008 to ensure that this value did not contribute a weighting of greater than 50%.

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Nucl.Sci.Eng. 32 (1968) 46

II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}[a]
Hg K_α	68.89 - 70.82	0.0219 ± 0.0008
Hg K_β	80.12 - 82.78	0.0061 ± 0.0003
Hg KX	68.89 - 82.78	0.0280 ± 0.0010

Note to table A:
[a] The conversion coefficients of F. Lagoutine et al [1] have been used.

B. CRP measurements

None

C. Other measurements

None

REFERENCE

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III GAMMA-RAY EMISSION PROBABILITY

Evaluated by A L Nichols (AEA Technology, Winfrith, UK), December 1987.

A **Recommended Value**

E_γ (keV)	P_γ
411.8044 ± 0.0011	0.9557 ± 0.0047

B **CRP Measurements**

None

C **Other Measurements**

E_γ (keV)	Elliott et al (1954) Ref 1	Keeler and Connor (1965) Ref 2 [a]	Bosch and Szichman (1967) Ref 3 [a]	Iwata and Yoshizawa (1980) Ref 4 [a]
411.804	-	100	100	100.0(4)
675.887	0.00820(56)	1.0	0.75	0.841(3)
1087.691	0.00163(12)	0.28	0.15	0.1664(21)

[a] Relative gamma-ray emission probabilities; Elliott et al (1954), Ref 1 measured the small β branch to the Hg-198 ground state to be 0.00025(5), and this value was used in conjunction with the theoretical internal conversion coefficients of Rosel et al (1978), Ref 9 to derive the absolute gamma-ray emission probabilities.

Internal Conversion Coefficients

E_γ (keV)	Transition Type	ICC	Kel'man and Metskhvarishvili (1959) Ref 5	Bergkvist and Hultberg (1965) Ref 6	Keeler and Connor (1965) Ref 2	Bosch and Szichman (1967) Ref 3
411.8044	E2	K	-	0.0302(4)	0.0299(4)	0.0302(4)
		L	-	-	0.0145(3)	-
		M	-	-	-	-
		K/L	2.69(2)	-	-	-
		K/LMN	-	-	-	2.08(6)
		$L_1/L_2/L_3$	1/1.05(2)/0.45(1)	-	-	-
		L/M/N/O	1/0.252(5)/0.077(4)/0.018(2)	-	-	-

ICC	Nagarajan et al (1972) Ref 7	El-Nesr and Mousa (1973) Ref 8
K	0.0301(3)	0.03035(45)
L	-	-
M	-	-
K/L	-	-
K/LMN	-	-
$L_1/L_2/L_3$	-	-
L/M/N/O	-	-

E_γ (keV)	Transition Type	Internal Conversion Coefficients					
		theoretical, Rosel et al (1978) Ref 9				evaluated, Hansen (1985) Ref 10	
		α_K	α_L	α_{M+}	α_{tot}	α_K	α_{tot}
411.8044	E2	0.0302(3)	0.0107(1)	0.0035(1)	0.0444(9)	0.0301(2)	0.044(2)

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I. HALF-LIFE

Recommended value: 46.595 ± 0.013 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
46.612 ± 0.019	Walz et al (1983) [1]
46.620 ± 0.030	Hoppes et al (1982) [2]
46.582 ± 0.002[c]	Houtermans et al (1980) [3]
46.600 ± 0.010	Rutledge et al (1980) [4]
46.760 ± 0.080	Emery et al (1972) [5]
47.000 ± 0.100[b]	Lagoutine et al (1968) [6]
46.595 ± 0.013[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[b] This value has been omitted in the calculation of the weighted mean on the basis of statistical considerations.
[c] The uncertainty was increased to 0.009 to ensure that this value did not contribute a weighting of greater than 50%.

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Int.J.Appl.Radiat.Isotopes 19 (1968) 475

II EMISSION PROBABILITIES OF X RAYS

Evaluated by W Bambynek (CBNM Geel Belgium)

A. Recommended values

	E (keV)	P_{KX}
Tl LX	8 95 14 40	0 060 ± 0 012
Tl $K_{\alpha 2}$	70 83	0 038 ± 0 002
Tl $K_{\alpha 1}$	72 87	0 064 ± 0 002
Tl $K_{\beta 1}$	82 43	0 022 ± 0 001
Tl $K_{\beta 2}$	85 19	0 0063 ± 0 0003
Tl KX	70 83 85 19	0 130 ± 0 004

B CRP measurements

None

C Other measurements

	E (keV)	Hansen et al (1970 1972) [1,2][a]		Schmidt Ott et al (1972) [3][a]	
Tl $K_{\alpha 2}$	70 83	0 037	2	0 0377	12
Tl $K_{\alpha 1}$	72 87	0 064	2	0 064	2
Tl $K_{\beta 1}$	82 43	0 023	1	0 0220	8
Tl $K_{\beta 2}$	85 19	0 006	4	0 0065	3
Tl KX	70 83 85 19	0 130	5	0 130	2

	E (keV)	Sergienko et al (1985) [5]		Mehta et al (1987) [6][b]	
Tl LX	8 95 14 40	0 0569	16	0 0624	15
Tl $K_{\alpha 2}$	70 83	0 0380	12	0 0382	6
Tl $K_{\alpha 1}$	72 87	0 0616	18	0 0645	10
Tl $K_{\beta 1}$	82 43	0 0213	61	0 0221	5
Tl $K_{\beta 2}$	85 19	0 0059	13	0 0063	1
Tl KX	70 83 85 19	0 127	2	0 131	1

Notes to table C

a Deduced from measurement of the KX/$K_{\alpha 1}$ emission rates, using $P_{K\alpha 1}$ = 0 064 2 evaluated by N Coursol (1982) [4]

b Deduced from measurements of the KX/γ(279) emission rates, using $P_{\gamma}(279)$ = 0 8148 8 evaluated by R G Helmer (this report)

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III. EMISSION PROBABILITIES OF SELECTED GAMMA-RAYS

Evaluated by R.G. Helmer (INEL, Idaho Falls, Idaho, USA)

A. Recommended Value

E (keV)	P_γ
279.1967 ± 0.0012 [a]	0.8148 ± 0.0008 [b]

Notes for Table A

[a] From Ref. [1] and based on data from Refs. [2,3]

[b] Computed as 0.9999(1)/(1+α). The uncertainty is from the 0.10% uncertainty in (1+α).

Table of data for possible beta-decay branch to $1/2^+$ ground state from $5/2^-$ parent.

	Raman and Gove (1973) [4]	Marty (1955) [5]	Wolfson (1956) [6]	This work
Log ft from systematic	>8.5			
Deduced P_β	<0.10			
Measured P_β		<0.000 04	< 0.000 3	
Deduced log ft		>12	>11.1	
Adopted P_β				0.000 1(1)

Table of internal-conversion data for 279-keV gamma ray which has M1+E2 character.

		Hansen (1985) [7]	Rösel et al [b] (1978) [8]	This work
Evaluation of measured data [a]				
	α_K	0.1640(10)		
	α	0.2271(12)		
M1 contribution deduced from Hansen [7] values				
	from α_K			24%
	from α			26%
Theoretical ICC for 25% M1				
	α_K		0.1605	
	α		0.2305(39)	
Adopted	α			0.2271(12)

Notes for table

[a] From 30 values of α_K and 6 of α, Hansen used 9 of α_K and 3 of α to determine these values.

[b] Uncertainties of 1% for the E2 contribution and 3% for the M1 contribution were assigned by N. Coursol of LMRI who provided the interpolated values.

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I. HALF-LIFE

Recommended value: $1.16 \times 10^{4} \pm 0.07 \times 10^{4}$ d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
11772 ± 329	Hoppes et al (1982) [1]
13405 ± 520	Yanokura et al (1978) [2]
13880 ± 1461	Rupnik (1972) [3]
13880 ± 1096	Appelman (1961) [4]
10227 ± 1096	Sosniak and Bell (1959) [5]
11031 ± 183[c]	*Harbottle (1959) [6]*
11651 ± 620[a]	*Weighted mean*

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.
[c] The uncertainty was increased to 258 to ensure that this value did not contribute a weighting of greater than 50%.

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II EMISSION PROBABILITIES OF X RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

	E (keV)	P_{KX}
Pb LX	9.19 - 14.91	0.325 ± 0.013
Pb $K_{\alpha 2}$	72.80	0.226 ± 0.012
Pb $K_{\alpha 1}$	74.97	0.382 ± 0.020
Pb $K_{\beta' 1}$	84.79	0.130 ± 0.010
Pb $K_{\beta' 2}$	87.63	0.039 ± 0.003
Pb KX	72.80 - 87.63	0.777 ± 0.026

B. CRP measurements

None

C. Other measurements

	E (keV)	Venugopala Rao et al. (1969) [1][a]	Venugopala Rao et al. (1971) [2]
Pb LX	9.19 - 14.91	0.342 20	0.364 36
Pb KX	72.80 - 87.63	0.777 40	-

	E (keV)	Faermann et al. (1971) [3][b]	Hansen et al. (1970, 1972) [4,5][b]
Pb $K_{\alpha 2}$	72.80	0.220 24	0.225 16
Pb $K_{\alpha 1}$	74.97	0.382 20	0.382 20
Pb $K_{\beta' 1}$	84.79	0.124 7	0.138 10
Pb $K_{\beta' 2}$	87.63	0.033 4	0.039 3
Pb KX	72.80 - 87.63	0.759 26	0.784 28

Notes to table C:

[a] Deduced from measurement of the KX/γ(569) emission rates, using $P_\gamma(569) = 0.9974\,3$, evaluated by Y. Yoshizawa et al. (this report).

[b] Deduced from measurements of the KX/$K_{\alpha 1}$ emission rates, using $P_{K\alpha 1} = 0.382\,20$, evaluated by Yu.V. Kholnov et al. [6].

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III GAMMA RAY EMISSION PROBABILITIES

Evaluated by Y Yoshizawa and K Shizuma (Hiroshima University)

A Recommended Values

E_γ (keV) [1]	P_γ
569 702 + 0 002	0 9774 + 0 0003
1063 662 ± 0 004	0 745 ± 0 002
1770 237 + 0 009	0 0687 ± 0 0004

B CRP measurements

E_γ (keV)	Yoshizawa et al (1980) [2]	Schima (1989) [3]	Debertin Schotzig (1989) [4]	Helmer (1989) [5]	Evaluated values [a]
328 1		0 0045(36)			
569 7	100 0(4)	100 00(49)	100 0(5)	100 00(10)	100 0(2)
897 7	0 122(13)	0 1274(52)			0 124(8)
1063 7	75 79(25)	76 584(367)	76 5(5)	76 4(5)	76 2(2)
1442 1	0 132(5)	0 1337(26)			0 133(3)
1770 2	7 026(29)	7 023(68)			7 03(3)

Note to Table

[a] These values are the weighted averages of the CRP measurements Other measurements shown in Table C are not adopted, because the experimental uncertainties are large except [11] and ambiguities are in calibrations The emission probability of the 569 keV gamma ray was calculated by the normalization of the 569 keV and the 897 keV transitions feeding to the ground state The experimental conversion coefficient 0 0219+0 0003 [6] was adopted for the 569 keV transition The electron capture transition to the ground state was neglected because of the 4th forbidden transition

C Comparison with other measurements

E_γ (keV)	Donnelly et al (1967)[7]	Aubin et al (1969)[8]	Hedin Backlin (1969)[9]	Rao et al (1969)[10]	Willet Emery (1973)[11]	Jardine (1975)[12]
569 7	100	100	100	100	100	100
897 3				0 150(15)		0 14(2)
1063 7	78 4(24)	78 0(6)	74 0(25)	78 7(40)	77 70(45)	75 5(23)
1442 2				0 150(15)		0 15(2)
1770 2	7 07(35)	7 1(2)		7 5(4)		6 95(20)

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I. HALF-LIFE

Recommended value: 698.2 ± 0.6 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
698.76 ± 0.32[c]	Jordan et al (1971) [1]
702.7 ± 7.3	Mays et al (1962) [2]
696.9 ± 1.5	Mays et al (1962) [2]
697.8 ± 0.7	Kirby et al (1956) [3]
698.2 ± 0.6[a]	Weighted mean

Notes to Table

[a] Uncertainty increased to include lowest uncertainty value.

[c] The uncertainty was increased to 0.64 to ensure that this value did not contribute a weighting of greater than 50%.

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II - EMISSION PROBABILITIES OF SELECTED GAMMA RAYS

Evaluated by N. Coursol (LMRI, Saclay,France)

A - Recommended values

Decay	E (keV)[a]	P[d]
228Th -> 224Ra	84.373 ± 0.003[b]	0.0122 ± 0.0002
212Pb -> 212Bi	238.632 ± 0.002	0.435 ± 0.004
224Ra -> 220Rn	240.987 ± 0.006[b]	0.0410 ± 0.0005
208Tl -> 208Pb	277.358 ± 0.010[b]	0.0230 ± 0.0003
212Pb -> 212Bi	300.094 ± 0.010[b]	0.0325 ± 0.0003
208Tl -> 208Pb	510.77 ± 0.10[c]	0.0818 ± 0.0010
208Tl -> 208Pb	583.191 ± 0.002	0.306 ± 0.002
212Bi -> 212Po	727.330 ± 0.009	0.0669 ± 0.0009
208Tl -> 208Pb	860.564 ± 0.005	0.0450 ± 0.0004
212Bi -> 212Po	1620.735 ± 0.010	0.0149 ± 0.0005
208Tl -> 208Pb	2614.533 ± 0.013	0.3586 ± 0.0006

Notes to Table A

a Gamma-ray energy values from R.G. Helmer (Nucl. Instr. Meth. 164 (1979) 355), except for those values marked by superscripts b and c.

b Gamma-ray energy values from W. Kurcewicz et al. (Nucl. Instr. Meth. 146 (1977) 613)

c Gamma-ray energy value from M. Kortelahti et al. (Nucl. Phys.A240 (1975) 87) updated by this evaluator (to relate to the Au198 gamma-ray energy value 411.80441(108) keV, Kessler et al. in Phys. Rev. Lett. 40 (1978) 171)

d Gamma-ray emission probabilities per decay of 228Th in radioactive equilibrium with its daughter products.

B - CRP measurements

None

C - Comparison with other measurements

E_γ (keV)	P_γ per 228Th decay: Schupp et al. (1960) [1]	Dalmasso et Marsol (1968) [2]	Péghaire (1969) [3]	Larsen et Jorgensen (1969) [4] [a]	Aubin et al. (1969) [5] [b]	Kortelahti et al. (1975) [6
4.373	/	/	0.0121 6	/	/	/
238.632	/	/	/	/	/	/
240.987	/	/	0.0395 13	/	/	/
277.356	/	/	/	0.0248 18	/	0.0244 1
300.094	/	/	/	/	/	/
510.77	/	/	/	0.083 4	/	0.078 3
583.191	/	/	/	/	0.307 6	0.308 11
727.331	0.0711 45	0.072 8	/	/	/	/
763.13	/	/	/	0.0072 7	/	0.0059 3
785.42	0.0109 17	0.009 2	/	/	/	/
860.564	/	/	/	0.047 4	/	0.0430 1
1620.742	0.0180 13	/	/	/	/	/
2614.533	/	/	/	/	/	/

E_γ (keV)	P_γ per 228Th decay (cont'd): Avignone et Schmidt (1978) [7] [c]	Sadasivan et Raghunath (1982) [8] [f]	Schotzig et Debertin (1983) [9] [g]	Vaninbroukx et Hansen (1983) [10] [h]	Gehrke et al. (1984) [11]
84.373	/	0.019 1	/	/	0.01248 29
238.632	0.500 14 [d]	/	0.435 12	0.440 6	0.433 4
240.987	/	0.039 2	0.0404 17	0.0405 9	0.0417 4
277.356	0.0220 7	0.024 1	/	0.0228 4	0.02304 22 [e]
300.094	0.0317 11	0.029 2	0.0327 9	0.0322 6	0.0328 4
510.77	0.0821 25	0.079 4	/	0.0827 14	0.0821 27
583.191	/	0.303 14	0.306 9	0.308 6	0.3052 17
727.331	0.0756 29 [e]	0.070 4	0.0656 20	0.0693 18	0.0658 5 [e]
763.13	0.0066 3	0.007 1	0.0073 5	/	0 00656 7
785.42	0.0117 6	0.0101 7	0.0107 5	/	0.01105 13
860.564	0.0500 22 [e]	0.042 2	0.0455 12	/	0 0451 4
1620.742	/	/	0.0138 8	/	0.0149 3
2614.533	/	/	0.356 11	/	0.3586 6

Table C (cont'd)

E_γ (keV)	P_γ per 228Th decay (cont'd): Evaluated values	Calculated values [j]	Recommended values
84.373	0.0124 3	0.01195 25	0.0122 2
238.632	0.435 4		0.435 4
240.987	0.0412 4	0.0396 4	0.0410 5
277.356	0.0230 3		0.0230 3
300.094	0.0325 3		0.0325 3
510.77	0.0818 10		0.0818 10
583 191	0.3056 15		0.306 2
727.331	0.0669 9		0.0669 9
763.13	0.0068 2 [i]		0.0068 2
785.42	0.0110 2		0.0110 2
860.564	0.0450 4		0.0450 4
1620.742	0.0149 5		0.0149 5
2614.533	0.358	0.3587 6	0.3586 6

Notes to Table C

a The P_γ values have been calculated from the measured relative intensities using P_γ = 0.306 2 for the 583 keV ray.

b The P_γ value has been calculated from the measured relative intensities using P_γ = 0.3586 6 for the 2615 keV reference ray.

c The P_γ values have been normalized using P_γ = 0.306 2 for the 583 keV reference ray.

d The quoted uncertainty has been increased (multiplied by 3) for the calculation of the mean.

e The quoted uncertainties have been increased (multiplied by 2) for the calculation of the means.

f The P_γ values have been renormalized using P_γ = 0.435 4 for the 239 keV reference ray. The value for the 84 keV ray has not been considered in the calculation of the evaluated value.

g The P_γ values for the 277, 583 and 727 keV rays have been obtained by applying corrections for the contributions of rays of 228Ac of nearly the same energies. These contributions were calculated from the literature values given in the author's Table 2.

h The results from the measurements with a Ge(Li) detector have been recalculated using P_γ = 0.306 2 for the 583 keV ray.

i Arithmetic means.

j These values were calculated from the transition probabilities feeding the considered level, taken from the literature and the theoretical total internal-conversion coefficients, obtained by cubic spline interpolation of Rosel et al. values'. Details are given in the table below. These calculated values are also considered for the calculation of the recommended values

D - Calculated values (per 228 Th decay)

Nuclide	Eγ (keV)	Multipolarity	Transition probability (P_{tr})	Total ICC [15]	$P_\gamma = P_{tr}/(1 + \alpha)$
228Th	84.40	E2	0.270 3 [12]	21.6 4	0.01195 25
224Ra	241.0	E2	0.0507 5 [13]	0.279 6	0.0396 4
208Tl	2614.6	E2	0.3594 6 [14] (branch 212Bi)	0.0019 1	0.3587 6

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I. HALF-LIFE

Recommended value: 2.350 ± 0.004 d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
2.346 ± 0.004	Bigham et al (1969) [1]
2.354 ± 0.008	Qaim (1966) [2]
2.366 ± 0.006	Cohen et al (1959) [3]
2.34 ± 0.02	Connor and Fairweather (1959) [4]
2.346 ± 0.004	Wish (1956) [5]
2.350 ± 0.004	Weighted mean

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II - EMISSION PROBABILITIES OF SELECTED GAMMA RAYS

Evaluated by F. Lagoutine (LMRI, Saclay, France)

A - Recommended Values

E_γ (kev) [1]	P_γ
106.123 ± 0.002	0.267 ± 0.004
228.183 ± 0.001	0.1112 ± 0.0015
277.599 ± 0.002	0.1431 ± 0.0020

B - CRP measurements

None

C - Other measurements

E_γ (keV)	Davies et al. (1968) [2] [a]	Ahmad et al. (1972) [3] [b]	Heath (1974) [4] [c]	Yurova et al. (1974) [5]	Starozhukov et al. (1977) [6]
61.46	/	/	0.0112 16		/
106.12	/	0.278 9	0.267 14		0.266 10
181.71	0.0008	0.00075 8	0.0013 2		/
209.75	0.035	0.0342 10	0.038 3		0.0336 14
226.42	/	/	0.0075 11		0.0024 3
228.18	0.119	0.114 3	0.126.11		0.1178 44
254.41	0.012	0.0011 1	0.0012 6		/
272.84	/	0.0008 1	/		/
277.60	0.1431*	0.145 4	0.166 13	0.141 4	0.150 5
285.46	/	0.0076 2	0.0091 9		0.0093 6
315.88	/	0.0152 5	0.019 2		0.0163 7
334.31	/	0.0195 7	0.024 5		0.021 1

E_γ (keV)	Mozhaev et al. (1979) [7]	Ahmad (1982) [8]	Vaninbroukx et al. (1984) [9]	Yongfu et al. (1986) [10]	Evaluated values
61.6	/	0.0129 6	0.0129 2	/	0.0100 15
106.12	/	0.264 8	0.2750 40	0.2608 38	0.267 4
181.71	/	0.00083 4	0.0007 1	/	0.00083 4
209.75	/	0.0330 8	0.0346 5	0.0328 5	0.0335 8
226.42	/	0.00290 16	0.0028 2	/	0.0028 3
228.18	/	0.112 3	0.1121 18	0.1105 14	0.1112 15
254.41	/	0.00110 6	0.0012 1	/	0.0011 2
272.84	/	0.00077 4	0.0008 1	/	0.0008 1
277.60	0.1430 24	0.145 4	0.1438 21	0.1421 13	0.1431 20
285.46	/	0.00790 25	0.0077 2	0.00765 9	0.0077 2
315.88	/	0.0160 5	0.0160 3	0.0155 2	0.0158 3
334.31	/	0.0206 6	0.0195 7	0.0199 2	0.0203 3

Notes to Table C

a Values not used in the evaluation no uncertainties given.

b Values not used in the evaluation, assumed superseded by Ref. [8].

c The P values have been calculated from the measured relative intensities using P_γ =0.267(4) for the 106.1 kev reference line.

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I. HALF-LIFE

Recommended value: $1.5785 \times 10^5 \pm 0.0024 \times 10^5$ d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in days)	Reference
157790 ± 70[c]	Ramthun and Müller (1975) [1]
158080 ± 580	Polyukhov et al (1974) [2]
155710 ± 770	Jove and Robert (1972) [3]
158200 ± 2600	Brown and Propst (1968) [4]
159470 ± 1100	Stone and Hulet (1968) [5]
158040 ± 260	Oetting and Gunn (1967) [6]
157853 ± 233	Weighted mean

Notes to Table

[c] The uncertainty was increased to 230 to ensure that this value did not contribute a weighting of greater than 50%.

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II. EMISSION PROBABILITIES OF LX RAYS

Evaluated by W. Bambynek (CBNM, Geel, Belgium)

A. Recommended Values

	E_{LX} (keV)	P_{LX}[a]
Np L_l	11.871	0.0085 ± 0.0003
Np L_α	13.927	0.132 ± 0.004
Np $L_{\beta\eta}$	17.611	0.194 ± 0.006
Np L_γ	20.997	0.049 ± 0.002

Note to table A:

[a] The recommended values have been deduced from the weighted means of the measured or adjusted values. As weights the squared reciprocals of the adjusted uncertainties were used. Usually the maximum of the internal or external errors have been assigned as the uncertainty of the weighted means according to Topping [1]. However, owing to the great spread of the various results of some transitions, in some cases the evaluator has assigned greater uncertainties.

B. CRP measurements

None.

C. Other measurements

	E (keV)	Beling et al. (1952) [2][a,b]	Day (1955) [3][a,c]	Magnusson (1957) [4][c]
Np L_l	11.871	-	0.0047 7[b]	0.008 7
Np L_α	13.927	0.151 14	0.101[b]	0.135 5
Np $L_{\beta\eta}$	17.611	0.238 15	0.191 10	0.184 10
Np L_γ	20.997	0.064 6	0.050 4	0.005 4

	E (keV)	Gehrke and Lokken (1971) [5][a]	Watson and Li (1971) [6][d]	Hansen et al. (1973) [7][b]
Np L_l	11.871	0.0081 7	0.0087 6	-
Np L_α	13.927	0.126 9	0.135 12	-
Np $L_{\beta\eta}$	17.611	0.192 14	0.193 13	0.210 6
Np L_γ	20.997	0.048 4	0.052 4	-

	E (keV)	Gallagher and Cipolla (1974) [8]	Campbell and McNelles (1974) [9][f]	Gunnink et al. (1976) [10][g]
Np L_l	11.871	-	0.0086 2	0.00806 40
Np L_α	13.927	-	0.1320 25	0.132 7
Np $L_{\beta\eta}$	17.611	0.1946 46	0.1925 40	0.192 10
Np L_γ	20.997	-	0.0485 15	0.0494 25

	E (keV)	Cohen (1980) [11]	Maria et al. (1974) [12][d]	Cohen (1988) [13][e]
Np L_l	11.871	0.0087 3	0.0078 8	0.00833 5
Np L_α	13.927	0.132 3	0.131 10	0.127 4
Np $L_{\beta\eta}$	17.611	0.1978 36	0.193 13	0.183 8
Np L_γ	20.997	0.0496 20	0.048 3	0.049620

Notes to table C:

a Measured relative to the 59.537-keV line. We have normalized the relative intensities with $P_\gamma(59.537) = 0.360\,4$.

b The data of Beling et al. [2], Hansen et al. [7], and partly of Day [3] were omitted as outlayers according to Dixon's criterion (Natrella [14]).

c Uncertainty was (re)estimated by the evaluator.

d Measured relative to the $L_{\beta 1}$ line. We have normalized the relative intensities with $P_{L\beta 1} = 0.124\,8$, deduced from $P_\gamma(26.345) = 0.024\,1$.

e Measured relative to L_α. We have normalized the relative intensities with $P_{L\alpha} = 0.127\,4$, quoted by the author.

f The statistical uncertainties used correspond to 2σ or 3σ. In the evaluation we have reduced the uncertainties to be comparable to other uncertainties quoted.

g The uncertainties of Gunnink et al. [10] were increased by the evaluator by 3% in addition to the quoted uncertainties to account for detector calibration.

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III.GAMMA-RAY EMISSION PROBABLITIES

Evaluated by W. Bambynek (CBNM, Geel, Belgium).

A. Recommended values

E (keV)	P_γ[a]
26.345 ± 0.001	0.024 ± 0.001
59.537 ± 0.001	0.360 ± 0.004

Note to table A:

[a] The recommended values have been deduced from the weighted means of the measured or adjusted values. As weights the squared reciprocals of the adjusted uncertainties were used. Usually the maximum of the internal or external errors have been assigned as the uncertainty of the weighted means according to Topping [1]. However, owing to the great spread of the various results of some transitions, in some cases the evaluator has assigned greater uncertainties.

B. CRP measurements

E (keV)	Denecke (1987) [2]
59.537	0.3636 17

C. Other Measurements

E (keV)	Prohaska (1951) [3][1a]	Beling et al. (1952) [4][1a,b]	Jaffe et al. (1955) [5][a]
26.345	-	0.030 3	0.04
59.537	0.32	0.400 15	0.40

E (keV)	Day (1955) [6][a,b]	Magnusson (1957) [7][c]	McIsaac (1955) [8][a]
26.345	0.0296	0.025 2	-
59.537	-	0.400 15	0.346 7

E (keV)	Michaelis (1965) [9][a]	Péghaire (1969) [10]	Gehrke and Lokken (1971) [11][b]
26.345	-	-	0.023 2
59.537	0.380 6	0.353 6	-

E (keV)	Faermann et al. (1971) [12][b]	Watson and Li (1971) [13][d]	Campbell and McNelles (1974) [14][e]
26.345	0.026 1	0.024 1	0.024 1
59.537	-	-	-

E (keV)	Chauham et al. (1974) [15][f]	Legrand et al. (1975) [16][e]	Plch et al. (1976) [17]
26.345	0.026 1	-	-
59.537	-	0.363 4	0.355 3

E (keV)	Gunnink et al. (1976) [18][g]	Genoux-Laubin and Ardisson (1978) [19][f]	Debertin and Peßara (1983) [20]
26.345	0.0245 6	0.0255 26	0.0241 5
59.537	-	-	-

E (keV)	Hutchinson and Mullen (1983) [21]	Ovechkin and Khokhlov (1984), [22][h]	Denecke (1987) [2]
26.345	-	0.0227	-
59.537	0.3582 12	0.359	0.3636 36

E (keV)	Cohen (1988) [23][i]
26.345	0.0240 9
59.537	-

Notes to table C:

[a] The data of Beling et al. [4], Prohaska [3], Jaffe et al. [5], McIsaac [8], Michaelis [9] and partly of Day [6] were omitted as outlayers according to Dixon's criterion (Natrella [24]).

[b] Measured relative to the 59.537-keV line. We have normalized the relative intensities with $P_\gamma(59.537) = 0.360\,4$.

[c] Uncertainty was (re)estimated by the evaluator.

[d] Measured relative to the $L_{\beta1}$ line. We have normalized the relative intensities with $P_{L\beta1} = 0.124\,8$, deduced from P_γ (26.345) = 0.024 1.

[e] The statistical uncertainties used correspond to 2σ or 3σ. In the evaluation we have reduced the uncertainties to be comparable to other uncertainties quoted.

[f] Recalculated from the emission probability quoted using $P_\gamma(59.537) = 0.360\,4$.

[g] The uncertainties of Gunnink et al. [18] were increased by the evaluator by 3% in addition to the quoted uncertainties to account for detector calibration.

[h] Omitted because it is not clear wether these values are measured or adopted data.

[i] Measured relative to L_α. We have normalized the relative intensities with $P_{L\alpha} = 0.127\,4$, quoted by the author.

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I. HALF-LIFE

Recommended value: $2.690 \times 10^6 \pm 0.008 \times 10^6$ d

Evaluated by K. Debertin (PTB, Braunschweig, FRG) and
M. J. Woods (NPL, Teddington, UK)

Measured values

Value (in years)	Reference
7360 ± 42	Aggarwal et al (1980) [1]
7380 ± 17[c]	Polyukhov et al (1974) [2]
7370 ± 40	Brown and Propst (1968) [3]
7226 ± 100	Beadle et al (1960) [4]
7292 ± 160	Barnes et al (1959) [5]
7366 ± 20	Weighted mean

Notes to Table

[c] The uncertainty was increased to 28 to ensure that this value did not contribute a weighting of greater than 50%.

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II GAMMA-RAY EMISSION PROBABILITIES

Evaluated by A L Nichols (AEA Technology, Winfrith, UK), December 1989.

A. Recommended values

E_γ (keV)	P_γ
43.53 ± 0.01	0.0594 ± 0.0011
74.66 ± 0.01	0.674 ± 0.010

B. CRP measurements

None

C Other measurements

E_γ (keV) [a]	Asaro et al (1960) Ref 1	van Hise and Engelkemeir (1968) Ref 2	Aleksandrov et al (1970) Ref 3	Ahmad and Wahlgren (1972) Ref 4 [b]	Pate et al (1975) Ref 5	Starozhukov et al (1977) Ref 6
					P_γ^{rel} [c]	
43.53(1)	0.04(1)	0.053(5)	0.05(1)	0.055(3)	8.40(60)	-
74.66(1)	0.69(3)	0.61(6)	0.73(3)	0.66(3)	100.0	0.591(40)

E_γ (keV) [a]	Popov et al (1979) Ref 7	Ahmad (1982) Ref 8	Holloway (1983) Ref 9		Holloway et al (1983) Ref 10		MacMahon (1984) Ref 11	Vaninbroukx et al (1984) Ref 12	Evaluated Values
			P_γ^{rel}	P_γ^{abs} [d]	P_γ^{rel}	P_γ^{abs} [d]			
43.53(1)	0.053(12)	0.062(3)	9.04(16)	0.057(2)	9.1(2)	0.061(2)	0.0587(17)	0.0604(14)[e]	0.0594(11)
74.66(1)	0.60(4)	0.68(2)	100	0.635(9)	100	0.67(1)	0.670(12)	0.685(15)	0.674(10)

[a] Calculated from derived nuclear levels of Np-239.

[b] Data of Ahmad and Wahlgren (1972) Ref 4 are not included in this evaluation: replaced by later measurements of Ahmad (1982) Ref 8.

[c] Relative gamma-ray emission probabilities were measured, and gamma-gamma coincidence studies revealed the existence of weak gamma-ray transitions at 43.1, 50.5, 55.4, 98.5, ~170 and ~195 keV; these data were used in the evaluation of the decay scheme but were not included in the weighted mean determinations of the absolute gamma-ray emission probabilities.

[d] Data of Holloway (1983) Ref 9 and Holloway et al (1983) Ref 10 are not included in this evaluation: replaced by re-assessed data communicated by MacMahon (1984) Ref 11 on the basis of adjustments to the detector calibration.

[e] Uncertainty increased to reduce the contribution of the datum to the sum of the weights to less than 50%.

Theoretical Internal Conversion Coefficients

E_γ (keV)	Transition Type	Theoretical Internal Conversion Coefficients [a]			
		α_K	α_L	α_{M+}	α_{tot}
43.53	E1	-	0.868(17)	0.296(6)	1.164(23)
74.66	E1	-	0.211(4)	0.070(1)	0.281(5)

[a] Internal conversion coefficient data derived from Rösel et al (1978) Ref 13.

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Part 3

RECOMMENDED DATA

The third part of this report lists the values of decay parameters of radionuclides used for X- and gamma-ray detector efficiency calibration as recommended by the CRP.

The data uncertainties are standard deviations. For the emission probabilities uncertainties are noted as last digit uncertainties, i.e. 12.3(4) means 12.3 ± 0.4 and 12.3(14) means 12.3 ± 1.4.

Table 1: Half-lives of radionuclides used for detector calibration

Table 2: X-ray standards: energies and emission probabilities

Table 3: Gamma-ray standards: energies and emission probabilities

References

Note:

The recommended data given in the following three tables are available from the IAEA Nuclear Data Section (P.O. Box 100, A-1400 Vienna, Austria) on a PC diskette "XG-Standards" by Hartmut Lemmel.

TABLE 1. HALF-LIVES OF RADIONUCLIDES USED FOR DETECTOR CALIBRATION

Nuclide	Decay Mode	-------- Half-life [days] -------- Value		Uncertainty	Exponent	Reference
11-Na-022	EC	950.8	±	0.9		[1]
11-Na-024	β-	0.62356	±	0.00017		[1]
21-Sc-046	β-	83.79	±	0.04		[1]
24-Cr-051	EC	27.706	±	0.007		[1]
25-Mn-054	EC	312.3	±	0.4		[1]
26-Fe-055	EC	999	±	8		[1]
27-Co-056	EC	77.31	±	0.19		[1]
27-Co-057	EC	271.79	±	0.09		[1]
27-Co-058	EC	70.86	±	0.07		[1]
27-Co-060	β-	1925.5	±	0.5		[1]
30-Zn-065	EC	244.26	±	0.26		[1]
34-Se-075	EC	119.64	±	0.24		[1]
38-Sr-085	EC	64.849	±	0.004		[1]
39-Y -088	EC	106.630	±	0.025		[1]
41-Nb-093m	IT	5890	±	50		[2]
41-Nb-094	β-	7.3	±	0.9	E+06	[2]
41-Nb-095	β-	34.975	±	0.007		[2]
48-Cd-109	EC	462.6	±	0.7		[2]
49-In-111	EC	2.8047	±	0.0005		[2]
50-Sn-113	EC	115.09	±	0.04		[2]
51-Sb-125	β-	1007.7	±	0.6		[2]
53-I -125	EC	59.43	±	0.06		[2]
55-Cs-134	β-	754.28	±	0.22		[2]
55-Cs-137	β-	1.102	±	0.006	E+04	[2]
56-Ba-133	EC	3862	±	15		[2]
58-Ce-139	EC	137.640	±	0.023		[2]
63-Eu-152	EC	4933	±	11		[2]
63-Eu-154	β-	3136.8	±	2.9		[2]
63-Eu-155	β-	1770	±	50		[2]
79-Au-198	β-	2.6943	±	0.0008		[2]
80-Hg-203	β-	46.595	±	0.013		[2]
83-Bi-207	EC	1.16	±	0.07	E+04	[2]
90-Th-228	α	698.2	±	0.6		[1]
93-Np-239	β-	2.350	±	0.004		[2]
95-Am-241	α	1.5785	±	0.0024	E+05	[2]
95-Am-243	α	2.690	±	0.008	E+06	[1]

TABLE 2. X-RAY STANDARDS: ENERGIES AND EMISSION PROBABILITIES [3]

Nuclide	Trans	Energy (keV)	Probability
24-Cr-051	VKα	4.95	0.201(3)
24-Cr-051	VKβ	5.43	0.027(1)
24-Cr-051	VKx	4.95-5.43	0.228(3)
25-Mn-054	CrKα	5.41	0.226(7)
25-Mn-054	CrKβ	5.95	0.030(1)
25-Mn-054	CrKx	5.41-5.95	0.256(8)
26-Fe-055	MnKα	5.89	0.249(9)
26-Fe-055	MnKβ	6.49	0.034(1)
26-Fe-055	MnKx	5.89-6.49	0.283(10)
27-Co-057	FeKα	6.40	0.510(7)
27-Co-057	FeKβ	7.06	0.069(1)
27-Co-057	FeKx	6.40-7.06	0.579(8)
27-Co-058	FeKα	6.40	0.235(3)
27-Co-058	FeKβ	7.06	0.032(1)
27-Co-058	FeKx	6.40-7.06	0.267(3)
30-Zn-065	CuKα	8.03-8.05	0.341(6)
30-Zn-065	CuKβ	8.91	0.046(1)
30-Zn-065	CuKx	8.03-8.91	0.387(6)
34-Se-075	AsKα	10.51-10.54	0.493(11)
34-Se-075	AsKβ	11.72-11.95	0.075(2)
34-Se-075	AsKx	10.51-11.95	0.568(13)
38-Sr-085	RbKα	13.34-13.40	0.500(3)
38-Sr-085	RbKβ	14.96-15.29	0.087(2)
38-Sr-085	RbKx	13.34-15.29	0.587(4)
39-Y -088	SrKα	14.10-14.17	0.522(6)
39-Y -088	SrKβ	15.83-16.19	0.094(2)
39-Y -088	SrKx	14.10-16.19	0.616(7)
41-Nb-093m	NbKα	16.52-16.62	0.0925(30)
41-Nb-093m	NbKβ	18.62-19.07	0.0179(7)
41-Nb-093m	NbKx	16.52-19.07	0.1104(35)
48-Cd-109	AgKα	21.99-22.16	0.821(9)
48-Cd-109	AgKβ	24.93-25.60	0.173(3)
48-Cd-109	AgKx	21.99-25.60	0.994(10)
49-In-111	CdKα	22.98-23.17	0.684(5)
49-In-111	CdKβ	26.09-26.80	0.146(3)
49-In-111	CdKx	22.98-26.80	0.830(5)
50-Sn-113	InKα	24.00-24.21	0.796(6)
50-Sn-113	InKβ	27.27-28.02	0.172(3)
50-Sn-113	InKx	24.00-28.02	0.968(6)

TABLE 2. (cont.)

Nuclide	Trans	Energy (keV)	Probability
53-I -125	TeKα	27.20-27.47	1.135(21)
53-I -125	TeKβ	30.98-31.88	0.255(6)
53-I -125	TeKx	27.20-31.88	1.390(25)
55-Cs-137	BaKα	31.82-32.19	0.0566(16)
55-Cs-137	BaKβ	36.36-37.45	0.0134(5)
55-Cs-137	BaKx	31.82-37.45	0.0700(20)
56-Ba-133	CsKα	30.63-30.97	0.980(14)
56-Ba-133	CsKβ	34.97-36.01	0.230(5)
56-Ba-133	CsKx	30.63-36.01	1.210(16)
58-Ce-139	LaKα	33.03-33.44	0.643(18)
58-Ce-139	LaKβ	37.78-38.93	0.154(5)
58-Ce-139	LaKx	33.03-38.93	0.797(22)
63-Eu-152	SmKα	39.52-40.12	0.591(12)
63-Eu-152	GdKα	42.31-43.00	0.00648(22)
63-Eu-152	SmKβ	45.38-46.82	0.149(3)
63-Eu-152	GdKβ	48.65-50.21	0.00176(18)
63-Eu-152	SmKx	39.52-46.82	0.740(12)
63-Eu-152	GdKx	42.31-50.21	0.00824(28)
63-Eu-152	(Sm+Gd)Kx	39.52-50.21	0.748(12)
63-Eu-154	GdKα	42.31-43.00	0.205(6)
63-Eu-154	GdKβ	48.65-50.21	0.051(2)
63-Eu-154	GdKx	42.31-50.21	0.256(6)
79-Au-198	HgKα	68.89-70.82	0.0219(8)
79-Au-198	HgKβ	80.12-82.78	0.0061(3)
79-Au-198	HgKx	68.89-82.78	0.0280(10)
80-Hg-203	TlLx	8.95-14.40	0.060(12)
80-Hg-203	TlKα2	70.83	0.038(2)
80-Hg-203	TlKα1	72.87	0.064(2)
80-Hg-203	TlKβ'1	82.43	0.022(1)
80-Hg-203	TlKβ'2	85.19	0.0063(3)
80-Hg-203	TlKx	70.83-85.19	0.130(4)
83-Bi-207	PbLx	9.19-14.91	0.325(13)
83-Bi-207	PbKα2	72.80	0.226(12)
83-Bi-207	PbKα1	74.97	0.382(20)
83-Bi-207	PbKβ'1	84.79	0.130(10)
83-Bi-207	PbKβ'2	87.63	0.039(3)
83-Bi-207	PbKx	72.80-87.63	0.777(26)
95-Am-241	NpLℓ	11.871	0.0085(3)
95-Am-241	NpLα	13.927	0.132(4)
95-Am-241	NpLβη	17.611	0.194(6)
95-Am-241	NpLγ	20.997	0.049(2)

TABLE 3. GAMMA-RAY STANDARDS: ENERGIES AND EMISSION PROBABILITIES

Nuclide	Energy (keV)	Emission Probability	Reference
11-Na-022	1274.542(7)	0.99935(15)	[4]
11-Na-024	1368.633(6)	0.999936(15)	[4]
11-Na-024	2754.030(14)	0.99855(5)	
21-Sc-046	889.277(3)	0.999844(16)	[5]
21-Sc-046	1120.545(4)	0.999874(11)	
24-Cr-051	320.0842(9)	0.0986(5)	[6]
25-Mn-054	834.843(6)	0.999758(24)	[5]
27-Co-056	846.764(6)	0.99933(7)	[5]
27-Co-056	1037.844(4)	0.1413(5)	
27-Co-056	1175.099(8)	0.02239(11)	
27-Co-056	1238.287(6)	0.6607(19)	
27-Co-056	1360.206(6)	0.04256(15)	
27-Co-056	1771.350(15)	0.1549(5)	
27-Co-056	2015.179(11)	0.03029(13)	
27-Co-056	2034.759(11)	0.07771(27)	
27-Co-056	2598.460(10)	0.1696(6)	
27-Co-056	3201.954(14)	0.0313(9)	
27-Co-056	3253.417(14)	0.0762(24)	
27-Co-056	3272.998(14)	0.0178(6)	
27-Co-056	3451.154(13)	0.0093(4)	
27-Co-056	3548.27(10)	0.00178(9)	
27-Co-057	14.4127(4)	0.0916(15)	[7]
27-Co-057	122.0614(3)	0.8560(17)	
27-Co-057	136.4743(5)	0.1068(8)	
27-Co-058	810.775(9)	0.9945(1)	[7]
27-Co-060	1173.238(4)	0.99857(22)	[4]
27-Co-060	1332.502(5)	0.99983(6)	
30-Zn-065	1115.546(4)	0.5060(24)	[6]
34-Se-075	96.7344(10)	0.0341(4)	[6]
34-Se-075	121.1171(14)	0.171(1)	
34-Se-075	136.0008(6)	0.588(3)	
34-Se-075	264.6580(17)	0.590(2)	
34-Se-075	279.5431(22)	0.250(1)	
34-Se-075	400.6593(13)	0.115(1)	

TABLE 3. (cont.)

Nuclide	Energy (keV)	Emission Probability	Reference
38-Sr-085	514.0076(22)	0.984(4)	[5]
39-Y -088	898.042(4)	0.940(3)	[8]
39-Y -088	1836.063(13)	0.9936(3)	
41-Nb-094	702.645(6)	0.9979(5)	[9]
41-Nb-094	871.119(4)	0.9986(5)	
41-Nb-095	765.807(6)	0.9981(3)	[9]
48-Cd-109	88.0341(11)	0.0363(2)	[8]
49-In-111	171.28(3)	0.9078(10)	[5]
49-In-111	245.35(4)	0.9416(6)	
50-Sn-113	391.702(4)	0.6489(13)	[9]
51-Sb-125	176.313(1)	0.0685(7)	[8]
51-Sb-125	380.452(8)	0.01518(16)	
51-Sb-125	427.875(6)	0.297(3)	
51-Sb-125	463.365(5)	0.1048(11)	
51-Sb-125	600.600(4)	0.1773(18)	
51-Sb-125	606.718(3)	0.0500(5)	
51-Sb-125	635.954(5)	0.1121(12)	
53-I -125	35.4919(5)	0.0658(8)	[8]
55-Cs-134	475.364(3)	0.0149(2)	[5]
55-Cs-134	563.240(4)	0.0836(3)	
55-Cs-134	569.328(3)	0.1539(6)	
55-Cs-134	604.720(3)	0.9763(6)	
55-Cs-134	795.859(5)	0.854(3)	
55-Cs-134	801.948(5)	0.0869(3)	
55-Cs-134	1038.610(7)	0.00990(5)	
55-Cs-134	1167.968(5)	0.01792(7)	
55-Cs-134	1365.185(7)	0.03016(11)	
55-Cs-137	661.660(3)	0.851(2)	[8]
56-Ba-133	80.998(5)	0.3411(28)	[7]
56-Ba-133	276.398(1)	0.07147(30)	
56-Ba-133	302.853(1)	0.1830(6)	
56-Ba-133	356.017(2)	0.6194(14)	
56-Ba-133	383.851(3)	0.08905(29)	
58-Ce-139	165.857(6)	0.7987(6)	[8]

TABLE 3. (cont.)

Nuclide		Energy (keV)		Emission Probability	Reference
63-Eu-152		121.7824(4)		0.2837(13)	[9]
63-Eu-152		244.6989(10)		0.0753(4)	
63-Eu-152		344.2811(19)		0.2657(11)	
63-Eu-152		411.126(3)		0.02238(10)	
63-Eu-152		443.965(4)		0.03125(14)	
63-Eu-152		778.903(6)		0.1297(6)	
63-Eu-152		867.390(6)		0.04214(25)	
63-Eu-152		964.055(4)		0.1463(6)	
63-Eu-152		1085.842(4)		0.1013(5)	
63-Eu-152		1089.767(14)		0.01731(9)	
63-Eu-152		1112.087(6)		0.1354(6)	
63-Eu-152		1212.970(13)		0.01412(8)	
63-Eu-152		1299.152(9)		0.01626(11)	
63-Eu-152		1408.022(4)		0.2085(9)	
63-Eu-154		123.071(1)		0.412(5)	[5]
63-Eu-154		247.930(1)		0.0695(9)	
63-Eu-154		591.762(5)		0.0499(6)	
63-Eu-154		692.425(4)		0.0180(3)	
63-Eu-154		723.305(5)		0.202(2)	
63-Eu-154		756.804(5)		0.0458(6)	
63-Eu-154		873.190(5)		0.1224(15)	
63-Eu-154		996.262(6)		0.1048(13)	
63-Eu-154		1004.725(7)		0.182(2)	
63-Eu-154		1274.436(6)		0.350(4)	
63-Eu-154		1494.048(9)		0.0071(2)	
63-Eu-154		1596.495(18)		0.0181(2)	
79-Au-198		411.8044(11)		0.9557(47)	[6]
80-Hg-203		279.1967(12)		0.8148(8)	[9]
83-Bi-207		569.702(2)		0.9774(3)	[5]
83-Bi-207		1063.662(4)		0.745(2)	
83-Bi-207		1770.237(9)		0.0687(4)	
90-Th-228		84.373(3)		0.0122(2)	[8]
90-Th-228	*	238.632(2)		0.435(4)	
90-Th-228	*	240.987(6)		0.0410(5)	
90-Th-228	*	277.358(10)		0.0230(3)	
90-Th-228	*	300.094(10)		0.0325(3)	
90-Th-228	*	510.77(10)	†	0.0818(10)	
90-Th-228	*	583.191(2)		0.306(2)	
90-Th-228	*	727.330(9)		0.0669(9)	
90-Th-228	*	860.564(5)		0.0450(4)	
90-Th-228	*	1620.735(10)		0.0149(5)	
90-Th-228	*	2614.533(13)		0.3586(6)	

* Indicates daughter in equilibrium with parent radionuclide
† Note the close distance to 511.003 keV annihilation radiation

TABLE 3 (cont.)

Nuclide	Energy (keV)	Emission Probability	Reference
93-Np-239	106.123(2)	0.267(4)	[10]
93-Np-239	228.183(1)	0.1112(15)	
93-Np-239	277.599(2)	0.1431(20)	
95-Am-241	26.345(1)	0.024(1)	[3]
95-Am-241	59.537(1)	0.360(4)	
95-Am-243	43.53(1)	0.0594(11)	[6]
95-Am-243	74.66(1)	0.674(10)	

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