Recommended standards for gamma ray intensities

Marie-Martine Bé, Valery Chechev

To cite this version:

Marie-Martine Bé, Valery Chechev. Recommended standards for gamma ray intensities. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Elsevier, 2013, 728, pp.157 - 172. 10.1016/j.nima.2013.05.134 . cea-01802664

Recommended standards for gamma ray intensities

Marie-Martine Bé[a], Valery P. Chechev[b]

a LNHB, CEA LIST Saclay, 91191 Gif sur Yvette cedex, France, mmbe@cea.fr, Tel : +33 169084641
b KRI, V.G. Khlopin Radium Institute, St Petersburg 194021, Russia

Abstract

Gamma ray data are used in more and more areas of application, and so over the years the demand for recommended gamma ray energies and intensities has increased. This paper proposes a list of gamma rays whose intensity is sufficiently well-known and they can be used for the calibration of gamma ray spectrometers and other applications; it is based on studies carried out by an international group of evaluators: the Decay Data Evaluation Project. One goal of this paper is to gather this set of data together in order to facilitate and generalize their use. In the first part, a brief description of the methodology followed throughout the evaluations is given, different methods of gamma ray intensity evaluation are presented, some typical examples of evaluations are shown; in the second part, the list of chosen nuclides is given along with their applications, and finally a list of recommended gamma ray intensities is presented.

Keywords

Applied radionuclides, Decay data, Gamma ray intensities, Evaluation techniques

1. Introduction

Over the years, there has been an increasing demand for recommended data such as gamma ray energies and intensities. Looking at various publications or databases related to decay data, the quantities of interest generally differ. Several reasons are at the origin of these Tapez une équation ici.differences, e.g. some results were not available at the time of the evaluation, different judgments brought to references could result in their rejection, different evaluation methodologies, etc. These data are used in many applications, for example, in the field of gamma ray spectrometry measurements, where the detectors used (such as Si(Li), HPGe) must be accurately calibrated. To meet the demand, a previous paper was published to recommend accurate gamma ray energies [1]. A parallel effort has been pursued by an international group (Decay Data Evaluation Project) to propose a list of gamma rays whose intensities are sufficiently well-known so as to make them appropriate for the calibration of gamma ray spectrometers and other applications. The Decay Data Evaluation Project (DDEP), was organized in 1995 by Helmer [2], [3]. It has included, throughout the years, various contributors from well-known scientific institutes (Table 1). The work has been constant and its recognition was achieved when the Bureau International des Poids et Mesures (BIPM—CCRI(II)) in 2004 decided to adopt these data as recommended values to be used in all the inter-comparison exercises in the field of ionizing radiation metrology. Since then, the DDEP evaluations have been published in a series entitled “Monographie BIPM-5” [4] for which six volumes have already been issued. The objective of the DDEP is to provide carefully recommended data describing the nuclide decay, among them the γ ray intensities which are extensively used in many fields of application. The DDEP brings together scientists from several laboratories, most of which are the radionuclide standard laboratories in their respective country. The methodology followed in each evaluation is the same and the evaluator provides written documentation of all data used, all decisions made and detailed calculations [5]. In conjunction with the IAEA Nuclear Data Section, two Coordinated Research Projects (CRP) have been organized and conducted with the participation of a number of DDEP evaluators using the DDEP methodology in both cases [6], [7], [8]. The aim of this paper, which is based on DDEP studies, is to provide a list of carefully evaluated gamma ray intensities for nuclides of interest in the field of detector calibration, nuclear waste management, medical applications, etc. In the first part, a brief description of the methodology followed throughout the evaluations is given, different methods of gamma ray intensity evaluation are presented, some typical examples of evaluations are shown; in the second part, the list of the chosen nuclides is given along with their applications, and finally a list of recommended gamma ray intensities is presented.

Table 1. List of the DDEP evaluators and contributors from 1995 to 2012.

Authors	Laboratory/list of evaluated nuclides
M.M. Bé, V. Chisté, X. Mougeot	Laboratoire National Henri Becquerel, France/ C-11, N-13, O-15, F-18, K-40, Ar-41, Ca-47, Sc-47, Fe-52, Mn-52, Co-58, Fe-59, Cu-64, Zn-65, Ga-67, Ga-68, Se-75, Kr-85, Rb-86, Rb-88, Y-90m, Sr-92, Y-92, Tc-99m, Ag-108, Ag-108m, I-123, Te-123m, Sb-124, I-125, Sb-126, Sn-126, Xe-127, I-131, Cs-134, Ce-139, Ce-144, Pr-144, Nd-147, Sm-153, Yb-169, Lu-176, Ta-178, Ta-182, Au-195, Pb-203, Bi-207, Pb-210, Bi-214, Pb-214, Ra-226, Am-243
E. Browne, C. Baglin	Lawrence Berkeley National Laboratory, USA/ Al-26, Sc-44, Ti-44, Ni-57, Ga-66, Eu-152, Re-188, Ir-192, Ir-194
V.P. Chechev, N.K. Kuzmenko	V.G. Khlopin Radium Institute, Russia/ Co-57, Mo-99, In-111, I-129, Ba-133, Cs-137, Ce-141, Eu-154, Eu-155, Tm-170, Ra-223, Pa-233, Th-233, Np-236, Np-236m, Np-237, Np-238, Np-239, U-239, Am-241, Cm-243, Cm-245
R.G. Helmer	Idaho National Engineering and Environmental Laboratory, USA/ Be-7, Na-24, Sc-46, Co-60, Nb-95, Nb-95m, Zr-95, Ag-110, Ag-110m, Sn-113, In-113m, Ba-140, La-140, Gd-153, Gd-159
F.G. Kondev	Argonne National Laboratory, USA/ Lu-177, Hg-206, Tl-209, Tl-210, Pb-211
T.D. MacMahon, A. Arinc, A. Pearce, M.J. Woods	National Physical Laboratory, UK/ Co-56,Ru-106, Ac-228, Pa-231
E. Schönfeld, R. Dersch	Physikalisch-Technische Bundesanstalt, Germany/ Cr-51, Mn-54, Sr-85, Y-88, Cd-109, Ho-166, Ho-166m, Re-186, Au-198, Tl-201
A.L. Nichols	University of Surrey, UK/ Mn-56, Pd-109, Sb-127, Te-132, Hg-203, Tl-208, Bi-212, Pb-212, Bi-215, Rn-219, Ra-224, Th-228, Am-244
M. Galán	Laboratorio de Metrología de RadiacionesIonizantes, Spain/ Na-22, I-133, Xe-133, Xe-133m, Xe-135m
A. Luca	IFIN-HH/Radionuclide Metrology Laboratory, Romania/ Bi-211, Ra-228, Pa-234, Th-234

Authors	Laboratory/list of evaluated nuclides
X. Huang, B. Wang	China Nuclear Data Center, China/ Bi-213, Fr-221, Fr-223, Ac-225, Ra-225, Th-231, U-235

Contributors	
R.B. Firestone	Lawrence Berkeley National Laboratory, USA
T. Kibèdi	Australian National University, Australia
B. Singh	McMaster University, Canada
J.K. Tuli	Brookhaven National Laboratory, USA
N. Nica	Texas A&M University, USA

2. Evaluation methodology

2.1. General evaluation approach and rules

The first step of an evaluation is to compile all the available existing data then an analysis, critical and statistical, is made for each quantity of the decay scheme. All evaluations are based on available experimental data, supplemented with theoretical calculations or considerations when necessary. Only the main stages in the compilation and evaluation are presented here, more details can be found in Ref. [9]. These stages comprise the following.•critical analysis of published results and, if necessary, correcion of these results to account for more recent values hitherto unavailable to the original experimentalists; as a rule, results without associated uncertainties are discarded; some results can be rejected and their rejection is documented.•data obtained through private communications are only used when there is no published article available and when all of the necessary information has been provided directly by the scientist carrying out the measurements.•adjustments may be made to the reported uncertainties.•recommended values are derived from an analysis of all the retained measurement results (or theoretical considerations), along with the standard deviations corresponding to the 1σ confidence level.

2.2. Evaluation of uncertainties and statistical process

The following definitions of uncertainties have been extracted from the "Guide to the expression of uncertainty in measurement" [10].

Uncertainty (*of measurement*): parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.
Standard uncertainty: uncertainty of the result of a measurement expressed as a standard deviation.
Type A evaluation (*of uncertainty*): method of evaluation of uncertainty by the statistical analysis of a series of observations.
Type B evaluation (*of uncertainty*): method of evaluation of uncertainty by means other than the statistical analysis of a series of observations.

- When necessary and when sufficient details are known, the uncertainties given by authors can be re-evaluated by combining the standard uncertainties σ_A and σ_B through the general law of variance propagation:

$$u_c = \sqrt{\sigma_A^2 + \sigma_B^2}$$

Where u_c is the combined standard uncertainty, σ_A is the type A standard deviation, and σ_B is the type B standard uncertainty.

- When the authors give insufficient information concerning their uncertainty calculations, the combined uncertainty u_c may be estimated by the evaluator, based on knowledge of the measurement method(s).

In the case of gamma ray intensities, the published results have generally been obtained over a number of years and by a variety of scientists from various laboratories. When several results have been published by the same laboratory only the last one is retained in the evaluation process. Hence, the data in the set can be considered as independent and a weighted average is calculated using the combined uncertainties of the individual values as weights. For n independent values a_i, each with a combined standard uncertainty u_{ci}, a weight p_i proportional to the inverse of the square of the individual u_{ci} can be assigned to each value.

$$a_w = \frac{\sum_{i=1}^{n} p_i \, a_i}{\sum_{i=1}^{n} p_i}$$

where the weights are $p_i = {}^{1}\!/_{u_{c_i}^2}$

An internal and an external uncertainty can be assigned to the mean value [11]:

$$\sigma_{int} \, (a_w) = \left[\sum\nolimits_i (1/u_{c_i}^2)\right]^{-1/2}$$

The internal variance $\sigma_{int}^2 \, (a_w)$ is the expected uncertainty of the mean, based on the individual *a priori* variances u_{ci} (by uncertainty propagation).

The external uncertainty is given by the equation:

$$\sigma_{ext} \, (a_w) = \left[\frac{\sum_i (a_i - a_w)^2 / u_{c_i}^2}{(n-1) \sum 1/u_{c_i}^2}\right]^{1/2}$$

The external variance $\sigma_{ext}^2 \, (a_w)$ includes the scattering of the data, and is based on the amount by which each a_i deviates from the mean when measured as a fraction of each given uncertainty u_{ci}.

A measure of the consistency of the data is given by the ratio [2], [3]:

$$\sigma_{ext}/\sigma_{int} = \sqrt{\chi^2/(n-1)}$$

If this ratio is significantly greater than unity, at least one of the input data most probably has an underestimated uci which should be increased. A critical value of $\chi^2/(n-1)$ at 1%

confidence level is used as a practical test for discrepant data. The following table lists critical values of $\chi^2/(n-1)$ for an increasing degree of freedom υ=n−1:

v	**Critical $\chi^2/(n-1)$**	*v*	**Critical $\chi^2/(n-1)$**
1	6.6	12	2.2
2	4.6	13	2.1
3	3.8	14	2.1
4	3.3	15	2.0
5	3.0	16	2.0
6	2.8	17	2.0
7	2.6	18–21	1.9
8	2.5	22–26	1.8
9	2.4	27–30	1.7
10	2.3		
11	2.2	>30	$1 + 2.33\sqrt{2/v}$

If $\chi^2/(n-1) \leq$ critical $\chi^2/(n-1)$, the recommended value is given by $a = a_w \pm \sigma_{int}(a_w)$

If $\chi^2/(n-1) >$ critical $\chi^2/(n-1)$, the method of limitation of the relative statistical weight [11] is recommended when there are three or more values; uncertainty of a value contributing more than 50% to the total weight is increased to give a contribution less than 50% (weighting factor < 0.50). The weighted and unweighted average and critical $\chi^2/(n-1)$ are then recalculated: if $\chi^2/(n-1) \leq$ critical $\chi^2/(n-1)$, the recommended value is given by

$$a = a_w \pm (\text{the larger of } \sigma_{int}(a_w) \text{ and } \sigma_{ext}(a_w))$$

If $\chi^2/(n-1) >$ critical $\chi^2/(n-1)$, the weighted or unweighted mean is chosen, depending on whether or not the uncertainties of the average values result in overlap. If overlap occurs, the weighted average is recommended; otherwise the unweighted average is chosen. In either case, the uncertainty can be increased to cover the most accurate value.

2.3. Determination of the best value and associated uncertainty for the γ ray intensities

From the results of the statistical process, as described above, the evaluated γ ray intensities are derived. However, to obtain confident γ ray intensity values, it is necessary to know not only the intensity values themselves but also the rest of the nuclide decay scheme. The overall consistency of the decay scheme being the best check of the quality of γ ray intensities. The goal of the decay data evaluation is to construct the decay scheme of the studied nuclide, i.e. to determine the energy and intensity of all emissions occurring in its decay: α, β^-, β^+, conversion and Auger electrons, γ rays and X rays, as well as the electron capture (EC) probabilities, branching ratios, etc.

When the decay scheme is built, its overall consistency is checked by controlling:

- at each nuclear level in the daughter nucleus, the sum of the probabilities of the transitions populating it is equal to the sum of those depopulating it;
- the total energy carried away by various emissions is equal to the available decay energy;
- the X-ray intensities deduced from the decay scheme data are consistent with the measured ones if available.

In most cases, the determination of the γ-ray energies and intensities is the first step, but to achieve the decay scheme construction other quantities are required:

- for each nuclear level, its energy and the probabilities of the α, β or EC transitions feeding it;
- for each γ transition, its placement in the decay scheme and its related internal conversion coefficients which are measured or theoretically calculated.

However, from time to time, the intensities of the γ rays are derived also from other measurements or physical quantities, for example:

- Sometimes the α emission intensities have been extensively measured, then using the information listed above the same process is conducted but using the α intensities as the starting point.
- The decay scheme characteristics, such as the probability balance, are determined from the knowledge of the internal conversion coefficients, measured or theoretically calculated.

Below the different methods used to obtain the best values for the γ ray intensities and examples illustrating them are given.

a) Evaluation based on relative γ ray intensities and internal conversion coefficients

Most often the γ ray intensities have been measured as *relative* values, i.e. one of the γ rays, generally the most intense, is chosen as a reference line and its intensity is arbitrarily fixed to a certain value (e.g. 100) and the intensity of the other rays are given relative to this reference value.

However, users require *absolute* values, i.e. intensities in percent of nuclide decays. The transformation from relative to absolute values assumes the knowledge of a normalization factor N which is deduced from examination of the decay scheme. One verification of the decay scheme consistency is that for 100% of nuclide decays, 100% of the transitions (α, β, γ, and EC) must populate the ground state of the daughter(s). That is

$$\sum_i I_{\gamma i}[1+\alpha_{Ti}] + \left(P_\beta + P_\alpha + P_{EC}\right) = \frac{100\%}{N}$$

Where the sum $\sum_i I_{\gamma i}[1+\alpha_{Ti}]$ is over the γ transitions feeding the ground state(s); $I_{\gamma i}$ is the relative emission intensity of the ith gamma-ray, α_{Ti} is its total internal conversion coefficient and $P_\beta + P_\alpha + P_{EC}$, is the sum of β, α, EC transitions populating the ground state. N is the normalization factor between the relative and absolute scales.

In the case where there are no α, β or EC transitions to the ground state, N, the normalization factor, is then deduced from the measured $I_{\gamma i}$ values and the related α_{Ti}s and, the associated uncertainty, dN, is calculated following the law of uncertainty propagation:

$$N = \frac{100\%}{\sum_i I_{\gamma i}[1+\alpha_{Ti}]} \quad \text{and} \quad \mathrm{d}N^2 = +\sum_i \left(\frac{\partial N}{\partial I_{\gamma i}}\, dI_{\gamma i}\right)^2 + \sum_i \left(\frac{\partial N}{\partial \alpha_{Ti}}\, d\alpha_{Ti}\right)^2$$

The α_T coefficients are obtained from theoretical calculations or measured values depending on the nuclide. When theoretical coefficients were preferred, in most cases they were interpolated from the tables of Band et al. [12] by using the computer code BrIcc [13] with the so called "Frozen orbital" approximation. In some earlier evaluations, they were interpolated from Rösel et al. tables [14]. For each evaluation, details on this point are refined in Ref. [5].

Example: ^{134}Cs decays by β^--particle emissions to excited levels in ^{134}Ba, none of which populate the ground state, and with a negligible electron capture branch. Several papers have been published, all of which report γ ray intensity values measured relative to the 604 keV γ ray. Measured values of the K conversion coefficients, α_K, have also been reported, and a good agreement was found compared with the theoretical values. Hence by application of the above reasoning, an absolute intensity value of 97.63 (8) % was calculated for the 604 keV γ ray, and all the other absolute intensities were then derived.

b) *Evaluation based on measured absolute γ ray intensities*

From time to time, *absolute* measurements of γ emission intensities are reported. Such measurements suppose that the mass activity of the nuclide under study was measured by using a method which is independent, as far as possible, of the decay scheme, such as the coincidence counting method.

Example: ^{153}Sm decays by β^--particle emissions to various levels in ^{153}Eu, including one to the ground state, hence the normalization can be tricky. Fortunately, several absolute measurements of the main γ emission intensities have been published, especially for the strongest γ ray of 103 keV. The value of 29.19 (16) % was adopted and used to convert all of the other relative γ ray intensities to absolute ones.

c) *Evaluation, from the decay scheme data, based on relative γ ray intensities and theoretical considerations*

In some cases, only the relative γ ray intensities are available but, fortunately, theoretical considerations can help in building the decay scheme.

Example: ^{124}Sb decays by β^{-}-particle emissions to excited levels in ^{124}Te. In 2009 an international exercise was conducted to improve its decay scheme [15], [16], with relative and absolute γ ray intensities determined by several laboratories. Looking at the decay scheme, it was apparent that it would be best to use the relative results and calculated internal conversion coefficients, because the energies of the transitions involved are relatively high and their respective multipolarities are E2, hence the conversion coefficients can be considered very reliable. This process led to the adoption of a value of 97.775 (20) % for the 602 keV γ ray, which compares very favorably with 97.77 (26) % as derived from the measured results.

d) Evaluation based on relative γ ray intensities and other parameters

Special cases may arrive, especially when there is a direct transition from the parent nuclide to the ground state of the daughter nuclide. Ideally, an experimental determination of the transition probability would have been made, but such measurements prove to be particularly difficult.

Example: ^{67}Ga decays by electron capture to excited levels in ^{67}Zn, with an additional transition direct to the ground state. The evaluated relative emission intensities were used, with the absolute emission intensity of the 93 keV γ ray $I(\gamma_{93})$ to calculate the absolute gamma-ray emission intensities. Initially, $I(\gamma_{93})$ was determined from the total internal conversion coefficient $\alpha_T(\gamma_{93})$ theoretically calculated and the evaluated values of the conversion electron intensities $I(ce_{93})$ deduced from measurement results.

e) Evaluation based on α particle emission intensities and balancing the decay scheme

For nuclides decaying by α emission, often several measurements of the α particle emission intensities are available; when, *a contrario*, the γ emission intensities have not been measured or have large uncertainties. In such cases, the construction of the decay scheme starts with the critical examination of the α emission intensity measurement results and the γ transitions are deduced from the decay scheme balance.

Example: ^{211}Bi decays mainly by α particle emission to a single excited level in ^{207}Tl. The available experimental data on the unique γ ray occurring in the ^{211}Bi α decay are discrepant. Therefore, the γ emission intensity was derived from the decay scheme balance using the much more precise values of the α particle intensity.

2.4. Comments on X-ray intensities and 511 keV gamma photons

Electron capture and internal conversion processes give rise to the creation of vacancies in the electronic shells and sub-shells of the daughter atom. The filling of a vacancy is followed by the emission of X-rays or Auger electrons and the creation of new vacancies in less bound shells. The intensities of the various K and L X-rays emitted following the re-arrangement process can be calculated according to parameters of the decay scheme (electron capture and γ transition probabilities, conversion coefficients) and the related atomic constants (fluorescence yields, Coster-Krönig transitions, etc.). They can then be compared with any measured values. Unfortunately, there are typically very few experimental results available. For this reason we do not consider X-rays in this paper.

Nonetheless, X-rays are commonly used, particularly to calibrate γ ray detectors in the 5–20 keV range (e.g. ^{55}Fe) or to control the amount of some actinides (e.g. ^{241}Am) in radioactive waste. Recommended data on X-ray intensities for a number of nuclides can be found in BIPM Monographie-5 [4], [8] and the associated comment files and also in the IAEA report [6], [7].

When a β^+ transition occurs, the positron annihilates with an electron of the medium being traversed, which leads to the creation of two γ photons of energy 511 keV. This 511 keV emission is extensively used in nuclear medicine imaging (PET) and is also employed in γ spectrometry techniques to determine the activity of a β^+ emitter in a solution [17].

It is noteworthy that a positron can annihilate before completely slowing down, then the two emitted photons have energies greater than m_0c^2, as would be obtained from annihilation at rest. In γ ray spectrometry, this phenomenon has the effect of removing, from the 511 keV peak, a fraction of the annihilation photons, producing a continuous photon spectrum. To take this effect into account the energy of this line is given as 511 keV *without uncertainty* since the energy is not exactly 511 keV. The magnitude of this effect depends on the material within which the positrons are stopped, such that the intensity of the 511 keV ray does not have a unique value but must be determined taking into account the experimental set-up.

As a rule, the adopted 511 keV ray emission intensity is two times the positron emission intensity (evaluation method “f” in Table 3).

3. Recommended gamma ray intensities

In Table 2 a list of chosen radionuclides is given. It corresponds to the list of nuclides for which decay data were evaluated by the DDEP collaboration up to the end of 2012 [5], [15].

Table 2. Nuclides and applications.

Nuclide	**Interest or applications (1)**	**Interest or applications (2)**
Be-7	Nuclear probe Am–Be	Detector efficiency calibration
C-11	PET	Nuclear astrophysics
N-13	PET	Nuclear astrophysics
O-15	PET	Nuclear astrophysics
F-18	PET	Nuclear astrophysics
Na-22	Medical applications	
Na-24	Detector efficiency calibration	
Al-26	Activation product	Nuclear astrophysics
K-40	Naturally occurring	
Ar-41	Environmental monitoring	

Nuclide	**Interest or applications (1)**	**Interest or applications (2)**
Sc-44	PET pre-therapeutic dosimetry	
Ti-44	Detector efficiency calibration	Nuclear astrophysics
Sc-46	Medical and technical applications	Nuclear astrophysics
Ca-47	Medical applications	
Sc-47	Medical applications	
Cr-51	Detector efficiency calibration	
Fe-52	Medical applications	
Mn-52	Medical applications	
Mn-52m	Medical applications	
Mn-54	Detector efficiency calibration	Activation product
Co-56	Detector efficiency calibration	
Mn-56	Detector efficiency calibration	
Co-57	Detector efficiency calibration	
Ni-57	Fusion reactors	
Co-58	Detector efficiency calibration	
Fe-59	Detector efficiency calibration	Medical applications
Co-60	Detector efficiency calibration	Medical applications
Cu-64	Reactor neutron fluence	PET pre-therapeutic dosimetry
Zn-65	Detector efficiency calibration	Environmental monitoring
Ga-66	Detector efficiency calibration	
Ga-67	Detector efficiency calibration	Medical applications
Ga-68	Medical applications	
Se-75	Detector efficiency calibration	

Nuclide	**Interest or applications (1)**	**Interest or applications (2)**
Kr-85	Technical applications	Environmental monitoring
Sr-85	Detector efficiency calibration	
Rb-86	Fission product	
Rb-88	Fission product	
Y-88	Detector efficiency calibration	
Y-90m	Fission product	
Sr-92	Rb-82 generator	
Y-92	Fission product	
Nb-95	Environmental monitoring	
Nb-95m	Environmental monitoring	
Zr-95	Reactor neutron fluence	Activation and fission product
Mo-99	Tc-99m generator	Fission yield determination
Tc-99m	Medical applications	
Rh-106	Fission product	
Ag-108	Fission product	Environmental monitoring
Ag-108m	Fission product	Waste management
Cd-109	Detector efficiency calibration	
Pd-109	Fission product	
Ag-110	Fission product	Environmental monitoring
Ag-110m	Detector efficiency calibration	Environmental monitoring
In-111	Detector efficiency calibration	Medical applications
In-113m	Medical applications	
Sn-113	In-113m generator	
I-123	Medical applications	

Nuclide	**Interest or applications (1)**	**Interest or applications (2)**
Te-123m	Detector efficiency calibration	
Sb-124	Fission product	Detector efficiency calibration
I-125	Medical applications	Detector efficiency calibration
Sb-126	Fission product	Waste management—daughter of Sn-126
Sn-126	Fission product	
Sb-127	Fission product	Fission yield determination
Xe-127	Fission product	
I-129	Fission product	Environmental monitoring—waste management
I-131	Medical applications	Reactor neutron fluence
Xe-131m	Fission product	
Te-132	Fission product	Reactor neutron fluence
Ba-133	Detector efficiency calibration	
I-133	Fission product	Environmental monitoring
Xe-133	Safeguards	Signature of atomic explosion
Xe-133m	Safeguards	Signature of atomic explosion
Cs-134	Fission product	Gamma standard
Xe-135m	Safeguards	Signature of atomic explosion
Cs-137	Detector efficiency calibration	Environmental monitoring—interim storage
Ce-139	Detector efficiency calibration	
Ba-140	Signature of atomic explosion	Burn up monitor
La-140	Signature of atomic explosion	Burn up monitor
Ce-141	Detector efficiency calibration	
Ce-144	Fission product	Burn up monitor
Pr-144	Fission product	Burn up monitor

Nuclide	**Interest or applications (1)**	**Interest or applications (2)**
Nd-147	Reactor neutron fluence	Burn up monitor
Eu-152	Detector efficiency calibration	
Gd-153	Medical applications	
Sm-153	Medical applications	Safeguards
Eu-154	Safeguards	Pu/U ratio in fuel
Eu-155	Fission product	Burn up monitor
Gd-159	Medical applications	
Ho-166	Detector efficiency calibration	Medical applications
Ho-166m	Detector efficiency calibration	
Yb-169	Detector efficiency calibration	
Tm-170	Medical applications	
Lu-176	Naturally occurring	
Lu-177	Medical applications	
Ta-178	Medical applications	
Ta-182	Detector efficiency calibration	
Re-186	Medical applications	
Re-188	Medical applications	
Ir-192	Medical applications	
Ir-194	Medical applications	
Au-195	Medical applications	
Au-198	Detector efficiency calibration	
Tl-201	Medical applications	
Hg-203	Detector efficiency calibration	
Pb-203	Medical applications	

Nuclide	**Interest or applications (1)**	**Interest or applications (2)**
Hg-206	Naturally occurring—U-238 chain	
Bi-207	Detector efficiency calibration	
Tl-208	Naturally occurring—Th-232 chain	
Tl-209	Np-237–Ra-225 chain	
Pb-210	Detector efficiency calibration	
Tl-210	Naturally occurring—U-238 chain	
Bi-211	Naturally occurring—U-235 chain	
Pb-211	Naturally occurring—U-235 chain	
Bi-212	Naturally occurring—Th-232 chain	Medical applications
Pb-212	Naturally occurring—Th-232 chain	Medical applications
Bi-213	Medical applications	
Bi-214	Naturally occurring—U-238 chain	
Pb-214	Naturally occurring—U-238 chain	
Bi-215	Naturally occurring—U-235 chain	
Rn-219	Naturally occurring—U-235 chain	
Fr-221	Np-237—Ra-225 chain	
Fr-223	Naturally occurring—U-235 chain	

Nuclide	**Interest or applications (1)**	**Interest or applications (2)**
Ra-223	Naturally occurring—U-235 chain	
Ra-224	Naturally occurring—Th-232 chain	
Ac-225	Np-237–Ra-225 chain	
Ra-225	Np-237–Ra-225 chain	
Ra-226	Naturally occurring—U-238 chain	Detector efficiency calibration
Ac-228	Naturally occurring—Th-232 chain	
Ra-228	Naturally occurring—Th-232 chain	
Th-228	Naturally occurring—Th-232 chain	
Pa-231	Naturally occurring—U-235 chain	
Th-231	Naturally occurring—U-235 chain	
Pa-233	Np-237 daughter	Thorium fuel cycle
Th-233	Thorium fuel cycle	
Pa-234	Naturally occurring—U-238 chain	
Th-234	Naturally occurring—U-238 chain	
U-235	Naturally occurring	Accurate mass determination
Np-236	Nuclear fuel cycle	Waste management
Np-236M	Nuclear fuel cycle	
Np-237	Waste management	Accurate mass determination for reactor neutron fluence

Nuclide	**Interest or applications (1)**	**Interest or applications (2)**
U-237	Nuclear fuel cycle	Radiation dose calculation
Np-238	Nuclear fuel cycle	
Np-239	Nuclear fuel cycle	
U-239	Nuclear fuel cycle	Short term decay heat
Am-241	Waste management	Detector efficiency calibration
Am-243	Waste management	Neutron capture measurements
Cm-243	Nuclear fuel cycle	
Am-244	Waste management	
Cm-245	Nuclear fuel cycle	

Applications of the isotopes listed are shown in the second and third columns of this table.

In Table 3 the recommended gamma ray intensities, greater than 1%, are presented (fourth column). In addition, the half-lives, the gamma-ray energies and the total internal conversion coefficients (ICC T) are also given, as recommended and published by the DDEP.

Table 3. Recommended γ ray intensities (>1%). Uncertainty (in parenthesis) given is the combined uncertainty at one standard deviation.

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
Be-7	53.22 (6) d	477.6035 (20)	10.44 (4)[c]	$7.3\ (11)\ 10^{-7}$
C-11	20.361 (23) min	511	199.500 (26)[f]	
N-13	9.9670 (37) min	511	199.636 (26)[f]	
O-15	2.041 (6) min	511	199.770 (12)[f]	
F-18	1.8288 (3) h	511	193.72 (27)[f]	
Na-22	2.6029 (8) a	511	180.7 (2)[f]	
		1274.537 (7)	99.94 (13)[c]	$6.71\ (9)\ 10^{-6}$
Na-24	14.9574 (20) h	1368.626 (5)	99.9935 (5)[c]	$1.04\ 10^{-5}$
		2754.007 (11)	99.872 (8)[c]	$2.8\ 10^{-6}$

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
Al-26	717 (24) 10^{3} a	511	163.5 (4)[f]	
		1129.67 (10)	2.5 (2)[c]	1.25 10^{-5}
		1808.65 (7)	99.76 (4)[a]	6.33 10^{-6}
K-40	1.2504 (30) 10^{9} a	1460.822 (6)	10.55 (11)[c]	1.028 (15) 10^{-4}
Ar-41	109.611 (38) min	1293.64 (4)	99.157 (20)[a]	7.44 (11) 10^{-5}
Sc-44	3.97 (4) h	511	188 (3)[b]	
		1157.020 (15)	99.875 (3)[a]	6.48 (19) 10^{-5}
Ti-44	60.0 (11) a	67.8679 (14)	93.0 (15)[a]	8.45 (25) 10^{-2}
		78.36 (3)	96.4 (11)[a]	3.2 (1) 10^{-2}
Sc-46	83.788 (22) d	889.271 (2)	99.9833 (5)[c]	1.67 (5) 10^{-4}
		1120.537 (3)	99.986 (36)[c]	9.5 (3) 10^{-5}
Ca-47	4.536 (3) d	489.23 (10)	6.9 (4)[c]	
		807.86 (10)	6.8 (4)[c]	
		1297.09 (10)	75 (2)[c]	
Sc-47	3.3492 (6) d	159.381 (15)	68.3 (4)[b]	4.5 (3) 10^{-3}
Cr-51	27.703 (3) d	320.0824 (4)	9.87 (3)[**][b]	1.69 (5) 10^{-3}
Fe-52	8.275 (8) h	168.688 (2)	99.2 (3)[c]	8.0 (1) 10^{-3}
		511	112 (2)[f]	
Mn-52	5.591 (3) d	346.03 (3)	1.01 (3)[a]	
		511	58.8 (8)[f]	
		744.214 (5)	90.34 (10)[a]	3.4 (3) 10^{-4}
		848.13 (3)	3.35 (2)[a]	
		935.52 (1)	94.90 (5)[a]	1.8 (2) 10^{-4}
		1246.25 (1)	4.23 (4)[a]	

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		1333.615 (12)	5.07 (3)[a]	
		1434.05 (1)	99.987 (2)[a]	6.9 (7) 10^{-5}
Mn-52m	21.1 (2) min	377.738 (5)	1.68 (2)[c]	
		511	193 (4)[f]	
		1434.05 (1)	98.2 (2)[c]	
Mn-54	312.13 (3) d	834.838 (5)	99.9746 (11)[c]	2.51 (11) 10^{-4}
Co-56	77.236 (26) d	511	39.21 (22)[f]	
		846.7638 (19)	99.9399 (23)[c]	3.03 (9) 10^{-4}
		977.363 (4)	1.422 (7)[b]	
		1037.8333 (24)	14.03 (5)[b]	
		1175.0878 (22)	2.249 (9)[b]	
		1238.2736 (22)	66.41 (16)[b]	
		1360.196 (4)	4.280 (13)[b]	
		1771.327 (3)	15.45 (4)[b]	
		2015.176 (5)	3.017 (14)[b]	
		2034.752 (5)	7.741 (13)[b]	
		2598.438 (4)	16.96 (4)[b]	
		3009.559 (4)	1.038 (19)[b]	
		3201.930 (11)	3.203 (13)[b]	
		3253.402 (5)	7.87 (3)[b]	
		3272.978 (6)	1.855 (9)[b]	
Mn-56	2.57878 (46) h	846.7638 (19)	98.85 (3)[c]	3.00 (9) 10^{-4}
		1810.726 (4)	26.9 (4)[c]	5.10 (15) 10^{-5}
		2113.092 (6)	14.2 (3)[c]	

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		2523.06 (5)	1.02 (2)[c]	
Co-57	271.80 (5) d	14.41295 (31)	9.15 (17)[c]	8.58 (18)
		122.06065 (12)	85.51 (6)[a]	2.36 (5) 10^{-2}
		136.47356 (29)	10.71 (15)[a]	0.148 (3)
Ni-57	35.9 (3) h	127.164 (3)	16.0 (5)[a]	2.15 (6) 10^{-2}
		511	86.8 (12)[f]	
		1377.62 (4)	81.2 (6)[a]	1.05 (3) 10^{-4}
		1757.55 (3)	6.1 (4)[a]	
		1919.62 (14)	12.5 (5)[a]	
Co-58	70.83 (10) d	511	30.0 (4)[f]	
		810.759 (2)	99.45 (1)[a]	3.4 (1) 10^{-4}
Fe-59	44.495 (8) d	192.349 (5)	2.918 (29)[b]	8.99 (15) 10^{-3}
		1099.245 (3)	56.59 (21)[b]	1.75 (5) 10^{-4}
		1291.590 (6)	43.21 (25)[b]	1.22 (4) 10^{-4}
Co-60	5.2711 (8) a	1173.228 (3)	99.85 (3)[d,c]	1.68 (4) 10^{-4}
Co-60	5.2711 (8) a	1332.492 (4)	99.9826 (6)[d,c]	1.28 (5) 10^{-4}
Cu-64	12.7004 (20) h	511	35.04 (30)[f]	
Zn-65	244.01 (9) d	511	2.842 (13)[b]	
		1115.539 (2)	50.22 (11)[b]	1.84 (7) 10^{-4}
Ga-66	9.49 (7) h	511	112 (8)[f]	
		833.5324 (21)	5.9 (5)c	
		1039.220 (3)	37 (3)[c]	
		1333.112 (5)	1.17 (9)[c]	
		1918.329 (5)	1.99 (16)[c]	

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		2189.616 (6)	5.3 (4)[c]	
		2422.525 (7)	1.88 (15)[c]	
		2751.835 (5)	22.7 (18)[c]	
		3228.800 (6)	1.51 (12)[c]	
		3380.850 (6)	1.46 (12)[c]	
		3791.004 (8)	1.09 (9)[c]	
		4085.853 (9)	1.27 (10)[c]	
		4295.187 (10)	3.8 (3)[c]	
		4806.007 (9)	1.86 (15)[c]	
Ga-67	3.2613 (5) d	91.263 (15)	3.09 (7)[d]	9.1 (6) 10^{-2}
		93.307 (12)	38.1 (7)[d]	0.854 (12)
		184.577 (17)	20.96 (44)[d]	1.69 (21) 10^{-2}
		208.939 (15)	2.37 (5)[d]	9.01 (14) 10^{-3}
		300.232 (21)	16.60 (37)[d]	3.88 (6) 10^{-3}
		393.528 (20)	4.59 (10)[d]	1.93 (3) 10^{-3}
Ga-68	67.83 (20) min	511	179.8 (8)[f]	
		1077.34 (5)	3.235 (30)[b]	2.47 (4) 10^{-4}
Se-75	119.781 (24) d	66.0518 (8)	1.053 (20)[b]	0.33 (3)
		96.7340 (9)	3.35 (7)[b]	0.893 (13)
		121.1155 (11)	16.86 (36)[b]	4.17 (6) 10^{-2}
		136.0001 (6)	57.7 (20)[b]	2.95 (5) 10^{-2}
		198.6060 (12)	1.46 (6)[b]	1.89 (11) 10^{-2}
		264.6576 (9)	58.75 (19)[b]	7.2 (3) 10^{-3}
		279.5422 (10)	24.89 (9)[b]	9.1 (4) 10^{-3}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		303.9236 (10)	1.308 (5)[b]	5.38 (8) 10^{-2}
		400.6572 (8)	11.388 (42)[b]	1.346 (19) 10^{-3}
Kr-85	10.752 (23) a	514.0048 (22)	0.435 (10)[b]	7.21 (22) 10^{-3}
Sr-85	64.850 (7) d	514.0048 (22)	98.5 (4)[c]	7.21 (22) 10^{-3}
Rb-86	18.642 (18) d	1076.78 (5)	8.71 (5)[b]	4.9 10^{-4}
Rb-88	17.773 (11) min	898.036 (4)	14.68 (13)[b**]	3.2 (2) 10^{-4}
		1836.052 (13)	22.73 (15)[b**]	
		2677.86 (4)	2.123 (21)[b**]	
Y-88	106.626 (21) d	898.036 (4)	93.90 (23)[c]	3.15 (23) 10^{-4}
		1836.052 (13)	99.32 (3)[c]	1.52 (15) 10^{-4}
Y-90m	3.19 (6) h	202.53 (3)	97.1 (14)[a]	2.72 (8) 10^{-2}
		479.51 (7)	90.97 (24)[a]	9.57 (29) 10^{-2}
Sr-92	2.66 (4) h	241.52 (3)	3.0 (1)[c]	
		430.56 (5)	3.3 (2)[c]	
		953.32 (9)	3.5 (2)[c]	
		1142.3 (1)	2.8 (2)[c]	
		1384.94 (6)	90.0 (3)[c]	
Y-92	3.54 (2) h	448.5 (1)	2.28 (20)[b]	5.90 (15) 10^{-3}
		561.1 (1)	2.39 (20)[b]	3.3 (1) 10^{-3}
		844.3 (1)	1.25 (12)[b]	
		934.5 (1)	13.9 (13)[b]	7.8 (2) 10^{-4}
		1405.4 (1)	4.8 (4)[b]	1.6 (1) 10^{-4}
Nb-95	34.991 (6) d	765.803 (6)	99.808 (7)[c]	1.47 (4) 10^{-3}
Nb-95m	3.61 (3) d	204.117 (2)	2.28 (10)[d,c]	5.15 (22) 10^{-2}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		235.69 (2)	25.1 (3)[d,c]	2.88 (9)
Zr-95	64.032 (6) d	724.193 (3)	44.27 (22)[d,c]	1.57 (5) 10^{-3}
		756.729 (12)	54.38 (22)[d,c]	1.42 (4) 10^{-3}
Mo-99	2.7479 (6) d	40.58323 (17)	1.022 (27)[b]	4.18 (13)
		140.511 (1)	89.6 (17)[b]	0.119 (3)
		181.068 (8)	6.01 (11)[b]	0.149 (3)
		366.421 (15)	1.194 (23)[b]	9.15 (18) 10^{-3}
		739.500 (17)	12.12 (15)[b]	1.73 (4) 10^{-3}
		777.921 (20)	4.28 (8)[b]	5.89 (12) 10^{-4}
Tc-99m	6.0067 (10) h	140.511 (1)	88.5 (2)[b,c,d]	0.119 (3)
Rh-106	30.1 (3) s	511.8534 (23)	20.52 (23)[b]	5.59 (8) 10^{-3}
		621.90 (4)	9.87 (15)[b]	3.24 (5) 10^{-3}
		1050.39 (3)	1.490 (25)[b]	1.007 (15) 10^{-3}
Ag-108	2.382 (11) min	632.98 (5)	1.62 (26)[c,d]	3.47 (10) 10^{-3}
Ag-108m	438 (9) a	79.131 (3)	6.9 (5)[c,d]	0.310 (9)
		433.938 (5)	90.1 (6)[c,d]	9.09 (27) 10^{-3}
		614.276 (4)	90.5 (16)[c,d]	3.35 (10) 10^{-3}
		722.907 (10)	90.8 (16)	2.19 (7) 10^{-3}
Cd-109	461.4 (12) d	88.0336 (10)	3.628 (28)[b**]	26.58 (20)
Pd-109	13.58 (12) h	88.0336 (10)	3.66 (6)[a]	26.58(20)
Ag-110	24.56 (11) s	657.7600 (11)	4.6 (4)[c]	3.18 (9) 10^{-3}
Ag-110m	249.78 (2) d	446.812 (3)	3.65 (5)[c,d]	8.9 (3) 10^{-3}
		620.3553 (17)	2.72 (8)[c,d]	3.97 (12) 10^{-3}
		657.7600 (11)	94.38 (8)[c,d]	3.18 (9) 10^{-3}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		677.6217 (12)	10.56 (6)[c,d]	3.24 (10) 10^{-3}
		687.0091 (18)	6.45 (3)[c,d]	2.92 (9) 10^{-3}
		706.6760 (15)	16.48 (8)[c,d]	2.75 (8) 10^{-3}
		744.2755 (18)	4.71 (3)[c,d]	2.32 (7) 10^{-3}
		763.9424 (17)	22.31 (9)[c,d]	2.30 (9) 10^{-3}
		818.0244 (18)	7.33 (4)[c,d]	1.94 (6) 10^{-3}
		884.6781 (13)	74.0 (12)[c,d]	1.52 (5) 10^{-3}
		937.485 (3)	34.51 (27)[c,d]	1.33 (4) 10^{-3}
		1384.2931 (20)	24.7 (5)[c,d]	6.5 (2) 10^{-4}
		1475.7792 (23)	4.03 (5)[c,d]	5.1 (2) 10^{-4}
		1505.028 (2)	13.16 (16)[c,d]	4.5 (1) 10^{-4}
		1562.2940 (18)	1.21 (3)[c,d]	
In-111	2.8049 (4) d	171.28 (3)	90.61 (20)[c]	0.1036 (24)
		245.35 (4)	94.12 (6)[c]	6.25 (7) 10^{-2}
In-113m	1.658 (5) h	391.698 (3)	64.85 (25)[a]	0.542 (6)
Sn-113	115.09 (3) d	255.134 (10)	2.095 (21)[a**]	4.6 (6) 10^{-2}
		391.698 (3)	64.85 (25)[a**]	0.542 (6)
I-123	13.2234 (37) h	158.97 (5)	83.31 (20)[a,b**]	0.1918 (19)
		528.96 (5)	1.25 (3)[a,b**]	
Te-123m	119.3 (1) d	158.97 (5)	83.99 (8)[b]	0.1918 (19)
Sb-124	60.208 (11) d	602.7260 (23)	97.775 (20)[c]	4.90 (7) 10^{-3}
		645.8520 (19)	7.422 (15)[c]	4.09 (6) 10^{-3}
		709.33 (2)	1.363 (5)[c]	4.02 (6) 10^{-3}
		713.776 (4)	2.273 (7)[c]	3.6 (4) 10^{-3}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		722.782 (3)	10.708 (22)[c]	3.14 (5) 10^{-3}
		968.195 (4)	1.887 (10)[c]	6.53 (11) 10^{-4}
		1045.125 (4)	1.852 (14[c]	5.67 (10) 10^{-4}
		1325.504 (4)	1.587 (7)[c]	8.27 (12) 10^{-4}
		1355.20 (2)	1.0412 (38)[c]	1.1 (5) 10^{-3}
		1368.157 (5)	2.620 (8)[c]	4.78 (7) 10^{-4}
		1436.554 (7)	1.234 (8)[c]	7.8 (5) 10^{-4}
		1690.971 (4)	47.46 (19)[c]	6.15 (9) 10^{-4}
		2090.930 (7)	5.493 (24)[c]	8.38 (12) 10^{-4}
I-125	59.388 (28) d	35.4925 (5)	6.63 (6)[b]	14.08(22)
Sb-126	12.35 (6) d	223.3 (2)	1.4 (2)[a]	
		278.6 (2)	2.2 (2)[a]	
		296.6 (2)	4.9 (4)[a]	3.56 (4) 10^{-2}
		414.4 (3)	83.6 (21)[a]	1.408 (20) 10^{-2}
		414.9 (3)	1.0 (3)[a]	
		555.0 (3)	1.8 (2)[a]	
		573.8 (2)	6.7 (3)[a]	
		593.0 (2)	7.5 (5)[a]	
		656.3 (2)	2.2 (1)[a]	
		666.1 (2)	99.68 (5)[a]	3.2 (1) 10^{-3}
		675.0 (2)	3.7 (8)[a]	
		695.0 (2)	99.68 (5)[a]	3.2 (1) 10^{-3}
		697.0 (2)	32 (6) a	
		720.3 (3)	53.8 (24)[a]	

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		856.7 (2)	17.5 (9)[a]	8.32 (12) 10^{-4}
		954.0 (2)	1.5 (5)[a]	
		989.3 (2)	6.8 (3)[a]	
		1034.9 (2)	1.00 (5)[a]	
		1213.0 (2)	2.3 (2)[a]	
Sn-126	2.38 (6) 10^{5} a	21.65 (1)	1.26 (18)[c]	2.09 (3)
		23.28 (1)	6.4 (9)[c]	6.07 (9)
		64.28 (1)	9.6 (15)[c]	0.651 (10)
		86.94 (1)	8.9 (13)[c]	2.71 (4)
		87.57 (10)	37 (4)[c]	0.274 (4)
Sb-127	3.85 (7) d	61.16 (2)	1.140 (14)[c,d]	4.2 (3)
		252.64 (9)	8.28 (14)[c,d]	6.52 (17) 10^{-2}
		290.5 (1)	1.84 (7)[c,d]	3.79 (6) 10^{-2}
		412.10 (5)	3.43 (18)[c,d]	1.431 (20) 10^{-2}
		445.3 (1)	4.18 (11)[c,d]	1.20 (4) 10^{-2}
		473.26 (4)	24.8 (7)[c,d]	1.072 (16) 10^{-2}
		543.2 (1)	2.62 (11)[c,d]	6.48 (9) 10^{-3}
		603.9 (2)	4.21 (11)[c,d]	5.92 (9) 10^{-3}
		685.09 (7)	35.4 (4)[c,d]	3.52 (5) 10^{-3}
		697.9 (1)	3.36 (18)[c,d]	3.36 (5) 10^{-3}
		721.5 (1)	1.77 (7)[c,d]	3.09 (5) 10^{-3}
		782.6 (1)	14.7 (3)[c,d]	3.19 (5) 10^{-3}
Xe-127	36.375 (20) d	57.608 (11)	1.274 (35)[b]	3.72 (6)
		145.252 (14)	4.23 (7)[b]	0.471 (7)

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[a]	ICC T
		172.132 (12)	25.53 (38)[b]	0.1650 (24)
		202.86 (1)	68.45 (45)[b]	0.1131 (18)
		374.991 (12)	17.26 (27)[b]	1.99 (3) 10^{-2}
I-129	16.1 (7) 10^{6} a	39.578 (4)	7.42 (8)[c]	12.41 (13)
I-131	8.0233 (19) d	80.1850 (19)	2.607 (27)[c,d]	1.579 (47)
		284.305 (5)	6.06 (6)[c,d]	5.00 (15) 10^{-2}
		364.489 (5)	81.2 (8)[c,d]	2.29 (7) 10^{-2}
		636.989 (4)	7.26 (8)[c,d]	4.74 (14) 10^{-3}
		722.911 (5)	1.796 (20)[c,d]	4.61 (14) 10^{-3}
Xe-131m	11.930 (16) d	163.930 (8)	1.98 (6)[c]	49.6 (15)
Te-132	3.230 (13) d	49.72 (1)	15.1 (3))[a]	5.62 (8)
		111.81 (8)	1.85 (18)[a]	0.71 (3)
		116.34 (13)	1.97 (7)[a]	0.606 (20)
		228.327 (3)	88.12 (13)[a]	9.90 (14) 10^{-2}
Ba-133	10.540 (6) a	53.1622 (6)	2.14 (3)[b]	6.02 (18)
		79.6142 (12)	2.65 (5)[b]	1.77 (4)
		80.9979 (11)	32.9 (3)[b]	1.74 (4)
		276.3989 (12)	7.16 (5)[b]	5.69 (12) 10^{-2}
		302.8508 (5)	18.34 (13)[b]	4.43 (9) 10^{-2}
		356.0129 (7)	62.05 (19)[b]	2.56 (5) 10^{-2}
		383.8485 (12)	8.94 (6)[b]	2.03 (4) 10^{-2}
I-133	20.87 (8) h	510.530 (22)	1.81 (6)[c]	
		529.8709 (30)	86.3 (2)[c]	8.10 (14) 10^{-3}
		706.575 (6)	1.49 (4)[c]	4.2 (6) 10^{-3}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		856.278 (9)	1.23 (4)[c]	2.35 (3) 10^{-3}
		875.328 (5)	4.47 (12)[c]	2.18 (3) 10^{-3}
		1236.443 (5)	1.49 (4)[c]	
		1298.227 (5)	2.33 (7)[c]	9.72 (14) 10^{-4}
Xe-133	5.2474 (5) d	80.9979 (11)	37.0 (3)[a]	1.698 (24)
Xe-133m	2.198 (13) d	233.219 (15)	10.16 (13)[c]	8.84 (13)
Cs-134	2.0644 (14) a	475.365 (2)	1.479 (7)[a]	1.14 (5) 10^{-2}
		563.246 (3)	8.342 (15)[a]	7.14 (10) 10^{-3}
		569.330 (2)	15.368 (21)[a]	9.36 (14) 10^{-3}
		604.720 (3)	97.63 (8)[a]	5.93 (9) 10^{-3}
		795.86 (1)	85.47 (9)[a]	3.02 (5) 10^{-3}
		801.950 (6)	8.694 (16)[a]	2.97 (5) 10^{-3}
		1167.967 (4)	1.791 (5)[a]	1.307 (19) 10^{-3}
		1365.194 (4)	3.019 (8)[a]	9.87 (14) 10^{-4}
Xe-135m	15.30 (3) min	526.570 (5)	80.84 (20)[c]	0.237 (3)
Cs-137	30.05 (8) a	661.657 (3)	84.99 (20)[b,c]	0.1102 (19)
Ce-139	137.641 (20) d	165.8575 (11)	79.90 (4)[c,d]	0.2516 (7)
Ba-140	12.753 (4) d	13.849 (4)	1.15 (3)[b]	56.6 (11)
		29.9656 (15)	14.32 (25)[b]	5.55 (11)
		162.6628 (24)	6.26 (9)[b]	0.282 (6)
		304.872 (4)	4.30 (4)[b]	5.19 (10) 10^{-2}
		423.721 (4)	3.11 (3)[b]	2.22 (4) 10^{-2}
		437.569 (3)	1.927 (19)[b]	2.05 (4) 10^{-2}
		537.303 (6)	24.39 (22)[b]	1.22 (2) 10^{-2}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
La-140	1.67850 (17) d	328.761 (4)	20.8 (3)[a]	4.64 (14) 10^{-2}
		432.513 (8)	2.995 (16)[a]	2.14 (7) 10^{-2}
		487.022 (6)	46.1 (4)[a]	1.17 (4) 10^{-2}
		751.653 (7)	4.392 (24)[a]	5.64 (17) 10^{-3}
		815.781 (6)	23.72 (12)[a]	4.82 (14) 10^{-3}
		867.839 (16)	5.58 (3)[a]	1.14 (4) 10^{-3}
		919.533 (10)	2.730 (23)[a]	2.590 (9) 10^{-2}
		925.198 (7)	7.04 (4)[a]	3.57 (11) 10^{-3}
		1596.203 (13)	95.40 (8)[a]	7.9 (2) 10^{-4}
		2521.390 (14)	3.412 (24)[a]	3.37 (10) 10^{-4}
Ce-141	32.503 (11) d	145.4433 (14)	48.29 (19)[b]	0.449 (7)
Ce-144	284.91 (5) d	80.120 (5)	1.36 (6)[b]	2.50 (3)
		133.515 (2)	11.1 (2)[b]	0.580 (6)
Pr-144	17.29 (3) min	696.510 (3)	1.34 (2)[b]	5 10^{-4}
Nd-147	10.987 (11) d	91.105 (2)	28.4 (18)[a]	2.03 (3)
		319.411 (18)	1.991 (19)[a]	6.07 (9) 10^{-2}
		439.895 (22)	1.203 (11)[a]	2.48 (4) 10^{-2}
		531.016 (22)	12.7 (9)[a]	1.61 (3) 10^{-2}
Eu-152	13.522 (16) a	121.7817 (3)	28.41 (13)[b]	1.165 (35)
		244.6974 (8)	7.55 (4)[b]	0.1080 (32)
		344.2785 (12)	26.59 (12)[b]	3.99 (12) 10^{-2}
		411.1165 (12)	2.238 (10)[b]	2.39 (7) 10^{-2}
		443.965 (3)	2.80 (2)[b]	6.00 (18) 10^{-3}
		778.9045 (24)	12.97 (6)[b]	1.90 (6) 10^{-3}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		867.380 (3)	4.243 (23)[b]	3.5 (1) 10^{-3}
		964.079 (18)	14.50 (6)[b]	2.70 (8) 10^{-3}
		1085.837 (10)	10.13 (6)[b]	2.10 (6) 10^{-3}
		1089.737 (5)	1.73 (1)[b]	2.30 (7) 10^{-3}
		1112.076 (3)	13.41 (6)[b]	2.00 (6) 10^{-3}
		1212.948 (11)	1.416 (9)[b]	7.00 (21) 10^{-4}
		1299.142 (8)	1.633 (9)[b]	7.00 (21) 10^{-4}
		1408.013 (3)	20.85 (8)[b]	6.00 (18) 10^{-4}
Gd-153	240.4 (10) d	69.67300 (13)	2.42 (7)[b]	5.31 (8)
		97.43100 (21)	29.0 (8)[b]	0.305 (5)
		103.18012 (17)	21.1 (6)[b]	1.694 (24)
Sm-153	1.92855 (5) d	69.67300 (13)	4.691 (41)[b]	5.28 (16)
		103.18012 (17)	29.19 (16)[b]	1.69 (5)
Eu-154	8.601 (4) a	123.0706 (9)	40.4 (5)[a,c]	1.197 (19)
		247.9288 (7)	6.89 (7)[a,c]	0.110 (2)
		591.755 (3)	4.95 (5)[a,c]	3.29 (10) 10^{-3}
		692.4205 (18)	1.79 (3)[a,c]	4.9 (6) 10^{-2}
		723.3014 (22)	20.05 (21)[a,c]	2.15 (5) 10^{-3}
		756.8020 (23)	4.53 (5)[a,c]	5.1 (12) 10^{-3}
		873.1834 (23)	12.17 (12)[a,c]	3.73 (8) 10^{-3}
		996.25 (5)	10.5 (1)[a,c]	2.79 (6) 10^{-3}
		1004.718 (7)	17.86 (18)[a,c]	2.76 (6) 10^{-3}
		1274.429 (4)	34.9 (3)[a,c]	7.37 (15) 10^{-4}
		1596.4804 (28)	1.783 (17)[a,c]	4.9 (1) 10^{-4}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
Eu-155	4.753 (14) a	45.299 (1)	1.31 (5)[b]	0.443 (11)
		60.0086 (10)	1.22 (5)[b]	9.48 (11)
		86.5479 (10)	30.7 (3)[b]	0.432 (7)
		105.3083 (10)	21.1 (6)[b]	0.255 (3)
Gd-159	18.479 (7) h	58.0000 (22)	2.49 (7)[b]	11.1 (3)
		363.5430 (18)	11.78 (5)[b]	1.04 (3) 10^{-2}
Ho-166	26.795 (29) h	80.5725 (13)	6.55 (8)[b]	6.90 (14)
Ho-166m	1132.6 (39) a[***]	80.5725 (13)	12.66 (23)[d]	6.90 (14)
		184.4107 (11)	72.5 (3)[d]	0.334 (7)
		215.871 (7)	2.66 (17)[d]	0.197 (4)
		259.736 (10)	1.078 (10)[d]	0.1087 (22)
		280.4630 (23)	29.54 (25)[d]	8.55 (17) 10^{-2}
		300.741 (3)	3.73 (3)[d]	6.91 (14) 10^{-2}
		365.768 (6)	2.46 (4)[d]	3.88 (8) 10^{-2}
		410.956 (3)	11.35 (17)[d]	8.78 (26) 10^{-3}
		451.540 (4)	2.915 (14)[d]	7.07 (21) 10^{-3}
		464.798 (6)	1.25 (4)[d]	2.01 (6) 10^{-2}
		529.825 (4)	9.4 (4)[d]	1.44 (3) 10^{-2}
		570.995 (5)	5.43 (20)[d]	4.21 (13) 10^{-3}
		611.579 (6)	1.31 (21)[d]	3.64 (11) 10^{-3}
		670.526 (4)	5.34 (21)[d]	8.16 (24) 10^{-3}
		691.253 (7)	1.32 (7)[d]	7.58 (23) 10^{-3}
		711.697 (3)	54.9 (9)[d]	2.66 (8) 10^{-3}
		752.280 (4)	12.2 (3)[d]	2.38 (7) 10^{-3}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		778.827 (6)	3.01 (8)[d]	5.79 (17) 10^{-3}
		810.286 (4)	57.3 (11)[d]	5.3 (1) 10^{-3}
		830.565 (4)	9.72 (18)[d]	5.03 (15) 10^{-3}
		950.988 (4)	2.744 (19)[d]	3.76 (11) 10^{-3}
Yb-169	32.018 (5) d	63.12044 (4)	44.05 (24)[b]	1.11 (4)
		93.61447 (8)	2.571 (17)[b]	3.89 (12)
		109.77924 (4)	17.36 (9)[b]	2.45 (4)
		118.18940 (14)	1.87 (1)[b]	1.66 (5)
		130.52293 (6)	11.38 (5)[b]	1.15 (4)
		177.21307 (6)	22.32 (10)[b]	0.590 (9)
		197.95675 (7)	35.93 (12)[b]	0.448 (7)
		261.07712 (9)	1.687 (8)[b]	2.83 (9) 10^{-2}
		307.73757 (9)	10.046 (45)[b]	6.66 (20) 10^{-2}
Tm-170	127.8 (6) d	84.25474 (8)	2.48 (9)[b]	6.39 (10)
Lu-176	37.6 (7) 10^{9} a	88.36 (2)	14.8 (2)[c,b**]	5.77 (8)
		201.83 (8)	78.2 (3)[c,b**]	0.279 (4)
		306.84 (8)	93.11 (9)[c,b**]	7.41 (11) 10^{-2}
Lu-177	6.647 (4) d	112.9498 (4)	6.22 (5)[b**]	2.272 (5)
		208.3662 (4)	10.37 (5)[b**]	6.8 (5) 10^{-2}
Ta-178	9.31 (3) min	93.13 (8)	6.6 (6)[c]	4.67 (5)
		511	2.2 (2)[f]	
		1340.85 (9)	1.0 (1)[c]	0.00232
		1350.55 (9)	1.2 (2)[c]	0.00229
Ta-182	114.61 (13) d	65.72215 (15)	2.97 (8)[a]	2.92 (20)

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		67.7497 (1)	43.6 (15)[a]	0.22 (3)
		84.68024 (26)	2.62 (6)[a]	7.66 (11)
		100.10595 (7)	14.22 (16)[a]	3.89 (6)
		113.67170 (22)	1.869 (20)[a]	3.19 (5)
		152.42991 (26)	7.01 (13)[a]	0.1258 (18)
		156.3864 (3)	2.662 (27)[a]	0.1177 (17)
		179.39381 (25)	3.099 (31)+	0.63 (7)
		198.35187 (29)	1.461 (15)[a]	0.317 (5)
		222.1085 (3)	7.54 (7)[a]	4.80 (7) 10^{-2}
		229.3207 (6)	3.634 (36)[a]	0.196 (3)
		264.0740 (3)	3.602 (36)	0.1254 (18)
		1001.6856 (12)	2.07 (5)[a]	4.55 (8) 10^{-3}
		1121.290 (3)	35.17 (33)[a]	3.60 (5) 10^{-3}
		1189.040 (3)	16.58 (16)[a]	4.567 (41) 10^{-3}
		1221.395 (3)	27.27 (27)[a]	3.05 (5) 10^{-3}
		1231.004 (3)	11.62 (11)[a]	3.01 (5) 10^{-3}
		1257.407 (3)	1.511 (15)[a]	2.89 (4) 10^{-3}
		1289.145 (3)	1.374 (17)[a]	1.231 (18) 10^{-2}
Re-186	3.7186 (17) d	137.157 (8)	9.42 (6)[b]	1.290 (39)
Re-188	17.005 (4) h	155.041 (4)	15.2 (6)[c,d]	0.820 (25)
		477.992 (25)	1.02 (9)[c]	2.60 (8) 10^{-2}
		632.981 (21)	1.28 (10)[c]	1.32 (4) 10^{-2}
Ir-192	73.827 (13) d	205.79430 (9)	3.34 (4)[a]	0.305 (9)
		295.95650 (15)	28.72 (14)[a]	0.106 (3)

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		308.45507 (17)	29.68 (15)[a]	9.6 (3) 10^{-2}
		316.50618 (17)	82.75 (21)[a]	8.49 (25) 10^{-2}
		468.0688 (3)	47.81 (24)[a]	2.95 (9) 10^{-2}
		484.5751 (4)	3.189 (24)[a]	2.63 (8) 10^{-2}
		588.5810 (7)	4.517 (22)[a]	1.70 (5) 10^{-2}
		604.41105 (25)	8.20 (4)[a]	2.66 (8) 10^{-2}
		612.4621 (3)	5.34 (8)[a]	1.55 (5) 10^{-2}
Ir-194	19.3 (1) h	293.541 (14)	2.5 (3)[c]	0.107 (3)
		328.448 (14)	13.1 (17)[c]	7.6 (2) 10^{-2}
		645.146 (20)	1.18 (16)[c]	1.38 (4) 10^{-2}
Au-195	184.7 (14) d	98.882 (4)	11.21 (15)[a,d]	6.86 (10)
Au-198	2.6944 (8) d	411.80205 (17)	95.54 (7)[c,d]	4.47 (5) 10^{-2}
Tl-201	3.0421 (17) d	135.312 (34)	2.604 (22)[b]	3.45 (10)
		167.45 (3)	10.0 (1)[b]	1.89 (8)
Hg-203	46.594 (12) d	279.1952 (10)	81.61 (5)[c**]	0.2261 (8)
Pb-203	51.929 (10) h	279.1952 (10)	80.94 (5)[a]	0.2261 (8)
		401.320 (3)	3.43 (6)[a]	0.1784 (25)
Hg-206	8.32 (7) min	304.896 (6)	26 (5)[b]	0.375 (6)
		649.42 (5)	2.2 (3)[b]	5.01 (7) 10^{-2}
Bi-207	32.9 (14) a	569.698 (2)	97.76 (3)[c]	2.16 (3) 10^{-2}
		1063.656 (3)	74.58 (22)[c]	1.278 (24) 10^{-1}
		1770.228 (9)	6.871 (26)[c]	4.42 (7) 10^{-3}
Tl-208	3.058 (6) min	277.37 (2)	6.6 (3)[c]	0.529 (8)
		510.74 (2)	22.5 (2)[c]	0.1019 (16)

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		583.187 (2)	85.0 (3)[c]	2.05 (3) 10^{-2}
		763.45 (2)	1.80 (2)[c]	3.54 (5) 10^{-2}
		860.53 (2)	12.4 (1)[c]	2.62 (4) 10^{-2}
		2614.511 (10)	99.755 (4)[c]	2.46 (4) 10^{-3}
Tl-209	2.161 (7) min	117.224 (7)	77.22 (27)[c]	0.295 (5)
		465.128 (24)	96.62 (5)[c]	3.50 (5) 10^{-2}
		1566.93 (5)	99.707 (5)[c]	2.94 (5) 10^{-3}
Pb-210	22.23 (12) a	46.539 (1)	4.252 (40)[b]	17.86 (25)
Tl-210	1.30 (3) min	83 (30)	1.98 (40)[c]	14
		97 (30)	4 (2)[c]	9
		296 (3)	79 (10)[c]	0.120 (5)
		356 (10)	4 (2)[c]	0.270 (22)
		382 (10)	3 (2)[c]	0.223 (17)
		480 (36)	2 (1)[c]	
		670 (20)	2 (1)[c]	
		799.6 (3)	98.969 (30)[c]	1.042 (31) 10^{-2}
		860 (30)	6.9 (20)[c]	
		910 (30)	3 (2)[c]	
		1070 (20)	11.9 (49)[c]	2.22 (7) 10^{-3}
		1110 (20)	6.9 (20)[c]	
		1210 (20)	16.8 (40)[c]	
		1310 (20)	20.8 (49)[c]	
		1410 (20)	4.9 (20)[c]	
		1490 (20)	2 (1)[c]	

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		1540 (30)	2 (1)[c]	
		1590 (30)	2 (1)[c]	
		1650 (30)	2 (1)[c]	
		2010 (30)	6.9 (20)[c]	
		2090 (30)	4.9 (20)[c]	
		2280 (12)	3 (2)[c]	
		2360 (30)	7.9 (30)[c]	
		2430 (30)	8.9 (30)[c]	
Bi-211	2.15 (2) min	351.03 (4)	13.00 (19)[e]	0.243 (4)
Pb-211	36.1 (2) min	404.834 (9)	3.83 (6)[b,d]	0.122 (8)
		427.150 (15)	1.81 (4)[b,d]	0.1783 (25)
		831.984 (12)	3.50 (5)[b,d]	2.8 (3) 10^{-2}
Bi-212	60.54 (6) min	39.858 (4)	1.07 (1)[d,e]	23.3 (4)
		727.330 (9)	6.65 (4)[d,e]	1.393 (20) 10^{-2}
		785.37 (9)	1.11 (1)[d,e]	3.87 (6) 10^{-2}
		1620.738 (10)	1.51 (3)[d,e]	6.20 (9) 10^{-3}
Pb-212	10.64 (1) h	238.632 (2)	43.6 (5)[b]	0.872 (13)
		300.089 (12)	3.18 (14)[b]	0.464 (7)
Bi-213	45.59 (6) min	440.44 (1)	26.1 (3) b	0.179 (3)
Bi-214	19.8 (1) min	609.312 (7)	45.49 (19)[b]	2.04 (3) 10^{-2}
		665.453 (22)	1.530 (7)[b]	5.79 (9) 10^{-3}
		768.356 (10)	4.892 (16)[b]	1.57 (21) 10^{-2}
		806.174 (18)	1.262 (6)[b]	1.127 (16) 10^{-2}
		934.061 (12)	3.10 (1)[b]	2.34 (10) 10^{-2}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[a]	ICC T
		1120.287 (10)	14.91 (3)[b]	1.522 (23) 10^{-2}
		1155.19 (2)	1.635 (7)[b]	1.35 (4) 10^{-2}
		1238.111 (12)	5.831 (14)[b]	1.200 (17) 10^{-2}
		1280.96 (2)	1.435 (6)[b]	1.101 (16) 10^{-2}
		1377.669 (12)	3.968 (11)[b]	4.04 (6) 10^{-3}
		1401.50 (4)	1.330 (7)[b]	5.3 (9) 10^{-3}
		1407.98 (4)	2.389 (8)[b]	3.89 (6) 10^{-3}
		1509.228 (15)	2.128 (10)[b]	7.32 (11) 10^{-3}
		1661.28 (6)	1.048 (9)[b]	2.96 (5) 10^{-3}
		1729.595 (15)	2.844 (10)[b]	2.78 (4) 10^{-3}
		1764.494 (14)	15.31 (5)[b]	5.11 (8) 10^{-3}
		1847.420 (25)	2.025 (12)[b]	
		2118.55 (3)	1.158 (5)[b]	3.56 (5) 10^{-3}
		2204.21 (4)	4.913 (23)[b]	3.33 (5) 10^{-3}
		2447.86 (10)	1.548 (7)[b]	1.424 (20) 10^{-3}
Pb-214	26.916 (44) min	53.2275 (21)	1.060 (7)[b]	12.88 (39)
		241.997 (3)	7.268 (22)[b]	0.888 (27)
		295.224 (2)	18.414 (36)[b]	0.482 (14)
		351.932 (2)	35.60 (7)[b]	0.319 (10)
		785.96 (9)	1.064 (13)[b]	4.10 (12) 10^{-3}
Bi-215	7.6 (2) min	271.228 (10)	1.95 (7)[c]	0.201 (7)
		293.56 (4)	23.8 (9)[c]	0.34 (5)
		517.60 (6)	1.02 (8)[c]	7.3 (10) 10^{-2}
		1105.2 (4)	1.50 (7)[c]	

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[a]	ICC T
Rn-219	3.98 (3) s	271.228 (10)	11.07 (22)[c]	0.201 (7)
		401.81 (1)	6.75 (22)[c]	5.55 (8) 10^{-2}
Fr-221	4.79 (2) min	218.12 (2)	11.42 (15)[b]	0.367 (5)
Fr-223	22.00 (7) min	20.27 (5)	1.4 (3)[b]	7.76 (22)
		49.80 (5)	2.5 (6)[b]	0.708 (10)
		50.10 (2)	33 (7)[b]	0.696 (10)
		79.65 (2)	9.0 (18)[b]	0.202 (3)
		234.70 (5)	2.7 (5)[b]	1.393 (16)
Ra-223	11.43 (3) d	122.319 (10)	1.238 (19)[c]	7.34 (11)
		144.27 (2)	3.36 (8)[c]	4.59 (7)
		154.208 (10)	5.84 (13)[c]	3.83 (6)
		269.463 (10)	14.23 (32)[c]	0.789 (14)
		323.871 (10)	4.06 (8)[c]	0.473 (17)
		338.282 (10)	2.85 (6)[c]	0.430 (6)
		445.033 (12)	1.28 (4)[c]	0.205 (3)
Ra-224	3.631 (2) d	240.986 (6)	4.12 (4)[c]	0.276 (4)
Ac-225	10.0 (1) d	99.89 (6)	1.08 (8)[b]	0.1073 (15)
Ra-225	14.82 (19) d	40.09 (5)	30.0 (7)[b]	1.293 (19)
Ra-226	1600 (7) a	186.211 (13)	3.555 (19)[b]	0.677 (10)
Ac-228	6.15 (3) h	99.505 (12)	1.26 (4)[b]	3.84 (6)
		129.065 (3)	2.50 (7)[b]	3.74 (6)
		209.248 (7)	3.97 (13)[b]	8.48 (12) 10^{-2}
		270.245 (7)	3.55 (10)[b]	4.70 (7) 10^{-2}
		328.004 (7)	3.04 (11)[b]	3.05 (5) 10^{-2}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[a]	ICC T
		338.320 (5)	11.4 (4)[b]	2.85 (4) 10^{-2}
		409.460 (13)	2.02 (6)[b]	0.21 (15)
		463.002 (6)	4.45 (24)[b]	5.14 (8) 10^{-2}
		755.313 (9)	1.03 (4)[b]	7.0 (1) 10^{-2}
		772.291 (7)	1.52 (6)[b]	2.44 (14) 10^{-2}
		794.942 (14)	4.31 (14)[b]	1.79 (14) 10^{-2}
		835.704 (8)	1.70 (7)[b]	1.415 (20) 10^{-2}
		911.196 (6)	26.2 (8)[b]	1.194 (17) 10^{-2}
		964.786 (8)	4.99 (17)[b]	1.119 (23) 10^{-2}
		968.960 (9)	15.9 (5)[b]	1.061 (15) 10^{-2}
		1588.200 (25)	3.06 (12)[b]	7 (3) 10^{-3}
		1630.618 (20)	1.52 (6)[b]	7 (3) 10^{-3}
Ra-228	5.75 (4) a	13.520 (36)	1.6 (1)[b]	5.86 (10)
Th-228	698.55 (32) d	84.373 (3)	1.19 (3)[a],c	21.2 (3)
Pa-231	32670 (260) a	27.37 (1)	10.8 (4)[b]	4.5 (6)
		283.690 (14)	1.65 (3)[b]	4.10 (6) 10^{-2}
		300.060 (14)	2.41 (5)[b]	0.764 (17)
		302.670 (14)	2.3 (3)[b]	3.55 (5) 10^{-2}
		330.04 (1)	1.36 (3)[b]	0.541 (19)
Th-231	25.52 (1) h	25.64 (2)	13.9 (7)[b]	4.37 (7)
		84.2140 (13)	6.70 (7)[b]	2.50 (25)
		89.95 (2)	1.01 (3)[b]	0.1598 (22)
Pa-233	26.98 (2) d	75.269 (10)	1.30 (3)[b]	11.4 (12)
		86.595 (5)	1.99 (10)[b]	7.08 (14)

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[a]	ICC T
		300.129 (5)	6.60 (21)[b]	0.87 (2)
		311.904 (5)	38.3 (5)[b]	0.80 (2)
		340.476 (5)	4.47 (3)[b]	0.62 (2)
		398.492 (5)	1.408 (14)[b]	8.35 (17) 10^{-2}
		415.764 (5)	1.747 (7)[b]	0.13 (8)
Th-233	22.15 (8) min	29.373 (10)	2.17 (7)[b]	3.07 (6)
		86.477 (10)	1.843 (22)[b]	1.43 (8)
Pa-234	6.70 (5) h	62.70 (1)	1.6 (5)[a,c]	0.426 (6)
		99.86 (2)	3.2 (6)[a,c]	13.42 (19)
		131.30 (1)	18.2 (16)[a,c]	0.265 (4)
		152.71 (2)	6.0 (7)[a,c]	2.14 (3)
		186.15 (2)	1.78 (19)[a,c]	3.79 (6)
		203.12 (3)	1.24 (15)[a,c]	1.4 (4)
		226.50 (3)	4.9 (6)[a,c]	1.3 (3)
		227.25 (3)	5.8 (6)[a,c]	2.17 (3)
		249.22 (1)	2.5 (4)[a,c]	5.94 (9) 10^{-2}
		272.28 (5)	1.09 (14)[a,c]	1.004 (14)
		293.79 (5)	3.0 (4)[a,c]	0.42 (10)
		369.50 (5)	2.5 (3)[a,c]	0.565 (8)
		372.0 (1)	1.23 (14)[a,c]	0.517 (8)
		458.68 (5)	1.14 (12)[a,c]	0.14 (5)
		506.75 (5)	1.30 (14)[a,c]	1.314 (19) 10^{-2}
		565.2 (1)	1.04 (11)[a,c]	0.179 (3)
		568.9 (2)	3.6 (6)[a,c]	0.1759 (25)

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		569.5 (1)	9.3 (12)[a,c]	0.1754 (25)
		666.5 (1)	1.18 (13)[a,c]	7.77 (11) 10^{-3}
		669.7 (1)	1.0 (1)[a,c]	7.70 (11) 10^{-3}
		692.6 (1)	1.25 (13)[a,c]	0.1040 (15)
		699.03 (5)	3.6 (4)[a,c]	
		705.9 (1)	2.29 (23)[a,c]	6.98 (10) 10^{-3}
		733.39 (5)	7.0 (8)[a,c]	8.93 (13) 10^{-2}
		738.0 (1)	1.16 (13)[a,c]	8.78 (13) 10^{-2}
		742.813 (5)	2.08 (21)[a,c]	6.36 (9) 10^{-3}
		755.0 (1)	1.23 (13)[a,c]	5 (4) 10^{-2}
		786.272 (22)	1.21 (13)[a,c]	5.73 (8) 10^{-3}
		796.1 (1)	2.6 (3)[a,c]	1.730 (25) 10^{-2}
		805.80 (5)	2.5 (3)[a,c]	5.49 (8) 10^{-3}
		819.2 (1)	1.9 (2)[a,c]	5.33 (8) 10^{-3}
		824.2 (2)	1.25 (15)[a,c]	
		825.1 (2)	1.9 (2)[a,c]	1.611 (23) 10^{-2}
		831.5 (1)	4.2 (5)[a,c]	5.18 (8) 10^{-3}
		876.0 (1)	2.55 (23)[a,c]	1.432 (20) 10^{-2}
		880.52 (4)	6.2 (8)[a,c]	1.418 (20) 10^{-2}
		880.52 (4)	4.3 (6)[a,c]	4.68 (7) 10^{-3}
		883.24 (4)	9.7 (11)[a,c]	1.409 (20) 10^{-2}
		898.67 (5)	3.3 (4)[a,c]	4.51 (7) 10^{-3}
		925.0 (1)	7.9 (9)[a,c]	1.288 (18) 10^{-2}
		926.0 (2)	1.8 (13)[a,c]	4.28 (6) 10^{-3}

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		926.7 (1)	7.3 (12)[a,c]	1.284 (18) 10^{-2}
		946.00 (3)	13.5 (15)[a,c]	4.12 (6) 10^{-3}
		947.7 (2)	1.63 (21)[a,c]	1.230 (18) 10^{-2}
		980.3 (1)	2.7[a,c]	3.87 (6) 10^{-3}
		980.3 (1)	1.77[a,c]	1.152 (17) 10^{-2}
		984.2 (1)	1.63 (21)[a,c]	3.85 (6) 10^{-3}
		1352.9 (1)	1.16 (12)[a,c]	1.766 (25) 10^{-2}
		1393.9 (1)	2.08 (21)[a,c]	1.634 (23) 10^{-2}
Th-234	24.10 (3) d	63.30 (2)	3.75 (8)[b]	0.405 (6)
		92.38 (1)	2.18 (19)[b]	5.27 (8)
		92.80 (2)	2.15 (19)[b]	0.1472 (21)
U-235	704 (1) 10^{6} a	109.19 (7)	1.66 (13)[b]	9.32 (14) 10^{-2}
		143.767 (3)	10.94 (6)[b]	0.207 (3)
		163.356 (3)	5.08 (3)[b]	0.1526 (22)
		185.720 (4)	57.0 (3)[b]	0.1124 (16)
		202.12 (1)	1.08 (2)[b]	2.53 (4)
		205.316 (4)	5.02 (3)[b]	8.87 (13) 10^{-2}
Np-236	1.55 (8) 10^{5} a	104.234 (6)	7.32 (13)[c]	10.99 (22)
		158.35 (3)	3.8 (4)[c]	2.14 (4)
		160.307 (3)	31.8 (15)[c]	1.76 (4)
Np-236m	22.5 (4) h	642.35 (9)	1.08 (6)[c]	0.15 (2)
Np-237	2.144 (7) 10^{6} a	29.374 (20)	14.3 (6)[b]	3.07 (6)
		86.477 (10)	12.26 (12)[b]	1.43 (8)
U-237	6.749 (16) d	26.34463 (24)	2.43 (6)[b]	8 (2)

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		59.54091 (10)	34.1 (9)[b]	1.16 (7)
		64.83 (2)	1.286 (17)[b]	0.400 (8)
		164.61 (2)	1.86 (3)[b]	1.70 (4)
		208.00 (1)	21.3 (3)[b]	2.98 (7)
		332.376 (16)	1.199 (16)[b]	0.146 (3)
Np-238	2.102 (5) d	923.99 (2)	2.604 (20)[b]	1.4 (1) 10^{-2}
		984.45 (2)	25.18 (13)[b]	1.25 (5) 10^{-2}
		1025.87 (2)	8.76 (6)[b]	1.20 (5) 10^{-2}
		1028.54 (2)	18.25 (13)[b]	1.17 (2) 10^{-2}
Np-239	2.356 (3) d	61.460 (2)	1.29 (2)[b]	0.473 (10)
		106.125 (2)	25.9 (3)[b]	0.26 (3)
		209.753 (2)	3.42 (3)[b]	2.94 (6)
		228.183 (1)	11.32 (22)[b]	2.41 (8)
		277.599 (1)	14.4 (1)[b]	1.42 (6)
		315.880 (3)	1.59 (1)[b]	3.72 (8) 10^{-2}
		334.310 (3)	2.04 (2)[b]	3.29 (7) 10^{-2}
U-239	23.46 (5) min	43.533 (1)	4.35 (28)[b]	1.14 (3)
		74.664 (1)	51.6 (13)[b]	0.276 (6)
Am-241	432.6 (6) a	26.3446 (2)	2.31 (8)[b]	8 (2)
		59.5409 (1)	35.92 (17)[b]	1.16 (7)
Am-243	7367 (23) a	43.53 (2)	5.89 (10)[b]	1.143 (16)
		74.66 (2)	67.2 (12)[b]	0.276 (4)
Cm-243	28.9 (4) a	209.753 (2)	3.29 (10)[b]	3.24 (5)
		228.183 (2)	10.6 (3)[b]	2.56 (4)

Parent nuclide	Half-ftlife	Energy (keV)	Intensity (%)[*]	ICC T
		277.599 (2)	14.0 (4)[b]	1.448 (21)
Am-244	10.1 (1) h	99.383 (4)	5.0 (11)[a,c]	19.3 (3)
		153.863 (2)	19 (4)[a,c]	2.81 (4)
		743.977 (5)	66 (8)[a,c]	7.7 (5) 10^{-2}
		897.840 (7)	28 (8)[a,c]	1.697 (24) 10^{-2}
Cm-245	8250 (70) a	133.081 (2)	2.81 (7)[a,c]	11.36 (17)
		175.0523 (14)	9.83 (22)[a,c]	5.21 (8)

a From the decay scheme using measured relative γ ray intensities and theoretical or measured ICCs (α_T).

b From the measured absolute intensities or using the measured absolute intensity of the strongest γ ray and relative intensities of the other γ-rays.

c From the decay scheme using theoretical considerations and relative γray intensity values.

d Evaluation based on relative γ-ray intensities and other parameters.

e Evaluation based on absolute α-particle intensities and decay scheme balance.

f Deduced from β^+-decay intensity, see Section 2.4 for explanations.

* The evaluation method is given according to Section 2.3.

** The published DDEP intensity value was updated taking into account/based on new experimental data for: ^{51}Cr [19], ^{88}Rb [20], ^{109}Cd [21], ^{113}Sn [22], ^{123}I [23], ^{176}Lu [24], ^{177}Lu [25], [26], and ^{203}Hg [27].

*** From recent accurate measurement of the Ho-166m half-life [28].

When DDEP evaluations are not available, e.g. for several nuclides of practical interest which were present in previous evaluations of some DDEP members [18], the above characteristics were updated by the authors. In addition, some published DDEP intensity values were updated in order to take into account new experimental data, by following the same evaluation methodology (see footnotes in Table 3).

4. Summary and comments

This article proposes a list of γ rays which are commonly used in various fields of application. The decay data characteristics of 150 nuclides have been studied and carefully evaluated, paying attention to the overall consistency of the decay scheme. A list of 656 γ-ray intensities is presented, as extracted from the DDEP database. These data appear across the seven volumes of Monographie-5 [4] published under the auspices of the Bureau International des Poids et Mesures (BIPM). As such, these data have been adopted for all international comparison exercises in the field of ionizing radiation metrology. One goal of this paper is to gather this set of data together in order to facilitate and generalize their use, for example, in the more and more numerous simulation studies of detector response. This evaluation work has been conducted by members of the Decay Data Evaluation Project, who have carried out and reviewed all the evaluations and, to whom, the authors of this article are greatly thankful. As in many areas of research, funding is continually being reduced and manpower is becoming more and more difficult to find, hence we would like to use this opportunity to encourage other scientists to collaborate with us and help us expand the Decay Data Evaluation Project.

References

[1] R.G. Helmer, C. van Der Leun. Nuclear Instruments and Methods in Physics Research A, 450 (2000), p. 35

[2] R.G. Helmer. Nuclear Instruments and Methods in Physics Research A, 422 (1999), p. 518

[3] M.-M. Bé, R.G. Helmer. Journal of Nuclear Science and Technology (Supp. 2) (2002), p. 481

[4] BIPM, Seven volumes available online 〈 http://www.bipm.org/en/publications/monographie-ri-5.html〉.

[5] Evaluations and comments available online 〈 http://www.nucleide.org/DDEP_WG/DDEPdata.htm.

[6] IAEA Report, Update of X ray and Gamma Ray Decay Data Standards for Detector Calibration and Other Applications, 2007, ISBN 92 0 113606-4.

[7] M.A. Kellett, M.-M. Bé, V. Chechev F.G. Xiaolong Huang, A. Kondev, G. Luca, A.L. Mukherjee, Nichols, A. Pearce. **New IAEA Actinide Decay Data Library.** Journal of the Korean Physical Society, 59 (2011), p. 1455

[8] M.-M. Bé, V. Chisté, C. Dulieu, X. Mougeot, V. Chechev, N. Kuzmenko, F.G. Kondev, A. Luca, A.L. Nichols, M. Galan, A. Arinc, X. Huang, B. Wang, Table of Radionuclides, Monographie BIPM-5, vol. 6, ISBN 13 978-92-822-2242-3, vol. 6, et 13 978-92-822-2243-0 (CD-Rom), CEA/LNE-LNHB, 91191 Gif-sur-Yvette, France and BIPM, Pavillon de Breteuil, 92312 Sèvres, France. Table of Radionuclides, Monographie BIPM-5, Commentaires, vol. 6, ISBN 13 978-92-822-2243-0 (CD-Rom), CEA/LNE-LNHB, 91191 Gif-sur-Yvette, France and BIPM, Pavillon de Breteuil, 92312 Sèvres, France, 2011.

[9] Table de Radionucléides. Introduction, nouvelle version. Introduction, revised version.Einleitung, überarbeiteteFassung, BNM-CEA/LNHB, BP 52, 91191 Gif-sur-Yvette Cedex, France, 2011, ISBN 2 7272 0201 6.

[10] Guide to the Expression of Uncertainty in Measurement, ISO CH-1211 Genève, 1993, ISBN 92 67 10188 9.

[11] W.L. Zijp, Netherland Energy Research Foundation, ECN, Petten, The Netherlands, Rep. ECN-179, 1985.

[12] I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor Jr., P.O.Tikkanen, S. Raman. Atomic Data and Nuclear Data Tables, 81 (2002), p. 1

[13] T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor Jr. Nuclear Instruments and Methods in Physics Research Section A, 589 (2008), p. 202

[14] F. Rösel, H.M. Friess, K. Alder, H.C. Pauli. Atomic Data and Nuclear Data Tables, 21 (1978), p. 92

[15] B. Chauvenet, M.-M. Bé, M.-N. Amiot, C. Bobin, M.-C. Lépy, T. Branger, I. Lanièce, A. Luca, M. Sahagia, A.C. Wätjen, K. Kossert, O. Ott, O. Nähle, P. Dryák, J. Sochorovà, P. Kovar, P. Auerbach, T. Altzitzoglou, S. Pommé, G. Sibbens, R. Van Ammel, J. Paepen, A. Iwahara, J.U. Delgado, R. Poledna, C.J. da Silva, L. Johansson, A. Stroak, C. Bailat, Y. Nedjadi, P. Spring. Applied Radiation and Isotopes, 68 (7–8) (2010), p. 1207

[16] M.-M. Bé, B. Chauvenet, M.-N. Amiot, C. Bobin, M.-C. Lépy, T. Branger, I. Lanièce, A. Luca, M. Sahagia, A.C. Wätjen, K. Kosser, O. Ott, O. Nähle, P. Dryák, J. Sochorovà, P. Kovar, P. Auerbach, T. Altzitzoglou, S. Pommé, G. Sibbens, R. Van Ammel, J. Paepen, A. Iwahara, J.U. Delgado, R. Poledna. Applied Radiation and Isotopes, 68 (10) (2010), p. 2026

[17] M.-C. Lépy, P. Cassette, L. Ferreux. Applied Radiation and Isotopes, 68 (7–8) (2010), p. 1423

[18] M.M. Bé, E. Browne, V. Chechev, V. Chisté, C. Dulieu, M. Galàn, R.G. Helmer, A. Luca, X. Mougeot, N. Kuzmenko, A.L. Nichols, A. Pearce, E. Schönfeld, NUCLÉIDE, Table de Radionucléides, CD-Rom, Version 3-2010, CEA/LIST-LNHB, 91191 Gif-sur-Yvette, France, EDP Sciences Editeur, 2010, ISBN 978-2-7598-0077-3.

[19] D.S. Moreira, M.F. Koskinas, I.M. Yamazaki, M.S. Dias. Applied Radiation and Isotopes, 68 (2010), p. 596

[20] H. Miyahara, A. Yoshida, G. Wurdiyanto, H. Nagata, N. Marnada. Applied Radiation and Isotopes, 56 (2002), p. 163

[21] K. Kossert, H. Janssen, R. Klein, M.K.H. Schneider, H. Schrader. Applied Radiation and Isotopes, 64 (2006), p. 1031

[22] A. Luca, M.-C. Lépy. Applied Radiation and Isotopes, 70 (2012), p. 1881

[23] M.F. Koskinas, K.C. Gishitomi, A.B. Brito, I.M. Yamazaki, M.S. Dias. Applied Radiation and Isotopes, 70 (2012), p. 2091

[24] O. Ott, K. Kossert, O. Sima. Appl. Radiat. Isot, 70 (2012), p. 1886

[25] S. Deepa, K. Vijay Sai, R. Gowrishankar, D.R. Rao, K. Venkataramaniah. Applied Radiation and Isotopes, 69 (2011), p. 869

[26] M.S. Dias, F. Silva, M.F. Koskinas. Applied Radiation and Isotopes, 68 (2010), p. 1349

[27] M.A.L. da Silva, R. Poledna, A. Iwahara, C.J. da Silva, J.U. Delgado, R.T. Lopes. Applied Radiation and Isotopes, 64 (2006), p. 1440

[28] Y. Nedjadi, C. Bailat, Y. Caffari, P. Froidevaux, C. Wastiel, N. Kivel, I. Guenther-Leopold, G. Triscone, F. Jaquenod, F. Bochud. Applied Radiation and Isotopes, 70 (2012), p. 1990