The Series of Environmental Radioactivity Measuring Methods

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Gamma-ray Spectral Analysis Using Germanium Detector in Emergencies

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Chapter 1 Introduction

Gamma-ray spectrometry using germanium detectors is a very effective measuring method to quickly identify radioactivity in environmental samples. This is important not only during normal operation but also in emergencies where radioactive materials are actually or potentially released from a nuclear reactor, fuel reprocessing facility, etc.

The published radioactivity measurement series that concern gamma-ray spectrometry include Gamma-ray Spectrometry Using Germanium Detectors (No. 7), Pretreatment of Samples for Device Analyses Using Germanium Detector, etc. (No. 13), Methods of Measuring Radioactive Iodine under Emergency (No. 15), Preparation of Samples for Gamma-ray Spectrometry in Emergencies (No. 24) and In-situ Measurement Using Germanium Detector (No. 33). This analytical method was issued in February 2004 as No. 29 of the Radioactivity Measurement Series describing the gamma-ray spectral analysis in emergencies.

Immediately following the accident at the Fukushima Daiichi Nuclear Power Station owing to the Great East Japan Earthquake that occurred on March 11, 2011 (hereafter referred to as “Fukushima Daiichi Nuclear Accident”), gamma-ray spectrometry using germanium detectors was widely utilized to monitor background radiation in emergencies. However, problems associated with the emergencies became apparent as the analysis and evaluation of gamma-ray spectrum became increasingly complex and included misidentification of gamma-ray peaks and contamination and decontamination of measuring equipment.

This revision of the analytical methods includes additional descriptions of actual cases and explanations of the emergency-specific problems and countermeasures, together with arrangements for widespread sharing of the knowledge gained due to the experiences associated with the Fukushima Daiichi Nuclear Accident.

Gamma-ray spectrometry using germanium detectors is an effective means to quickly ascertain radioactivity, and as such, an increasing number of scientists have used this method in the aftermath of the Fukushima Daiichi Nuclear Accident. Therefore, it is necessary to ensure that these individuals have sufficient knowledge about the measurement equipment and analytical methods to mitigate misidentification. It is also important to understand the purposes of the acquired measurement results, given that these results may vary significantly under different conditions for measurement and/or analysis.

It should be noted that measurement equipment and analytical software are provided by several vendors, and therefore, the following points must be observed when employing this analytical method.

Equipment adjustment and software operation are different and specific to the types or class. Therefore, this document describes the major and basic procedures of operation. For actual operation, it is necessary to consult the user manual or other such documents of the equipment or software provided by the vendor. It is also necessary to thoroughly verify the state of the equipment prior to use because an insufficient adjustment will result in misidentification or oversight of nuclides and erroneous quantification.

Chapter 2 Glossary

During the measurement in emergencies using germanium detectors, it is likely that numerous gamma-rays are injected into the detector, which may induce the phenomena outlined in the following. This section thus explains the terms that are specific to measurement in emergencies. For basic terms for germanium detectors, see Radioactivity Measurement Series No. 7 “Gamma-ray Spectrometry Using Germanium Detectors” (Reference 1).

Pulse Pile-up (Reference 2)

A phenomenon in which gamma-rays are injected and a pulse is generated before the attenuation of the pulse generated within the detector circuit, following the initial injection of gamma-rays, resulting in several overlapping pulses. Consequently, the gamma-ray peak has a tailing on the high-energy side (trailing sideway; see Figures E.3 and E.4), the counts are reduced (the counts of the number of individual pulses and gamma-ray peaks are lower than the actual numbers) and sum peaks appear. In coincidence summing, several gamma-ray pulses cascade, while in random summing, several overlapping gamma-ray pulses are attributed to different nuclides.

Cascade (Reference 2)

Gamma-rays are described as cascading when they are emitted almost simultaneously to effect energy transition between several energy levels in relation to one disintegration event.

Coincidence summing (References 1 and 2)

This is also called the true coincidence summing, where several cascading gamma-rays enter the detector almost simultaneously. Consequently, the output is the total energy and there is a reduction of the counts for the peak of each gamma ray.

Random summing (Reference 2)

Random summing occurs when gamma-rays of different nuclides (e.g., ^{137}Cs + ^{134}Cs), or gamma-rays generated in the disintegration of the same nuclide (e.g., ^{137}Cs + ^{137}Cs) enter the detector almost simultaneously. As such, the output is equivalent to the total sum of the gamma-ray energy. As the injection of gamma-rays increases, random summing becomes more frequent, thereby reducing the gamma-ray peak counts.

Sum peak

A phenomenon in which sum peaks appear owing to coincidence and random summing as several gamma-rays enter the detector almost simultaneously. Consequently, the output is a signal equivalent to the total energy of the incident gamma-rays. Sum peak is particularly prevalent in nuclides that are consequential in nuclear reactor accidents, including ^{134}Cs and ^{132}I.

Dead time

The time is the time spent to convert the injected gamma-rays into signals. The detector cannot process subsequent injection of gamma-rays during this interval (being dead).
Thus, dead time is obtained by subtracting the live time from real time (i.e., true time).

Chapter 3 Equipment calibration and adjustment

3.1 Equipment calibration

The calibration of a germanium detector involves energy and peak efficiency calibration. As such, the peak-to-total (P/T) ratio must be obtained in advance as a function of the gamma-ray energy to implement coincidence summing effect correction. Calibrations are normally conducted during the installation of the equipment but the energy and peak efficiency calibrations must be performed regularly.[*1] Although there are no differences in the manner in which the calibrations are performed during normal operation or in emergencies, it is necessary to ensure in particular, the energy calibration is executed appropriately in the case of an emergency because the gamma-ray peaks on the gamma-ray spectrum will be close to one another.

3.1.1 Energy calibration

Energy calibration of the germanium detector is important for two main reasons: gain adjustment that is performed on the measurement equipment using the radiation source, and the preparation of an energy calibration formula expressed as a function of channels (ch) on the horizontal axis of a multi-channel analyzer (pulse-height analyzer) and gamma-ray energy (keV). The former entails the alignment of the center of the gamma-ray peaks to the intended channels (ch) on the multichannel analyzer. The latter involves the calculation of the relationship between several gamma-ray energies (keV) and the peak center channels (ch) using measured radiation source spectra. Software can be used to easily create an energy calibration formula and a relational expression between the half-width and the gamma-ray energy is established at the same time. This relational expression is used, for example, when calculating the peak counting rate by specifying the peak region of a gamma ray using software.

The details of the gain adjustment are given under “3.2 Equipment adjustment.” The preparation of the energy calibration formula is described below.

(1) Mains steps in developing an energy calibration formula.

The latest software is designed to readily facilitate the determination of the formula using the spectrum of the measured multi-nuclide standard volume sources.[*2] It is expressed as a function of either the first-order or the second-order equation as follows:

$$E = a + b \cdot P \tag{3.1}$$

$$E = a + b \cdot P + c \cdot P^2 \tag{3.2}$$

E: gamma-ray energy (keV), P: gamma-ray peak center channel (ch)

a, b, c: Constant

[*1] If the relative efficiency of the detector is altered due, for example, to the repair of the germanium crystal, it is necessary to recalculate the relationship between P/T ratio and gamma-ray energy as a function.

[*2] It is possible to energy-calibrate a standard point source that includes multiple nuclides.

Given that germanium detectors have excellent energy linearity, a calibration formula can achieve sufficiently good correlations using a first-order equation. With a second-order equation, the second-order factor (the constant c in equation 3.2) yields a very small value. The procedures for energy calibration based on consumer software using multi-nuclide standard volume source are as follows:

(1) Register the nuclear data of the nuclides included in the multi-nuclide standard volume source into the nuclear data library for calibration.[*3]
(2) Measure the multi-nuclide standard volume source with the germanium detector.[*4]
It is desirable that the measurement time is set so that the peak area for each gamma ray is 10000 counts or more.
(3) Calculate the channels (ch) for which each gamma-ray peak is centered.
(4) Prepare the energy calibration formula[*5] based on the energy (keV) and peak center channel (ch) of each gamma ray.
(5) Save the energy formula that is created.

(2) Precautions for operating in emergencies

Gamma-ray spectrometry using consumer software identifies the nuclides contained in the sample based on the energy calibration formula and the nuclear data library for analysis (see "5.2 Nuclear data library for analysis"). For this reason, inappropriate energy calibration formulae may result in misidentification of nuclides or the incorrect assertion that an extant nuclide does not exist or non-existent nuclide does exist.

To avoid misidentification, it is desired that the creation of an energy calibration formula and the adjustment of gain should be conducted more frequently, compared to normal operation. An effective simple measure, however, is to examine the gamma-ray peak on the measured gamma-ray spectrum and verify that the center of the peak is not misaligned.[*6] It is noted that, because germanium detectors have excellent energy linearity, the verification of only one gamma-ray peak center channel (ch) is sufficient under normal operation. However, in an emergency, more than one peak should be verified considering the risk of misidentifying the gamma-ray peak generated by artificial radionuclides.

Table 3.1 illustrates major natural radionuclides that appear in the gamma-ray spectrum, their gamma-ray energy, and emission rates.

[*3] Preparing an energy calibration formula requires information on gamma-ray energy.
[*4] Measurement should be made with the dead time at 5% or lower. If the dead time is more than 5%, the measurement may be taken with a greater distance between the detector and the radiation source. Note, however, that this method cannot be applied to efficiency calibration.
[*5] Consumer software will create the relational expression between the half-width (FWHM) and gamma-ray energy.
[*6] Misalignment of peak centers for ^{40}K and ^{137}Cs must be within ±1 keV.

Table 3.1 Gamma-ray energy and emission rates of major natural radionuclides that appear in the gamma-ray spectrum

Nuclides	Gamma-ray energy (keV)	Emission rate (%)
^{212}Pb	238.6	43.6
^{214}Pb	351.9	35.60
^{208}Tl	583.2	85.0
^{214}Bi	609.3	45.49
^{228}Ac	911.2	25.8
^{40}K	1460.8	10.66

Note 1: The nuclear data are taken from ENSDF[*7] (as of October 2017).

Note 2: Although gamma-ray energy and emission rate are expressed to one and two decimal places, respectively, the latter is also expressed to one decimal place if it does not have a value at the second decimal place.

Conducting gamma-ray spectrometry in emergencies will result in an increase in the baseline count of the gamma-ray spectra owing to the presence of numerous artificial radionuclides, which may impede the verification of the gamma-ray peaks of natural radionuclides as illustrated in Table 3.1. For this reason, the gamma-ray peaks of the artificial radionuclides shown in Table 3.2 need to be taken into consideration as they are emitted in accidents at nuclear reactors or other such places.

Table 3.2 Examples of gamma-ray energy and emission rates of artificial radionuclides released in a nuclear reactor accident

Nuclides	Gamma-ray energy (keV)	Emission rate (%)
^{131}I	364.5	81.5
^{134}Cs	604.7	97.62
^{137}Cs	661.7	85.10
^{132}I	667.7	98.70
^{132}I	772.6	75.6
^{134}Cs	795.9	85.46
^{60}Co	1173.2	99.85
^{60}Co	1332.5	99.98

Note 1: The nuclear data are taken from ENSDF (as of October 2017).

Note 2: Although gamma-ray energy and emission rate are expressed to one and two decimal places, respectively, the latter is also expressed to one decimal place if it does not have a value at the second decimal place.

[*7] ENSDF (Evaluated Nuclear Structure Data File) refers to the data files held and managed by the National Nuclear Data Center of the US institution, Brookhaven National Laboratory.

3.1.2 Efficiency calibration

The efficiency of germanium detectors in the detection of gamma-ray peaks changes depending on the gamma-ray energy, and the materials and configurations of standard sources. In general, the efficiency is obtained by first preparing an efficiency formula using multi-nuclide standard volume sources of varied heights when employing a cylindrical measurement vessel, as described in the Radioactivity Measurement Series No. 7 "Gamma-ray Spectrometry Using Germanium Detectors." If a Marinelli beaker is used, the efficiency is determined based on the efficiency calibration formula that is obtained using a multi-nuclide standard source in the same configuration as the measured sample.
In an emergency, an active carbon cartridge may be incorporated for measuring ^{131}I, in the atmosphere. In this case, the utilization of a standard source[*8] that is in the same configurations as the sample will facilitate the acquisition of quantification results based on gamma-ray peak efficiency that does not require self-absorption correction.

(1) Steps involved in the preparation of an efficiency calibration formula.
The efficiency calibration formula that is used for cylindrical measuring vessels and Marinelli beakers during the normal operation can be applied in emergencies without modification. Although it is possible to create an efficiency calibration formula for containers that are not normally used, it is desirable that one is prepared before an emergency arises, based on postulated measurement vessels and sample configurations (e.g., active carbon cartridge) for measurement in emergencies.

(1) Register the nuclear data of the nuclides included in the standard source into the nuclear data library for calibration.[*9]
(2) Measure the standard source with a germanium detector[*10] [*11]
It is desirable that the measurement time is set so that the peak area for each gamma ray is 10000 to 20000 counts or more.
(3) Obtain peak counting rate (count/s) for each gamma-ray peak, then subtract the gamma-ray dose (γ/s) of the standard source on the day of measurement to calculate the gamma-ray peak efficiency (ε_i).
(4) Prepare an efficiency calibration formula by selecting a functional type[*12], which yields the smallest difference between the peak efficiency (ε_i) of each gamma ray and the actual measured efficiency.

[*8] Mock iodine of ^{131}I can be used as a standard source. Given that ^{131}I has a short half-life of 8.03 days, the standard source has added ^{133}Ba and ^{137}Cs, which emit gamma-rays with an energy similar to that of ^{131}I (364.5 keV).
[*9] Preparing an efficiency calibration formula requires that the half-life cycle, emission rate, the date of standard source assay and the strength of assay (Bq) as well as the gamma-ray energy.
[*10] Measurement should be made with the dead time at 5% or lower.
[*11] Performing the efficiency calibration in advance with the source placed away from the detector using a jig may prove useful if measurement is necessary in an emergency.
[*12] For multi-nuclide mixed standard sources, two functions are used: $Ln(\varepsilon) = a + b \times Ln(E) + c \times \{ Ln(E) \}^2$, where ε is gamma-ray peak efficiency, E is gamma-ray energy, a, b and c are constants, and Ln is the natural logarithm. The connecting point between these two functions is called a boundary value. In addition, an n^{th} order function including first-order equation may be selected as a functional style, depending on the type and count of the nuclides contained in the standard source.

(5) Save the efficiency calibration formula that is created.

(2) Precautions for operating in emergencies50505

In emergencies, the measurement of an environmental sample often yields high count rates. In this case, pulse pile-up, random summing, etc. cause gamma-ray peaks to reduce the net counting rate, which differs from the measurement conditions under which the efficiency calibration is conducted. It is therefore necessary to be aware of the risk of under-representation. Refer to "6.1.2 Problems in measuring at high counting rates" for details.

3.1.3 Function of P/T ratio and gamma-ray energy

The P/T ratio is the ratio between the count in the peak region of a gamma-ray spectrum and the total counts that are obtained by measuring a monochromatic gamma-ray source.[*13] The P/T ratio is required to correct the count loss of the gamma-ray peaks for the nuclides that are prone to coincidence summing of ^{60}Co and ^{134}Cs. Refer to the Radioactivity Measurement Series No. 7 "Gamma-ray Spectrometry Using Germanium Detectors."

(1) Steps involved in the preparation of a function of P/T ratio and gamma-ray energy

To prepare a function to express the relationship between the P/T ratio and gamma-ray energy, it is necessary to utilize a monochromatic gamma-ray source at an appropriate energy interval over the entire energy region. It is extremely difficult to prepare the function by measuring several monochromatic gamma-ray sources. In general, the relative efficiency is used to obtain an approximation according to the following equations:[*14]

$$P/T = \beta + \alpha \times Ln(RE) \quad (3.3)$$

$$Ln(\alpha) = -1.11 - 0.30 \times Ln(E) \quad (3.4)$$

$$Ln(\beta) = -7.97 + 3.31 \times Ln(E) - 0.383 \times \{Ln(E)\}^2 \quad (3.5)$$

where RE: relative efficiency (%), E: gamma-ray energy (keV) and Ln: natural logarithm

The P/T ratio can be obtained by entering a value for the relative efficiency in the above equation. However, in practice, it is necessary to consult the software manual and enter the relative efficiency (%) for the germanium detector in use, because there are slight differences in the operation of the software depending on the vendor.

[*13] A source that contains only one kind of nuclide that emits monoenergetic gamma-rays, such as ^{109}Cd and ^{137}Cs.

[*14] There is a report (Reference 3) concerning the P/T ratio and approximation formulae that detectors with a relative efficiency of up to 30% can approximate reasonably well. Detectors with a relative efficiency of over 30% should preferably be verified by means of a certified reference material such that nuclides prone to coincidence summing are appropriately corrected.

(2) Precautions for operating in emergencies

The function of the P/T ratio and gamma-ray energy can be used irrespective of whether it is meant for normal operation or an emergency. However, the coincidence summing effect correction requires a cascade file to be set up, and in cases where the analysis of the nuclides are prone to frequent coincidence summing; emitted as a result of a nuclear reactor accident, those nuclides that are registered in the cascade file must be known. Refer to “4.2 Coincidence summing effect correction” for further details.

3.2 Equipment adjustment

It is expected that many gamma-ray peaks will be detected in the gamma-ray spectrum in an emergency, because of artificial radionuclides. To correctly identify nuclides, it is necessary that the equipment should be correctly adjusted and calibrated. The adjustments that the equipment user may perform include the gain adjustment (including the zero adjustment of ADC, analog-digital converters) and the pole-zero adjustment for which the gain adjustment is the important parameter in terms of the identification of nuclides. The latest multi-channel analyzers and software allow users to easily perform gain and pole-zero adjustments (for example, by touching a screen or using a mouse to click).

This document will describe the gain adjustment in the next section, which is an important operation in emergencies. For the details regarding the pole-zero adjustment, refer to the Radioactivity Measurement Series No. 7 “Gamma-ray Spectrometry Using Germanium Detectors.”

3.2.1 Gain adjustment

It is customary to adjust a multi-channel analyzer by assigning the entire 4096 channels over the energy range of 2048 keV to realize 0.5 keV/ch. This may be extended to the maximum number of channels to 8192 and the energy range to approximately 3000 keV depending on the analyzer model and configuration.

Given that the relationship between gamma-ray energy (keV) and channels are excellently linear over the entire energy range, the gain adjustment is considered an adjustment of the inclination of linear equation. Some models require an adjustment by the parallel transition of a y-axis fragment of the linear equation, known as the ADC zero adjustment. Note that the models that require the ADC zero adjustment are designed so that it is mandatory that the lines intersect at the zero point.

(1) Procedures for gain adjustment (including ADC zero adjustment)

Usually, nuclides ^{60}Co (1332.5 keV) and ^{57}Co (122.1 keV) are used for gain adjustment and ADC zero adjustment, respectively. An example of the gain adjustment (0.5 keV/ch) procedures is described below.

It should be noted that, once the gain adjustment has been performed, it is recommended that the energy calibration formula should be recreated before applying it to spectral analysis. It is also useful to record the set points before and after the gain adjustment because these are useful indicators of the present and past conditions of the equipment.

(1) Measure the radiation sources containing ^{60}Co and ^{57}Co.

- If the sources of ^{60}Co and ^{57}Co are separate, measure them together or replace one with the other as necessary. Note that, when measuring the radiation sources, the distance between the detector and the source must be adjusted so that the dead time is 5% or less.

(2) Adjust the gain so that when measuring the ^{60}Co source, the peak center of 1332.5 keV gamma ray is assigned to 2665 ch.
- Do not change the settings for the coarse gain, as this feature alters the gain value by a large margin, resulting in a significant alteration of the channel for peak center.
- The gain modification should be made by adjusting the settings for the fine gain. Record the set points before and after the adjustment.

(3) Next, measure the ^{57}Co source and perform ADC zero adjustment to set the peak center of the 122.1 keV gamma ray to 244 ch.

(4) Operation (3) will result in the gamma-ray peak center of ^{60}Co (1332.5 keV) being taken off the alignment, therefore, repeat operation (2).

(5) Operation (4) will result in the gamma-ray peak center of ^{57}Co (122.1 keV) being taken off the alignment, therefore, repeat operation (3).

(6) Repeat operations (2) and (3) until the gamma-ray peaks of ^{60}Co (1332.5 keV) and ^{57}Co (122.1 keV) center at 2665 ch and 244 ch, respectively.

(7) When sufficient adjustments have been made, measure the sources of ^{60}Co and ^{57}Co for approximately 10 minutes, then save the spectra.
- It is desirable at this stage to record the peak center channel (ch) and energy resolution (keV) for ^{60}Co as a reference for equipment management.

(8) Measure a multi-nuclide standard volume source and perform the energy calibration using several peaks across the entire energy range, then save the calibration formula.

Note that operations (3) to (6) are not necessary for equipment that does not require ADC zero adjustment.

(2) Precautions for operating in emergencies

The germanium detector needs to be cooled using liquid nitrogen,[*15] but procurement of liquid nitrogen may prove to be difficult in an emergency. If the liquid nitrogen is exhausted and the detector heats up as a result and the germanium crystal is allowed to warm up to the ambient temperature,[*16] it is necessary to ensure that the detector has sufficiently cooled [*17] before applying a high voltage for the second time. In this case, repeat the gain adjustment after the application of a high voltage and recreate the energy calibration formula if necessary.

Note that it is less likely that the gain will be misaligned if the air conditioning in the measurement chamber is appropriately controlled (ideally, the room temperature and the humidity should be 23 ± 2 ℃ and 50 to 60%, respectively, in a stable condition), ensuring that the equipment is not exposed to the draft from the air conditioner or direct sunlight. A misaligned gain may result in drifting of the gamma-ray peaks, compromising the accuracy in the identification including misrecognition of nuclides.

To avoid this situation, the environment inside the measurement chamber must be perfectly controlled, and as stated in "3.1.1 Energy calibration," it is necessary to prepare the energy calibration formula and to perform the gain adjustment regularly. Otherwise, attention should be focused on the gamma-ray peaks on the measured spectra and the centering of the peaks at the respective channels (ch) should be verified.

[*15] Other than liquid nitrogen cooling system, there are systems of electric cooling and hybrid cooling (liquefying vapored nitrogen by cooling it electrically), both of which require a power supply for operation.

[*16] It is possible that after the liquid nitrogen dries out, it will take several days (approximately 3 days) before the germanium crystal warms up to the ambient temperature. If the cryostat can be verified visually, the state whereby the ambient temperature is reached may be assumed when the cryostat becomes free of condensation.

[*17] If the detector is re-cooled before the germanium crystal returns to the ambient temperature, there is a risk that the gas in the detector may be deposited on the germanium crystal, resulting in the increase of the leakage current to compromise the expected performance of the detector. If this is the case, it is necessary to to allow the temperature of the detector to return to the ambient temperature. Therefore, cooling of the detector must be carefully performed.

Chapter 4 Various corrections

In gamma-ray spectrometry, the radioactivity concentration (e.g., Bq/kg) is calculated by applying the gamma-ray peak efficiency to the count rate (cps) obtained by measuring samples to get the radioactivity per sample, and then dividing the returned value by the sample volume.[*1] The general formula for the radioactivity is as follows:

$$A = \frac{n_s - n_b}{(\varepsilon \cdot a) \cdot W} \times f_{SA} \times f_{SUM} \times f_D \quad (4.1)$$

A: Radioactivity concentration (Bq/kg, etc.)
n_s: Net count rate (cps) of sample
n_b: Background count rate (cps)
ε: Gamma-ray peak efficiency
a: Gamma-ray emission ratio (= gamma-ray emission rate/100)
W: Sample volume (kg, etc.)
f_{SA}: Self-absorption correction factor
f_{SUM}: Coincidence summing effect correction factor
f_D: Decay correction factor

The above equation expresses the calculation process to obtain the radioactivity concentration at a specific point in time by applying the self-absorption correction, coincidence summing effect correction, decay correction and background correction. These corrections contain complex equations, but the latest software can facilitate the easy calculation of the correction factors by entering and setting the required values, enabling the acquisition of the radioactivity concentration. Meanwhile, the radioactivity concentration will be altered if these corrections are performed. Therefore, it is necessary to record and report the analytical conditions (whether these corrections are performed, etc.) in addition to the resulting radioactivity concentration values.
These corrections require the correction factors to be calculated, irrespective of whether it is in normal operation or in an emergency, but there are certain problems concerning the sample measurement and spectral analysis that are specific to emergency situations. Therefore, in this chapter, each correction is described with points of caution. Concerning the details regarding these corrections, refer also to the Radioactivity Measurement Series No. 7 “Gamma-ray Spectrometry Using Germanium Detectors.”

[*1] The weight (g or kg) of the sample, volume of air absorbed (m^3), surface area (cm^2 or m^2) of the reservoir to catch the fallout.

4.1 Self-absorption correction

Self-absorption is a phenomenon in which gamma rays are reduced in the sample as they pass through it, caused by the absorption and/or scattering that occur as the rays interact with the sample. The standard-volume radiation source used in the efficiency calibration and the sample may not be identical in terms of the density and the material. For this reason, the self-absorption correction is necessary before performing the spectral analysis.

The items consumer software requires for settings to carry out self-absorption correction include the material, density, and height of the sample. While the density and height of the sample are straightforward to input, the selection of material may be difficult to determine. In emergency situations, it is necessary to measure a large number of samples within a short period of time, and it is desirable that the materials suitable for samples be decided in advance.

Potential environmental samples to be measured in emergencies include liquid samples (drinking water, cow's milk, sea water, etc.), raw samples (greens and herbs), and soil/marine soil, etc. The guideline for determining the sample material is to consider the proportion of water contained in the sample, which is a simple method. The dividing line is 50%. If the sample comprises more than 50% of water, its material is set to water. For samples with less than 50% of water content, it is appropriate to select marine soil/soil/ashed material, etc. (See Explanation A). Table 4.1 illustrates major environmental samples and their material categories based on this guideline. Thus, Table 4.1 can be used as a guide to determine sample materials.[*2]

Note that, if the sample is pretreated with a precipitate collection during its preparation, it is necessary to select the precipitates (e.g., ammonium phosphomolybdate), an option available with commercial software, as it will be different from water and soil categories in terms of the extent to which gamma rays decrease.

[*2] Samples that are not listed in Table 4.1 should be considered with reference to the Standard Tables of Food Composition in Japan (Reference 4) for the water content.

Table 4.1 Major environmental samples and their material categories

Environmental sample	Material category
Airborne particles	Marine soil/soil/ashed material, etc.
Soil or marine soil	Marine soil/soil/ashed material, etc.
Grains or milk powder	Marine soil/soil/ashed material, etc.
Fallout or precipitation	Water
Sea water	Water
Drinking water	Water
Cow's milk or raw milk	Water
Greens vegetables	Water
Other (peas and beans, mushrooms, meats, eggs, cheese, butter and other solid dairy products, condensed milk, seaweeds, fish, etc.)	Water

Note 1: Regarding the active carbon cartridge, if the radiation source for the calibration and sample are in the same form, there is no need for correction as the effect of self-absorption is cancelled out.
In the case where active carbon is injected into a U-8 container, etc., the radiation source for the calibration and sample for measurement are not in the same form, and therefore it is necessary to perform the self-absorption correction by setting the material to "marine soil/soil/ashed material, etc."

Note 2: Water samples such as fallout, precipitation, and drinking water should be without pretreatments such as concentration.

Note 3: Raw samples should be without pretreatments such as drying.

4.2 Coincidence summing effect correction

Many radionuclides emit a number of gamma rays as they decay and undergo an energy level transition into a stable state (ground state). During this transition, consecutive emissions of several gamma rays at a number of energy levels cause coincidence summing[*3] (these gamma rays are called cascade gamma rays). As a result, the signals corresponding to each gamma ray energy level are lost, and a signal is output as a total of these gamma-ray energies, appearing as a sum peak in the gamma-ray spectrum. This reduces the peak count rate for gamma rays at the point where a true gamma-ray energy should appear, leading to underestimation. Therefore, it is necessary to correct this.

The items consumer software requires for settings to carry out coincidence summing effect correction include the relative efficiency (or P/T ratio file) and cascade file. It is necessary to check the cascade file in advance, because registered radionuclides are not necessarily uniform among the software vendors, and the coincidence summing effect correction cannot be performed for the radionuclides that are not included in the cascade file. Table 4.2 lists major radionuclides that are included in a cascade file.[*4]

Table 4.2 Major radionuclides mostly included in a cascade file

^{22}Na	^{46}Sc	^{58}Co
^{59}Fe	^{60}Co	^{88}Y
^{133}Ba	^{134}Cs	^{152}Eu

When conducting gamma-ray spectrometry in emergencies, the spectral analysis is made more complex by sum peaks due to coincidence summing. Figure 4.1 illustrates the gamma-ray spectrum of a soil sample taken immediately after the Fukushima Dai-ichi Nuclear Accident, where sum peaks appeared in the ^{134}Cs spectrum.

There were many radionuclides that caused sum peaks, such as ^{134}Cs and ^{132}I,[*5] during and after the Fukushima Dai-ichi Nuclear Accident and Chernobyl Disaster. Normally, these would be treated as unknown peaks in spectral analysis using consumer software.[*6] In order to identify sum peaks correctly, it is necessary to correctly understand the applicable radionuclides in terms of their energy level transitions due to gamma ray emissions. The considerations of the sum peaks of ^{134}Cs and ^{132}I are described in Explanation B.

[*3] Where a thin windowed counter is used, be mindful of the coincidence summing with X rays. It is possible to mitigate the coincidence summing with X rays by installing a copper plate (of the same diameter as the end cap and approximately 0.5 mm thick) on the detector end cap. If the copper plate is installed, the efficiency calibration must be performed under the same conditions.

[*4] Some examples of the nuclides not in Table 4.2 are stated in ISO 7503-3:2016 (en) Annex B.

[*5] At the Fukushima Dai-ichi Nuclear Accident, other radionuclides such as ^{110m}Ag were detected as being prone to coincidence summing.

[*6] This happens because those nuclides' sum peak information is not included in the nuclear data library used in the analysis.

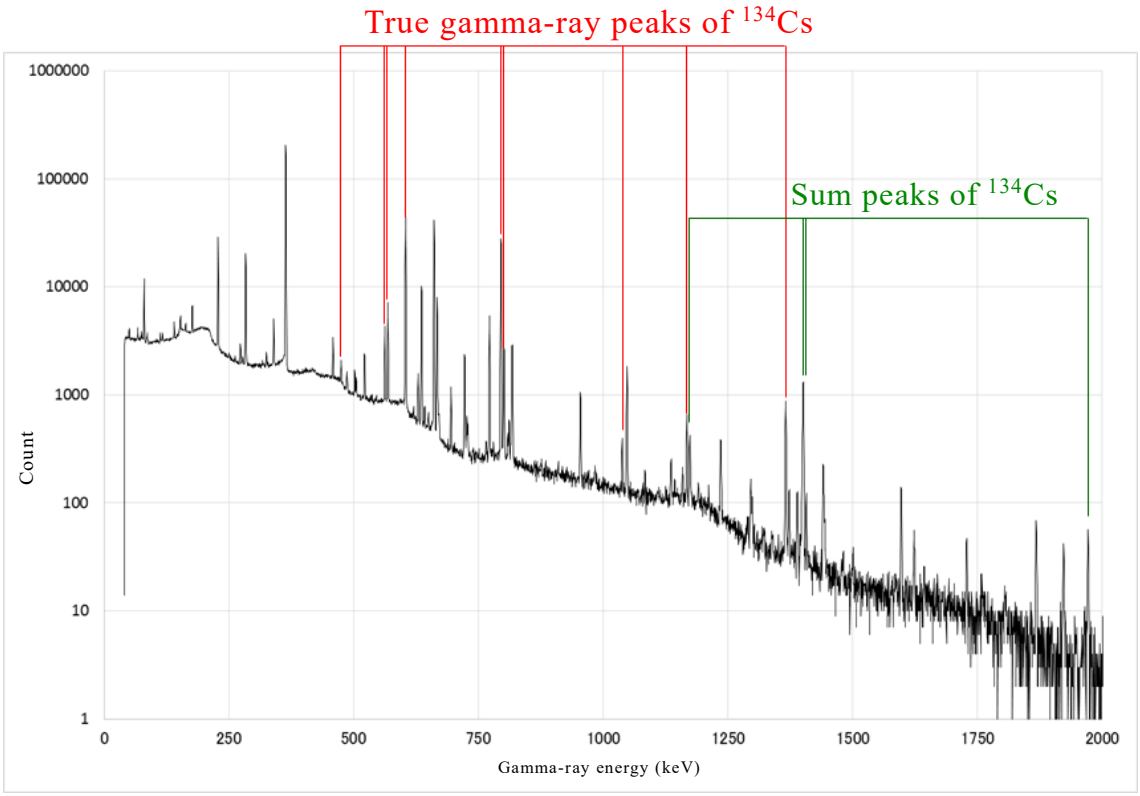


Figure 4.1 Gamma-ray spectrum that shows sum peaks of ^{134}Cs
(from a soil sample taken immediately after the Fukushima Dai-ichi Nuclear Accident)

4.3 Decay correction

The radioactivity of a radionuclide diminishes over time according to the half-life of the nuclide. The activity level obtained is of the time of measurement; thus, it is necessary to perform the decay correction to obtain the radioactivity at other specific times.

4.3.1 Baseline date of decay correction

It is customary to set the baseline date of radioactivity decay correction to the date on which the environmental sample was taken or delivered. If the sample involves a period of sampling time, such as the collection of airborne particles or fallout, the baseline date of decay correction for this sample is essentially set to the middle point of the sampling period. However, this does not exclude the possibilities to set the date at the beginning or end of the period to maintain the integrity with the past data. When using consumer software, note the following concerning the decay correction of the sampling period.

- The decay correction terms of the sampling period are applied as shown in the formula below, and the calculation of the decay correction for the collection period is based on an assumption that the level of radionuclide activity remains constant during the same period.[*7] [*8]

$$DF_S = \frac{\lambda t_s}{1-e^{-\lambda t_s}} \qquad (4.2)$$

DF_S: decay correction term during the sample collection period
λ: disintegration constant
t_s: time passed between the baseline date (e.g., the middle point of the collection period) and the end of the collection

Note that the decay correction concerning the period between the end of the sample collection and the start of the measurement will take "$e^{\lambda t}$" as the decay correction term, as shown in Formula 4.3 under "4.3.2 General formula of decay correction."

It is important that the decay correction be considered for its necessity and the date according to the purpose[*9] for which the measurement results will be used, and the results be recorded and reported together with the clarification as to when the decay correction was performed, such that a third party would be able to understand the significance of the figures from the measurement.

[*7] See the *Guidelines concerning the Measurement of Radioactive Emissions at Light Water Reactor Facilities for Power Generation* by the Nuclear Safety Commission of Japan (Amendment of March 2001). It is based on an assumption that the radioactivity concentration (deposits) is constant during the collection period.

[*8] In the case where the assumption that the level of radiation concentration is constant does not apply owing to a passing radioactive plume or deposition of radioactive materials briefly taking place only once during the collection period, it may be appropriate to set the decay correction date to the time when the deposition started and use $e^{\lambda t}$ as the decay correction term, provided that the date and time of the passing/deposition can be identified or estimated. In this case, consumer software can be configured with these dates and times entered as the start and end date/time of collection to perform the decay correction.

[*9] It is important that the measurement operators understand the intended purpose of the results before undertaking the measurement, etc. Where necessary, they should consult the measurement supervisor who is responsible for collating and evaluating the measurement results. For example, the results may be used for the evaluation of internal exposure doses, or for the comparison with the threshold values concerning the intake limitation of food materials.

4.3.2 General formula of decay correction

As stated in the Radioactivity Measurement Series No. 7 "Gamma-ray Spectrometry Using Germanium Detectors," given $A \pm \sigma$ to be the radioactivity level at the time of the measurement, the radioactivity level time t earlier, $A_0 \pm \sigma_0$, is expressed as follows:

$$A_0 = A \times e^{\lambda t} \quad , \quad \sigma_0 = \sigma \times e^{\lambda t} \tag{4.3}$$

λ: disintegration constant

Using T as the half-life, the formula is as follows:

$$A_0 = A \times \left(\frac{1}{2}\right)^{-\left(\frac{t}{T}\right)} \quad , \quad \sigma_0 = \sigma \times \left(\frac{1}{2}\right)^{-\left(\frac{t}{T}\right)} \tag{4.4}$$

The decay correction where the radionuclide had its half-life shorter than the measurement duration needs to take the decay correction during the measuring period into consideration, and Formula 4.3 becomes as follows:

$$A_0 = \frac{\lambda t_m}{1-e^{-\lambda t_m}} \times A \times e^{\lambda t} \quad , \quad \sigma_0 = \frac{\lambda t_m}{1-e^{-\lambda t_m}} \times \sigma \times e^{\lambda t} \tag{4.5}$$

$A \pm \sigma$: radioactivity at the time of measurement
$A_0 \pm \sigma_0$: radioactivity at time t earlier
λ: disintegration constant
t_m: measuring time (real time)

Some radionuclides disintegrate sequentially, turning into a different type of radionuclide rather than disintegrating to a stable nuclide. In this case, the initial nuclide and the newly created nuclide are called "parent" and "daughter" nuclides, respectively. While the decay correction for the parent nuclide is expressed by Formula 4.3 or 4.5, that for the daughter nuclide requires the impact of the parent nuclide to be taken into account. In this case, the decay correction for the daughter nuclide is calculated according to Formulae 4.6 and 4.7.

$$A_{d0} = A_d \times e^{\lambda_d t} - A_p \times \frac{\lambda_d}{\lambda_d - \lambda_p} \times \left\{ e^{\lambda_d t} - e^{\lambda_p t} \right\} \quad (4.6)$$

$$\sigma_{d0} = \sqrt{\left[\{\sigma_d \times e^{\lambda_d t}\}^2 + \frac{{\lambda_d}^2}{(\lambda_d - \lambda_p)^2} \times \left\{ e^{\lambda_d t} - e^{\lambda_p t} \right\}^2 \times {\sigma_p}^2 \right]} \quad (4.7)$$

$A_p \pm \sigma_p$: radioactivity of the parent nuclide at the time of measurement

$A_d \pm \sigma_d$: radioactivity of the daughter nuclide at the time of measurement

$A_{d0} \pm \sigma_{d0}$: radioactivity of the daughter nuclide at time t earlier

λ_p: disintegration constant for the parent nuclide

λ_d: disintegration constant for the daughter nuclide

Furthermore, Formulae 4.6 and 4.7 with the attenuation during the measuring period considered are transformed as follows:

$$A_{d0} = \frac{A_p \times \lambda_d \times t_m}{\lambda_d - \lambda_p} \times \left\{ \frac{\lambda_p \times e^{\lambda_p t}}{1 - e^{-\lambda_p t_m}} - \frac{\lambda_d \times e^{\lambda_d t}}{1 - e^{-\lambda_d t_m}} \right\} + \frac{A_d \times \lambda_d \times t_m \times e^{\lambda_d t}}{1 - e^{-\lambda_d t_m}} \quad (4.8)$$

$$\sigma_{d0} = \sqrt{\left[{\sigma_p}^2 \times \frac{(\lambda_d \times t_m)^2}{(\lambda_d - \lambda_p)^2} \times \left\{ \frac{\lambda_d \times e^{\lambda_d t}}{1 - e^{-\lambda_d t_m}} - \frac{\lambda_p \times e^{\lambda_p t}}{1 - e^{-\lambda_p t_m}} \right\}^2 + {\sigma_d}^2 \times \left\{ \frac{\lambda_d \times t_m \times e^{\lambda_d t}}{1 - e^{-\lambda_d t_m}} \right\}^2 \right]} \quad (4.9)$$

$A_p \pm \sigma_p$: radioactivity of the parent nuclide at the time of measurement

$A_d \pm \sigma_d$: radioactivity of the daughter nuclide at the time of measurement

$A_{d0} \pm \sigma_{d0}$: radioactivity of the daughter nuclide at time t earlier

λ_p: disintegration constant for the parent nuclide

λ_d: disintegration constant for the daughter nuclide

t_m: measuring time (real time)

4.3.3 Problems associated with emergency situations

In an emergency, applying the decay correction to sequentially decaying radionuclides (especially daughter nuclides that form transient equilibrium) may cause some problems in the measurement results (see Explanation C). The nuclides that form transient equilibrium and were detected following the Fukushima Dai-ichi Nuclear Accident include the following:

- ^{99}Mo (half-life of 65.92 h)/^{99m}Tc (half-life of 6.01 h)
- ^{129m}Te (half-life of 33.6 days)/^{129}Te (half-life of 69.6 min)[*10]
- ^{132}Te (half-life of 3.20 days)/^{132}I (half-life of 2.30 h)
- ^{140}Ba (half-life of 12.75 days)/^{140}La (half-life of 1.68 days)

These daughter nuclides, once they reach the transient equilibrium, maintain a constant radioactivity ratio and decay according to the half-lives of the parent nuclides. Meanwhile, the radioactivity ratio at the time of measurement does not necessarily equal the radioactivity ratio when the transient equilibrium is reached; moreover, the measurement value accounts for statistical fluctuation. For this reason, applying the decay correction to daughter nuclides may result in an over- or under-estimation.

It is also possible that, between sequentially decaying parent and daughter nuclides, only one of them may be detected (see Explanation C). One of the reasons for this is that, owing to the Compton scattering undergone by gamma rays of high energies, the baseline count of the peak area increases and fails to be recognized as a peak.[*11] Similarly, the difference in the gamma-ray emission rates between the parent and daughter nuclides may prevent the detection of the parent nuclide (Reference 5). In the case where only the daughter nuclide is detected, measurement using consumer software should use the half-life of the daughter nuclide for the decay correction. In this case, it is necessary to report the measurement results with their reasons to avoid misunderstanding.

[*10] ^{129m}Te/^{129}Te is an isomeric transition and thus, like other nuclides that form transient equilibrium, applying the decay correction may cause problems in the results.

[*11] When the nuclides with short half-lives decay, the baseline count in the gamma-ray spectrum decreases. In some cases, this reveals gamma-ray peaks that had been hidden before.

4.3.4 Application of decay correction in emergencies

As stated in "4.3.1 Baseline date of decay correction," it is necessary to determine whether the decay correction must be applied based on the intended purpose of the measurement results.[*12] With "4.3.3 Problems associated with emergency situations" considered, separate descriptions are given below on "the nuclides that require no consideration for sequential decay" and "the nuclides that decay sequentially." In any case, it is necessary to record and report the results with accounts of whether decay correction was applied and/or at what point it was performed, such that a third party could correctly understand the significance of the measurement values.

(1) The nuclides that require no consideration for sequential decay (^{131}I, ^{134}Cs, ^{137}Cs, etc.)

Nuclides including ^{131}I, ^{134}Cs, and ^{137}Cs do not have problems through the application of decay correction. Select either "decay correction performed" or "decay correction not performed" according to the purpose, then record and report the measurement results with accounts about whether decay correction was applied and the date of decay correction (where it was performed).

(2) The nuclides that decay sequentially[*13]
(^{99}Mo/^{99m}Tc, ^{129m}Te/^{129}Te, ^{132}Te/^{132}I, ^{140}Ba/^{140}La)

Of the transient equilibrium nuclides that sequentially decay, parent nuclides have no problems with the decay correction, and therefore, (1) above applies. As for daughter nuclides, there may be problems; thus, it is necessary to select "decay correction performed" or "decay correction not performed" according to the purpose. If the decay correction is to be performed, one of the following two methods is adopted:

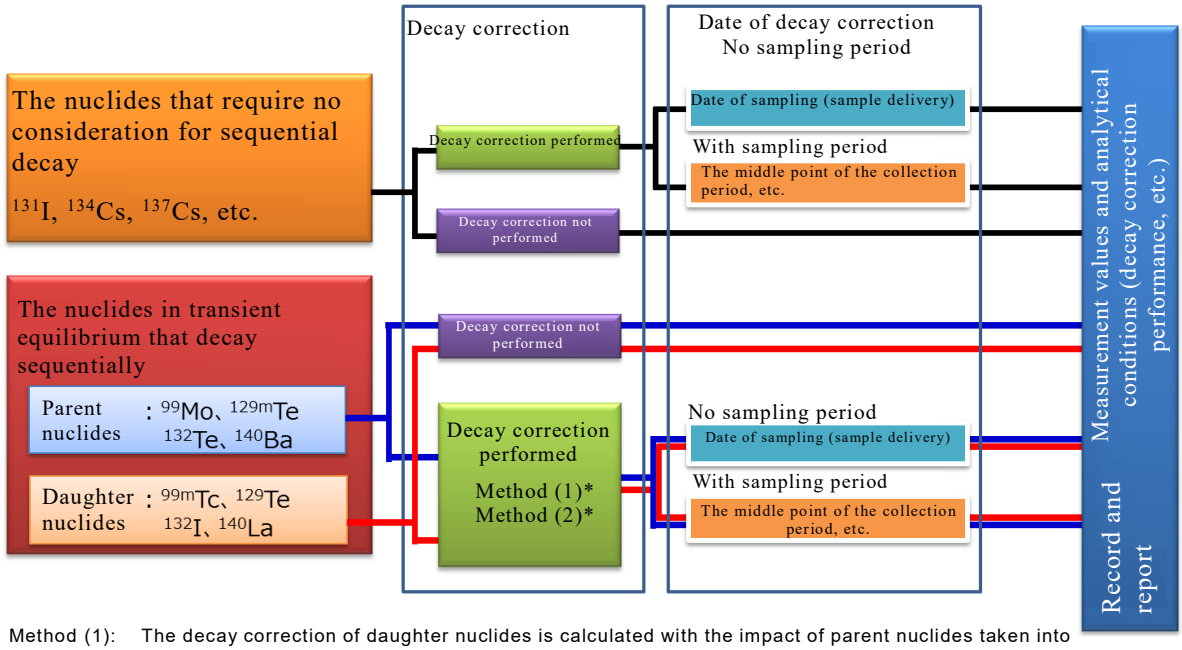
- Decay correction with the impact of parent nuclides taken into account, as described in the Radioactivity Measurement Series No. 7 "Gamma-ray Spectrometry Using Germanium Detector" (Formulae 4.6 to 4.9 under "4.3.2 General formula of decay correction")
- Decay correction based on the half-life of the parent nuclide as that of the daughter nuclide, assuming that the transient equilibrium is reached at the time of emission

In the same way as (1) above, whether the decay correction was performed and the date and method of decay correction (if it was performed) should be recorded and reported together with the obtained results.

Figure 4.2 shows a flow chart that illustrates the decay correction of artificial radionuclides.

[*12] If a measurement supervisor who is responsible for collating and evaluating the measurement results gave instructions as to whether the decay correction should be applied, including the baseline date, the analysis shall be performed based on these instructions.

[*13] Nuclides ^{95}Zr and ^{95}Nb also sequentially decay, but their half-lives are 64.03 days and 34.99 days, respectively. Because it takes considerable time before they reach the transient equilibrium, applying the decay correction indicated in Formulae 4.6 to 4.9 in an emergency situation does not cause problems.



* Method (1): The decay correction of daughter nuclides is calculated with the impact of parent nuclides taken into account, as described in the Radioactivity Measurement Series No. 7 “Gamma-ray Spectrometry Using Germanium Detector.”

Method (2): The decay correction of daughter nuclides is calculated based on the parent nuclide’s half-life on an assumption that the transient equilibrium is reached at the time of emission.

Figure 4.2 Flow of decay correction for artificial radionuclides

4.4 Background correction

In order to remove the risk of including the count that does not derive from a sample in the radioactivity calculation, it is necessary to perform a measurement without samples installed in the detector and subtract the resulting background count in the analysis. The background correction takes the peaks in the background spectrum from the sample spectrum as a background contribution if the peak areas are more than twice the counting error (2σ).[*14] Because it is often the case that the measuring time is different between the sample and background measurement, it is necessary that the subtraction is performed on the basis of the counting rate per second (cps) or per 1000 s (cpks).

Under normal circumstances, gamma-ray peaks that appear in the background spectrum are mainly attributed to natural radionuclides that exist in the detector, shields, laboratory, etc. However, in emergencies, they may appear due to artificial radionuclides emitted from contaminated measurement equipment. For this reason, it is necessary to perform background measurements regularly to check if the measurement equipment is contaminated.

In gamma-ray spectrometry, the background measurement for the subtraction from the sample spectrum is referred to as "background for correction" whereas that for checking the contamination of detectors is referred to as "background for the verification of contamination." Descriptions as to how these are handled are given in Chapter 7 "Background measurement and measures for contamination/decontamination of measurement equipment."

[*14] When measuring environmental samples of unknown values, it may be described as "the uncertainty of the counting statistics" instead of "counting error." "Counting error" is used here for the reasons that it is conventionally used in the field of background radiation measurement and that the employed terms must be coherent throughout the Radioactivity Measurement Series.

Chapter 5 Nuclear data library for emergency situations

5.1 Master library of nuclear data for emergency situations

The nuclear data concerning the radionuclides that could possibly be emitted into the environment in emergencies is designated as the "master library of nuclear data for emergency situations." The radionuclides which satisfy the following are registered in the Master library of nuclear data for emergency situations:

(1) Fission product nuclides, rare gases, and volatile materials as well as radionuclides produced through these
(2) Radionuclides produced as a result of nuclear reactions of neutrons, etc.
(3) Products of uranium and thorium disintegration as well as radionuclides existing in the background

The selection of radionuclides to be registered has been informed by the Guidelines concerning the "Measurement of Radioactive Emissions at Light Water Reactor Facilities for Power Generation," "The Plan for Environmental Radiation Monitoring around the Rokkasho Reprocessing Plant," and the Radioactivity Measurement Series No. 7 "Gamma-ray Spectrometry Using Germanium Detectors."

The nuclear data for the "Master library of nuclear data for emergencies" are initially taken from a reliable compilation of nuclear data[*1] (see Appendix 1). From this source, the nuclear data of the radionuclides that are subject to analysis in emergencies are extracted and organized into a "Nuclear data library for analysis" (see Explanation D).

5.2 Nuclear data library for analysis

The nuclear data library for analysis concerning gamma-ray spectrometry is based on the reports of radionuclides detected in the past accidents of nuclear facilities (Chernobyl Nuclear Power Plant accident (hereafter, the "Chernobyl Disaster"), the criticality accident at the uranium processing facility (hereafter, the "JCO Accident") and the Fukushima Dai-ichi Nuclear Accident) (References 1 and 6 to 28). The types of released radionuclides are organized into two tables: artificial radionuclides detected following the Fukushima Dai-ichi Nuclear Accident and Chernobyl Disaster and those following the JCO Accident (see Table 5.1). These are added to the general-purpose nuclear data library for normal times (see Table 5.1) to create a library for analysis (see Figure 5.1). Note that the preparation of a nuclear data library for analysis is a complex and time-consuming practice; therefore, it must be prepared in advance. It is equally advisable to avoid increasing the number of libraries at hand.

Thus, although, in emergencies, two libraries will be employed as a nuclear data library for analysis, use the one that contains the general-purpose nuclear data library along with the artificial radionuclides detected following the Fukushima Dai-ichi Nuclear Accident and Chernobyl Disaster ((A)+(B) in Figure 5.1) if it is not clear as to which library to choose.

[*1] This refers to the Evaluated Nuclear Structure Data File (ENSDF) held and managed by the National Nuclear Data Center of the US institution Brookhaven National Laboratory.

This library can be considered to be a general-purpose library applicable to all cases of nuclear facility accidents (including fuel reprocessing facility accidents[*2] and underground nuclear testing[*3]). In the case of a criticality accident, use the nuclear data library that contains the nuclear data library for normal times in addition to the artificial radionuclides detected following the JCO Accident ((A)+(C) in Figure 5.1).[*4]

Table 5.1 Types of artificial radionuclides detected following nuclear facility accidents and general-purpose nuclear data library for normal times

General-purpose nuclear data library for normal times (A)

^{7}Be	^{40}K	^{51}Cr
^{54}Mn	^{58}Co	^{59}Fe
^{60}Co	^{65}Zn	^{95}Zr
^{95}Nb	^{103}Ru	^{106}Ru
^{125}Sb	^{131}I	^{134}Cs
^{137}Cs	^{140}Ba	^{140}La
^{144}Ce	^{208}Tl	^{214}Bi
^{228}Ac	^{234m}Pa	

^{108m}Ag	^{110m}Ag	^{141}Ce
^{152}Eu	^{154}Eu	^{212}Pb
^{212}Bi	^{214}Pb	^{226}Ra

Fukushima Dai-ichi Nuclear Accident and Chernobyl Disaster (B)

^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{85}Kr	^{86}Rb	^{91}Sr
^{91}Y	^{95}Zr	^{95}Nb	^{99}Mo	^{99m}Tc	^{103}Ru	^{106}Ru
^{110m}Ag	^{113}Sn	^{125}Sb	^{127}Te	^{129}Te	^{129m}Te	^{130}I
^{131m}Te	^{131}I	^{131m}Xe	^{132}Te	^{132}I	^{133}I	^{133}Xe
^{133m}Xe	^{134}Cs	^{135}Xe	^{136}Cs	^{137}Cs	^{140}Ba	^{140}La
^{141}Ce	^{144}Ce	^{147}Nd	^{152}Eu	^{203}Pb	^{239}Np	

JCO Accident (including neutron-activated nuclides) (C)

^{24}Na	^{46}Sc	^{51}Cr	^{54}Mn	^{56}Mn	^{59}Fe	^{60}Co
^{65}Zn	^{82}Br	^{91}Sr	^{95}Zr	^{95}Nb	^{103}Ru	^{122}Sb
^{124}Sb	^{131}I	^{133}I	^{134}Cs	^{135}I	^{137}Cs	^{138}Cs
^{140}Ba	^{140}La	^{153}Sm	^{198}Au			

Note 1: The radionuclides in gray cells are duplicates of the general-purpose nuclear data library (A).

Note 2: The nuclide ^{85}Kr,[*5] detected after Fukushima Dai-ichi Nuclear Accident, needs caution for handling as its gamma-ray energy level is close to positron annihilation radiation (511 keV).

Note 3: Radioactive xenon is a nuclide that was detected with a portable germanium detector (Reference 29) and in a background spectrum (see Explanation G).

[*2] If applying it to an accident of reprocessing facilities, add ^{129}I and ^{241}Am as necessary.

[*3] Handling with caution is necessary because the composition of the artificial radionuclides released in a nuclear test is different from that of the radionuclides derived from nuclear facility accidents.

[*4] This is a nuclear data library for analysis that includes the fission product nuclides reportedly detected in the JCO Accident.

[*5] The gamma-ray emission rate of ^{85}Kr (514.0 keV) is low at 0.43% and expected to be difficult to detect using gamma-ray spectrometry.

[Nuclear accidents similar to Fukushima Dai-ichi Nuclear Accident and Chernobyl Disaster]

[Nuclear accidents similar to JCO Accident]

Figure 5.1 Types of nuclear data library for analysis

Note that, owing to the selection of radionuclides, the nuclear data library for analysis used in gamma-ray spectrometry possibly reduces the risk of misidentification of nuclides, but it is expected that certain gamma-ray peaks in the measured spectrum are treated as those of unknown nuclides. Therefore, these unknown peaks must be verified against the nuclear data included in Appendix 2, and they must subsequently be added to the nuclear data library for analysis.

Chapter 6 Measurement and spectral analysis

In emergencies, unlike in normal times, gamma-ray spectrometry using a germanium detector require certain precautions in measuring and analyzing, such as avoiding the contamination of the detector and increased dead time, as well as the misidentification of more complex gamma-ray spectra and nuclides. Keeping these points in mind, this chapter describes a series of tasks from measurement to analysis, evaluation, and reporting.
As for the preparation of samples, refer to the Radioactivity Measurement Series No. 24 “Preparation of Samples for Gamma-ray Spectrometry in Emergencies.”

6.1 Measurement of samples

The procedures starting from setting the sample on the detector’s end cap to removing the sample after the measurement are described below. Note that the risk of contaminating the detector can be reduced by keeping the sample in double polyethylene bags and replacing the outer bag with a new one just before taking the sample into the measurement chamber.[*1]

6.1.1 Procedures of measuring the sample

The procedures of sample measurement are as follows:

(1) Verify that the sample is the correct material for the measurement.
- Verify the details on the sample container (label, etc.) against the sampling records and logs for the name of the sample, sampling location, date of sampling, sample identification number, etc.
- To prevent a mix-up of samples, always consult a supervisor, etc. when the information does not match, or some details are missing.

(2) Place the sample on the detector’s end cap.[*2] [*3]
- The orientation between the sample and detector (geometry[*4]) should be the same as that of the standard radiation source for efficiency calibration.[*5]
- When using an automatic sample changer, measurement without using a protective bag must be handled cautiously to prevent the contamination of the detector.

[*1] It is recommended that the detector’s end cap also be covered in a polyethylene bag. In this way, it may be easily removed in the case of contamination.

[*2] When measuring an active carbon cartridge, place the suction side to face the detector’s end cap to prevent underestimation.

[*3] In the case of a Marinelli beaker, the geometry may not be identical to that of the radiation source for calibration if the bag containing the beaker is sufficiently vacuumed (if the bag is not stuck on the beaker). If there is an attached monitor for liquid nitrogen, it can be verified by the changes in weight (approximately 0.3 kg as a guide).

[*4] The geometry includes the height of the container and also the height of the sample inside the container. For Marinelli beakers, it is necessary to fill the container with the sample up to the marked line, as with the radiation source for calibration. However, U-8 containers, etc. do not require the same if efficiency calibration has been performed with several calibration radiation sources of varying heights, because the correction can be made using a relational expression of the peak efficiency (or an inverse of the peak efficiency) and sample height.

[*5] It is best to use a jig designed to recreate the geometry. Where a jig is not available, make some arrangements, such as marking, to ensure the same geometry.

(3) Delete the gamma-ray spectrum from a previous measurement.
- If a gamma-ray spectrum remains in the memory of a multichannel analyzer from a previous measurement, ensure that it is saved, and then delete it.

(4) Configure the measuring time (preset time).
- As a guide, the measuring time is from 10 min to 1 h, depending on the purpose.

(5) Start measuring.
- Record the start time of the measurement.
- Verify that the start time indicated on the multichannel analyzer (or PC) matches the actual time.
- Verify that the measuring time (live time[*6]) is in progress.
- Check the dead time and, if it is more than 10%, make necessary arrangements, such as reducing the volume of the sample.[*7]
- Verify that the peaks in focus (^{40}K and ^{137}Cs, etc.) have no drift (misalignment) of $\pm$1 keV or more.
- Verify this at a long interval[*8] and if there are drifts, check the air-conditioning facilities, etc., readjust the gain, and perform other measures as necessary.
- Verify that there are no wide peaks with high count rates in the low-energy region (below several dozen keV).[*9]
- If a recognizable peak forms within a short period of time, identify the nuclide that corresponds to the peak as much as possible. If the sample is of an artificial radionuclide, contact the pretreatment staff to notify them of the possibility of cross-contamination during the sample preparation.

(6) Record the measurement details.
- The measurement information to be recorded is listed in Table 6.1 as an example. Therefore, it is necessary to have a notebook ready for recording the measurement information.

(7) End the measurement.
- Stop measuring when the measuring time reaches the predetermined duration.
- If a preset time is configured, verify that the measurement has terminated.
- If necessary, record the live time and measurement end time.
- Save the gamma-ray spectrum of the measurement to a PC, etc. Pay attention to have the correct measurement number when saving the data. Correct saving of the data can be easily verified by reloading the saved gamma-ray spectrum.

[*6] Note that the live time progresses slowly if the dead time is substantial.

[*7] If the efficiency calibration was conducted with the standard radiation source removed away from the detector, measurement performed with the same geometry may lower the dead time below 10%.

[*8] Check once in 10 to 30 min, depending on the preset time.

[*9] There is the possibility of interference by electrical noise, and it occurs, improvements may be made by rearranging the wiring or changing the lower limit discriminator (LLD). If improvement is not forthcoming, it is necessary to contact the vendor of the detector.

(8) Remove the sample.
- Check that the sample is in the same state as it was in the detector just before the measurement started.
- Check the record of the sample thus removed and confirm its identity.

(9) Store the sample.
- The sample must be promptly moved to a storage place such as a refrigerator when the measurement is over, paying attention not to mix with the samples that are not yet measured.
- Where it is possible, measured samples that have a high level of radioactivity should be stored separately from those with a low level of radioactivity.
- When a sample of high radioactivity is measured, it is advisable to take a background measurement to check for contamination. For more details, refer to "7.3 Background measurement for the verification of contamination."

Table 6.1 Example of measurement information to be recorded

Item	Description
(1) Measurement number	Detector-dependent number (incremental number, etc.)
(2) Measurement start time	Time when the measurement commenced (record the date and the exact time to the minute)
(3) Measurement end time	Time when the measurement terminated (record the date and the exact time to the minute) This procedure is not required if the measurement is terminated automatically by the use of preset time.
(4) Measuring time	The period of time passed while measuring Record the preset time or live time when the measurement is terminated
(5) Measuring staff	The name of the staff member who conducted the measurement
(6) Measurement sample	The name and ID number of the sample measured Additionally, record the container used for measurement, as well as the volume, height, density and material of the sample, if necessary.
(7) Remarks	Take a note of points noticed during the measurement

Figure 6.1 illustrates the flow of the sample measurement procedures, and Table 6.2 shows an example of a list of checkpoints for measuring staff.

Measurement

←(1) **Verify that the sample is the correct material for the measurement.**

- Verify the details on the sample container against the sampling records and logs to ensure that the sample is the one intended.
- To prevent a mix-up of samples, consult appropriate staff for confirmation if necessary.

←(2) **Place the sample on the detector's end cap.**

- Verify that the sample is placed in the same geometry as the standard radiation source for efficiency calibration.
- Take care not to contaminate the detector.

←(3) **Delete the gamma-ray spectrum from a previous measurement (after confirming that it has been saved).**

←(4) **Configure the measuring time (preset time) (between 10 min and 1 h as a guide).**

←(5) **Start the measurement**

- Record the measurement start time.
- Verify that the start time indicated on the multichannel analyzer (or PC) matches the actual time.
- Verify that the measuring time (live time) is in progress.
- Check the dead time.
  If it is 10% or more, make necessary arrangements, such as reducing the volume of the sample.
- Verify that the peaks in focus are not drifting.
  Check again at an interval (every 10 to 30 min).
- Verify that the low-energy region contains no wide peaks.
- If a peak of an artificial radionuclide is recognized within a short period of time, warn the sample preparation staff of the risk of cross-contamination.

←**(6) Record the measurement information (see Table 6.1).**

←**(7) End the measurement.**

- Press the stop button (if a preset time is not set up)
- Verify that the measurement has terminated (if a preset time is set up)
- If necessary, record the live time and measurement end time.
- Save the measured gamma-ray spectrum.

←**(8) Remove the sample.**

- Verify the geometry (relative orientation of the sample and detector).
- Verify the sample that is removed from the detector against the record.

Figure 6.1 Sample measurement procedure flow

*

←**(9) Store the sample.**

- Store the sample at a designated place.
- Where possible, store a sample of a high level of radioactivity separately from others.
- Check the detector for contamination as necessary.
  After measuring a sample of a high level of radioactivity, take a background measurement to check for contamination.

Analysis

Figure 6.1 Sample measurement procedure flow (continued)

Table 6.2 Examples of items for measurement staff to check when undertaking the measurement

No.	Description	Check
(1) Verify that the sample is the correct material for the measurement.		
1	Verify the details on the sample container against the sampling records and logs to ensure that the sample is the one intended.	
2	To prevent a mix-up of samples, consult appropriate staff for confirmation if necessary.	
(2) Place the sample on the detector's end cap.		
3	The sample is placed in the same geometry as the standard radiation source for efficiency calibration.	
4	Take care not to contaminate the detector.	
(3) Delete the gamma-ray spectrum from a previous measurement.		
5	Delete the gamma-ray spectrum from a previous measurement (after confirming that it has been saved).	
(4) Configure the measuring time.		
6	Configure the measuring time (preset time) (from 10 min to 1 h as a guide).	
(5) Start the measurement.		
7	Record the measurement start time.	
8	The measuring time (live time) is in progress.	
9	Check the dead time and, if it is 10% or more, necessary arrangements, such as reducing the volume of the sample, are implemented.	
10	The peaks in focus are not drifting.	
11	The low-energy region contains no wide peaks.	
12	No peaks of artificial radionuclides appear in a short period of time. (If such peaks are recognized, contact the pretreatment staff to warn of the cross-contamination during the sample preparation.)	
(6) Record the measurement information.		
13	Record the measurement information (measurement ID number, measurement start time, etc.).	
(7) End the measurement		
14	Press the stop button (if a preset time is not set up).	
15	The measuring time has run out (if a preset time is set up).	
16	Record the live time and measurement end time (if necessary).	
17	Save the measured gamma-ray spectrum.	

Table 6.2 Examples of items for measurement staff to check when undertaking the measurement (continued)

No.	Description	Check
(8) Remove the sample.		
18	The geometry (relative orientation of the sample and detector) is identical to the one at the beginning of measurement.	
19	Check the removed sample against the record and verify the conformity.	
(9) Store the sample.		
20	Store the sample at a designated place.	
21	Where possible, store a sample of a high level of radioactivity separately from others.	
22	Check the detector for contamination as necessary.	

6.1.2 Problems associated with performing high-count-rate measurement

Measuring in emergencies sometimes necessitates the measurement of high-radioactivity-level samples, resulting in a high-count-rate measurement. When this is the case, incident gamma rays are in a significantly large number, and electronic devices with their signal processing will be overloaded.

A high-count-rate measurement is associated with the following problems:

- Increased dead time
- Pulse Pile-up
- Random summing

Pulse pile-up and random summing cause the net count rate of gamma-ray peaks to decline and result in underestimation. As the dead time increases, the measurement will be prolonged. These problems concerning the measurement are described in detail in Explanation E.

If the dead time is found to be long upon the start of the sample measurement (approximately 10% as a guide), it is necessary to implement appropriate measures such as reducing the sample volume to reduce the number of gamma rays emitted from the sample.[*10] When reducing the sample volume, apart from trying to prevent contamination, observe the following points:

- If a sample in a 2-L Marinelli beaker is to be reduced, it should be transferred to a smaller Marinelli beaker (e.g., 1-L beaker) or a small, cylindrical container such as a U-8 container.[*11]
- When using a small cylindrical container such as a U-8 type, simply reduce the volume of the sample in the container.[*12]
- Regarding the new container in which to place the sample for measurement, efficiency calibration must be performed using a standard radiation source in the same container.

Similarly, when measuring a sample that contains a large number of nuclides that release high-energy beta rays, such as $^{90}Sr/^{90}Y$ and $^{106}Ru/^{106}Rh$, the beta rays may produce breaking radiation as they collide with metal objects such as the end cap. If this happens, the gamma-ray

[*10] Moving the sample away from the detector may reduce the number of incident gamma rays, but this method requires that the efficiency calibration has been performed in advance with the same geometry.

[*11] A sample in a Marinelli beaker is in the same form as the standard radiation source. Reducing the volume of the sample in a Marinelli beaker removes it from the geometry of efficiency calibration and therefore it is not possible to quantify.

[*12] If a small cylindrical container such as a U-8 container is used, the efficiency at the geometry of the reduced sample volume can be calculated using a relational expression of the peak efficiency (or an inverse of the peak efficiency) and their height, provided that efficiency calibration has been performed in advance with approximately five standard radiation sources of varying heights.

spectrum counts in the low-energy region is generally increased, thereby burying certain gamma-ray peaks such that they cannot be detected.
This situation can be avoided by installing an acrylic tube of a few millimeters thickness on the end cap, as it will absorb the beta rays and prevent a count hike. This acrylic tube also prevents the contamination of the detector. However, it will be necessary to perform efficiency calibration with this acrylic tube on the end cap in advance.

6.1.3 Checking the soundness of measurement equipment, etc. and other points of caution about measuring

Regular inspection is useful for maintaining the soundness of the measurement equipment, etc. This is described below, along with other points of caution. It is also recommended that the detector be regularly checked for the efficiency calibration formula to be correct, using radiation sources.[*13]

(1) Daily inspection

- Verify that the energy calibration formula in use is appropriate.
  Verify that the peaks in focus are not drifting at their peak centers.[*14]
  If the energy calibration formula is found to be inappropriate, perform the gain adjustment once again or create a new energy calibration formula (see "3.1.1 Energy calibration").
- Verify that the measurement equipment is not contaminated.
- If the measurement equipment is contaminated, perform the background measurement for correction with appropriate frequency (see "7.2.1 Background measurement for correction").
- Verify that the air-conditioning is controlled appropriately (ideally, the room temperature is 23 ± 2°C and the humidity is 50 to 60% and stable).
- Check that the end cap, etc. has no condensation.[*15]
- Confirm that liquid nitrogen is available for procurement (except if the electric cooling system is employed without the need for liquid nitrogen).

[*13] Gamma-ray peak efficiency (or peak count rate) is checked for being stable and constant (taking the radioactive decay over time into account) using a multinuclide standard-volume radiation source and/or a checking radiation source for efficiency calibration. The energy resolution and relative efficiency must also be regularly checked to ascertain the equipment performance.

[*14] Verify that the drift of peak centers for ^{40}K and ^{137}Cs is within ±1 keV.

[*15] If the end cap, etc. develops condensation, compromised vacuum is suspected in the detector. Therefore, it is recommended that the detector be taken out of operation and serviced by a manufacturer, etc.

(2) Other points of caution about measuring

- The storage place for unmeasured samples must be clearly designated, just as the one for measured samples.
- Always use designated garments (white lab coats, etc.) and footwear in the measurement chamber to mitigate contamination.
- Where the measurement equipment has limited compatible types of measurement containers, these must be clearly marked.[*16]

[*16] For example, the size and the shield structure of the detector are incompatible with a 2-litter Marinelli beaker.

6.2 Spectral analysis

The latest consumer software for spectral analysis allows the user to perform the peak search, nuclide identification, quantification, output of analysis logs, etc. of the measured gamma-ray spectrum with easy-to-use operations (see Explanation F).

Consumer software can be used both in normal and emergency situations. However, in emergencies, a measured gamma-ray spectrum displays many gamma-ray peaks owing to artificial radionuclides. These peaks are treated as unknown peaks if they cannot be identified against the nuclear data library for analysis. In such a case, there is a risk of misidentification of nuclides. Likewise, gamma-ray peaks of low emission rates could also be observed. This necessitates a review of low-emission-rate gamma-ray peaks in addition to high-emission-rate gamma peaks for quantification in order to improve the accuracy of nuclide identification. Furthermore, statistical fluctuations of the baseline may contribute to the detection of peaks that would otherwise be undetected.

Overall, when using consumer software for gamma-ray spectrometry in emergencies, it is important to visually verify the gamma-ray spectrum instead of submitting an output log of automated analysis.

6.2.1 Procedures of spectral analysis

The procedures of spectral analysis are as follows:

(1) Register the sample information.[*17]

- Name and type of the sample, sampling location, sampling start/end time, measurement container, sample volume (weight, suction flux, etc. including the unit used), height, density, material category, name of the measurement operator, etc.

(2) Register necessary calibration files.

- Energy calibration file (including the relational expression of the half-width and gamma-ray energy), relative efficiency or P/T ratio file,[*18] cascade file, and efficiency calibration file

(3) Configure the analytical conditions.

- Select the nuclear data library for analysis.
- Select the peak search sensitivity level (normally at 3)
- Select the condition for decay correction.

  Select from the options provided, which may include the sampling start or end date/time, the middle point of the sampling period,[*19] and no decay correction.
- Select the peak area calculation method (Covell method or function fitting).
- Register the background correction file.

  Select the background spectrum for correction.

(4) Run the analysis.

[*17] Mainstream software allows users to perform the registering actions even during the measurement.

[*18] These may vary depending on the consumer software in use, and thus it is necessary to refer to its user manual.

[*19] If there is not an option for the middle point of the sampling period, this timing may be obtained through other means and set to the sampling start date/time. Then, the sampling start date/time is selected as the correction condition.

(5) Output the results log.
- Data to be output include the peak search results, peak quantification results, and gamma-ray spectrum chart.

(6) Verification of analysis results.
- Verify the accuracy of the information included in the analysis results log, including the sample information, used calibration files, and analytical conditions.
- Check the peaks in focus (^{40}K, ^{137}Cs, etc.) in the gamma-ray spectrum for drifts of ±1 keV or more.
- Verify the detected artificial radionuclides.
  Check the formation of gamma-ray peaks by magnifying the gamma-ray spectrum (to determine whether statistical fluctuations in the baseline counts over the peak area affected the detection).
- Check the gamma-ray peaks of low emission rates to enhance the accuracy of nuclide identification.
- As for nuclides that decay sequentially, check the gamma-ray peaks of either a parent or daughter nuclide.
- Check for gamma-ray peaks by other radioisotopes (e.g., isotopes of radioactive iodine).[*20]
- Unknown peaks should be identified by the corresponding nuclides with reference to the nuclear data in the order of energy (Appendix 2). Where necessary, register the nuclear data of the identified nuclides to the nuclear data library for analysis and run the analysis again.

Figure 6.2 illustrates the flow of the procedures to analyze a measured gamma-ray spectrum, and Table 6.3 shows an example of a list of checkpoints for measuring staff during the analysis.

[*20] The radioactive iodine and radioactive cesium that were detected in relation to Fukushima Dai-ichi Nuclear Accident are ^{130}I, ^{131}I, ^{132}I, and ^{133}I for the former, and ^{134}Cs, ^{136}Cs, and ^{137}Cs for the latter. For example, if ^{131}I is detected, check for the gamma rays emitted by the other radioisotopes. Radioisotopes released in a nuclear accident differ depending on the type of accident. Refer to the nuclides registered in the nuclear data library for analysis described in Chapter 5.

Gamma-ray spectrum

←(1) Registration of sample information

- Register the name and type of the sample, sampling location, sampling start/end date/time, measurement container, sample volume (including the unit used), height, density, material category, name of the measurement operator, etc.

←(2) Registration of necessary calibration files

- Register the energy calibration file (including the relational expression of the half-width and gamma-ray energy).
- Register either the relative efficiency or P/T ratio file and cascade file.
- Register the efficiency calibration file.

←(3) Configuration of the analytical conditions

- Select the nuclear data library for analysis.
- Select the peak search sensitivity level (normally at 3).
- Select the condition for decay correction.
  Select from the options provided, which may include the sampling start or end date/time, the middle point of the sampling period, and no decay correction.
- Select the peak area calculation method.
  Choose either the Covell method or the function fitting.
- Register the background correction file.
  Select the background spectrum for correction.

←(4) Run the analysis.

←(5) Output the results log.

- Data to be output include the peak search results, peak quantification results, and gamma-ray spectrum chart.

←(6) Verification of analysis results.

- Verify the details in the analysis results log.
- Verify that the peaks in focus (^{40}K, ^{137}Cs, etc.) in the gamma-ray spectrum have no drifts.
- Verify the detected artificial radionuclides.
  Check the formation of gamma-ray peaks by magnifying the gamma-ray spectrum (to determine whether statistical fluctuations in the baseline counts affected the detection).
- Check the gamma-ray peaks of low emission rates to enhance the accuracy of nuclide identification.
- As for nuclides that decay sequentially, check the gamma-ray peaks of either a parent or daughter nuclide.
- Check for gamma-ray peaks by other radioisotopes (e.g., radioactive iodine).
- As for unknown peaks, identify the nuclides with reference to the nuclear data in the order of energy.
  Where necessary, register the nuclear data of the identified nuclides to the nuclear data library for analysis and run the analysis again.

Evaluation

Figure 6.2 Flow of the procedures to analyze measured gamma-ray spectrum

Table 6.3 Examples of checkpoints for measurement staff during the analysis

No.	Description	Check
(1) Registration of sample information		
1	Name and type of the sample, sampling location, sampling start/end date/time, measurement container, sample volume (including the unit used), height, density, material category, name of the measurement operator, etc. are registered correctly.	
(2) Registration of necessary calibration files		
2	The energy calibration file (including the relational expression of the half-width and gamma-ray energy) is registered correctly.	
3	Either the relative efficiency or P/T ratio file and cascade file are registered correctly.	
4	The efficiency calibration file is registered correctly.	
(3) Configuration of the analytical conditions		
5	The nuclear data library for analysis is selected correctly.	
6	The peak search sensitivity level is selected correctively.	
7	The decay correction conditions are selected appropriately.	
8	The peak area calculation method is selected appropriately.	
9	The background correction file is registered correctly.	
(4) Execution of the analysis		
(5) Output of analysis results log		
10	The peak search results, peak quantification results, and gamma-ray spectrum chart are output.	
(6) Verification of analysis results		
11	The accuracy of the details in the analysis results log is verified (e.g., cross-checking by two members).	
12	The peaks in focus (^{40}K, ^{137}Cs, etc.) in the gamma-ray spectrum have no drifts.	

Table 6.3 Examples of checkpoints for measurement staff during the analysis (continued)

No.	Description	Check
13	Concerning gamma-ray peaks of detected artificial radionuclides • Gamma-ray spectra are checked by magnifying the gamma-ray spectrum to distinguish the detection owing to statistical fluctuations of the baseline counts. • Single escape, double escape, sum peak, and random sum peak are considered for the possibility of occurrence. • Where there are artificial radionuclides that release a number of gamma rays, the gamma-ray peaks of low emission rates are also verified. • As for nuclides that decay sequentially, the gamma-ray peaks of the parent/daughter nuclide are checked. • Gamma-ray peaks by other radioisotopes (e.g., radioactive iodine) are checked.	
14	Concerning unknown gamma-ray peaks • Gamma-ray spectra are checked by magnifying the gamma-ray spectrum to distinguish the detection owing to statistical fluctuations of the baseline counts. • Single escape, double escape, sum peak, and random sum peak are considered for the possibility of occurrence. • Unknown peaks are identified with reference to the nuclear data in the order of energy. • Where unknown peaks are identified, the nuclear data of the identified nuclides are registered to the nuclear data library for analysis and the analysis is repeated if necessary.	

6.2.2 Handling of unknown peaks

The peaks detected in the gamma-ray spectrum are checked against the nuclear data library for analysis, and if there are no corresponding gamma-ray energies within the identification margin of error, they are treated as unknown peaks. While the identification of unknown peaks possibly creates a significant workload, it is possible to accomplish it by using the nuclear data organized in the order of energy (see Appendix 2).[*21]

It is necessary to consider the following points before proceeding with the identification process.

- The peaks detected only analytically owing to the statistical fluctuations of the baseline counts
- Single escape, double escape, sum peak, and random sum peak

The random sum peak is a phenomenon in which several gamma rays (except cascade gamma rays) enter the detector almost simultaneously, rendering the output signal to be a sum of the energies and, for this reason, not recorded in the nuclear data. Therefore, identifying random sum peaks requires finding the right combination of nuclides from the candidates extracted from the

[*21] If repeating the measurement in order to verify the identification results, it is useful to check if the result of the re-measurement is diminished in line with the half-life of the identified nuclide. If it is possible, the second-time measurement is preferably performed with a different detector. By doing so, it is possible to check for influences exerted by faults in the measurement equipment, contamination, fluctuation of the background conditions, and calibration. If a second detector is not available, it is desirable that the background measurement for correction be performed before the second measurement (this can also serve as a contamination check) and the measurement equipment be inspected, after which the second measurement be carried out with a longer measuring time.

large peaks in the gamma-ray spectrum.

6.2.3 About misidentification of radionuclides

Misidentification of radionuclides occurs when the data about the nuclides to be identified are not registered in the nuclear data library and the gamma-ray energy of a different nuclide falls within the identification margin of error. Similarly, the single escapes, double escapes, and sum peaks unregistered with the nuclear data library may likewise cause misidentification. In one common example, the ^{134}Cs sum peak (569.3 keV + 604.7 keV) is mistaken for ^{60}Co (1173.2 keV). In this case, the misidentification can be avoided by verifying that there are no gamma-ray peaks for ^{60}Co (1332.5 keV) in the high-energy area. Similarly, misidentification of ^{132}I can occur for its gamma rays at 809.5 and 1290.8 keV as ^{58}Co (810.8 keV) and ^{59}Fe (1291.6 keV) if the nuclear data library has no data on ^{132}I, but does have data on ^{58}Co and ^{59}Fe.

Meanwhile, samples for measurement in emergencies can be expected to contain a high level of water. It is possible that neutrons as secondary particles of cosmic rays decelerate because of the water and become likely to interact with the detector's component materials. Take the germanium in the germanium detector, for example; the atoms interact with neutrons to produce ^{75m}Ge, which emits gamma rays (139.7 keV), and this can be mistaken for a ^{99m}Tc gamma ray (140.5 keV) (Reference 30).

6.2.4 Handling of multiple peaks of the same nuclide

Some radionuclides emit several gamma rays, and verifying multiple detected gamma rays is effective in enhancing the accuracy of nuclide identification. However, for the purposes of radioactivity quantification and reporting of results, it is necessary to establish how to handle gamma-ray peaks in advance.

In general, there are two methods: to focus on the main peak (the primary peak that has the highest emission rate) and to use the weighted average of the values taken from multiple peaks. Although both methods are described below for points of cautions, the one that focuses on the main peak shall be considered to be the basic method for gamma-ray spectrometry.

(1) The method to focus on the main peak

This method takes the primary peak that has the highest emission rate.

However, for the purpose of verifying the validity of the quantification result, the quantification results from gamma-ray peaks of other energies should not be ignored but used as references. If the quantification yields a large value, it is necessary to consider a possible contribution by ghost peaks (e.g., ^{137}Cs (661.7 keV) against ^{110m}Ag (657.8 keV)). If ghost peaks are found to be interfering, it is necessary to determine whether to use the gamma-ray peak with the second highest emission rate for the quantification. Note that, when interference on the primary peak by other nuclides' gamma-ray peaks is anticipated, it is advised that the nuclear data library for analysis be configured in advance, such that the secondary peaks are used for quantification.

(2) The method to use weighted average

With multiple gamma-ray peak quantification results, give the one with a smaller counting error

greater weight and obtain the average (see Explanation F). It is anticipated in emergencies that quantification results contain low emission rate and relatively large counting error, in which case they are not useful for this method of using the weighted average. Therefore, it is advisable to determine in advance the gamma-ray energies with which to obtain the weighted average, considering their emission rates and peak efficiencies. Furthermore, the gamma-ray peak used to obtain the weighted average should be verified for their quantification results to ensure that they are not misrepresented owing to the interference of ghost peaks.

Note that the weighting values for taking the average always reduces the counting error, resulting in the weighted average being 3σ or more (σ: counting error), even if not all gamma-ray peaks were detected.

6.3 Evaluation of analysis results

The evaluation of analysis results presupposes that the measurement and analysis were conducted correctly. Analysis results can vary significantly if, for example, the geometry used in measuring was different from that for a calibration radiation source, or various corrections (self-absorption correction, coincidence summing effect correction, decay correction, etc.) were configured inappropriately.[*22] [*23] Therefore, it is necessary to ensure that the analysis results are thoroughly checked before use.

Even with analysis results that are assured of the correctness of measurement and analysis, it may prove difficult to determine whether the data are accurate solely based on the results about the artificial radionuclides thus obtained. Thus, it is necessary to consider the type of nuclear accident, distance from the radiation source, weather conditions, time passed, half-life concerned, physical and chemical behaviors (e.g., volatility; see Explanation D), and so on in order to determine the validity of the detected peaks.[*24] [*25]

According to the literature published after nuclear accidents (References 31 to 50), the evaluation of radioactivity ratio[*26] [*27] between artificial radionuclides is a common practice, not specific to Fukushima Dai-ichi Nuclear Accident, and this can provide evidence to verify the validity of the data. Nevertheless, immediately after the occurrence of a nuclear accident, ascertaining the number of artificial radionuclides released is assumed to be difficult; therefore, further accumulation of data is necessary.

In this sense, it is valid to perform the evaluation with reference to a database containing measurement results of the same or similar samples. In this case, natural radionuclides instead of artificial radionuclides are examined in terms of radioactivity concentration. It is expected that the radioactivity concentration levels of the natural radionuclides in the same or similar samples are approximately the same. Thus, it is possible in some cases to determine the validity of the data by comparing these results and verifying that no significant discrepancies are present.

[*22] Self-absorption correction has the material type, sample height, and density to be configured, and coincidence summing effect correction determines whether to perform the correction. Decay correction requires attention in particular to verify that the results of decay correction for daughter nuclides that form transient equilibrium have no problem (see Chapter 4).

[*23] It is also necessary to pay attention to the configurations of gamma-ray peak regions for analysis. For example, the gamma peaks of ^{134}Cs (604.7 keV) and ^{214}Bi (609.3 keV) are so close that it may happen that they are not distinguished from one another and a sum of these two is shown in the result. Thus, it is necessary to check other gamma-ray peaks of greater emission rates (for example, 795.9 keV for ^{134}Cs) and to visually verify the regions of peak analysis.

[*24] Regarding the detected radionuclides, it is necessary to consider the possibilities of other sources (e.g., past nuclear explosion tests within the Earth's atmosphere and medical radioactive materials).

[*25] The decay of nuclides with short half-lives will lower the baseline count in the gamma-ray spectrum, which may reveal gamma-ray peaks of other artificial radionuclides that had been hidden before.

[*26] Once a sufficient amount of measurement data is gathered, the radioactivity ratio between ^{134}Cs and ^{137}Cs may help to verify if the coincidence summing effect correction has been performed.

[*27] Upon the evaluation of the ^{134}Cs/^{137}Cs radioactivity ratio, following points must be considered for their possible influences: (1) ^{137}Cs is accumulated in the atmosphere from past nuclear explosion tests and the Fukushima Dai-ichi Nuclear Accident, and (2) when the radioactivity concentration levels of ^{134}Cs and ^{137}Cs become low, the relative error increases in the measurement result, resulting in fluctuations in the radioactivity ratio.

6.4 Reporting analysis results

It is desirable that the analysis results that have been validated be reported using designated report formats. Tables 6.4 and 6.5 show examples of a report format. The format should include not only the radioactivity concentration of detected radionuclides, but also the sample and measurement information as well as the analytical conditions applied. It should be noted that, when copying the content to elsewhere, due care must be taken to eliminate errors, such as a cross-check by two people reading out the content.

In view of the possibility that a third-party person may have difficulties in evaluating the measurement results solely based on the figures reported, the report should include the analysis log output and gamma-ray spectrum charts as necessary.

Figure 6.3 illustrates a flow covering 6.2.1(6) “Verification of analysis results” to 6.4 “Reporting analysis results” concerning detected peaks in a gamma-ray spectrum.

Table 6.4 Example of a report format 1

Results of measuring nuclides using germanium detector

1. Institution that performed the measurement	
Institution that performed the analysis	
Chief personnel	
Measurement personnel	

2. Sample measured			
Name of sample			
Sampling location			
Date of sampling	/ / : ~ / /		
Measurement container		Sample volume*1	
Height of sample		Density	

*1: Unit used must be included, such as (g-FW (fresh weight), g-DW (dry weight), kg-FW, kg-DW, mL, L, m^2, m^3)

3. Measurement equipment	
Detector model	
Shield thickness	
Relative efficiency	
Resolution (1.33 MeV)	

4. Measurement and analysis			
(1) Measurement			
Measurement number		Measurement start date/time	/ / :
Measuring time			
(2) Analysis			
Self-absorption correction	Y / N		
Decay correction	Date of decay correction		/ / :
	Decay correction for the nuclides that require no consideration for sequential decay		Y / N
	Decay correction for daughter nuclides that decay sequentially*2		N / influence of parent nuclide considered / half-life of parent nuclide
Coincidence summing effect correction	Y / N	Nuclides subject to coincidence summing effect correction	

*2: Record the method of decay correction for the daughter nuclides that sequentially decay (N: no decay correction; influence of parent nuclide considered: decay correction performed with the influence of parent nuclide taken into account; half-life of parent nuclide: the half-life of parent nuclide is taken for the half-life of the daughter nuclide on an assumption that the nuclide is in transient equilibrium at the time of release).

5. Measurement results			
Nuclides	Radioactivity concentration ( )*3	Nuclides	Radioactivity concentration ( )*3
	±		±
	±		±
	±		±
	±		±
	±		±
	±		±

*3: The unit of radioactivity concentration must be shown.

(Remarks)

Table 6.5 Example of a report format 2

Results of measuring nuclides using germanium detector

1. Institution that performed the measurement

Institution that performed the analysis	
Chief personnel	
Measurement personnel	

2. Sample measured

Name of sample	
Type of sample	
Sampling location	
Date of sampling	/ / : ~ / / :
Measurement container	U-8 container, Marinelli beaker (2 L, 1 L, 0.7 L), Other
Sample volume*1	(g-FW , g-DW , kg-FW , kg-DW , mL , L , m^2 , m^3)
Height of sample	(mm , cm)
Density	(g/cm^3)
(Remarks)	

*1: Ensure that fresh weight (FW) is distinguished from dry weight (DW).

3. Measurement and analysis

(1)Measurement			
Measurement number		Measuring time	(s)
Measurement start date/time	/ / :		
(2)Analysis			
Self-absorption correction	Y / N		
Decay correction	Date of decay correction	/ / :	
	Decay correction for the nuclides that require no consideration for sequential decay	Y / N	
	Decay correction for daughter nuclides that decay sequentially*2	N / influence of parent nuclide considered / half-life of parent nuclide	
Coincidence summing effect correction	Y / N		
Nuclides subject to coincidence summing effect correction			
(Remarks)			

*2: Record the method of decay correction for the daughter nuclides that decay sequentially (N: no decay correction; influence of parent nuclide considered: decay correction performed with the influence of parent nuclide taken into account; half-life of parent nuclide: the half-life of parent nuclide is taken for the half-life of the daughter nuclide on an assumption that the nuclide is in transient equilibrium at the time of release).

Table 6.5 Example of a report format 2 (continued)

4. Details of measurement equipment

Detector model	
Shield thickness	(mm)
Relative efficiency	(%)
Resolution (1.33 MeV)	(keV)
(Remarks)	

5. Measurement results

Nuclides	Radioactivity concentration ( )*3	Remarks
	±	
	±	
	±	
	±	
	±	
	±	
	±	
	±	
	±	

*3: The unit of radioactivity concentration must be shown.

6. Remarks

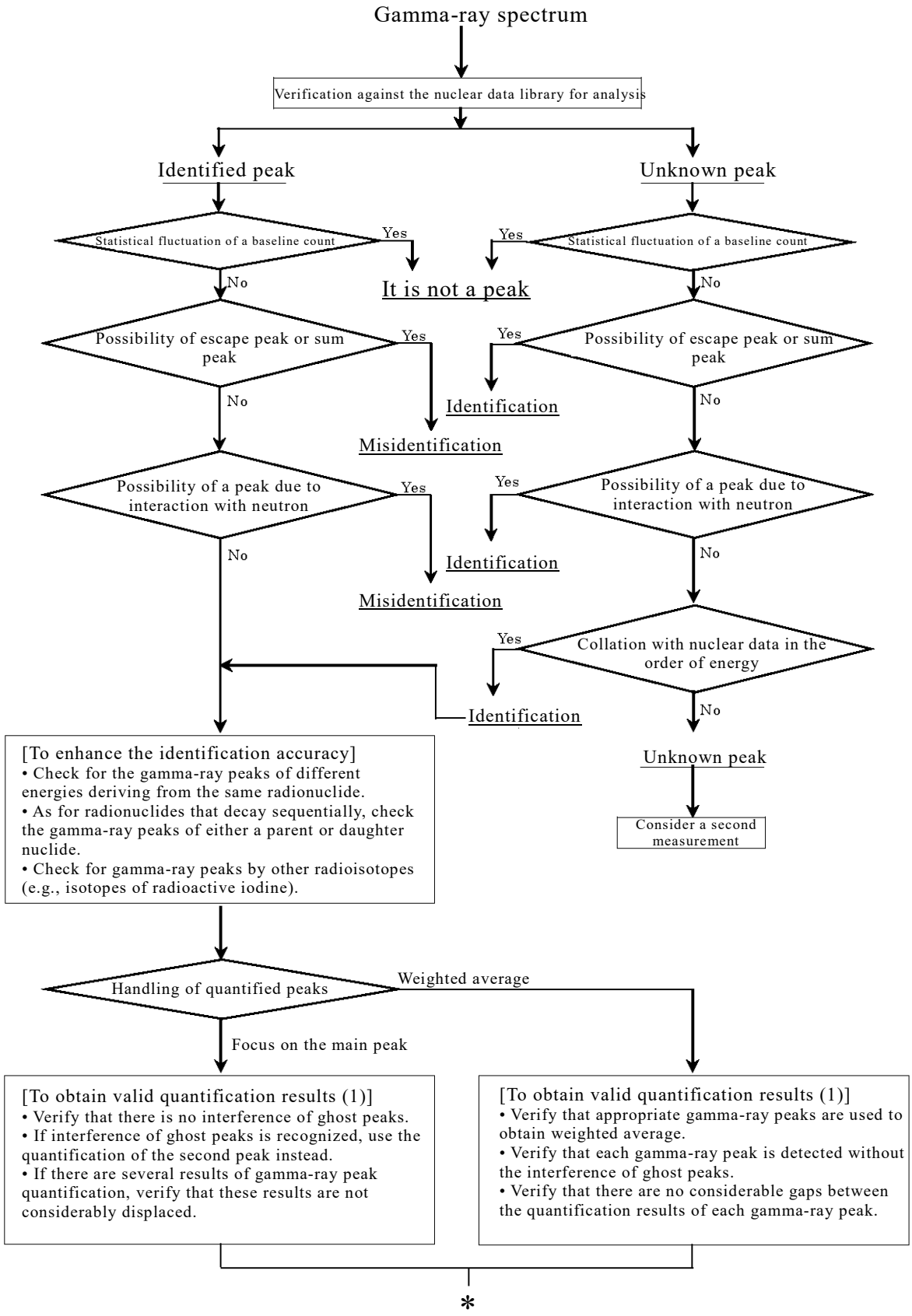


Figure 6.3 Example of flow chart leading up to the reporting of analysis results

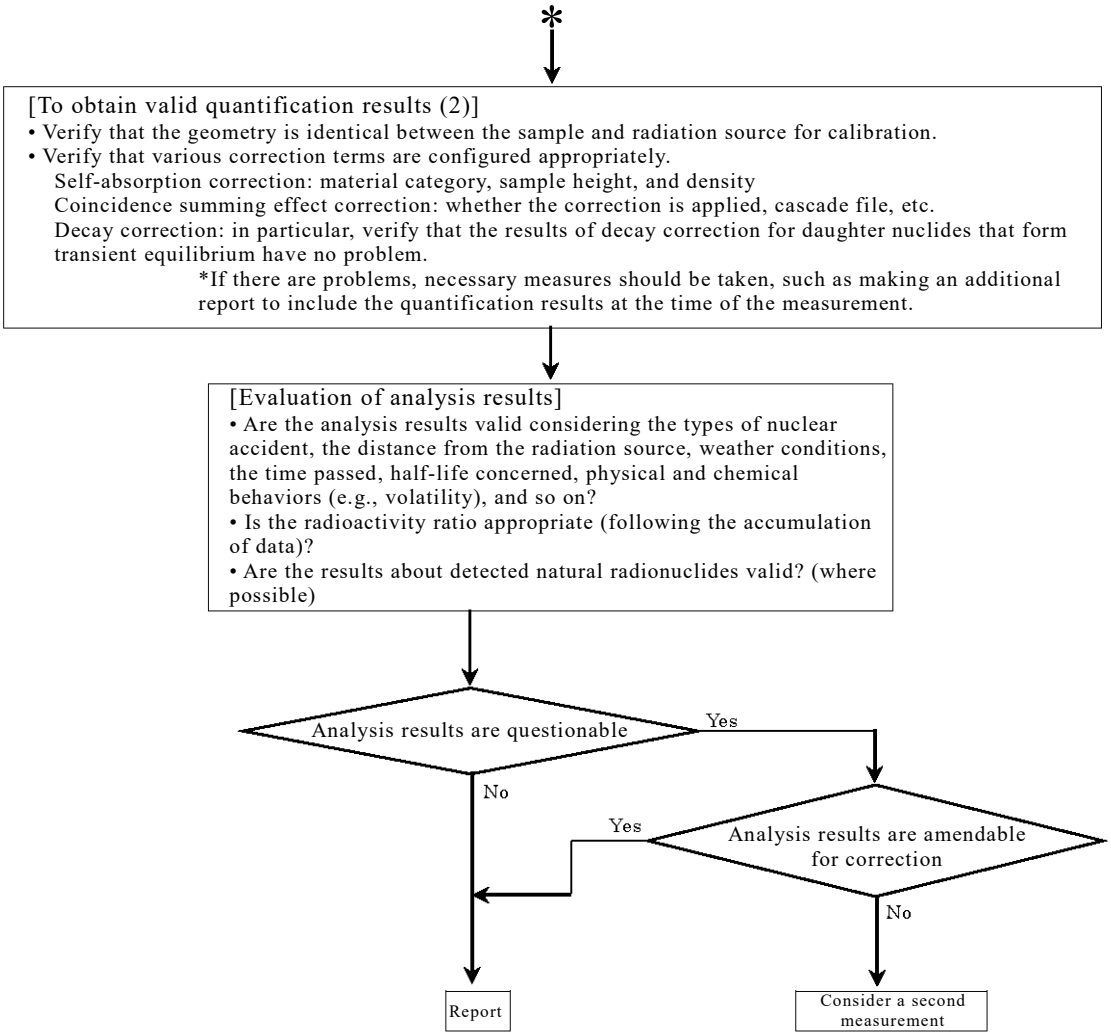


Figure 6.3 Example of flow chart leading up to the reporting of analysis results (continued)

Chapter 7 Background measurement and measures for contamination/decontamination of measurement equipment

In emergencies, there is a heightened risk of contaminating the measurement equipment by unintentionally introducing the artificial radionuclides released in a nuclear accident into the measurement chamber (see Explanation G). It is therefore necessary to put measures in place to prevent the contamination of measurement equipment by the external environment and samples, and to check for contamination regularly. It is also recommended that decontamination procedures be established in advance in case of contamination. In an event where the measurement equipment is contaminated and its impact on the measurement results is inescapable, measures should be implemented to enable measuring again, such as providing other measurement equipment or applying appropriate background correction.

7.1 Principles concerning the background measurement in emergency

The only way to check for equipment contamination is to verify the chronological changes in the background spectrum and counts, obtained by operating a detector without setting a sample. No chronological change[*1] in the background spectrum in terms of the gamma-ray peaks and counts of artificial radionuclides signifies the absence of measurement equipment contamination.[*2] For this reason, measurements in emergencies involve two types of background measurement: one for correction to subtract the contribution made by gamma-ray peaks existing in the background spectrum, and the other for verifying that the measurement equipment is not contaminated. In light of the possibility that the number of samples to measure significantly increases in emergency situations, c the frequency and measuring time of background measurement must be considered for these purposes.

7.2 Background measurement for correction

This background measurement takes gamma-ray peaks of 2σ or more in the background spectrum as the contributory portion, which will be used to correct the gamma-ray spectrum of a sample.

7.2.1 Background measurement for correction

The measuring time for background measurement for correction is preferably at least twice as long as the time spent for measuring samples in order to enhance the accuracy of the correction as much as possible. This is particularly desirable when the measurement equipment is contaminated, because it helps prevent the detection of peaks in error due to the statistical fluctuation in the background measurement.

As for the frequency of performing background measurement, once a month is sufficient, provided that the measurement equipment is not contaminated. However, if there is the risk of contamination with nuclides of short half-lives (e.g., ^{131}I) or introducing them in the measurement chamber, it is necessary to measure the background for correction at least once a day, for their influences change daily. If contamination with ^{134}Cs is confirmed, performing the background measurement for correction at an interval of approximately one

[*1] It is useful to check gamma-ray peaks of the natural radionuclides that are detected in the background spectrum for ensuring the soundness of the measurement equipment, etc.

[*2] Be aware that some detectors, etc. manufactured after the Fukushima Dai-ichi Nuclear Accident use materials contaminated with ^{137}Cs, which is attributed to the accident.

week will help to maintain the effect of physical attenuation below 1%. If the contamination is only with ^{137}Cs, whose half-life is longer, background measurement at an interval of approximately one month can keep the effect of attenuation to a negligible level of below 0.2%.

7.2.2 Background measurement for correction using blank samples[*3]

Some collection devices (such as filters and active carbon cartridges for airborne particles) that were delivered after the Fukushima Dai-ichi Nuclear Accident were contaminated with ^{134}Cs or ^{137}Cs during the manufacturing processes. If these filters and active carbon cartridges were used to collect and measure the atmosphere and the background measurement for correction was applied, the analysis results could be overestimated. Therefore, it may be better to measure filters and active carbon cartridges from the same unused lot with the detector and carry out the analysis using the results as the background measurement for correction in order to obtain more appropriate analysis results. As for the measuring time and frequency, the guidance given in the previous section is applicable here.

7.3 Background measurement for the verification of contamination

This background measurement is for verifying that the measurement equipment is not contaminated.

The background measurement for the verification of contamination is performed for approximately the same duration as measuring samples, and as frequently as appropriate. In emergencies, it may be difficult to identify the timing at which contamination occurred, because it is expected that environmental samples would be measured one after another. If the background measurement for verification of contamination were performed less frequently, the interval during which the occurrence of contamination is suspected would become prolonged; therefore, the number of samples to be resubmitted for measurement would increase. If the interval were short, the number of re-measured samples could be reduced; however, the machine time available for measuring environmental samples would be diminished. Therefore, it is necessary to judge the situations case by case to determine the frequency of performing the background measurement. If samples include those that have the environmental radioactivity levels similar to the levels in an ordinary operation, it is advisable that the background measurement for the verification of contamination be performed immediately after measuring a sample with high radioactivity concentration. Note that, if background measurement for correction is performed frequently (once in one or two days), this can be treated as background measurement to verify contamination.

7.4 Precautions for measurement equipment contamination and methods of decontamination

Measures to prevent contamination include, first, a system that prevents contaminants from being introduced into the measurement chamber. Apart from those described in Chapter 6, effective anticontamination measures include installing adhesive sheets on the floors along the work flow and performing regular cleaning (Reference 51). As measures on facilities to prevent contamination from the external environment, it is desired to maintain positive pressure, use clean booths, treat outdoor air with HEPA filters, and so on. It is also effective to fill gaps around window frames and stop running the air-conditioning and ventilation

[*3] A blank sample refers to unused filters and active carbon cartridges for airborne particles.

systems.
Anti-contamination measures for the measurement equipment include covering the detector with a polyethylene bag and lining the inner side of shields with acrylic sheets. In this way, in the case of contamination, decontamination may be easily performed by removing the polyethylene bag or acrylic sheets.
In case of contamination, it is desirable that spare items be provided as replacements for those easily removable anticontamination measures. As for decontamination without easily removable components, possible actions include dry-wiping, wet-wiping with cloth and water or liquid alcohol,[*4] and cleaning after an overhaul. However, that precision machinery needs due caution when conducting cleaning after an overhaul, as it may cause faults in the machines. Consult manufacturer's manuals or vendors, and ensure the safety of the work. In the case where shields are contaminated, it may prove effective to remove the inner lining and perform an overhaul to clean parts in plastic and lead. When using lead blocks as shields, placing the contaminated part away from the detector may help to reduce the effect of the contamination.
These contaminations are not necessarily removable. It is possible that contaminated components may have to be employed (in measuring) as they are. If this is the case, it is necessary to perform background measurement for the verification of contamination to manage and control the contamination, while adjusting the measurement results with appropriate background measurement for correction to offset the contributions of the contamination.

[*4] When wiping an acrylic sheet, wipe it gently. Excessive alcohol wiping on acrylic sheets will cause swelling and cracks in the sheets, and thereby weaken the material.

Explanation

Explanation A　Self-absorption correction in emergencies

As stated in the Radioactivity Measurement Series No. 7 “Gamma-ray Spectrometry Using Germanium Detectors,” the linear attenuation coefficient employed in self-absorption correction varies depending on the gamma-ray energy and sample material; if the sample material consists of an element of atomic number less than or equal to that of calcium (Z = 20), it can be expressed in a single equation, and the value is obtainable, provided that the sample’s apparent density and gamma-ray energy are given. The following formula expresses the relationship between the mass attenuation coefficient in marine soil/soil/ashed material, etc. and the gamma-ray energy.

$$\mu_m(\mu/\rho) = e^{\left\{-2.361-0.3949\times Ln(En/400)-0.06914\times\left(Ln(En/400)\right)^2\right\}} \qquad \text{(A.1)}$$

$\mu_m(\mu/\rho)$: mass attenuation coefficient in marine soil/soil/ashed material, etc. (cm^2/g^{-1})
μ: linear attenuation coefficient in marine soil/soil/ashed material, etc. (cm^{-1})
ρ: density of marine soil/soil/ashed material, etc. (g/cm^{-3})
En: Gamma-ray energy (keV)

The linear attenuation coefficient (cm^{-1}) divided by the density yields the mass attenuation coefficient (cm^2/g^{-1}). Figure A.1 illustrates major materials and their mass attenuation coefficients.
The element compositions of environmental samples vary, and those of soil are not generally known. However, the mass attenuation coefficient in environmental samples does depend so much on the kinds of sample materials. Nevertheless, the difference in material causes significant differences in the low-energy area. Therefore, it is necessary to select appropriate materials.

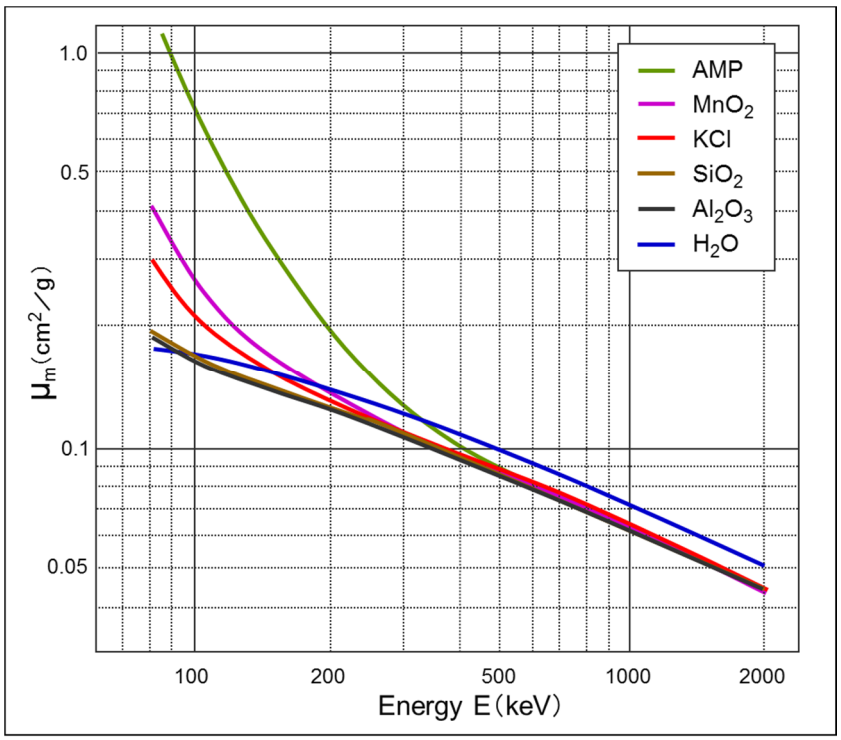


Figure A.1　Major materials and mass attenuation coefficients

In emergency situations, it is necessary to urgently measure many environmental samples. It is desirable that materials of environmental samples to be measured be established in advance, so that there will be no hesitation in determining the materials of samples to measure. The environmental samples measured in emergency situations include water samples (drinking water, cow's milk, seawater, etc.), raw samples such as greens and herbs, and soil/marine soil/sludge, etc. According to Figure A.1, the mass attenuation coefficients may be organized roughly into three groups: possible major components of soil, marine soil, sludge, etc., such as SiO_2 (silicon dioxide) and Al_2O_3 (aluminum oxide); water as a major component of raw samples; and AMP (ammonium phosphomolybdate) and MnO_2 (manganese dioxide) employed in radionuclide precipitate collection. Because the samples measured in emergency situations are often chemically untreated in advance, AMP and MnO_2 may be safely excluded, and the samples for measurement may be assumed to be either water or marine soil/soil/ashed material, etc. As stated in Chapter 4, if AMP, MnO_2, etc. were used during the preparation of samples, it would be necessary to select the material type using consumer software.

The choice between water and marine soil/soil/ashed material, etc. can be determined by the water content, with 50% of water being the dividing line between samples of water and those of soil, etc. If the sample comprises more than 50% of water, it is appropriate to set the material to water. For samples with less than 50% of water content, marine soil/soil/ashed material, etc. could possibly be chosen.

Based on this idea, Chapter 4 presents Table 4.1, which shows major environmental samples with probable material types indicated. Samples to which Table 4.1 is not applicable should be considered with reference to the Tables of Food Composition in Japan (Reference 3) for their water content.

Explanation B Sum peaks of ^{134}Cs and ^{132}I

Explanation B.1 ^{134}Cs

^{134}Cs has a half-life of 2.07 years. Owing to beta-decay, it releases an excessive amount of energy in gamma rays and transits to lower energy levels. Table B.1 lists the major gamma rays relevant to the decay of ^{134}Cs. The numbers in [ ] indicate the numbers in the incremental order of energies.

Table B.1 Major gamma rays relevant to the decay of ^{134}Cs

Gamma-ray energy (keV)	Emission rate (%)
475.4 [(1)]	1.48
563.2 [(2)]	8.34
569.3 [(3)]	15.37
604.7 [(4)]	97.62
795.9 [(5)]	85.46
802.0 [(6)]	8.69
1038.6 [(7)]	0.99
1168.0 [(8)]	1.79
1365.2 [(9)]	3.02

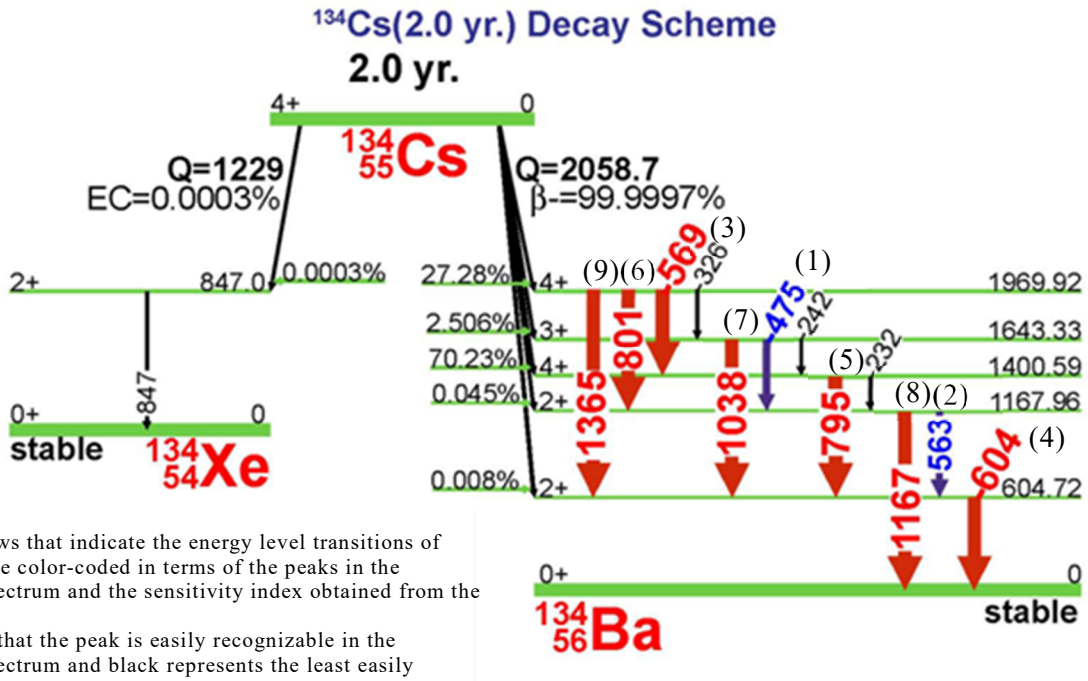
Note 1: The nuclear data are taken from ENSDF (as of October 2017).

Note 2: Nine gamma rays of more than 0.5% of emission rate are numbered from 1 to 9 in the order of gamma-ray energy.

Note 3: Gamma-ray energies and emission rates are expressed to one and two decimal places, respectively.

A sum peak occurs when several gamma rays released in cascade enter the detector almost simultaneously, and the energy from each ray is detected in an aggregate and output in the spectrum as a single signal of the total energy. Thus, it should be understood in conjunction with the decay scheme of ^{134}Cs shown in Figure B.1 and considering the energy transition patterns of cascading gamma rays.

As for the gamma rays listed in Table B.1, possible combinations between (1) and (9), numbered in ascending order of energy, are listed in Table B.2 for the possibilities of appearing in the gamma-ray spectrum as sum peaks.



Note: the arrows that indicate the energy level transitions of gamma rays are color-coded in terms of the peaks in the gamma-ray spectrum and the sensitivity index obtained from the baseline area.
Red indicates that the peak is easily recognizable in the gamma-ray spectrum and black represents the least easily recognizable peaks. Blue is in the middle of the two (they do not show the order of emission rates).

Figure B.1 ^{134}Cs decay scheme

Source: Online Spectrum Catalogs for Ge and Si (Li), Idaho National Laboratory (URL: http://www4vip.inl.gov/gammaray/catalogs/ge/catalog_ge.shtml)

Table B.2 Gamma-ray sum peak identification table in conjunction with ^{134}Cs decay

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)		*1		*4				*4	
(2)			*4	*2		*3			
(3)				○	*3			*4	
(4)					○	○	*4		○
(5)									
(6)								○	
(7)									
(8)									
(9)									

*1: The energy level transition equivalent to the gamma ray (7).

*2: The energy level transition equivalent to the gamma ray (8).

*3: The energy level transition equivalent to the gamma ray (9).

*4: Sum peaks are less likely to appear for the reasons that they take place via energy level transitions of gamma rays of low emission rates, etc.

From Table B.2, it can be seen that the energy levels of sum peaks that appear in the gamma-ray spectrum are as follows:

- 1174.0 keV ((3) + (4))
- 1400.6 keV ((4) + (5))
- 1406.7 keV ((4) + (6))
- 1969.9 (1970.0) keV ((4) + (9), (6) + (8))

A gamma-ray spectrum with the sum peaks shown above is illustrated in Figure B.2 (identical to Figure 4.1).

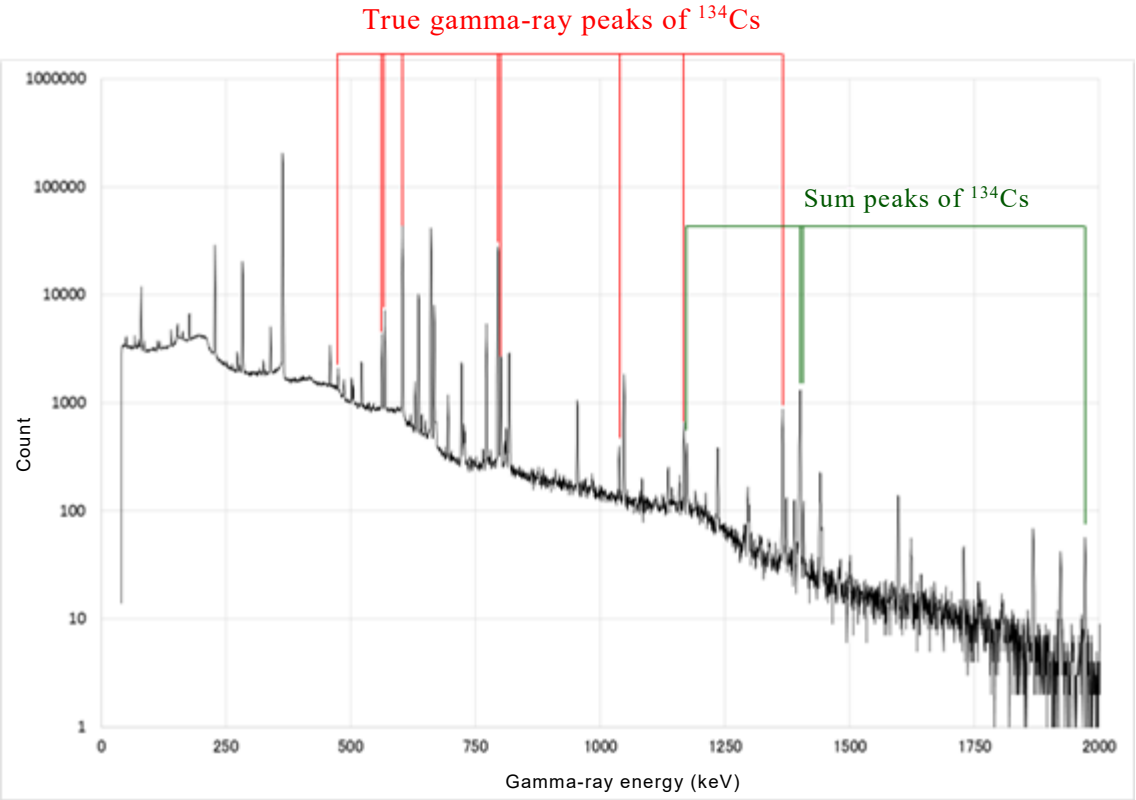


Figure B.2 Gamma-ray spectrum that shows sum peaks of ^{134}Cs
(from a soil sample taken at the Fukushima Dai-ichi Nuclear Accident)

Explanation B.2 ^{132}I

Similar to ^{134}Cs, ^{132}I with its half-life of 2.30 hours is another artificial radionuclide known to cause sum peaks, as it releases many gamma rays simultaneously. Table B.3 lists the major gamma rays relevant to the decay of ^{132}I. The numbers in [ ] indicate the numbers in an incremental order of energies for the gamma rays that have the emission rate of 3% or more.

Table B.3 Major gamma rays relevant to the decay of ^{132}I

Gamma-ray energy (keV)	Emission rate (%)	Gamma-ray energy (keV)	Emission rate (%)
262.9	1.28	780.0	1.18
505.8 [(1)]	4.94	809.5	2.6
522.7 [(2)]	16.0	812.0 [(9)]	5.5
547.2	1.14	876.6	1.04
621.2	1.58	954.6 [(10)]	17.6
630.2 [(3)]	13.3	1136.0 [(11)]	3.01
650.5	2.57	1143.3	1.35
667.7 [(4)]	98.70	1172.9	1.09
669.8 [(5)]	4.6	1290.8	1.13
671.4 [(6)]	3.5	1295.1	1.88
727.0	2.2	1372.1	2.47
727.2 [(7)]	3.2	1398.6 [(12)]	7.01
728.4	1.6	1442.6	1.40
772.6 [(8)]	75.6	1921.1	1.23

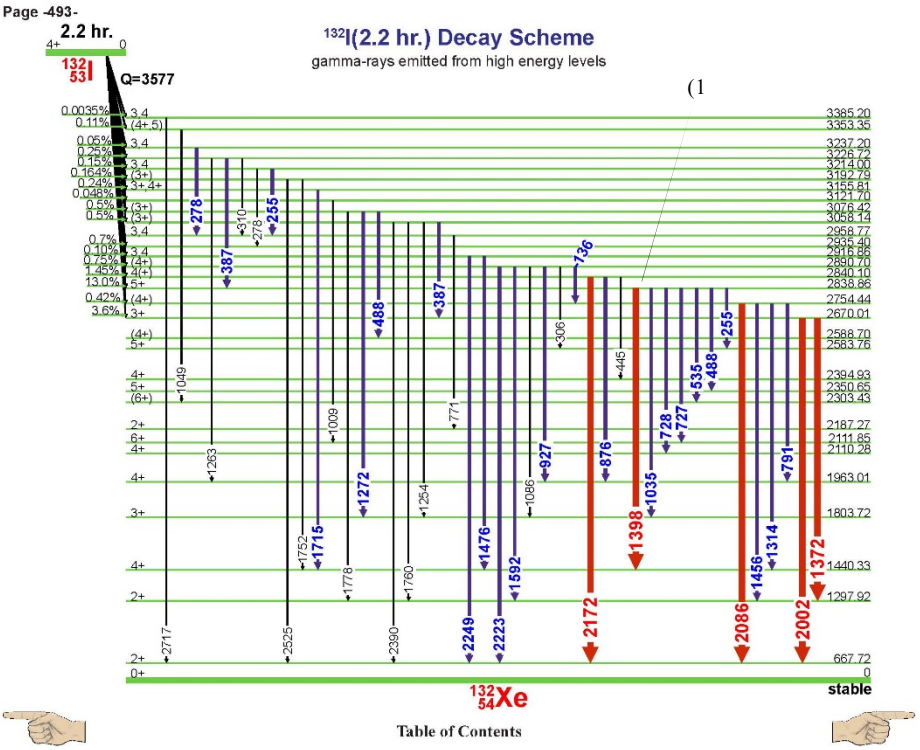
Note 1: The nuclear data are taken from ENSDF (as of October 2017).

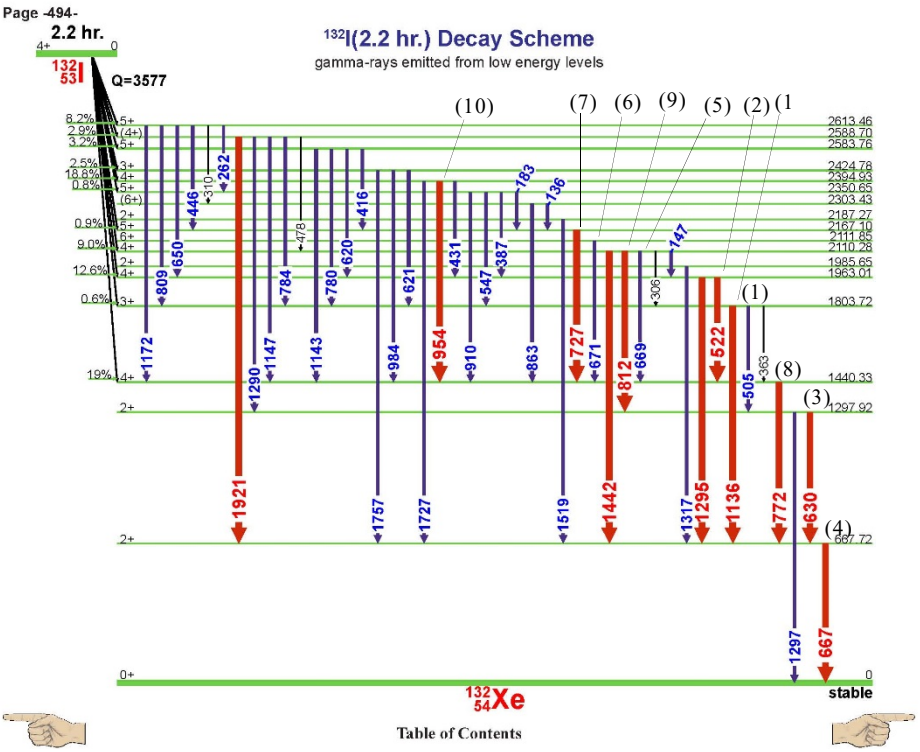
Note 2: Gamma rays included in the table are of emission rate 1% or more and energy 2000 keV or less.

Note 3: Twelve gamma rays of emission rate 3% or more are numbered from 1 to 12 in ascending order of gamma-ray energy.

Note 4: Gamma-ray energies and emission rates are expressed to one and two decimal places, respectively.
However, note that those gamma-ray energies that have no value at the second decimal place are shown to one decimal place.

Figure B.3 shows the decay scheme of ^{132}I. This nuclide releases many gamma rays, and thus the energy level transition patterns are complex for cascading gamma rays. As gamma rays with low emission rates are less likely to cause coincidence summing, for simplification, only those gamma rays with emission rates of 3% or more, numbered from (1) to (12) in Table B.3, are considered. Possible combinations between (1) and (12), numbered in ascending order of energy, are listed in Table B.4 for the possibilities of appearing in the gamma-ray spectrum as sum peaks.





Note: the arrows that indicate the energy level transitions of gamma rays are color-coded in terms of the peaks in the gamma-ray spectrum and the sensitivity index obtained from the baseline area.
Red indicates that the peak is easily recognizable in the gamma-ray spectrum and black represents the least easily recognizable peaks. Blue is in the middle of the two (they do not show the order of emission rates).

Figure B.3 ^{132}I decay scheme

Source: Online Spectrum Catalogs for Ge and Si (Li), Idaho National Laboratory (URL: http://www4vip.inl.gov/gammaray/catalogs/ge/catalog_ge.shtml)

Table B.4 Gamma-ray sum peak identification table in conjunction with ^{132}I decay

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)			*1	*4								
(2)				○				*2				
(3)				*2					*2			
(4)					○	○	○	○	○	○	○	*3
(5)								*2				
(6)								*4				
(7)								○				
(8)										*4		*3
(9)												
(10)												
(11)												
(12)												

*1: The energy level transition equivalent to the gamma ray (11).

*2: The energy level transition equivalent to the other gamma rays.

*3: 2000 keV or more.

*4: Difficult to distinguish from the energy level transitions of the other gamma rays.

From Table B.4, it can be seen that the energy levels of sum peaks that appear in the gamma-ray spectrum are as shown below. Note that it is difficult to distinguish the sum peak ((8)+(10)) from the ^{132}I gamma ray of 1727.2 keV, but sum peaks below are included as the gamma ray's emission rate is 0.067%.

- 1190.4 keV ((2) + (4))
- 1337.5 keV ((4) + (5))
- 1339.1 keV ((4) + (6))
- 1394.9 keV ((4) + (7))
- 1440.3 keV ((4) + (8))
- 1479.7 keV ((4) + (9))
- 1499.8 keV ((7) + (8))
- 1622.3 keV ((4) + (10))
- 1727.2 keV ((8) + (10))
- 1803.7 keV ((4) + (11))

A gamma-ray spectrum with some of the sum peaks shown above is illustrated in Figure B.4.

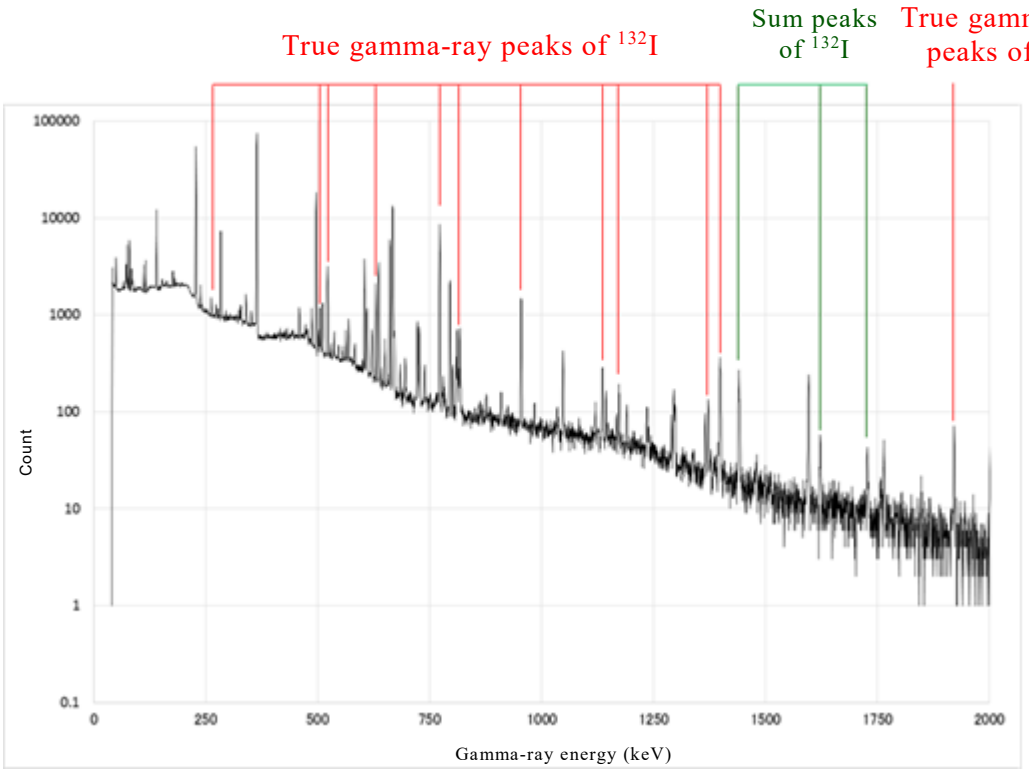


Figure B.4 Gamma-ray spectrum that shows sum peaks of ^{132}I
(from airborne particles sampled at the Chernobyl Disaster)

As shown in Figure B.3, almost all ^{132}I energy-level transitions after beta-decay take place via the energy level of 667.7 keV (emission rate of 98.70%). Hence, sum peaks other than those mentioned above may appear in the gamma-ray spectrum. Therefore, it may be necessary to consider sum peaks as a result of a combination of a 667.7-keV gamma ray and a gamma ray with an emission rate less than 3%.

Explanation C　Decay correction for nuclides in transient equilibrium

Some nuclides that establish transient equilibrium are problematic if decay correction is applied to their daughter nuclides, as it may result in over- or under-estimation. In some cases, recalculation is necessary to obtain the radioactivity concentration of the measurement without applying decay correction.[*1]

This document introduces the cases in which the application of decay correction is problematic. It also includes a case of the nuclides that establish transient equilibrium in which only their daughter nuclides were detected.

Explanation C.1　Theoretical calculation based on hypothesis

C.1.1 Insufficient information on emission sources

In nuclear accidents, information on emission sources cannot always be obtained. Moreover, the emission may have taken place more than once. The case introduced here presupposes such a situation and describes how the application of decay correction can be problematic.

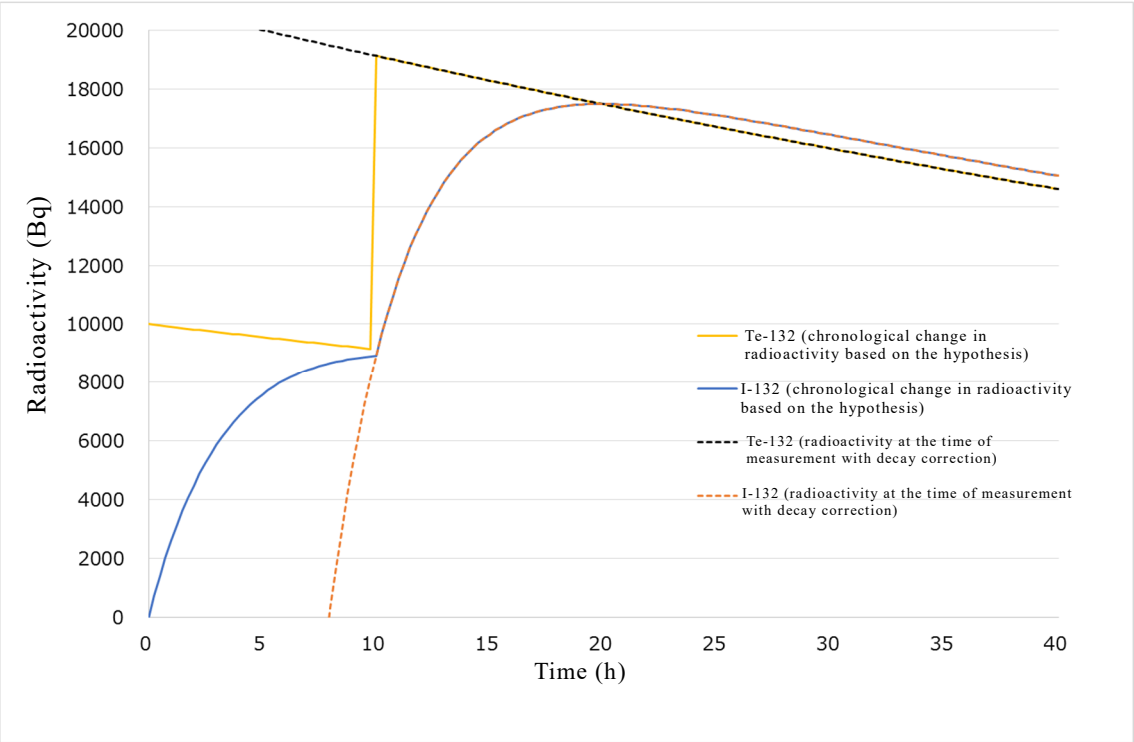
[Hypothesis] The initial emission was followed by a second emission of the same magnitude 10 hours later

10000 Bq of ^{132}Te (half-life of 3.20 days) was released (at time t = 0 and t = 10 h), at which times the daughter nuclide ^{132}I (half-life of 2.30 hours) had zero radioactivity. The chronological changes of ^{132}Te and ^{132}I are indicated in Figure C.1 by the yellow and blue lines, respectively.

If decay correction is applied to the nuclide in transient equilibrium based on the radioactivity after 40 h, the results could show a picture that is different from the actual event. The results of ^{132}Te and ^{132}I with decay correction are illustrated in Figure C.1 by the black and orange dotted lines, respectively.

As seen in Figure C.1, contrary to the hypothesis that the emission took place twice, the radioactivity does not reach the original state at t = 0 with the decay correction.

[*1] There was a case in which, immediately after the occurrence of the Fukushima Dai-ichi Nuclear Accident, applying decay correction to artificial radionuclides with very short half-lives yielded an astronomical value, necessitating the recalculation of the measurement results without applying the decay correction.



Note 1: The decay correction during measurement is not considered.

Note 2: The vertical axis is linear.

Note 3: The horizontal axis indicates the time elapsed (h) after the emission.

Figure C.1 Chronological changes in radioactivity of ^{132}Te and ^{132}I, and decay correction results

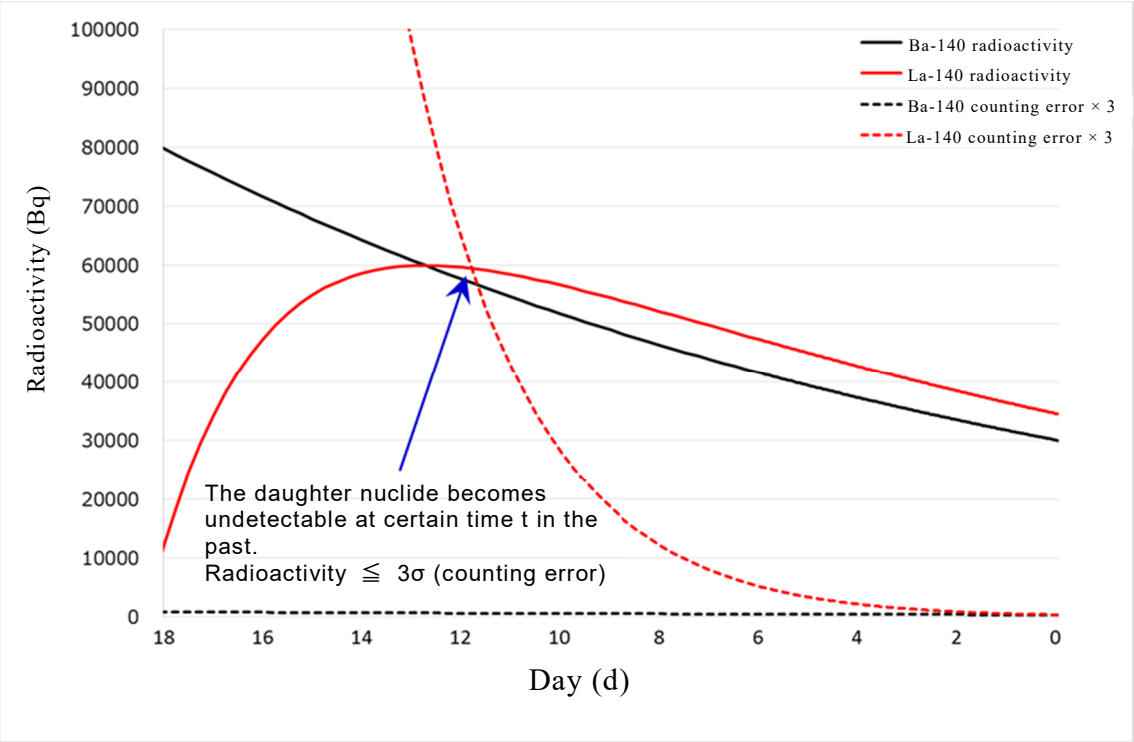
C.1.2 Problems concerning the decay correction affecting the detection judgment

The decay correction may render the radionuclide whose radioactivity is more than three times the counting error at the time of measurement as having radioactivity within three times the counting error at certain point in time.

[Hypothesis]

The parent nuclide ^{140}Ba (half-life of 12.75 days) and daughter nuclide ^{140}La (half-life of 1.68 days) had radioactivities of 30000 ± 100 Bq and 34500 ± 100 Bq, respectively, at the time of measurement. To simplify, the detection threshold is three times each nuclide's counting error. Figure C.2 illustrates the radioactivities of ^{140}Ba and ^{140}La at the measurement with decay correction applied in the black and red solid lines, respectively, and three times the counting error with decay correction in the black and red dotted lines, respectively.

As shown in Figure C.2, the radioactivity of the daughter ^{140}La becomes smaller than three times the counting error at time t; thus, it is not detected.



Note 1: The decay correction during measurement is not considered.

Note 2: The vertical axis is linear.

Note 3: The horizontal axis shows retrospective days from the time of measurement.

Figure C.2 Results of decay correction applied to ^{140}Ba and ^{140}La radioactivity levels

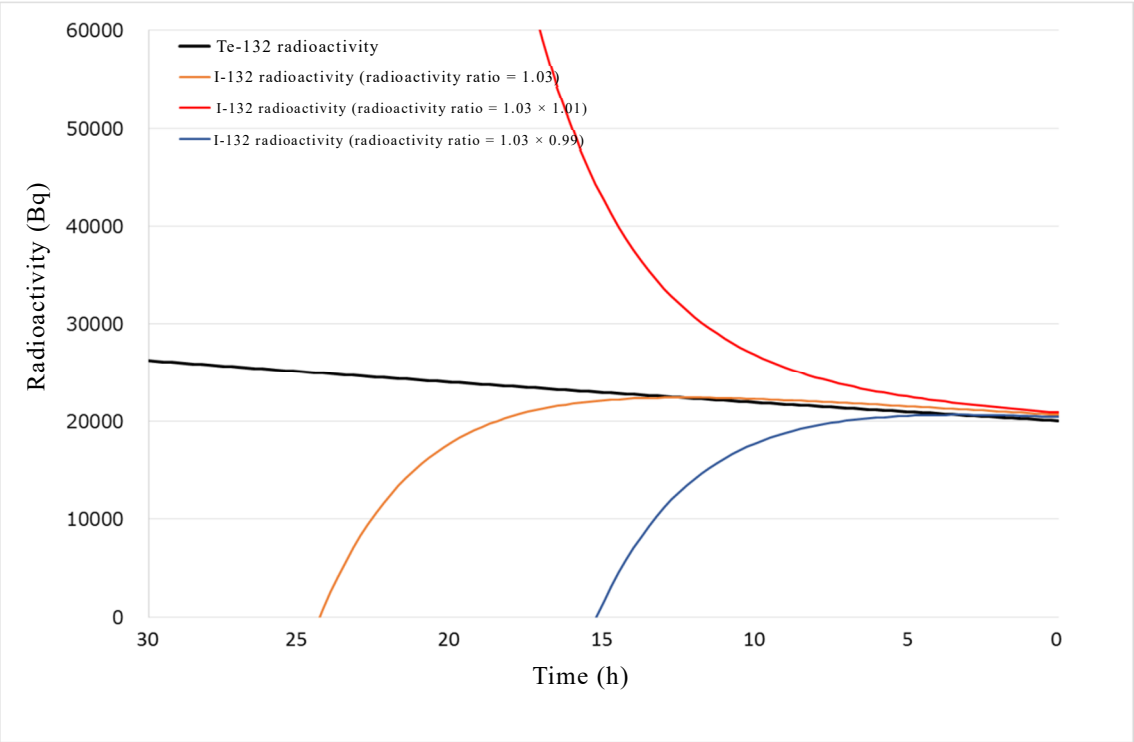
C.1.3 Problems concerning the variation in measured values

The radioactivity ratio between parent and daughter nuclides becomes stable once they establish the transient equilibrium. Meanwhile, as measured values involve statistical fluctuations, the measured outcomes do not necessarily yield the appropriate radioactivity ratio. An inappropriate radioactivity ratio will lead to completely different results from the true state.

[Hypothesis]

The radioactivity ratio between ^{132}Te and ^{132}I is approximately 1.03 when the transient equilibrium is established between them. Figure C.3 illustrates the results of decay correction applied to a hypothetical measurement result that is ±1% off this value. The radioactivity of ^{132}Te and ^{132}I with decay correction applied based on the appropriate radioactivity ratio are illustrated by the black and orange lines. The red line indicates the result of applying decay correction based on a radioactivity ratio varied by 1% positively and the blue line represents one with a radioactivity ratio varied by 1% negatively. The measuring time is 1800 s, and the decay correction during the measurement is accounted for.

As shown in Figure C.3, a positive variation from the appropriate radioactivity ratio by 1% results in overestimation and a negative variation by 1% results in assigning the zero radioactivity to a different time, yielding underestimated results.



Note 1: The decay correction during measurement is considered.

Note 2: The vertical axis is linear.

Note 3: The horizontal axis shows retrospective hours from the time of measurement.

Figure C.3 Results of applying decay correction to ^{132}Te and ^{132}I at different radioactivity ratios

Explanation C.2 Problems based on actual measurement data

C.2.1 Soil samples

There are cases involving measured soil samples in which the radioactivity concentration of ^{132}I is underestimated if decay correction is applied to the sampling data.

Table C.1 includes information on the measurement of soil samples. Figure C.4 illustrates the gamma-ray spectrum, and Tables C.2 and C.3 respectively list the detected artificial radionuclides and radioactivity concentration levels on the day of measurement and the day of sampling, to which the decay correction is applied.

Table C.1 Measurement information of the soil sample

Sampling date	March 28, 2011
Date of measurement	March 30, 2011
Measuring time	1800 s
Storage period	180257 s (approximately 50 h)

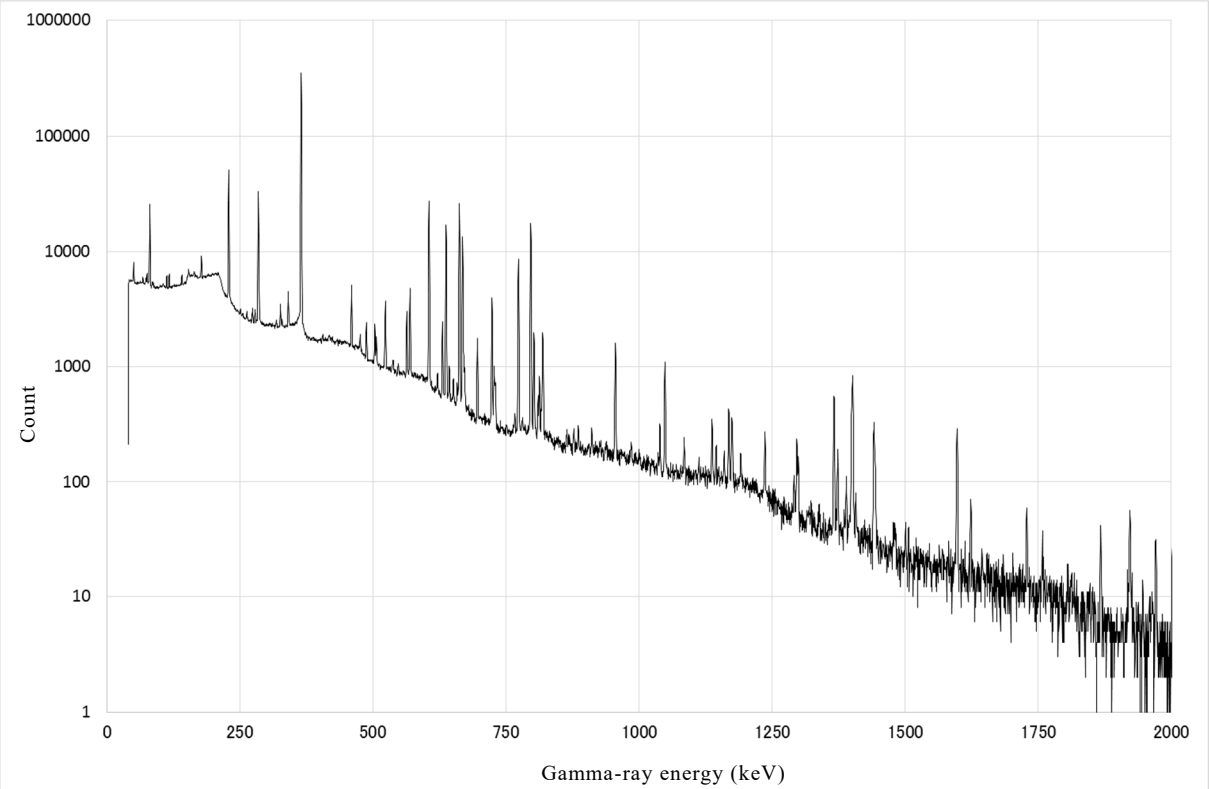


Figure C.4 Gamma-ray spectrum of a measured soil sample

Table C.2 Artificial radionuclides detected in the soil sample

^{95}Nb	^{99m}Tc	^{110m}Ag	^{129m}Te	^{131}I
^{132}Te	^{132}I	^{134}Cs	^{136}Cs	^{137}Cs
^{140}Ba	^{140}La			

Table C.3 Radioactivity concentration in the soil sample on the measurement date and

sampling date with decay correction

Nuclides	Half-life	Radioactivity concentration on the measurement date (Bq/kg)	Radioactivity concentration on the sampling date (Bq/kg)	Remarks
^{95}Nb	34.99 days	$(2.0 \pm 0.58) \times 10^{3}$	$(2.0 \pm 0.60) \times 10^{3}$	
^{99m}Tc	6.01 h	$(3.9 \pm 0.40) \times 10^{3}$	$(1.3 \pm 0.13) \times 10^{6}$	Transient equilibrium (daughter)
^{110m}Ag	249.83 days	$(3.4 \pm 0.57) \times 10^{3}$	$(3.4 \pm 0.57) \times 10^{3}$	
^{129m}Te	33.6 days	$(8.5 \pm 0.20) \times 10^{5}$	$(8.8 \pm 0.21) \times 10^{5}$	Transient equilibrium (parent)
^{131}I	8.03 days	$(3.8 \pm 0.004) \times 10^{6}$	$(4.5 \pm 0.005) \times 10^{6}$	
^{132}Te	3.20 days	$(3.0 \pm 0.01) \times 10^{5}$	$(4.6 \pm 0.02) \times 10^{5}$	Transient equilibrium (parent)
^{132}I	2.30 h	$(2.3 \pm 0.01) \times 10^{5}$	$(-3.0 \pm 0.06) \times 10^{11}$	Transient equilibrium (daughter)
^{134}Cs	2.07 yrs.	$(5.3 \pm 0.02) \times 10^{5}$	$(5.3 \pm 0.02) \times 10^{5}$	
^{136}Cs	13.16 days	$(3.7 \pm 0.08) \times 10^{4}$	$(4.1 \pm 0.09) \times 10^{4}$	
^{137}Cs	30.08 yrs.	$(5.1 \pm 0.02) \times 10^{5}$	$(5.1 \pm 0.02) \times 10^{5}$	
^{140}Ba	12.75 days	$(1.8 \pm 0.24) \times 10^{4}$	$(2.0 \pm 0.27) \times 10^{4}$	Transient equilibrium (parent)
^{140}La	1.68 days	$(1.4 \pm 0.05) \times 10^{4}$	$(7.5 \pm 3.7) \times 10^{3}$	Transient equilibrium (daughter)

Note: For example, "$(3.9 \pm 0.40) \times 10^{3}$" means "3900 ± 400."

Although ^{132}I is detected on the measurement date (230000 ± 1000 Bq/kg), it would not be detected on the date of sampling if decay correction is applied, resulting in an underestimation. Caution is also required when using consumer software, as it applies the half-life of a daughter nuclide that establishes transient equilibrium (in the current case, ^{99m}Tc) to perform the decay correction if it is detected and its parent nuclide (in the current case, ^{99}Mo) is not detected. Moreover, although ^{140}La is detected on the sampling date in the current case, it should be noted with caution that the radioactivity concentration does not necessarily exceed 3σ (three times the counting error).

C.2.2 Airborne particles

There are cases involving measured samples of airborne particles in which the radioactivity concentration of ^{132}I is overestimated if decay correction is applied to the sampling date.

Table C.4 includes information on the measurement of airborne particle samples. Figure C.5 illustrates the gamma-ray spectrum, and Tables C.5 and C.6 respectively list the detected artificial radionuclides and radioactivity concentration levels on the day of measurement and the day of sampling, to which the decay correction is applied.

Table C.4 Measurement information of the airborne particle sample

Sampling date	March 24, 2011
Date of measurement	March 24, 2011
Measuring time	28800 s
Storage period	35824 s (approximately 10 h)

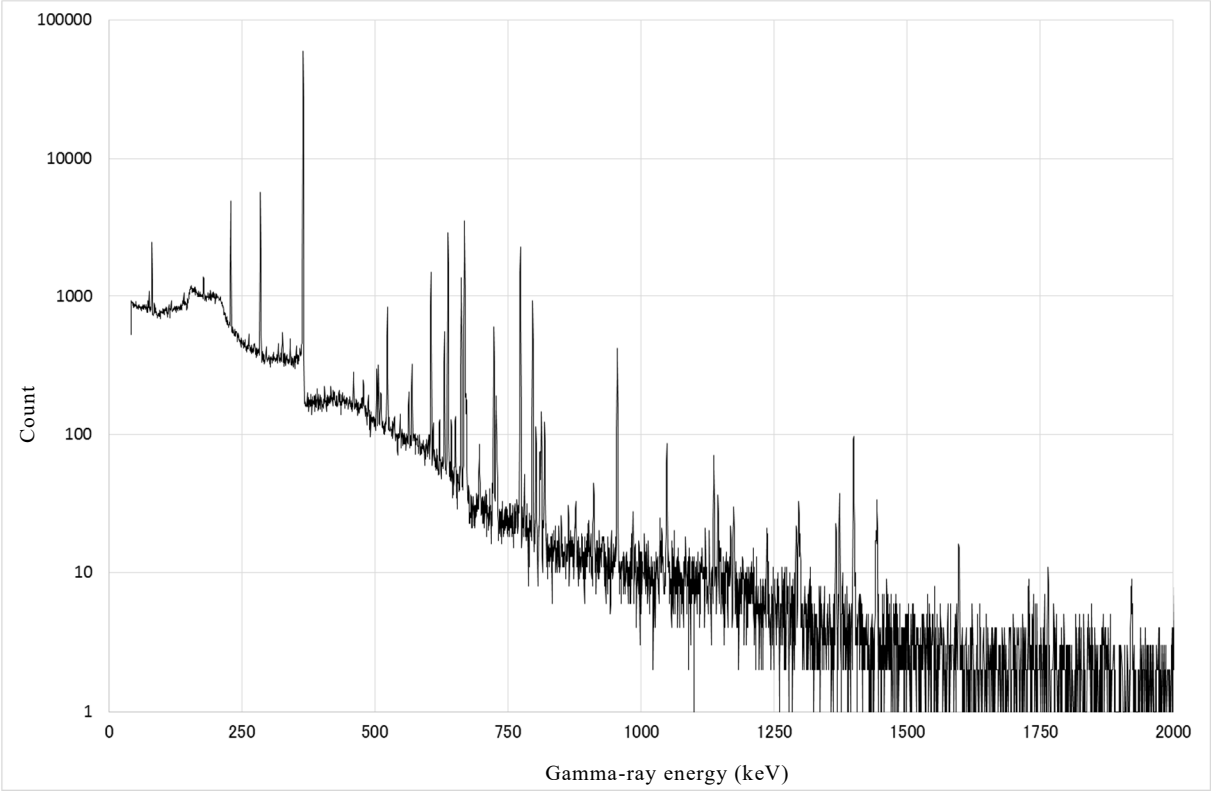


Figure C.5 Gamma-ray spectrum of a measured airborne particle sample

Table C.5 Artificial radionuclides detected in the airborne particle sample

^{99m}Tc	^{129m}Te	^{131}I	^{132}Te	^{132}I
^{134}Cs	^{136}Cs	^{137}Cs	^{140}La	

Table C.6 Radioactivity concentration in the airborne particle sample on the measurement date and sampling date with decay correction

Nuclides	Half-life	Radioactivity concentration on the measurement date (mBq/m^3)	Radioactivity concentration on the sampling date (mBq/m^3)	Remarks
^{99m}Tc	6.01 h	0.64 ± 0.19	3.1 ± 0.91	Transient equilibrium (daughter)
^{129m}Te	33.6 days	25 ± 4.0	26 ± 4.0	Transient equilibrium (parent)
^{131}I	8.03 days	460 ± 1	490 ± 1	
^{132}Te	3.20 days	21 ± 0.3	24 ± 0.3	Transient equilibrium (parent)
^{132}I	2.30 h	40 ± 0.4	950 ± 25	Transient equilibrium (daughter)
^{134}Cs	2.07 yrs.	16 ± 0.3	16 ± 0.3	
^{136}Cs	13.16 days	1.6 ± 0.16	1.7 ± 0.16	
^{137}Cs	30.08 yrs.	17 ± 0.3	17 ± 0.3	
^{140}La	1.68 days	0.43 ± 0.11	0.55 ± 0.14	Transient equilibrium (daughter)

Considering ^{132}Te and ^{132}I, which establish transient equilibrium, the radioactivity ratio ($^{132}I/^{132}Te$) is approximately 1.9 on the measurement date, but it is greater, at approximately 39.6, on the sampling date. If the decay correction is applied to an earlier time, the radioactivity ratio will be even greater and the radioactivity concentration of the daughter ^{132}I will be overestimated. Note, also, that ^{99m}Tc and ^{140}La in the current case are treated with their own half-lives for decay correction, because their parent nuclides, ^{99}Mo and ^{140}Ba, were undetected.

Explanation C.3 Partial detection of nuclides in transient equilibrium

Samples with a high volume of radioactivity cause an increase in baseline counts owing to the Compton scattering of high-energy gamma rays. This makes it difficult to detect gamma-ray peaks toward the low-energy region, and it may lead to the only partial detection of nuclides in transient equilibrium.[*2] [*3]

As a real case, Figure C.6 illustrates a spectrum in which parent ^{140}Ba was undetected and its daughter ^{140}La in transient equilibrium was detected.

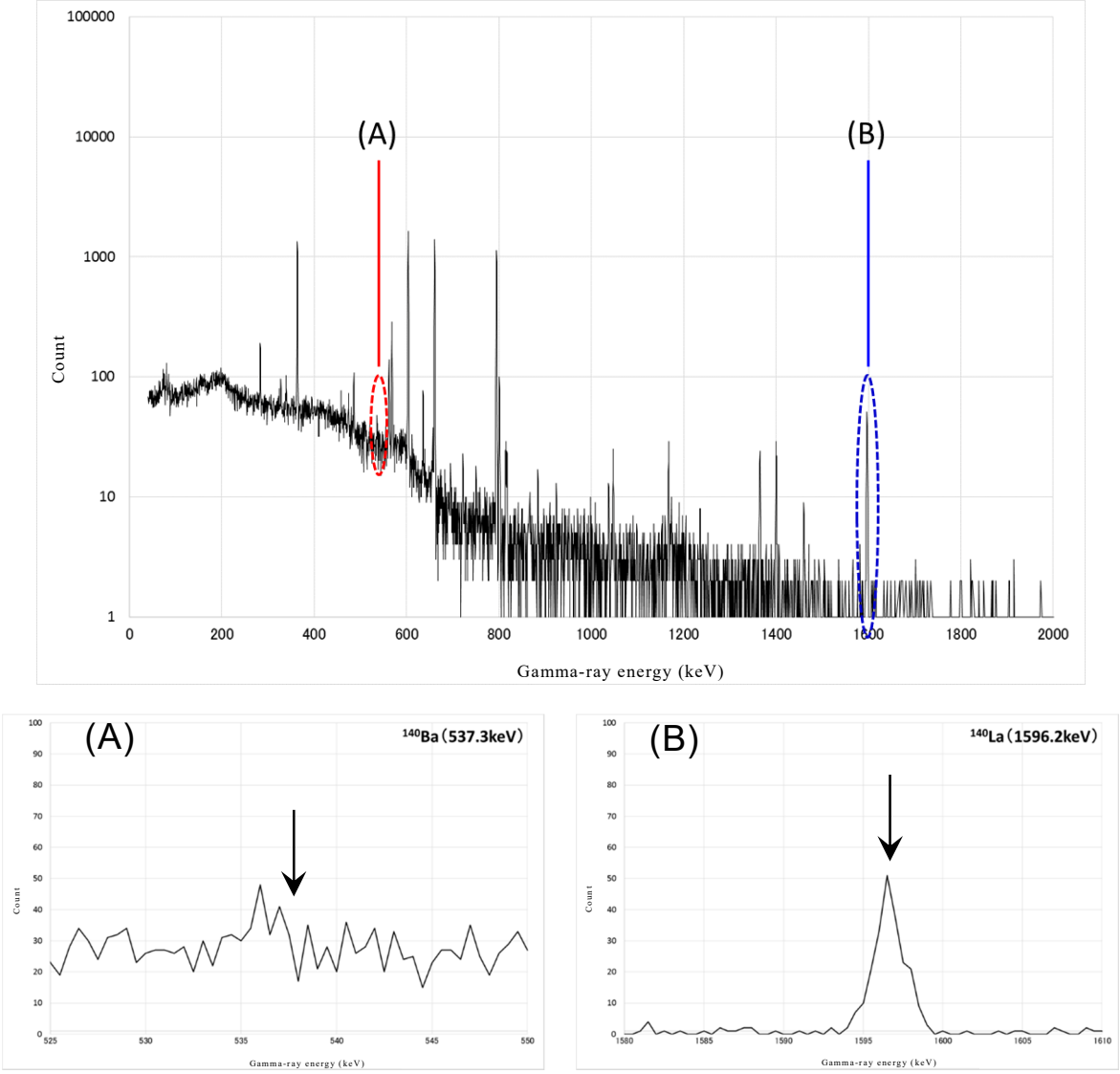


Figure C.6 Case in which nuclides in transient equilibrium were partially detected (Marine organisms sampled after Fukushima Dai-ichi Nuclear Accident)

To avoid misunderstanding, it is advisable to clearly note the values and the reason why nuclides in transient equilibrium are partially detected.

[*2] When nuclides with short half-lives decay, the baseline count in the gamma-ray spectrum decreases. In some cases, this reveals the previously hidden gamma-ray peaks.

[*3] There are also possible explanations in terms of the differences in emission rates of the gamma rays.

Explanation D　Nuclear data library for emergency situations

Explanation D.1　Master library of nuclear data for emergency situations

In perpetuation of the nuclides selected in the first edition of this document (February 2004),[*1] the radionuclides to be registered in the master library of nuclear data for emergency situations are those that conform to the following descriptions.

(1) Fission product nuclides, rare gases, and volatile materials as well as nuclides produced through these
(2) Nuclides produced as a result of nuclear reactions of neutrons, etc.
(3) Disintegration products of uranium and thorium as well as nuclides existing in the background

With reference to (1) to (3) above, the applicable radionuclides are listed in Tables D.1 to D.3, respectively.

Table D.1　Fission product nuclides, rare gases, and volatile materials as well as nuclides produced through these

^{77}Ge	^{78}As	^{84}Br	^{85m}Kr	^{87}Kr
^{88}Kr	^{88}Rb	^{90m}Y	^{91}Sr	^{91}Y
^{91m}Y	^{92}Sr	^{92}Y	^{93}Y	^{95}Zr
^{95}Nb	^{97}Zr	^{97}Nb	^{97m}Nb	^{99}Mo
^{99m}Tc	^{103}Ru	^{105}Ru	^{105}Rh	^{105m}Rh
^{106}Rh	^{113}Ag	^{115m}In	^{117}Cd	^{117m}Cd
^{125}Sn	^{127}Sb	^{128}Sb	^{129}Sb	^{129}Te
^{130}Sb	^{131}Sb	^{131m}Te	^{131}I	^{132}Te
^{132}I	^{133m}Te	^{133}I	^{133m}Xe	^{134}Te
^{134}I	^{135}I	^{135}Xe	^{135m}Xe	^{137}Cs
^{138}Cs	^{139}Ba	^{140}Ba	^{140}La	^{141}La
^{141}Ce	^{142}La	^{143}Ce	^{144}Ce	^{144}Pr
^{145}Pr	^{147}Nd	^{149}Nd	^{149}Pm	^{151}Pm
^{153}Sm	^{156}Eu	^{157}Eu		

[*1] The selection has been informed by the Guidelines concerning the "Measurement of Radioactive Emissions at Light Water Reactor Facilities for Power Generation" (Nuclear Safety Commission, amended March 2001), "The Plan for Environmental Radiation Monitoring around the Rokkasho Reprocessing Plant" (Nuclear Safety Commission, 2003), the Radioactivity Measurement Series No. 7 "Gamma-ray Spectrometry Using Germanium Detectors," etc.

Table D.2 Nuclides produced as a result of nuclear reactions of neutron, etc.

^{22}Na	^{24}Na	^{41}Ar	^{46}Sc	^{51}Cr
^{54}Mn	^{56}Mn	^{56}Co	^{57}Co	^{58}Co
^{59}Fe	^{60}Co	^{63}Zn	^{65}Ni	^{65}Zn
^{75}Se	^{76}As	^{82}Br	^{88}Y	^{108m}Ag
^{110m}Ag	^{113}Sn	^{114m}In	^{115}Cd	^{124}Sb
^{125}Sb	^{133}Ba	^{134}Cs	^{136}Cs	^{139}Ce
^{152}Eu	^{154}Eu	^{181}Hf	^{182}Ta	^{187}W
^{192}Ir	^{198}Au	^{203}Hg	^{237}U	^{239}Np
^{241}Am				

Table D.3 Disintegration products of uranium and thorium as well as nuclides existing in the background

^{7}Be	^{40}K	^{74}Ga	^{74}As	^{75}Ge
^{75m}Ge	^{206}Tl	^{207}Bi	^{208}Tl	^{210}Pb
^{210}Po	^{211}Pb	^{211}Bi	^{212}Pb	^{212}Bi
^{214}Pb	^{214}Bi	^{219}Rn	^{223}Ra	^{224}Ra
^{226}Ra	^{227}Th	^{228}Ac	^{228}Th	^{231}Th
^{231}Pa	^{234}Th	^{234m}Pa	^{235}U	

Through the Fukushima Dai-ichi Nuclear Accident, apart from the artificial radionuclides stated in Tables D.1 to D.3, the following are reported to have been detected: ^{86}Rb, ^{122}Sb, ^{127}Te, ^{129m}Te, ^{130}I, ^{131m}Xe, ^{133}Xe, and ^{203}Pb. Additionally, ^{85}Kr was released into the environment at the Fukushima Dai-ichi Nuclear Accident, despite its low emission rate of 0.43%; this made it difficult to ascertain the emission with gamma-ray spectrometry. In the case of a fuel reprocessing plant accident, owing its large inventory, ^{129}I bears importance. Therefore, the ten nuclides shown above are also included in the master library of nuclear data for emergency situations.

Explanation D.2 Nuclear data library for analysis

It is not necessarily the case that all the radionuclides registered in the master library of nuclear data for emergency situations are released into the environment in a nuclear accident and detected in the gamma-ray spectrum of an environmental sample. It is necessary to consider the type of nuclear accident, weather condition, distance, properties of released radionuclides (rare gas, volatile, nonvolatile), etc. Table D.4 provides information useful to determine whether the released radionuclide is volatile or nonvolatile (Reference 52). Note that ^{89}Sr, ^{90}Sr, Pu isotopes, and ^{242}Cm in Table D.4 are not normally quantified using gamma-ray spectrometry.

Table D.4 Latest estimation[a] of the radioactivity of major radionuclides released in the Chernobyl Disaster

	Half-life	Radioactivity released (PBq = 1015 Bq)
Rare gases		
^{85}Kr	10.72 yrs.	33
^{133}Xe	5.25 days	6500
Volatile elements		
^{129m}Te	33.6 days	240
^{132}Te	3.26 days	~1150
^{131}I	8.04 days	~1760
^{133}I	20.8 h	910
^{134}Cs	2.06 yrs.	~47[b]
^{136}Cs	13.1 days	36
^{137}Cs	30.0 yrs.	~85
Elements with intermediate volatility		
^{89}Sr	50.5 days	~115
^{90}Sr	29.12 yrs.	~10
^{103}Ru	39.3 days	168 or more
^{106}Ru	368 days	73 or more
^{140}Ba	12.7 days	240
Nonvolatile elements (including fuel particles)[c]		
^{95}Zr	64.0 days	84
^{99}Mo	2.75 days	72 or more
^{141}Ce	32.5 days	84
^{144}Ce	284 days	~50
^{239}Np	2.35 days	400
^{238}Pu	87.74 yrs.	0.015
^{239}Pu	24065 yrs.	0.013
^{240}Pu	6537 yrs.	0.018
^{241}Pu	14.4 yrs.	~2.6
^{242}Pu	376000 yrs.	0.00004
^{242}Cm	18.1 yrs.	~0.4

a Most data are taken from reference documents [UNSCEAR (2000), Dreicer, et al. (1996)].

b This is based on the $^{134}Cs/^{137}Cs$ ratio as of April 26, 1986, which is 0.55 [Mück, et al. (2002)].

c This is based on the emission ratio of fuel particles, which is 1.5% [Kashparov, et al. (2003)].

The nuclear data library for analysis to be used in gamma-ray spectrometry is a nuclear data library that contains the nuclides that have been reported in research papers, etc. that have been detected through nuclear accidents in Japan and abroad (the Chernobyl Disaster, JCO Accident, and Fukushima Dai-ichi Nuclear Accident).

The nuclides that have been detected in the Fukushima Dai-ichi Nuclear Accident and Chernobyl Disaster include fission product nuclides and secondary products through the activation of neutrons from reactor materials. In the JCO Accident, because many radionuclides and neutron beams were released into the environment, many secondary product nuclides from the environmental samples and neutron beams were detected. Meanwhile, it is also necessary to consider in terms of the gamma-ray spectra from emergency situations that gamma-ray peaks due to natural radionuclides may be observed. Hence, the nuclear data library for analysis should include the nuclear data library of the artificial radionuclides that were detected in nuclear accidents and a nuclear data library in use at ordinary times.

Table D.5 illustrates an example of a general-purpose nuclear data library for ordinary times. As for the artificial radionuclides detected in nuclear accidents, two separate tables are provided to divide the artificial radionuclides from the Fukushima Dai-ichi Nuclear Accident and Chernobyl Disaster, on the one hand, and those from the JCO Accident, on the other (see Table 5.1 in Chapter 5). The nuclear data library for analysis is formed by combining these tables (see Figure 5.1 in Chapter 5).

Table D.5 Example of a general-purpose nuclear data library for normal times

^{7}Be	^{40}K	^{51}Cr	^{54}Mn	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn
^{95}Zr	^{95}Nb	^{103}Ru	^{106}Ru	^{125}Sb	^{131}I	^{134}Cs	^{137}Cs
^{140}Ba	^{140}La	^{144}Ce	^{208}Tl	^{214}Bi	^{228}Ac	^{234m}Pa	

* Other registered nuclides include ^{108m}Ag, ^{110m}Ag, ^{141}Ce, ^{152}Eu, ^{154}Eu, ^{212}Pb, ^{212}Bi, ^{214}Pb and (^{226}Ra). Note that the gamma ray of ^{226}Ra (186.2 keV) is only for reference purposes as it is almost identical with the gamma ray of ^{235}U (185.7 keV).

D.2.1 Nuclides reportedly detected in the Fukushima Dai-ichi Nuclear Accident

The artificial radionuclides that were reportedly detected in the Fukushima Dai-ichi Nuclear Accident are listed in Table D.6. Figures D.1 and D.2 illustrate the gamma-ray spectra of environmental samples (airborne particles and soil).

Table D.6 Artificial radionuclides reportedly detected in the Fukushima Dai-ichi Nuclear Accident

^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{85}Kr	^{86}Rb	^{91}Sr	^{91}Y
^{95}Zr	^{95}Nb	^{99}Mo	^{99m}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{113}Sn
^{125}Sb	^{127}Te	^{129}Te	^{129m}Te	^{130}I	^{131m}Te	^{131}I	^{131}Xe
^{132}Te	^{132}I	^{133}I	^{133m}Xe	^{133}Xe	^{134}Cs	^{135}Xe	^{136}Cs
^{137}Cs	^{140}Ba	^{140}La	^{203}Pb	^{239}Np			

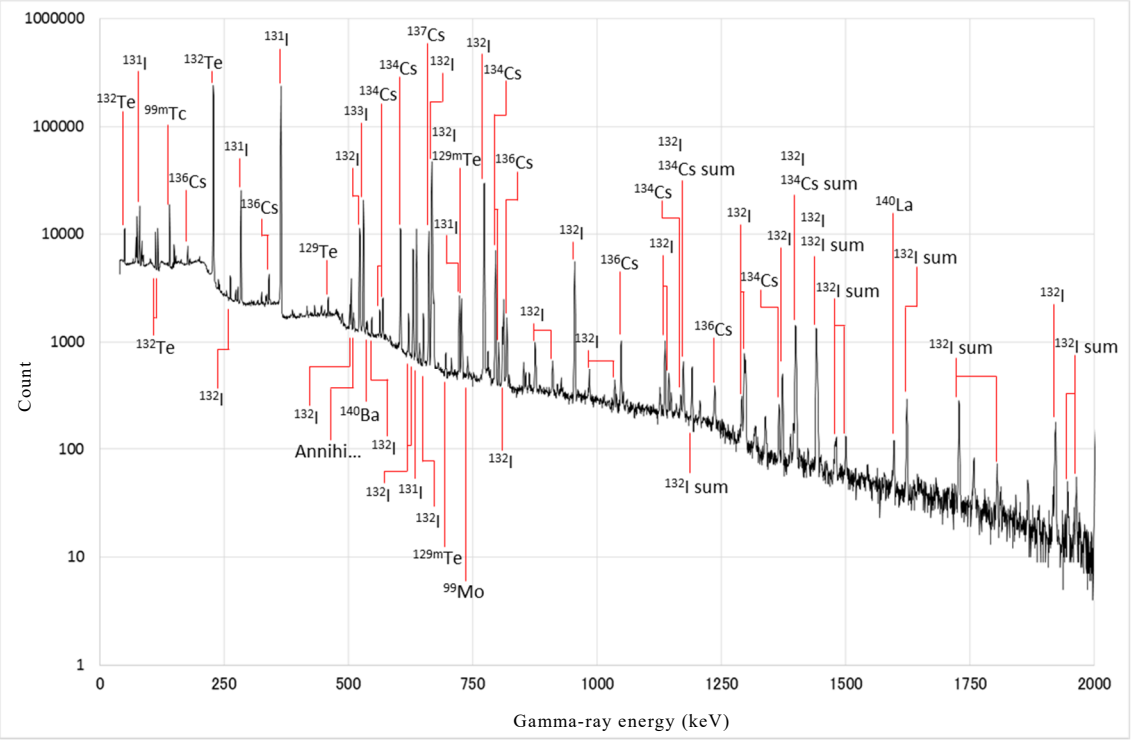


Figure D.1 Gamma-ray spectrum of environmental sample (airborne particles) sampled in the Fukushima Dai-ichi Nuclear Accident

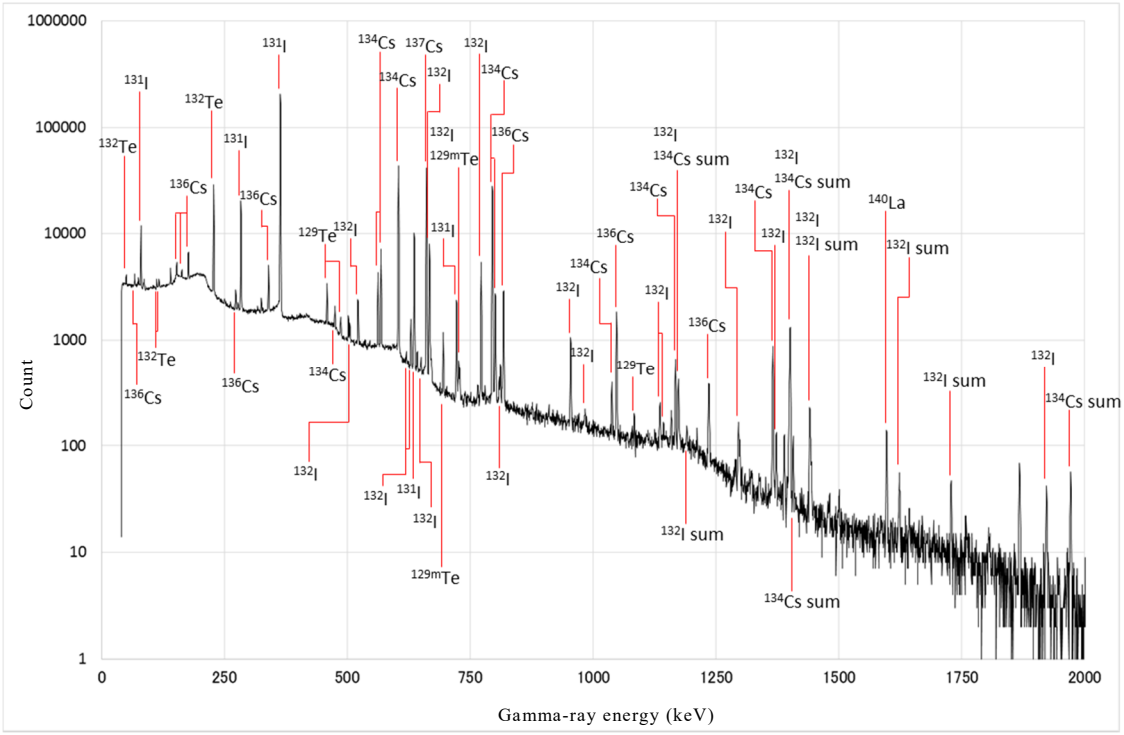


Figure D.2 Gamma-ray spectrum of environmental sample (soil) sampled in the Fukushima Dai-ichi Nuclear Accident

D.2.2 JCO Accident

The artificial radionuclides that were reportedly detected in the JCO Accident are shown in Table D.7.

Figure D.3 shows an illustrative gamma-ray spectrum of an environmental sample (vegetables) collected in the JCO Accident.

Table D.7 Artificial radionuclides reportedly detected in the JCO Accident

^{24}Na	^{46}Sc	^{51}Cr	^{54}Mn	^{56}Mn	^{59}Fe	^{60}Co	^{65}Zn
^{82}Br	^{91}Sr	^{95}Zr	^{95}Nb	^{103}Ru	^{122}Sb	^{124}Sb	^{131}I
^{133}I	^{134}Cs	^{135}I	^{137}Cs	^{138}Cs	^{140}Ba	^{140}La	^{153}Sm
^{198}Au							

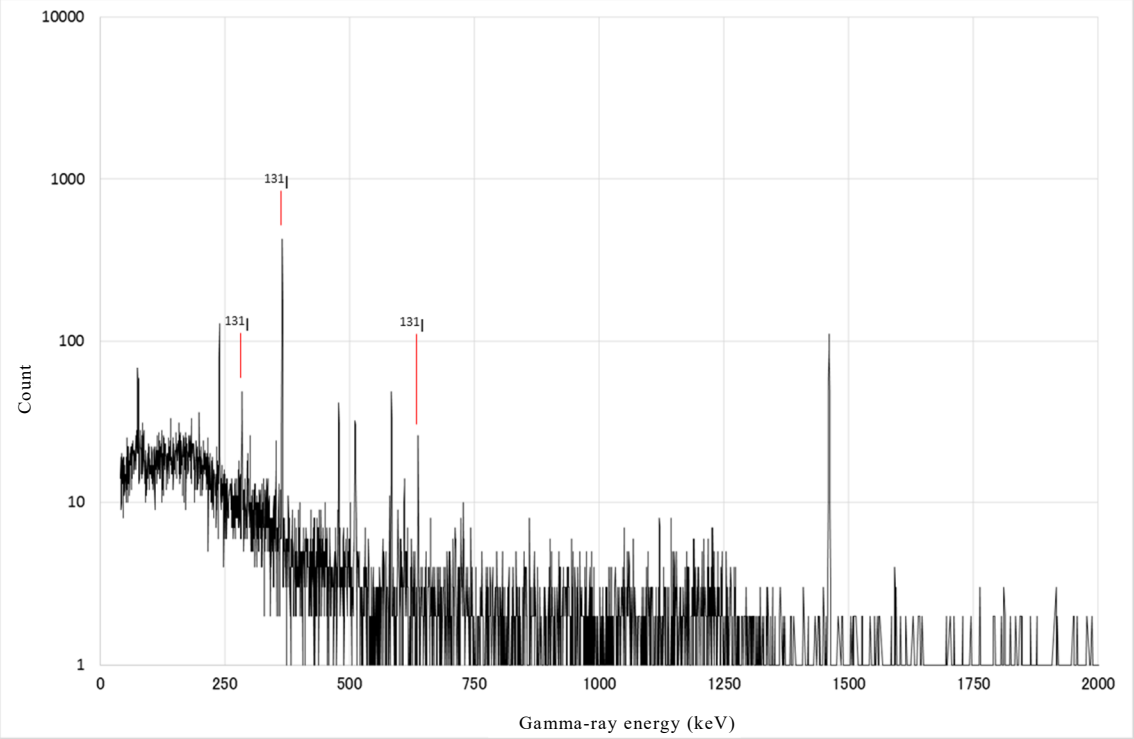


Figure D.3 Gamma-ray spectrum of environmental sample (vegetables) sampled in the JCO Accident

D.2.3 Chernobyl Disaster

The artificial radionuclides that were detected in the Chernobyl Disaster are shown in Table D.8. Figure D.4 shows an illustrative gamma-ray spectrum of an environmental sample (airborne particles) collected in the Chernobyl Disaster.

Table D.8 Artificial radionuclides detected in the Chernobyl Disaster

^{60}Co	^{95}Zr	^{95}Nb	^{99}Mo	^{99m}Tc	^{103}Ru	^{106}Ru	^{110m}Ag
^{125}Sb	^{129m}Te	^{131}I	^{132}Te	^{134}Cs	^{136}Cs	^{137}Cs	^{140}Ba
^{140}La	^{141}Ce	^{144}Ce	^{147}Nd	^{152}Eu			

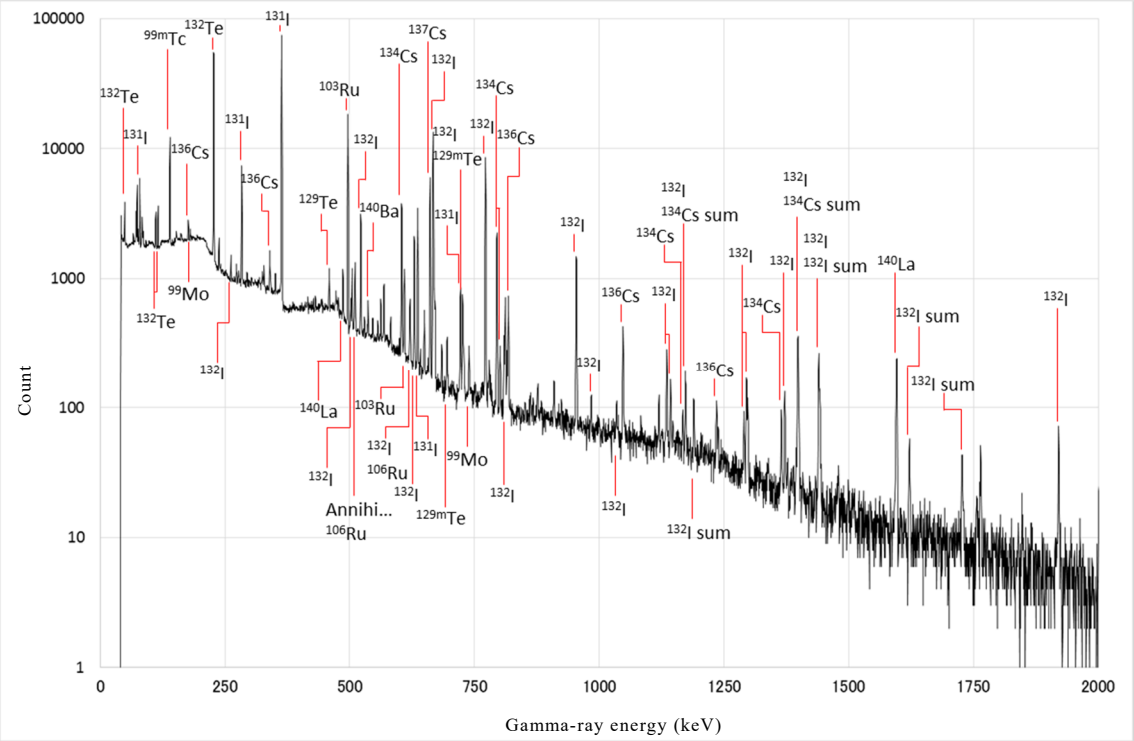


Figure D.4 Gamma-ray spectrum of environmental sample (airborne particles) sampled in the Chernobyl Disaster

Explanation E　Problems in measuring at high count rates

When running a measurement of samples with high radioactivity levels in emergencies at a high count rate, a significantly large number of gamma rays enter the detector and overload the electronic devices responsible for signal processing. As a result, certain problems arise, such as an increase in dead time.
Problems that may occur with measurement at high count rates include the following:

- Increased dead time
  Consequently, the overall time needed for measurement increases (slow progress on the live time).
- Pulse pile-up
  Consequently, the peak resolution decreases (tailing towards the high-energy side).
  As a result, the peak count rate is lowered (leading to underestimation).
- Random summing
  As a result, the peak count rate is lowered (leading to underestimation).

Explanation E.1　Increased dead time

A measurement with a large dead time, in which the number of signals to be processed increases, requires a long time to complete the measurement. As an actual measurement example, Figure E.1 illustrates the gamma-ray spectrum of a plant sampled immediately after the Fukushima Dai-ichi Nuclear Accident. For the purpose of comparison, Figure E.1 also depicts a gamma-ray spectrum of the same sample, but of a smaller volume to reduce the dead time.
Samples with a large dead time may require tens or hundreds of times longer than the intended measuring time.

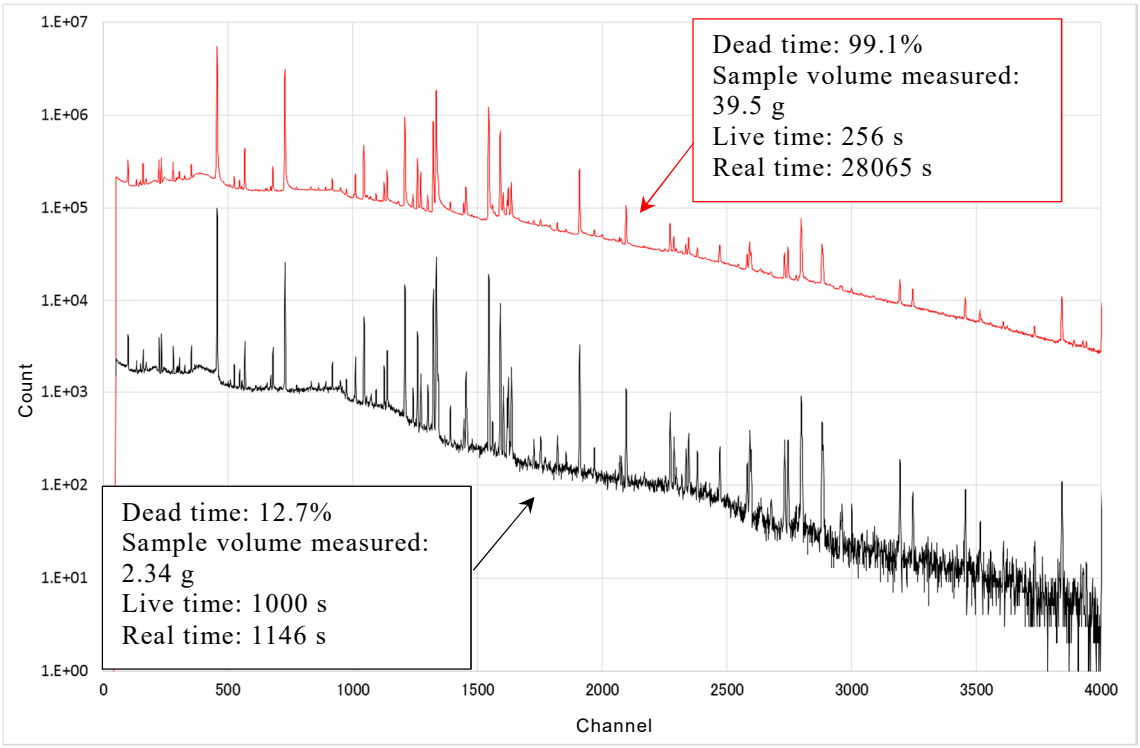


Figure E.1 Comparison between a gamma-ray spectrum with large dead time (red) and a gamma-ray spectrum of the same sample, but with reduced volume to diminish the dead time (black) (Data source: Fukushima Prefectural Center for Environmental Creation, Environmental Radiation Center)

Explanation E.2 Pulse pile-up

Pulse pile-up refers to a phenomenon in which a multiple number of gamma rays are injected simultaneously and the sum of the energies is yielded as a signal output. This may result in adding other signals to all energy signals of the gamma ray, causing tailing in the direction of the high-energy side, leading to a degradation in the resolution and possibly increasing the count on the high-energy side. The signal that should have been output at the position of gamma-ray peak is output further toward the high-energy side, and this lowers the net count rate. As a result, the radioactivity concentration will be underestimated. Note that sum peaks appear in the gamma-ray spectrum as a result of the pulses of cascading gamma rays added together (coincidence summing effect) or the pulses of energy derived from gamma rays that originate in different incidents of disintegration added up (random summing).

As a reference, Figure E.2 shows an image of an oscilloscope screen displaying a gamma-ray energy measured with a dead time of 5% or lower, and one with 10% or more. Figure E.3 illustrates gamma-ray spectra with these dead times. Figure E.4 shows the gamma-ray peak of ^{134}Cs (604.7 keV), tailing as the environmental sample was measured with a large dead time.

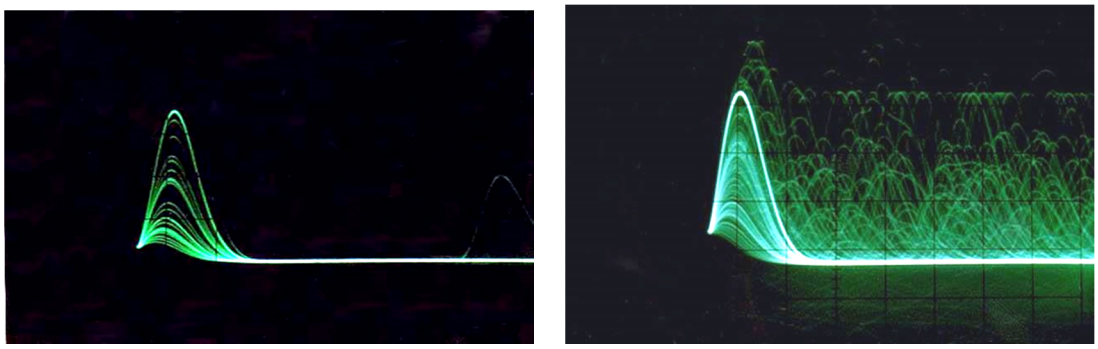


Figure E.2 Oscilloscope screens showing waveforms
(left: dead time 5% or lower, right: dead time 10% or higher)

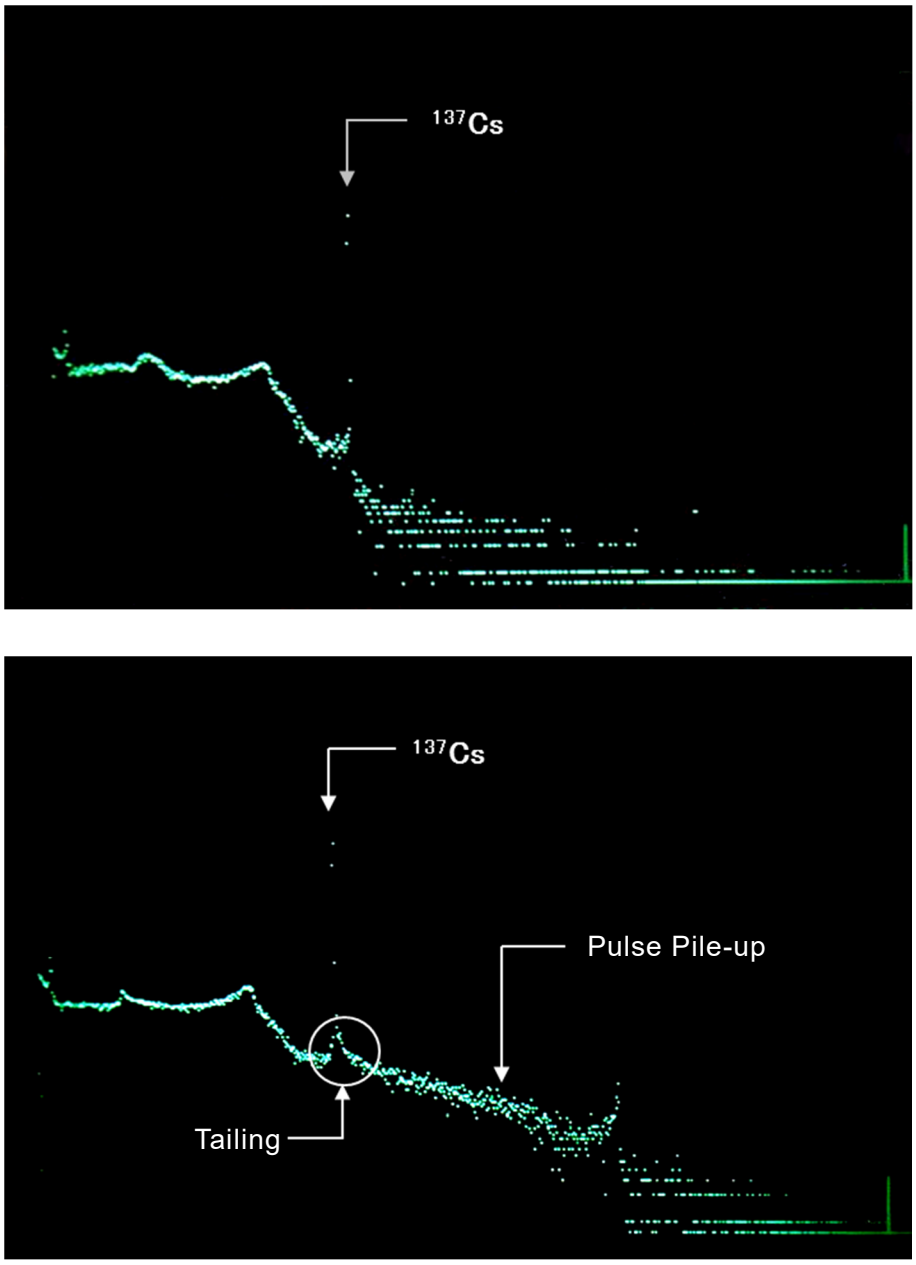


Figure E.3 Gamma-ray spectrum with different dead times
(top: dead time 5% or lower, bottom: dead time 10% or higher)

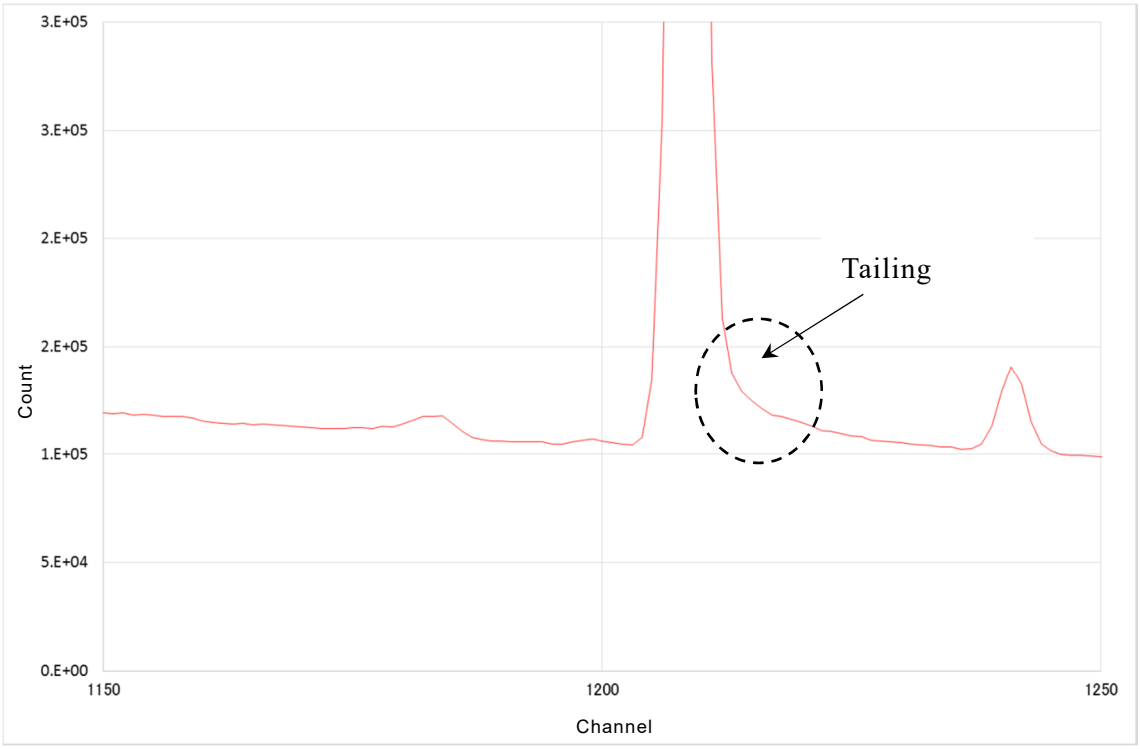


Figure E.4 ^{134}Cs gamma-ray peak (604.7 keV) of an environmental sample with a large dead time (Data source: Fukushima Prefectural Center for Environmental Creation, Environmental Radiation Center)

Explanation E.3 Random summing

Gamma-ray spectra in emergencies need to be carefully examined, not only for the contributions of sum peaks due to cascade gamma rays, but also for random summing due to gamma rays from different nuclides (e.g., ^{137}Cs + ^{134}Cs). Furthermore, sum peaks due to different decay events of the same nuclide (e.g., ^{137}Cs + ^{137}Cs) may appear in the spectrum as random summing. Random summing causes peaks to be treated as unknown peaks in the analysis, and therefore it must be identified by selecting and combining nuclides based on large peaks in the spectrum. As with the aforementioned pulse pile-up, the signal that should have appeared at the peak position is summed with the signals due to other gamma rays, which lowers the peak count rates and results in the underestimation of the radioactivity concentration.

Explanation E.4 Solutions to measurement at high count rates

Environmental samples in emergencies are assumed as likely to involve high count rates, and the measurement may be prone to the problems described in Explanations E.1 to E.3. Solutions to these problems include the reduction of the sample volume to lower its radioactivity level, and measurement in a geometry that places the sample farther away from the detector. If adopting the latter solution, it is necessary to perform the peak efficiency calibration in the same geometry in advance.

Explanation F　Gamma-ray spectral analysis using consumer software

Explanation F.1　Number of nuclear data to be handled in emergencies

The master library of nuclear data for emergency situations has several times more nuclides and peaks than the general-purpose nuclear data library for normal times. Therefore, it is necessary to ensure that the gamma-ray spectrometry software has all the nuclides and gamma-ray peaks found in the master library of nuclear data for emergency situations registered, and that it is compatible with the nuclides and gamma-ray peaks included in the nuclear data library for analysis.

Explanation F.2　Spectral analysis

The spectral analysis processes the gamma-ray spectrum obtained from the measurement and performs the peak search, identification of nuclides, and quantification of radioactivity concentration. In emergencies, it also requires a function to detect only the primary peak in addition to a function to detect all major peaks of the applicable nuclides for analysis. In this section, the methods required for gamma ray-spectral analysis in emergencies are outlined based on the Radioactivity Measurement Series No. 7 “Gamma-ray Spectrometry Using Germanium Detectors.” For more details, refer to the manual.

F.2.1　Peak search

For the purposes of configuring the peak area, etc., functions are required to search peaks in a gamma-ray spectrum from 0 to 4000 channels, and to create full width and half maximum (FWHM: the width at a half peak height) and channel–energy relational expression (energy calibration formula). In the following, the calculation procedures are outlined and each calculation process is described.

(1) An example of calculation procedures

(1) Obtain a tentative FWHM from, e.g., past measurement data to create a Laplacian Gaussian smoothing filter (where possible, vary the filter width, etc. according to the FWHM of the peak, count values, and nearby peaks. This will allow searches against peaks in the low- and high-energy regions as well as compound peaks.)

(2) Apply the Laplacian smoothing to the spectral data, then conduct a peak search while determining the detection of peaks with reference to the counting error.
Calculate the center channel of the detected peak in terms of the Laplacian smoothed spectrum, using either the three-point count value estimation or the first derivative zero-crossing method to obtain the default value of the peak center, which is required in operation (4).

(3) Select a peak that is free of other nearby peaks (up to three times the FWHM) in order to prepare the FWHM and channel–energy relational expression.

If there are no significant peaks of artificial radionuclides recognized, in the background spectrum for example, Pb-KαX (usable despite another X-ray peak right next to it) or gamma ray peaks of ^{214}Pb, ^{208}Tl, ^{214}Bi, ^{40}K, etc. are suspected.

(4) Perform the function fitting of the selected peak through "first-order equation + Gaussian function." List the obtained peak center, peak width, and (area as well as their) errors.[*1]

(5) Fit the FWHM to the function

$a + b \times \sqrt{\text{Channel}}$

and run a χ^2 test,

where,

a) Use the positron annihilation radiation (511.0 keV) and single escape peak only in the preparation of the channel–energy relational expression, as they are not governed by the equation above.

b) Verify χ^2 to see if it is within the set confidence interval, and if this is not the case, remove the peaks one by one in the descending order of value in the formula below and repeat the function fitting and χ^2 test.

$$\frac{|FWHM_i - FWHM(E_i)|}{\sqrt{\Delta_i^2 + \Delta(E_i)^2}}$$

FWHM$_i$: Half-width of each peak

FWHM(E$_i$): Half-width obtained by the relational expression of half-width−energy

Δi: Half-width error of each peak

Δ(E$_i$): Error of the equation half-width−energy

(6) If minute calculation is required, check whether the result from (5) is discrepant with the FWHM used in (1) by more than the statistical fluctuation; if so, correct it and return to (1) to recommence from the preparation of the filter.

(2) Preparation of the Laplacian Gaussian smoothing filter for peak search

(1) Differentiate the Gaussian function with the width "W," which is one to two times wider than the FWHM of the spectrum, twice over, to create a value filter.

$$F(X) = \exp\left\{-\frac{2.773}{W^2}(X-P)^2\right\}$$

P: *Peak* center

Assume that X - P = j, and differentiate the j twice, then it returns the value filter as follows:

$$F''(j) = \left\{\frac{5.546}{W^2}\left[1 - \frac{5.546j^2}{W^2}\right]\exp\left[-\frac{5.546j^2}{2\cdot W^2}\right]\right\}$$

[*1] When measuring environmental samples of unknown true values, it may be described as "variance" instead of "error." "Error" is used here for the reasons that it is conventionally used in the field of background radiation measurement and that terms must be used consistently throughout the Radioactivity Measurement Series.

(2) Obtain $F''(j)$ by changing the value of j from $-3 \times$ W to $3 \times$ W by a degree of one, to obtain the Laplacian Gaussian smoothing filter. The range of j is sufficient as above, or otherwise the value for $F''(j)$ will be too small.

(3) Calculation of Laplacian smoothing and counting error

Using the Laplacian Gaussian smoothing filter obtained in F.2.1 (2), calculate the Laplacian smoothing and its counting error.

The equation to obtain the Laplacian smoothing is as follows:

$$N''(i) = \sum_{j=-k}^{k} F''(j) \cdot N(i+j)$$

N(i + j): Count value of the (i + j) channel

F″(j): Laplacian Gaussian smoothing filter

k: 3 × W

The equation for the counting error of N″ (i) is as follows:

$$\sigma''(i) = \sqrt{\sum_{j=-k}^{k} F''(j)^2 \cdot N(i+j)}$$

(4) Determination of peaks

Calculate the Laplacian smoothing and counting error for the counts of each channel from 0 to 4000, then collate and organize them in the order of the channels. Compare the Laplacian smoothing with its error of the same channel. Regions where the Laplacian smoothing value x (−1) is greater than two to three times the error are identified as peaks.

(1) As for the guideline for peak determination, a very sensitive criterion would result in picking up non-peak events; therefore, the appropriate line is to identify the Laplacian smoothing values that are two to three times more than the coefficient of variation as possible peaks.

$$N''(i) \leqq -2.5 \times \sigma''(i)$$

(2) For a thorough peak search to identify even small peaks, adjust the "−2.5" in the equation above, without allowing it to turn positive. However, this will increase the number of peaks that result not from radioactivity but are simply caused by the statistical fluctuation of the counts. To determine whether the peaks found through a peak search indicate the existence of radioactivity requires the calculation of the peak area and identification of the nuclide.

(5) Calculation of peak center channel

Obtain the center channel of a peak detected through the peak search. Use the following two calculation methods to obtain the default value for function fitting.

(1) Calculation of peak center channel by three-point count value estimation.

Within a single peak, the channel with the highest count is h, and the count is N_h; the counts of channels h − 1 and h + 1 are N_{h-1} and N_{h+1}, respectively.

A parabolic approximation of the peak center and its vicinity gives the peak center channel P and its error as follows:

$$P = h + \frac{1}{2}\left(\frac{N_{h+1} - N_{h-1}}{2N_h - N_{h-1} - N_{h+1}}\right)$$

(2) Calculation of peak center channel by the first derivative zero-crossing method.

a) Assume that the peak center is located between the channels with the highest and second highest counts.

b) The channels adjacent to the peak are m and m + 1, and the first derivatives of their counts are ΔN_m and ΔN_{m+1}, respectively.

c) ΔN_m and ΔN_{m+1} are obtained by replacing i in the following equation with m and m + 1.

$\Delta N_i = \sum_{-k}^{k} k \cdot N_{i+k}$ N_i: count of channel i

The value of k is determined based on the stretch and symmetry of the peak, and 1 to 1.5 keV is sufficient.

k = 2: $\Delta N_i = 2\left(N_{i+2} - N_{i-2}\right) + N_{i+1} - N_{i-1}$

k = 3: $\Delta N_i = 3\left(N_{i+3} - N_{i-3}\right) + 2\left(N_{i+2} - N_{i-2}\right) + N_{i+1} - N_{i-1}$

d) The peak center channel is thus obtained by

$$P = m + \frac{\Delta N_m}{\left(\Delta N_m - \Delta N_{m+1}\right)}$$

However, if $\Delta N_m > 0$, $\Delta N_{m+1} \leq 0$ are not satisfied, repeat the same calculation with the preceding or subsequent channel by one degree.

(6) Calculation of peak FWHM

This section explains how to obtain the FWHM, which is used in the peak search, the determination of peak area, etc.

a) Perform the function fitting of a peak through "Gaussian function + first-order equation."

The Gaussian function + first-order equation is expressed below.

$$F(i, C_k) = C_1 + C_2(i - P) + C_3 \cdot \exp\{C_4(1 - P)^2\}$$

C_1, C_2, C_3, and C_4: constant

P: peak center channel

b) Pseudo-fit to the Gaussian function (not possible to obtain an error).
c) Obtain the FWHM by distributing the count proportionally (use the peak center obtained in (2)).

(7) Peak search by varying the filter width

While the peak search method described above is a general technique, the peak search by varying the filter width allows more thorough exploration to find small peaks nestled in a skirt of larger peaks and those with a wide half-width on the high-energy side. The following is an example of this method.

(1) Configure a filter with an appropriate width. With a detector of half-width of 1.9 to 2.0 keV (1332.5 keV), 1 to 6 is sufficient for W.
(2) Search all channels at the largest filter width.
(3) Search all channels at the second largest filter width.
(4) Repeat the search of all channels by altering the filter widths until the smallest filter width is tried.
(5) Compare the outcomes with the previous peak search results to see if the same peaks or any new peaks are recognized within the peak center margin of error. This verification is the peak search result. However, in practice, peaks may be verified when peaks are identified in three or more consecutive searches of varied filter widths.

F.2.2 Preparation of the channel−energy relational expression

The relational expression of channel and energy can be created[*2] using the peaks in the target spectrum for analysis, such as the sample and background.[*3] The calculation processes are as follows:

(1) Based on the peak search result (F.2.1 (1)[3]), determine the peak to be used for calculating the channel−energy relational expression.

a) Identify the nuclide corresponding to the chosen peak with reference to previous calculation results, nuclear data tables, etc. and look up its energy.

b) Obtain the channel−energy relational expression by the least squares.

c) Verify the χ^2 to see if it is within the set confidence interval, and if this is not the case, remove the peaks one by one in the descending order of value in the formula below and repeat the function fitting and χ^2 test.

$$\frac{|P_i - P(E_i)|}{\sqrt{\Delta_i^2 + \Delta(E_i)^2}}$$

P_i: Each peak's peak center

$P(E_i)$: Peak center obtained by the relational expression of channel−energy

Δ_i: Peak center margin of error for each peak

$\Delta(E_i)$: Error of channel−energy relational expression

(2) Calculate the channel−energy relational expression and its error.

a) Select three or more clearly defined peaks at appropriate intervals.

b) If three peaks are used, employ a second-order equation.

c) Even if the number of used peaks is much greater, restrict the equation to the fourth order or below.

d) It is possible to use two parabola, each joined with the other at their vertexes.

F.2.3 Peak analysis

Function fitting is used to calculate the peaks, which requires precise treatment of the error. Unlike the calculation of FWHM, function fitting for an area calculation demands precision. Therefore, it is better not to use the simple combination of the Gaussian function and first-order equation as a function for fitting.

(1) Function fitting

Set the fitting area to be approximately eight times the FWHM on each side of the peak center. Owing to slight variations in the peak shape depending on the detectors, it is difficult to fix a single peak function. Thus, it is desirable for a peak function to be created according to specific

[*2] See Chapter 3 for the method to create the expression using a multi-nuclide standard-volume radiation source.

[*3] Though it is possible to recalibrate using the measured spectrum itself, care must be taken to prevent changes in the in-room environment from affecting the measurement equipment (alteration of gains). In emergencies, it is necessary to verify the appropriateness of the channel–energy relational expression for the measurements to avoid misidentification.

detectors. An example is shown below of a function applicable to spectra with a small counting error.

Connect a normal curve with an asymmetric distribution of FWHM (W_l and W_r) at its vertex. Set X_0 to the peak center, and express the cascade A toward the low-energy side by

$$\frac{a}{1 + e^{\{(x-x_0)/(1.5 \cdot W_l)\}}}$$

Similarly, express the tail B on the low-energy side by

$$\frac{b}{1 + c(x - x_0)^2} \times \frac{1}{1 + e^{\{(x-x_0)/(1.5 \cdot W_l)\}}}$$

Combining the above yields the following formula:

$$P(x) = h \times e^{\{-2.7726 \cdot (x-x_0)^2/(W_l \text{ or } W_r)^2\}} + \frac{1}{1 + e^{\{(x-x_0)/(1.5 \cdot W_l)\}}} \times \left\{a + \frac{b}{1 + c(x - x_0)^2}\right\} + g$$

h: Height of the peak
W_l: Width applied to the left-hand side of the peak
W_r: Width applied to the right-hand side of the peak
a: Height of the cascade
b: Height of the tailing
c: Breadth of the tailing
g: Height of the baseline

The fitting parameters are h, a, b, c, W_l, W_r, g, and the peak center x_0.

1) Configuration of fitting parameters
   a) If there are no assumed nuclides, calculate the peak center by applying either the three-point count value estimation or the first derivative zero-crossing method to a Laplacian-smoothed spectrum.
   b) If a nuclide is assumed, calculate the peak center by the channel−energy relational expression, and do not use this as a fitting parameter unless the count is high.
   c) Use only the peak height and the baseline as fitting parameters, which are obtained through the function fitting. In the function fitting, it is advisable to prepare in advance the functions of the parameters for cascade, asymmetry, tailing, FWHM, etc. based on the measured energy dependence and use them as fixed parameters.
   d) After the fitting calculation, obtain the errors of the fitting parameters, etc.
   e) It is advisable to run χ^2 in order to verify the goodness of fit.
2) Combined peaks
   a) Combined peaks could be applied with the function fitting, provided that there is a recess between the peaks.
   b) Even if it is difficult to see a recess owing to overlapping of peaks, as long as the dislocation is visible, the calculation could at least be possible by fixing the distance between the peak centers (which presupposes the tentative identification of nuclides). If this is possible, use the nuclide identification results to repeat the calculation.
   c) If peaks are practically overlapped completely, use the data of other peaks of the same nuclide to perform the calculation. The contribution factoring method is one of them.

Assigning X to the channel number, the fitting function Y is

$$Y = C_1 + C_2X + C_3\exp\{C_4(X - C_5)^2\} + C_6\exp\{C_7(X - C_8)^2\}$$

- $C_1 + C_2X$ is a first order equation of the baseline.
- $C_3\exp\{C_4(X - C_5)^2\}$ is a peak function (Gaussian function), where C_3 is the height, C_5 is the center , and $(4\ln2/C_4)$ is the half-width.
- $C_6\exp\{C_7(X - C_8)^2\}$ is a peak function (Gaussian function), where C_6 is the height, C_8 is the center, and $(4\ln2/C_7)$ is the half-width. ln represents the natural logarithm.

(2) Calculation of FWHM, etc. using the function fitting result

To obtain the FWHM, determine the channel of which the peak function value is half the peak value. That is, when giving the function value, it requires an "inverse function program" to obtain the variable to realize the function.

Given $Y = P(X)$ as a peak function, its inverse function is $X = P^{-1}(Y)$, and the values of X on either side of the peak where Y is half of the peak height, that is $P_H^{-1}(Y_{1/2})$ and $P_L^{-1}(Y_{1/2})$, are given as X_l and X_r. Then,

$$\text{FWHM} = X_r - X_l$$

Meanwhile, calculate the error for X_r and X_l using the least squares.

$$\sigma_x{}^2 = \sum_{i\,j} \frac{\delta P^{-1}}{\delta C_i} \cdot \sigma(C_i, C_j) \cdot \frac{\delta P^{-1}}{\delta C_j}$$

$C_{i,j}$: Fitting parameter of the peak function

$\sigma(C_i,C_j)$: Standard deviation of $C_{i,j}$ obtained by the least squares

$$\frac{\delta P^{-1}}{\delta C_i} = \frac{1}{\delta P(X_{l,r})/\delta C_i}$$

Substitute them in the calculation.

As the FWHM is expressed as an inverse function of the peak function, the calculation of the error will require partially differentiating the inverse function. This calculation is performed on the basis that the partial derivative of an inverse function is equal to the inverse value of the partial derivative.

$$\frac{\delta P^{-1}}{\delta C_i} = \frac{\delta P^{-1}(X)}{\delta W_{l,r}}\bigg|_{X=X_{l,r}} = \frac{1}{\frac{\delta P(X)}{\delta W_{l,r}}\Big|_{X=X_{l,r}}}$$

$$= 0.5 \times \frac{P(W_{l.r}+\delta, X_{l,r}) - P(W_{l.r} - \delta, X_{l,r})}{\delta^*}$$

*Substitute approximately 0.1 channel in the calculation.

The error of the FWHM is given by the square root of sum of squares of the errors of X_l and X_r.

(3) Asymmetry of a peak

Peaks are generally asymmetrical, and the breadths are expressed in terms of $^{1}/_{10}$ width (FWTM: full width at tenth maximum) measured at one-tenth height of the maximum count.

Asymmetry of peak = {FWTM (left) − FWTM (right)} / FWTM (right)

F.2.4 Calculation of peak area

After performing the peak search with the spectrum obtained from the sample measurement, calculate the radioactivity based on the peak area, following the identification of the nuclide. With spectra obtained in emergencies, if the measurement was performed with a dead time of 5% or less, the peak shape would not be affected. However, with a dead time of more than 5%, analysis is often difficult because the peak may be deformed owing to peak shifts, tailing, etc., and there may be interference of ghost peaks.

There are two methods of peak analysis.

(1) By identifying the peaks detected through the peak search and calculating the peak areas to quantify the radioactivity levels.

(2) By calculating the peak area of a target nuclide, irrespective of whether its peaks are detected, and quantifying its radioactivity level.

The former method may not yield the data about the nuclides of interest, and the latter is not capable of handling unexpected nuclides. Thus, the latter method is employed when analyzing any major nuclide, such as radioactive iodine and radioactive cesium, or when there is only one peak or the second and subsequent peaks are extremely small. Otherwise, the former method should be used.

As computers are used to perform the analysis, it is advisable to output charts and tables to show the analytical progress to verify the appropriateness of the function formulae, used parameters, peak areas, nuclear data, etc.

The computer must be equipped with a feature compatible with the calculation of peak areas by the Covell method and function fitting. As for function fitting, the peak area is the part that is expressed by the Gaussian function. Exclude the areas created by tailing or cascading from the peak area. Although there may be a slight discrepancy between the results of the Covell method and that of the function fitting, this will not cause practical problems.

It is good practice to research how the asymmetry, tailing, and cascading change with respect to energy in advance and consider them when performing the peak analysis.

To the extent that the peak has a simple shape, a first-order equation + simple Gaussian function suffices to calculate the peak area, unless there are compound peaks or small peaks nestled in a tailing end.

F.2.5 Correcting background

To remove the risk of including a count that does not result from a sample in the radioactivity calculation, perform a background measurement, that is, a measurement without samples installed in the detector, and subtract the resulting count in the analysis. As a guideline, the background measurement time should be equal to or double the duration of the sample measurement. Moreover, it is advisable to perform the background measurement after measuring a sample with high levels of radioactivity concentration, even for a short period, to check for contamination.

In the case where either the detector or the inside of the shield is contaminated and cannot be decontaminated completely, it is necessary to take background measurements and apply the correction constantly. The calculation method for background correction is shown below.

$$N \pm \sigma_N = \left(\frac{S}{T_S} - \frac{B}{T_B}\right) \pm \sqrt{\left(\frac{\sigma_S}{T_S}\right)^2 + \left(\frac{\sigma_B}{T_B}\right)^2}$$

N: net peak count rate

σ_N: counting error of the net peak count rate

S: sample peak area

σ_S: counting error of the sample peak area

B: background peak area

σ_B: counting error of the background peak area

T_S: sample measuring time

T_B: background measuring time

The background used for correction may be taken before sample measurement, after sample measurement, or as an average of several background measurements.

F.2.6 Calculation of radioactivity concentration

(1) Decay correction method

The radioactivity of a radionuclide is reduced over time. The activity level obtained through a measurement is that of the time of the measurement. Therefore, it is necessary to calculate the activity level for other times.

The relationship between the per-hour attenuation $-dN/dt$, attenuation constant λ, and the number of atoms at that time N can be expressed as $-dN/dt = \lambda N$. The integral of this equation gives a general equation of decay correction. Some radionuclides do not turn into stable elements but continue decaying. These are called the nuclides of sequential radioactive decay. In this case, the general equation for the daughter nuclide's decay correction must account for the radioactive contributions of its parent nuclide. Thus, it becomes a very complex formula when the decay correction is also considered during the measurement.

For more details about the decay correction of the nuclides of sequential radioactive decay, see Chapter 4 of this analytical method manual.

(2) Calculation of radioactivity concentration

The radioactivity concentration is calculated according to the following equation.

$$A = \frac{n_s - n_b}{(\varepsilon \cdot a) \cdot W} \times f_{SA} \times f_{SUM} \times f_D$$

A: Radioactivity concentration (Bq/kg, etc.)

n_s: Net count rate (cps) of sample

n_b: Background count rate (cps)

ε: Gamma-ray peak efficiency

a: Gamma-ray emission ratio (= gamma-ray emission rate/100)

W: Sample volume (kg, etc.)

f_{SA}: Self-absorption correction factor

f_{SUM}: Coincidence summing effect correction factor

f_D: Decay correction factor

The peak area in the background spectrum does not have to be subtracted if it is less than 2σ.

(3) Handling of multiple peaks of the same nuclide

The nuclides that emit multiple gamma rays can be identified more precisely if each gamma-ray peak is examined.

In emergency situations, several nuclides that generate many gamma peaks are detected, such as ^{134}Cs and ^{132}I.

(4) Handling procedures

If a peak of some type is detected, it is recommended that the following procedures are followed to handle it where possible.

(1) Select possible candidate nuclides for the peak.

(2) Investigate the “main” peaks of these candidate nuclides in the nuclear data table, then remove the areas of compromised credibility due to ghost peaks, etc., as well as the sections of sum peaks and escape peaks (though these may be used for the identification process).

(3) Calculate the radioactivity of all remaining peak areas. If using many peak data does not seem plausible, an alternative is as follows: Calculate the radioactivity of each peak, reorder them in the order of smaller counting errors, and identify a large gap, wherefrom the rest may be disregarded.

(4) Examine the values to see if they match the nuclear data within their respective counting errors to verify that the assumptions about the nuclides are valid. If they are not the assumed nuclides, change the assumption and revert to (2).

(5) Take a weighted average of the counting error.

Before pursuing the calculation of the weighted average, consider whether:

a. The measurement equipment involves several devices (with possible biases).
b. The sample is a segment of a larger sample.
c. The efficiency curve possibly has a problem, as the peak's energy shows a significant discrepancy. These are the factors that may be involved in the data. Where these are the case and if the counting errors are the only indication, the weighted average is not a valid method. If it is the peaks that appear in one spectrum and of the same nuclide, it is appropriate to assume that the differences are solely attributable to the counting error.

The weighted average will diminish the counting error. For example, calculating using several peaks of 3σ (σ: counting error) or less sometimes results in 3σ or more.

(5) Calculation of weighted average

If multiple radioactivity values $A_i \pm \sigma_i$ are obtained, use the following equation to obtain the weighted average ($A_t \pm \sigma_t$).

$$A_t = \sum_i \frac{A_i}{\sigma_i^2} \Big/ \sum_i \frac{1}{\sigma_i^2}, \quad \frac{1}{\sigma_t^2} = \sum_i \frac{1}{\sigma_i^2}$$

F.2.7 Nuclides with single-energy gamma rays and those that involve a large gap in emission rates between the main and subordinate peaks

A gamma-ray spectrum obtained in emergencies is expected to involve many gamma-ray peaks, which makes it difficult to identify such nuclides that only emit one-energy gamma rays or that are captured only by their main peaks because their subordinate peaks are significantly small. Therefore, analysis software must be configured with the following options as analytical procedures.

(1) If the peaks detected in the analytical result are in the energy regions corresponding to the nuclides shown in Tables F.1 and F.2, these peaks are marked (flagged) for attention.

(2) The nuclear data library for analysis should register even subtle emissions for enhanced performance in the analysis of spectral data, and with reference to Tables F.1 and F.2, the peak search should be performed both for all main peaks as well as for primary peaks only, then analyses should be conducted on the results of these searches for the subsequent considerations.

Table F.1 Nuclides that emit one-energy gamma rays

Name of nuclide	Half-life	Half-life unit	Energy (keV)	Emission rate (%)
^{7}Be	53.22	Days	477.6	10.44
^{22}Na	2.60	Years	1274.5	99.94
^{24}Na	15.00	Hours	1368.6	99.99
^{40}K	1.25E+09	Years	1460.8	10.66
^{51}Cr	27.70	Days	320.1	9.91
^{54}Mn	312.20	Days	834.8	99.98
^{65}Zn	243.93	Days	1115.5	50.04
^{91}Y	58.51	Days	1204.8	0.26
^{91m}Y	49.71	Minutes	555.6	95.0
^{97m}Nb	58.7	Seconds	743.4	97.90
^{105m}Rh	40	Seconds	129.6	20.00
^{133m}Xe	2.20	Days	233.2	10.12
^{135m}Xe	15.29	Minutes	526.6	80.6
^{137}Cs	30.08	Years	661.7	85.10
^{139}Ce	137.64	Days	165.9	79.90
^{141}Ce	32.51	Days	145.4	48.4
^{203}Hg	46.59	Days	279.2	81.56
^{206}Tl	4.20	Minutes	803.1	0.0050
^{210}Pb	22.20	Years	46.5	4.25
^{210}Po	138.38	Days	803.1	0.0010
^{211}Bi	2.14	Minutes	351.1	13.02
^{224}Ra	3.66	Days	241.0	4.10
^{226}Ra	1600	Years	186.2	3.64

Note 1: The nuclear data are taken from ENSDF (as of October 2017).

Note 2: Half-lives, gamma-ray energies, and emission rates are expressed to two, one, and two decimal places, respectively. Note that, where there is not a value at the second decimal place or the first decimal place, they are shown to one decimal place or as integers (except the emission rates of ^{206}Tl and ^{210}Po).

Note 3: The emission rates of ^{206}Tl and ^{210}Po are extremely small; thus, they are shown to four decimal places.

Table F.2 Nuclides with emission rate differences between the main and subordinate peaks

Name of nuclide	Half-life	Half-life unit	Energy (keV)	Emission rate (%)
^{41}Ar	109.61	Minutes	1293.6	99.16
			1677.0	0.05
^{58}Co	70.86	Days	810.8	99.45
			864.0	0.69
^{75}Ge	82.78	Minutes	264.6	11.4
			198.6	1.19
^{75m}Ge	47.7	Seconds	139.7	39.5
			136.0	0.02
^{92}Sr	2.61	Hours	1383.9	90
			953.3	3.52
^{95}Nb	34.99	Days	765.8	99.81
			204.1	0.03
^{97}Zr	16.75	Hours	743.4	93.09
			507.6	5.03
^{97}Nb	72.1	Minutes	657.9	98.23
			1024.4	1.09
^{99m}Tc	6.01	Hours	140.5	89
			142.6	0.02
^{103}Ru	39.25	Days	497.1	91.0
			610.3	5.76
^{115m}In	4.49	Hours	336.2	45.8
			497.4	0.05
^{131}I	8.03	Days	364.5	81.5
			637.0	7.16
^{133}I	20.83	Hours	529.9	87.0
			875.3	4.51
^{135}Xe	9.14	Hours	249.8	90
			608.2	2.90
^{141}La	3.92	Hours	1354.5	1.64
			1693.3	0.07
^{144}Ce	284.91	Days	133.5	11.09
			80.1	1.36
^{149}Pm	53.08	Hours	286.0	3.10
			859.5	0.11

Table F.2 Nuclides with emission rate differences between the main and subordinate peaks (continued)

Name of nuclide	Half-life	Half-life unit	Energy (keV)	Emission rate (%)
^{198}Au	2.69	Days	411.8	95.62
			675.9	0.81
^{212}Pb	10.64	Hours	238.6	43.6
			300.1	3.30
^{241}Am	432.6	Years	59.5	35.9
			26.3	2.27

Note 1: The nuclear data are taken from ENSDF (as of October 2017).

Note 2: Half-lives, gamma-ray energies, and emission rates are expressed to two, one, and two decimal places, respectively. Where the second decimal place has no values, the figure is expressed to one decimal place.

Explanation F.3 Analysis of measurement data

(1) Analyze the spectral data saved in the computer with the gamma-ray spectrometry software.

(1) Entry of measurement conditions

Enter the name, height, and volume of the sample, type of measurement container, applied efficiency, energy calibration formulae, etc., and start the analysis.

(2) Spectral analysis

Following the analytical procedures specific to the software used, perform the spectral analysis. After the analysis, output the peak search results, peak quantification results, and spectrum chart.

(2) Verify the data outputs to check if the measurement number, name of the sample, sample volume, sample container, etc. are correctly entered.

(3) Collate the output peak search results against the peaks shown in the spectrum chart.
In this step, check the accuracy of the analysis, except for those peaks identified in the result due to the statistical fluctuation with no corresponding peaks in the spectrum. Verify the identified nuclides for their accuracy, and consider the possibilities of sum peaks or escape peaks for the unknown peaks (see Chapter 6).

(4) As for the nuclides that exceed three times the counting error, verify the peak and its channel based on the output results to ensure that it is not a misidentification.

(5) If any of the peaks identified in the output spectrum have not been identified with respect to its nuclide, use the nuclear data set to identify it.

Explanation G　Cases of background spectra where contamination was verified

Cases are introduced here in which background contamination was verified following the Fukushima Dai-ichi Nuclear Accident: one through the exterior air entering the measurement chamber, and the other by the traffic of people and samples resulting in the contamination of the detector. It is conceivable that contamination routes and types of artificial radionuclides vary depending on the time elapsed since a nuclear accident.

Explanation G.1　Immediately after the Fukushima Dai-ichi Nuclear Accident

Figures G.1 and G.2 show the background spectra taken from the same detector, measured immediately after the Fukushima Dai-ichi Nuclear Accident, on March 15 and 16, 2011, respectively. The germanium detector used for this background measurement was located in the city of Chiba. In Chiba City, the highest level of spatial radiation dose rate was observed on March 15, 2011, as a consequence of the Fukushima Dai-ichi Nuclear Accident, and ^{133}Xe was reported to be the most significant contributing artificial radionuclide (Reference 53).

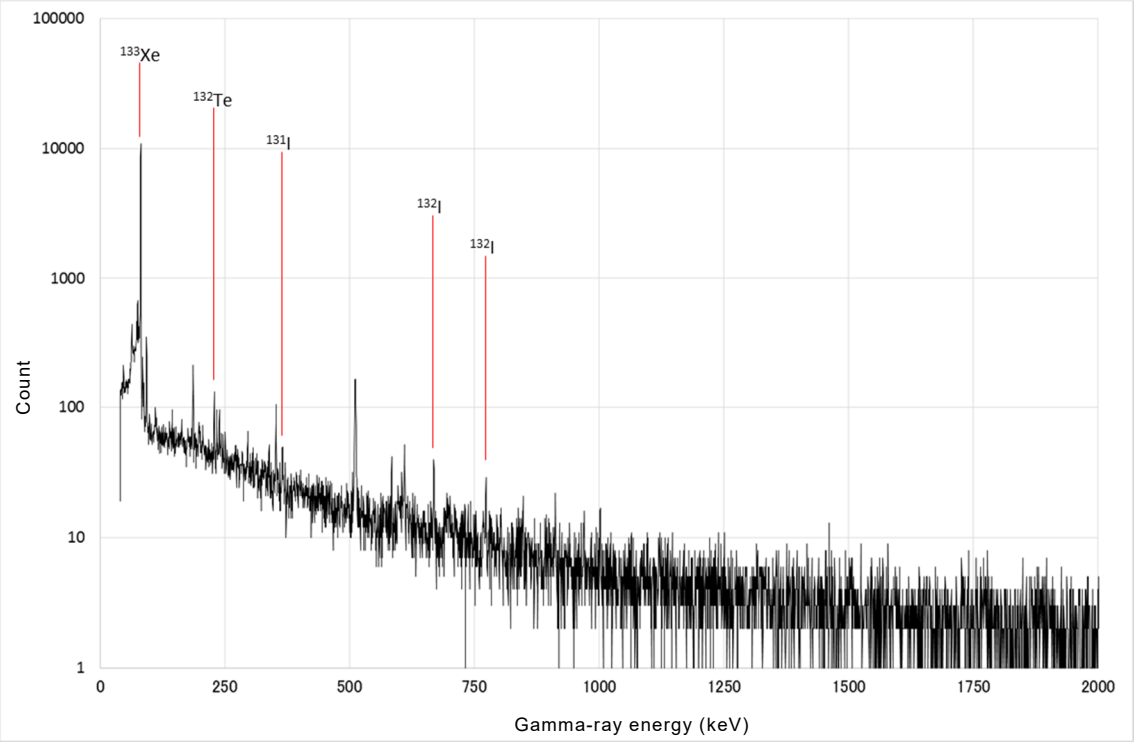


Figure G.1　Background spectrum obtained on March 15, 2011 (Chiba City)

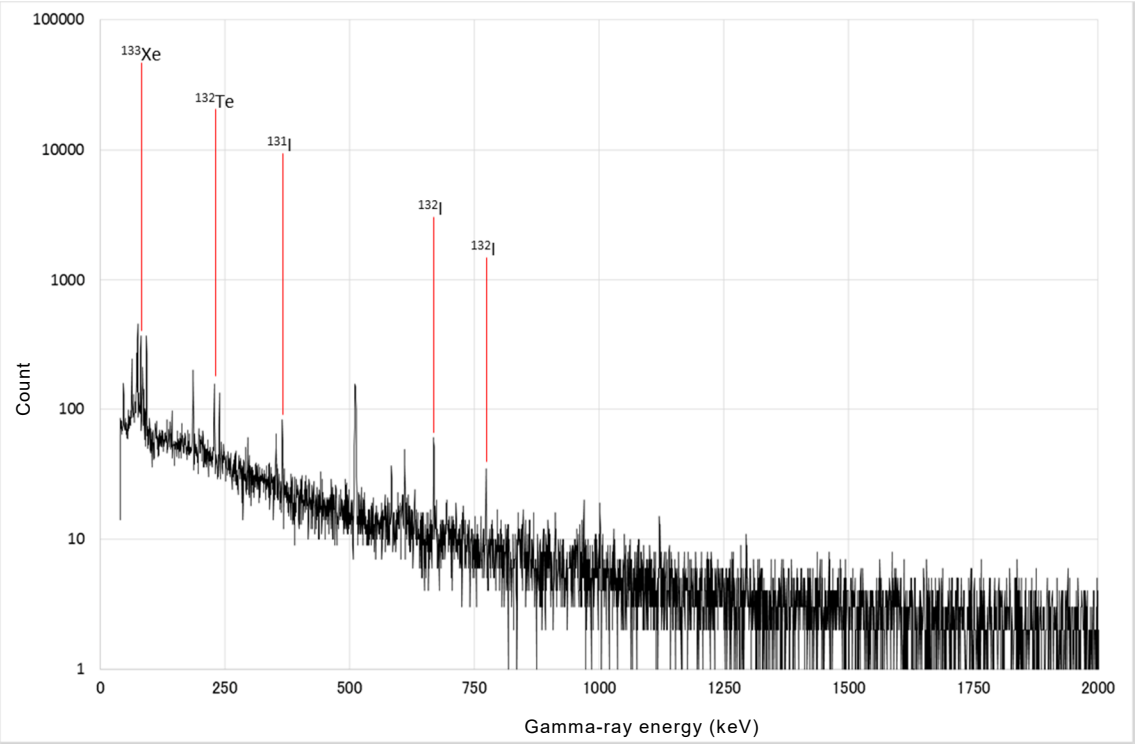


Figure G.2 Background spectrum obtained on March 16, 2011 (Chiba City)

The artificial radionuclides detected in the background spectra included the rare gas ^{133}Xe and the volatile elements (see Table D.4 in Explanation D) ^{131}I, ^{132}Te, and ^{132}I. The background samples whose spectra are shown in Figures G.1 and G.2 were measured before samples of high radioactivity concentration were brought in for measurement; thus, it was unlikely that the samples were the source of cross-contamination. As these artificial radionuclides are easily gasified and diffused, it is possible that the external air containing the artificial radionuclides in gas form penetrated the measurement chamber and inside the shields, resulting in their detection in the background spectra.

These spectra were measured for approximately 50000 s each, and the counts of ^{133}Xe increased by more than 100 times in one day, between March 15 and 16. Supposing that the contamination was introduced by the external air, it depends on the nuclides' physical half-lives and concentration levels in the external air; thus, it is expected that the contributions of the contamination to the background spectra fluctuate as time elapses. Thus, it is necessary to ascertain the changing situation of the contamination and perform appropriate background correction, which is also true if the contamination is found to be of nuclides with short half-lives. Therefore, depending on the situation of the contamination immediately after an emergency event, it could be better if the background measurement for correction were performed more frequently (at least once a day).

Explanation G.2 Several months after Fukushima Dai-ichi Nuclear Accident

The nuclides with short half-lives decayed as time passed, and ^{134}Cs and ^{137}Cs were the primary contaminating artificial radionuclides recognized in the background spectra. Artificial radionuclides were deposited in the surroundings and it was difficult to eliminate the risk of contamination, regardless of how thoroughly countermeasures were implemented. A measurement was taken in September 2011 (approximately six months after the accident), and Figure G.3 shows the background spectrum from this measurement, where ^{134}Cs and ^{137}Cs were detected. Note that Figure G.3 includes a magnified image of the region around the ^{137}Cs peak (661.7 keV).

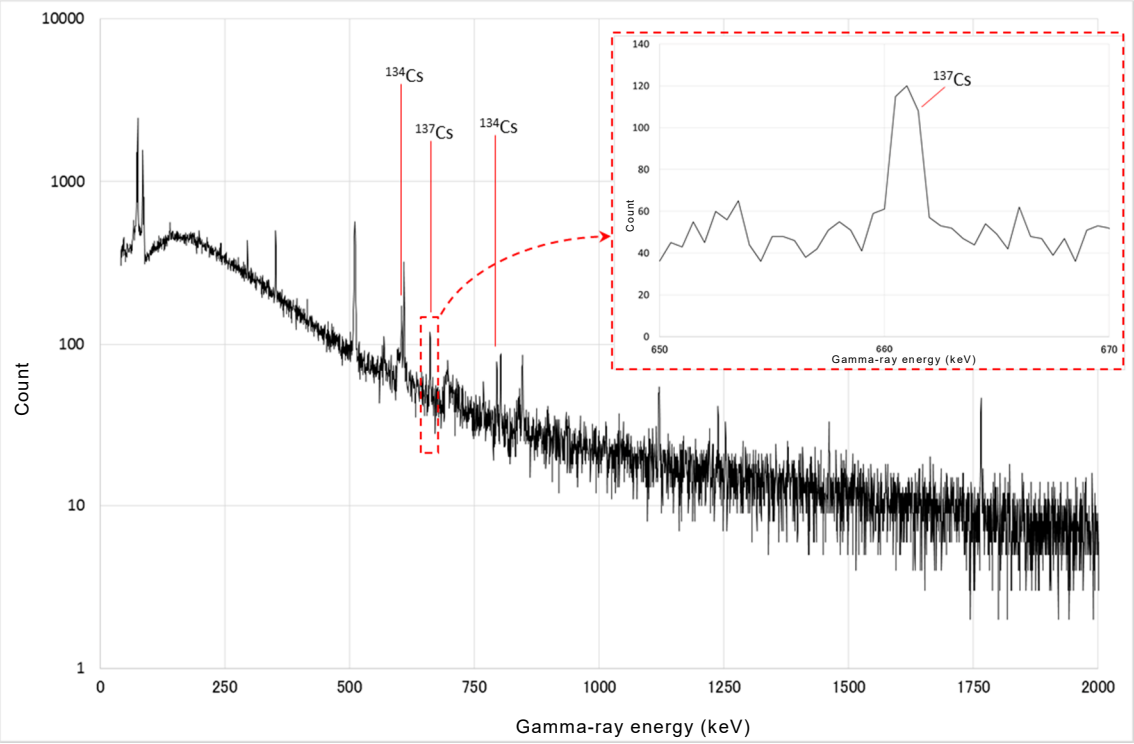


Figure G.3 Background spectrum in which ^{134}Cs and ^{137}Cs were detected

The contaminated detector was removed from the operation until the decontamination was confirmed. Dry-wiping was applied to the detector for decontamination. It should be remembered that, where the timing of the contamination of measurement equipment is difficult to identify, the samples must be arranged for a second measurement using a different detector if the contribution from the contamination is not negligible. Figure G.4 illustrates a background spectrum taken after the completion of the decontamination.

In this case, it was fortunate that dry-wiping was sufficient to remove the contamination. However, if it were not sufficient, further decontamination measures would be necessary, such as an overhaul. In a case where the contamination persists, it would be necessary to ascertain the situation of the contamination and offset the contributions by means of an appropriate background spectrum for correction.

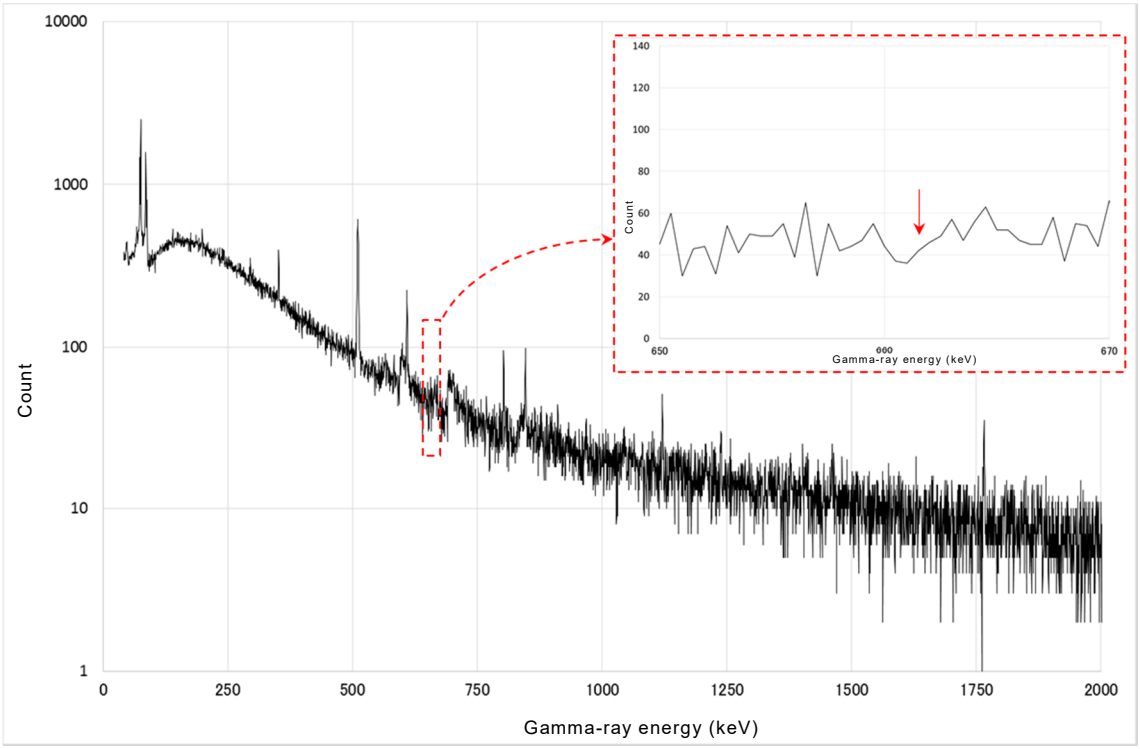


Figure G.4 Background spectrum after decontamination

Appendix

Appendix 1 Master library of nuclear data for emergency situations

While it is assumed that most users of gamma-ray spectrometry will use consumer software to perform spectral analysis, the general expectation is that they use the vendor's nuclear data master libraries and nuclear data library for analysis. Therefore, descriptions of the preparation of the master library of nuclear data published in the first edition of this document are included in this edition as an appendix.

Appendix 1.1 Nuclear data library

Prepare "master library of nuclear data for emergency situations" with target nuclides for analysis registered. This will be required for use in emergency situations. To prepare this, first, it is necessary to obtain nuclear data from a reliable source, and then extract the data regarding the nuclides to be analyzed in emergency situations, forming the "nuclear data library for analysis." When analyzing actual samples, this nuclear data library for analysis will be used. Figure 1.1 illustrates the flow of procedures to prepare the "nuclear data library for analysis" for gamma-ray spectrometry and to perform gamma-ray spectral analysis using the "nuclear data library for analysis" thus created.

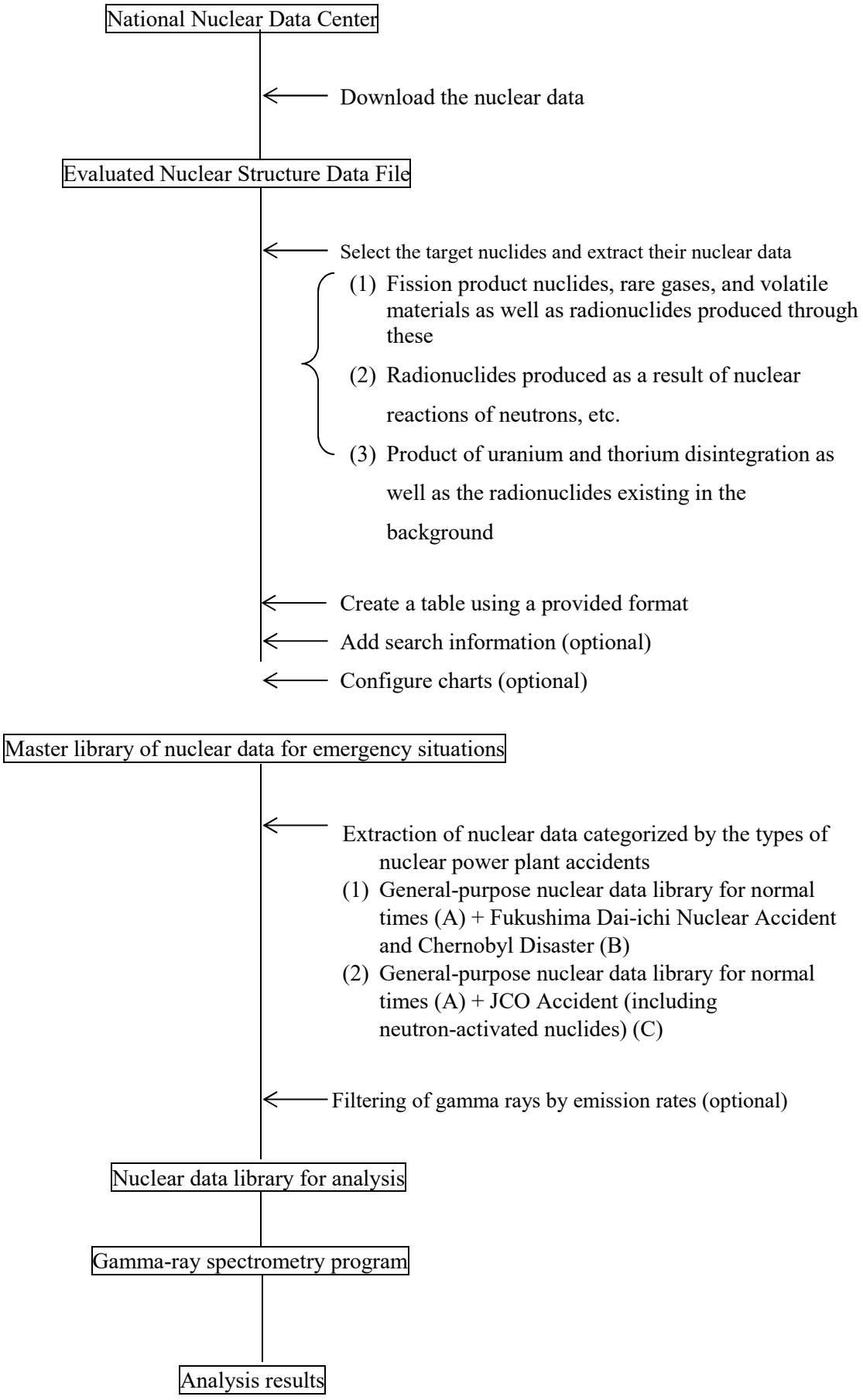


Figure 1.1 Flow from downloading nuclear data to performing gamma-ray spectral analysis

Appendix 1.2 Master library of nuclear data for emergency situations

Among several nuclear data sets, identify one that is deemed reliable. Extract nuclear data of all target nuclides from this data set to prepare a master library of nuclear data for emergency situations.
Nuclear data in electronic data files are increasingly available today. This type of nuclear data set facilitates the easy extraction and reorganization of data, making it possible to prepare nuclear data libraries with little effort.

(1) Preparation of master library of nuclear data for emergency situations

This section explains how to obtain nuclide information and prepare a nuclear data library with the Evaluated Nuclear Structure Data File (ENSDF) as a base dataset.

1) Obtaining the base nuclear data set

ENSDF is an electronically prepared nuclear data set, made available for use without having to obtain a copyright license by its proprietary organization, the US National Nuclear Data Center (NNDC). The electronic files of ENSDF can be downloaded from the NNDC website (http://www.nndc.bnl.gov).

These files are collated into several files by mass numbers.

ENSDF_171001_099.ZIP (contains nuclear data of mass numbers up to 99)
ENSDF_171001_199.ZIP (contains nuclear data of mass numbers between 101 and 199)
ENSDF_171001_299.ZIP (contains nuclear data of mass numbers between 200 and 299)
*as of October 2017

The files above are ZIP compressed files, with each containing many files organized by mass numbers. These files can be decompressed using a computer program for decompression compatible with the ZIP format to extract the contained files.

For example, decompressing the file ENSDF_171001_199.ZIP will return files named ensdf.181, ensdf.182, etc.

The data pertaining to the nuclide of mass number 181 is in the file ensdf.181. Note that the mass number here refers to the mass number of the daughter nuclides, after the target radionuclide has disintegrated.

2) Selection of nuclides to register

For the nuclides to be registered in the master library of nuclear data for emergency situations, select the "Fission product nuclides, rare gases, and volatile materials as well as radionuclides produced through these" (see Table 1.1), "Radionuclides produced as a result of nuclear reactions of neutron, etc." (see Table 1.2), and "Product of uranium and thorium disintegration as well as the radionuclides existing in the background" (see Table 1.3). The radionuclides to be registered in the master library of nuclear data other than those included in Tables 1.1 to 1.3 are: ^{86}Rb, ^{85}Kr, ^{122}Sb, ^{127}Te, ^{129m}Te, ^{129}I, ^{130}I, ^{131m}Xe, ^{133}Xe, and ^{203}Pb (see Explanation D.1).

Note that, in the first edition of this gamma-ray spectrometry document (February 2004), "rare gases and volatile materials as well as radionuclides produced through these" (see Table 1.4) are categorized separately among the "Fission product nuclides, rare gases, and volatile materials as well as radionuclides produced through these," as they are highly likely to be released abnormally into the adjacent environment and affect a wide area.

Table 1.1 Fission product nuclides, rare gases, and volatile materials as well as radionuclides produced through these

^{77}Ge	^{78}As	^{84}Br	^{85m}Kr	^{87}Kr
^{88}Kr	^{88}Rb	^{90m}Y	^{91}Sr	^{91}Y
^{91m}Y	^{92}Sr	^{92}Y	^{93}Y	^{95}Zr
^{95}Nb	^{97}Zr	^{97}Nb	^{97m}Nb	^{99}Mo
^{99m}Tc	^{103}Ru	^{105}Ru	^{105}Rh	^{105m}Rh
^{106}Rh	^{113}Ag	^{115m}In	^{117}Cd	^{117m}Cd
^{125}Sn	^{127}Sb	^{128}Sb	^{129}Sb	^{129}Te
^{130}Sb	^{131}Sb	^{131m}Te	^{131}I	^{132}Te
^{132}I	^{133m}Te	^{133}I	^{133m}Xe	^{134}Te
^{134}I	^{135}I	^{135}Xe	^{135m}Xe	^{137}Cs
^{138}Cs	^{139}Ba	^{140}Ba	^{140}La	^{141}La
^{141}Ce	^{142}La	^{143}Ce	^{144}Ce	^{144}Pr
^{145}Pr	^{147}Nd	^{149}Nd	^{149}Pm	^{151}Pm
^{153}Sm	^{156}Eu	^{157}Eu		

Table 1.2 Radionuclides produced as a result of nuclear reactions of neutrons, etc.

^{22}Na	^{24}Na	^{41}Ar	^{46}Sc	^{51}Cr
^{54}Mn	^{56}Mn	^{56}Co	^{57}Co	^{58}Co
^{59}Fe	^{60}Co	^{63}Zn	^{65}Ni	^{65}Zn
^{75}Se	^{76}As	^{82}Br	^{88}Y	^{108m}Ag
^{110m}Ag	^{113}Sn	^{114m}In	^{115}Cd	^{124}Sb
^{125}Sb	^{133}Ba	^{134}Cs	^{136}Cs	^{139}Ce
^{152}Eu	^{154}Eu	^{181}Hf	^{182}Ta	^{187}W
^{192}Ir	^{198}Au	^{203}Hg	^{237}U	^{239}Np
^{241}Am				

Table 1.3 Product of uranium and thorium disintegration as well as the radionuclides existing in the background

^{7}Be	^{40}K	^{74}Ga	^{74}As	^{75}Ge
^{75m}Ge	^{206}Tl	^{207}Bi	^{208}Tl	^{210}Pb
^{210}Po	^{211}Pb	^{211}Bi	^{212}Pb	^{212}Bi
^{214}Pb	^{214}Bi	^{219}Rn	^{223}Ra	^{224}Ra
^{226}Ra	^{227}Th	^{228}Ac	^{228}Th	^{231}Th
^{231}Pa	^{234}Th	^{234m}Pa	^{235}U	

Table 1.4 Rare gases and volatile materials as well as radionuclides produced through these

^{84}Br	^{85m}Kr	^{87}Kr	^{88}Kr	^{88}Rb
^{91}Sr	^{91}Y	^{91m}Y	^{92}Sr	^{92}Y
^{93}Y	^{95}Zr	^{95}Nb	^{131}I	^{132}I
^{133}I	^{134}I	^{135}I	^{135m}Xe	^{137}Cs
^{138}Cs	^{139}Ba	^{140}Ba	^{140}La	^{141}La
^{141}Ce	^{142}La	^{144}Ce	^{144}Pr	^{145}Pr

3) Extraction of nuclear data for each nuclide from the nuclear data set

For extracting data of individual nuclides from ENSDF, a dedicated and useful program, RADLST, is available on the NNDC website. RADLST extracts nuclear data of target nuclides and outputs them as a separate text file. Then, use RADLST to process the decompressed ENSDF files organized by mass numbers to obtain the data about the nuclides listed in Tables 1.1 to 1.3. Extract necessary data (half-lives, emission rates, energies, etc.) from the files specific to each nuclide, using a computer program to edit text files, such as a text editor or word processor, and then create a table in a basic format as shown in Table 1.5. Collate the created nuclide-specific tables into a single file, which will serve as a nuclear data library.

Table 1.5 Basic format for nuclear data library

Item	Data type	Descriptions
Mass number	Integer	Value indicating the mass number
Elemental symbol	String	Elemental symbol
Name of nuclide	String	Name of nuclide
Half-life	Real number	Half-life value
Half-life uncertainty	Real number	Value for half-life uncertainty
Half-life (unit)	String	Unit for indicating the half-life (Y: year, D: day, H: hour, M: minute, S: second)
Energy	Real number	Value for a gamma-ray energy (unit: keV)
Energy uncertainty	Real number	Value for the uncertainty of gamma-ray energy (unit: keV)
Emission rate	Real number	Value for the emission rate (unit: %)
Emission rate uncertainty	Real number	Value for the uncertainty of emission rate (unit: %)

The column “Data type” in the Table shows whether the information is in letters or numbers.

Appendix 1.3 Abundance in the time elapsed after fission[*1]

Fission product nuclides, rare gases, volatile materials, and radionuclides produced through these have different half-lives; therefore, the abundance of these nuclides varies as time elapses after fission. Table 6.1 displays the abundance of each nuclide in the time elapsed by either "o" or "x" to indicate whether the fission product nuclides exist or not following the fission.

Appendix 1.3.1 Calculation method for abundance

Taking the nuclides produced through a fission of ^{235}U, gamma-ray counts of each nuclide are calculated along the time trajectory, using the fission yield, gamma-ray emission rate, half-life, and counting efficiency of the germanium detector. The following is an example of the calculation.
It is possible to obtain radioactivity A_0 per unit fission for each nuclide that is produced through ^{235}U fission as follows:

$$A_0 = \lambda N_F$$

λ: disintegration constant of each nuclide, N_F: fission yield

The count rate C_0 of the gamma rays emitted from this nuclide can be obtained with the following formula:

$$C_0 = A_0 \cdot B \cdot E$$

$$B: \gamma\ \text{Gamma} - \text{ray emission ratio}\left(= \frac{\gamma\ \text{Gamma} - \text{ray emission rate}}{100}\right)$$

E: counting efficiency of germanium detector

The count rate C of the gamma rays emitted from the nuclide above in the time elapsed following fission can be obtained with the following formula:

$$C = C_0 e^{-\lambda t}$$

λ: disintegration constant of each nuclide, t: time elapsed

The maximum count rate of gamma rays (those of ^{133}I, ^{140}La, etc.) are calculated at each point in the time trajectory; those with count rates less than 1/10000 of the maximum count rate are regarded as immeasurable, and thus labeled with an "x" in terms of abundance.

[*1] The abundance in the time elapsed after fission is described in the first edition of the gamma-ray spectrometry material (February 2004) as necessary information for preparing a nuclear data library for analysis. It is kept in this material because it is relevant to the master library of nuclear data for emergency situations and that it can serve as a point of reference when performing spectral analysis and adding more nuclide data to the nuclear data library for analysis.

Those with count rates more than 1/10000 of the maximum count rate are considered to be measurable, and thus labeled with an “o” for abundance.
Note that where the energy area twice as wide as the half-width of a measured gamma ray includes a peak that has a count rate greater than that of the gamma-ray peak, this is treated as a ghost peak and thus, also, marked with an “x” for abundance.

Appendix 1.3.2 Time elapsed

The time elapsed after fission starts from 5 h, considering the time required for preparing the sample, following the sampling, before starting the measurement at the laboratory.
The time intervals are set at 5 h, 10 h, 1 day, 3 days, 5 days, 10 days, and 30 days after fission, as the abundance varies depending on the time elapsed.

Table 1.6 Fission product nuclides (5 h to 30 days after fission)

Abundance: "o" indicates that a peak exists and "x" indicates that there are no peaks.

Quantified nuclide	*	Half-life	Gamma ray (keV)	Time elapsed after fission (abundance)						
				5 h	10 h	1 day	3 days	5 days	10 days	30 days
^{77}Ge		11.21 h	215.5	×	○	○	×	×	×	×
^{78}As		90.7 min	613.8	○	○	×	×	×	×	×
			694.9	○	×	×	×	×	×	×
			1308.7	○	×	×	×	×	×	×
^{84}Br	○	31.76 min	881.6	○	×	×	×	×	×	×
^{85m}Kr	○	4.48 h	151.2	○	○	○	×	×	×	×
			304.9	○	○	○	×	×	×	×
^{87}Kr	○	76.3 min	402.6	○	○	×	×	×	×	×
^{88}Kr	○	2.83 h	196.3	○	○	○	×	×	×	×
			834.8	○	○	○	×	×	×	×
			1529.8	○	○	○	×	×	×	×
^{88}Rb (^{88}Kr)	○	17.77 min	1836.0	○	○	○	×	×	×	×
			898.0	○	○	○	×	×	×	×
^{90m}Y		3.19 h	202.5	○	○	○	×	×	×	×
			479.5	○	○	○	×	×	×	×
^{91}Sr	○	9.65 h	1024.3	○	○	○	○	○	×	×
			749.8	○	○	○	○	○	×	×
			652.9	○	○	○	○	○	×	×
^{91}Y	○	58.51 days	1204.8	×	×	○	○	○	○	○
^{91m}Y (^{91}Sr)	○	49.71 min	555.6	○	○	○	○	○	×	×
^{92}Sr	○	2.61 h	1383.9	○	○	○	×	×	×	×
			430.5	○	○	×	×	×	×	×
			1142.4	○	○	×	×	×	×	×
^{92}Y	○	3.54 h	934.5	○	○	○	×	×	×	×
			1405.4	○	○	○	×	×	×	×
			561.1	○	○	○	×	×	×	×
^{93}Y	○	10.18 h	266.9	○	○	○	○	×	×	×
			947.1	○	○	○	○	×	×	×
			1917.8	○	○	○	○	×	×	×
^{95}Zr	○	64.03 days	756.7	○	○	○	○	○	○	○
			724.2	×	×	×	○	○	○	○
^{95}Nb	○	34.99 days	765.8	×	○	○	○	○	○	○

* Rare gases and volatile materials as well as radionuclides produced through these are marked with an "o."

Note 1: The nuclear data are taken from ENSDF (as of October 2017).

Note 2: Half-life and gamma-ray energy are expressed to one and two decimal places, respectively. Note that the half-life that has no value at the second decimal place is expressed to the first decimal place, and the half-life that has no value at the first decimal place is expressed as an integer.

Table 1.6 Fission product nuclides (5 hours to 30 days after fission) (continued)

Quantified nuclide	*	Half-life	Gamma ray (keV)	Time elapsed after fission (abundance)						
				5 h	10 h	1 day	3 days	5 days	10 days	30 days
^{97}Zr		16.75 h	1148.0	○	○	○	○	○	×	×
			1750.2	○	○	○	○	○	×	×
^{97}Nb		72.1 min	657.9	○	○	○	○	○	×	×
^{97m}Nb(^{97}Zr)		58.7 secs.	743.4	○	○	○	○	○	○	×
^{99}Mo		65.92 h	739.5	○	○	○	○	○	○	○
			777.9	○	○	○	○	○	○	○
^{99m}Tc(^{99}Mo)		6.01 h	140.5	○	○	○	○	○	○	○
^{103}Ru		39.25 days	497.1	○	○	○	○	○	○	○
			610.3	×	×	×	○	○	○	○
^{105}Ru		4.44 h	724.3	○	○	○	×	×	×	×
			469.4	○	○	○	×	×	×	×
			316.4	○	○	○	×	×	×	×
^{105}Rh		35.36 h	318.9	○	○	○	○	○	×	×
^{105m}Rh(^{105}Ru)		40 secs.	129.6	○	○	○	×	×	×	×
^{106}Rh(^{106}Ru)		30.07 secs.	621.9	×	×	×	×	×	×	○
^{113}Ag		5.37 h	298.6	○	○	×	×	×	×	×
^{115m}In(^{115}Cd)		4.49 h	336.2	×	×	×	○	×	×	×
^{117}Cd		2.49 h	1303.3	○	○	×	×	×	×	×
^{117m}Cd		3.36 h	1066.0	○	○	×	×	×	×	×
^{125}Sn		9.64 days	1067.1	×	×	×	○	○	○	×
^{127}Sb		3.85 days	685.7	○	○	○	○	○	○	○
			473.0	×	○	○	○	○	○	○
^{128}Sb		9.05 h	754.0	○	○	○	×	×	×	×
^{129}Sb		4.37 h	813.0	○	○	×	×	×	×	×
			1030.7	○	○	○	×	×	×	×
^{129}Te(^{129}Sb)		69.6 min	459.6	○	○	○	×	×	×	×
^{130}Sb		39.5 min	793.4	○	×	×	×	×	×	×
^{131}Sb		23.03 min	943.4	○	×	×	×	×	×	×
^{131m}Te		33.25 h	852.2	○	○	○	○	○	○	×
			1206.6	○	○	○	○	○	○	×
^{131}I	○	8.03 days	364.5	○	○	○	○	○	○	○
			637.0	○	○	○	○	○	○	○
			284.3	×	○	○	○	○	○	○
^{132}Te		3.20 days	228.2	○	○	○	○	○	○	×
			116.3	×	○	○	○	○	○	×
^{132}I	○	2.30 h	667.7	○	○	○	○	○	○	○
			772.6	○	○	○	○	○	○	○
			954.6	×	○	○	○	○	○	○
			522.7	○	○	○	○	○	○	○
^{133m}Te		55.4 min	912.7	○	×	×	×	×	×	×
			647.5	○	×	×	×	×	×	×

Table 1.6 Fission product nuclides (5 hours to 30 days after fission) (continued)

Quantified nuclide	*	Half-life	Gamma ray (keV)	Time elapsed after fission (abundance)						
				5 h	10 h	1 day	3 days	5 days	10 days	30 days
^{133}I	○	20.83 h	529.9	○	○	○	○	○	×	×
			875.3	○	○	○	○	○	×	×
			1298.2	×	×	○	○	×	×	×
			1236.4	○	○	○	○	○	×	×
^{133m}Xe		2.20 days	233.2	×	×	○	×	×	×	×
^{134}Te		41.8 min	767.2	○	×	×	×	×	×	×
			210.5	○	×	×	×	×	×	×
			278.0	○	×	×	×	×	×	×
^{134}I	○	52.5 min	847.0	○	○	×	×	×	×	×
			1072.6	○	○	×	×	×	×	×
			595.4	○	○	×	×	×	×	×
^{135}I	○	6.58 h	1260.4	○	○	○	○	×	×	×
			1131.5	○	○	○	○	×	×	×
			1678.0	○	○	○	○	×	×	×
^{135}Xe		9.14 h	249.8	○	○	○	○	○	×	×
			608.2	○	○	○	○	×	×	×
			408.0	×	×	○	×	×	×	×
^{135m}Xe (^{135}I)	○	15.29 min	526.6	○	○	○	○	×	×	×
^{137}Cs	○	30.08 yrs.	661.7	×	×	×	○	○	○	○
^{138}Cs	○	33.41 min	1435.9	○	×	×	×	×	×	×
			462.8	○	×	×	×	×	×	×
			1009.8	○	×	×	×	×	×	×
^{139}Ba	○	82.93 min	165.9	○	○	×	×	×	×	×
			1254.6	○	×	×	×	×	×	×
			1420.5	○	×	×	×	×	×	×
^{140}Ba	○	12.75 days	537.3	○	○	○	○	○	○	○
			162.7	○	○	○	○	○	○	○
			437.6	○	○	○	○	○	○	○
^{140}La(^{140}Ba)	○	1.68 days	1596.2	○	○	○	○	○	○	○
			487.0	○	○	○	○	○	○	○
			815.8	×	○	○	○	○	○	○
			328.8	○	○	○	○	○	○	○
^{141}La	○	3.92 h	1354.5	○	○	○	×	×	×	×
			1693.3	○	○	×	×	×	×	×
^{141}Ce	○	32.51 days	145.4	○	○	○	○	○	○	○
^{142}La	○	91.1 min	641.3	○	○	○	×	×	×	×
			894.9	○	○	×	×	×	×	×
			1901.3	○	○	×	×	×	×	×
^{143}Ce		33.04 h	293.3	○	○	○	○	○	○	×
			664.6	○	○	○	○	○	○	×
^{144}Ce	○	284.91 days	133.5	×	○	○	○	○	○	○
^{144}Pr(^{144}Ce)	○	17.28 min	696.5	×	×	×	○	○	○	○

Table 1.6 Fission product nuclides (5 hours to 30 days after fission) (continued)

Quantified nuclide	*	Half-life	Gamma ray (keV)	Time elapsed after fission (abundance)						
				5 h	10 h	1 day	3 days	5 days	10 days	30 days
^{145}Pr	○	5.98 h	979.0	×	○	○	×	×	×	×
^{147}Nd		10.98 days	439.9	×	×	×	○	○	○	○
			398.2	×	×	×	×	×	○	○
^{149}Nd		1.73 h	211.3	○	○	×	×	×	×	×
			423.6	○	○	×	×	×	×	×
^{149}Pm		53.08 h	286.0	×	×	×	○	×	×	×
^{151}Pm		28.40 h	340.1	○	○	○	○	○	○	×
			717.7	×	○	○	○	○	×	×
^{153}Sm		46.50 h	103.2	○	○	○	○	○	○	×
^{156}Eu		15.19 days	1230.7	×	×	×	×	×	○	○
			1242.4	×	×	×	×	×	○	○
			646.3	×	×	×	×	×	○	○
^{157}Eu		15.18 h	370.5	×	○	○	×	×	×	×

Appendix 2 Nuclear data

Tables 2.1 and 2.2 summarize the nuclear data of the nuclides[*1] to be registered in the master library of nuclear data for emergency situations.[*2] [*3] Table 2.1 includes nuclear data of nuclides that have the emission rate of 0.01% or more (except for ^{206}TI and ^{210}Po), and Table 2.2 includes nuclear data arranged in the order of gamma-ray energies, where the gamma rays have the emission rate of 0.1% or more. Note that the nuclear data in Tables 2.1 and 2.2 are organized according to the following points.

(1) The nuclear data are taken from ENSDF as of October 2017.
(2) The units for half-lives are as follows: Y: year, D: day, H: hour, M: minute, and S: second.
(3) Regarding powers of ten, for example, "1.248E+9" means "1.248×10^9."
(4) The uncertainties in the tables should be understood as follows:

Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)
37.2	22

This means that the gamma-ray energy is "37.2 ± 2.2 (keV)."

Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)
701.7	3

This means that the gamma-ray energy is "701.7 ± 0.3 (keV)."

Half-life	Half-life uncertainty	Half-life unit
1.248E+9	3	Y

This means that the half-life is "$(1.248 \pm 0.003) \times 10^9$ years."

(5) The number of decimal places accorded to each nuclear data point in Tables 2.1 and 2.2 are according to the number of decimal places as extracted from ENSDF using RADLST (see Appendix 1). However, the gamma-ray energy in Table 2.2 is expressed to the first decimal place.
(6) In Table 2.2, an "s" attached to the right of a nuclide indicates that it is a sum peak, and the entry only shows the gamma-ray energy (the total energy of the involved gamma rays). For example, "^{132}I s" is a sum peak of ^{132}I.

[*1] The target nuclides are those with gamma-ray energies of 2000 keV or below.

[*2] The nuclear data of ^{106}Ru (half-life of 371.8 days) are not included in Table 2.1, because the nuclide is a beta-decaying nuclide and does not emit gamma rays. When registering in the master library of nuclear data for emergency situations and nuclear data library for analysis, use the gamma-ray energy and emission rate of its daughter nuclide ^{106}Rh (half-life of 30.07 s), as radioactive equilibrium is assumed between them, and the half-life is taken from ^{106}Ru.

[*3] Transitions from different energy levels may yield an identical gamma-ray energy value (e.g., ^{74}Ga of 1134.5 keV).

Table 2.1 Nuclear data by nuclides

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{7}Be	53.22	6	D	477.6035	20	10.44	4
^{22}Na	2.6018	22	Y	1274.537	7	99.940	14
^{24}Na	14.997	12	H	1368.626	5	99.9936	15
^{40}K	1.248E+9	3	Y	1460.820	5	10.66	17
^{41}Ar	109.61	4	M	1293.64	4	99.160	20
				1677.0	3	0.052	5
^{46}Sc	83.79	4	D	889.277	3	99.9840	10
				1120.545	4	99.9870	10
^{51}Cr	27.704	3	D	320.0824	4	9.910	10
^{54}Mn	312.20	20	D	834.848	3	99.9760	10
^{56}Mn	2.5789	1	H	846.7639	19	98.85	3
				1037.8334	24	0.040	5
				1238.2738	22	0.040	4
				1810.726	4	26.9	4
^{56}Co	77.236	26	D	263.434	5	0.0220	3
				411.145	4	0.024	3
				486.55	11	0.0540	20
				655.003	5	0.043	4
				674.570	5	0.024	3
				733.514	4	0.191	3
				787.743	5	0.311	3
				846.7700	20	99.9399	23
				852.732	4	0.049	3
				896.510	6	0.073	3
				977.372	5	1.421	6
				996.948	5	0.111	4
				1037.843	4	14.05	4
				1088.894	9	0.055	4
				1140.368	6	0.132	3
				1159.944	6	0.094	6
				1175.101	4	2.252	6
				1198.888	5	0.049	5
				1238.288	3	66.46	12
				1271.92	6	0.0200	7
				1335.40	3	0.1224	12
				1360.212	4	4.283	12
				1442.746	6	0.180	4
				1462.322	6	0.074	4
				1640.475	5	0.0616	19
				1771.357	4	15.41	6
				1810.757	4	0.640	3
				1963.741	8	0.707	4
^{57}Co	271.74	6	D	14.4129	6	9.16	15
				122.06067	12	85.60	17
				136.4736	3	10.68	8
				570.09	20	0.0158	10
				692.41	7	0.149	10
^{58}Co	70.86	6	D	810.7594	20	99.450	10
				863.951	6	0.686	10
				1674.725	7	0.517	10
^{59}Fe	44.495	9	D	142.6510	20	1.02	5
				192.343	5	3.08	12
				334.80	20	0.270	12
				382.0	4	0.018	3
				1099.245	3	56.5	19
				1291.590	6	43.2	14
				1481.70	20	0.059	7
^{60}Co	1925.28	14	D	1173.228	3	99.85	3
				1332.492	4	99.9826	6
^{63}Zn	38.47	5	M	365.2	4	0.0115	25

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{63}Zn	38.47	5	M	443.13	20	0.016	5
				449.93	5	0.236	19
				515.0	10	0.021	9
				584.82	15	0.033	5
				624.3	3	0.014	4
				669.62	5	8.2	3
				675.0	6	0.015	4
				742.25	10	0.067	9
				899.0	4	0.012	3
				962.06	4	6.5	4
				1123.72	7	0.111	13
				1130.7	3	0.013	3
				1149.50	16	0.019	3
				1208.8	3	0.012	3
				1327.03	8	0.069	5
				1374.47	13	0.034	3
				1389.66	8	0.043	6
				1392.55	8	0.097	16
				1412.08	5	0.75	5
				1547.04	6	0.122	7
				1573.71	20	0.0164	18
				1861.3	3	0.0139	21
				1866.1	3	0.020	3
^{65}Ni	2.51719	26	H	366.27	3	4.81	6
				507.90	10	0.293	5
				609.50	10	0.155	5
				770.60	20	0.104	8
				852.70	20	0.097	12
				1115.53	4	15.43	14
				1481.84	5	23.59	14
				1623.42	6	0.498	15
				1724.92	6	0.399	12
^{65}Zn	243.93	9	D	1115.5391	20	50.04	10
^{74}Ga	8.12	12	M	233.2	5	0.16	3
				258.8	5	0.11	3
				302.0	7	0.11	4
				365.0	7	0.09	3
				444.2	5	0.06	3
				471.1	5	0.39	5
				484.9	3	1.06	6
				492.99	6	5.0	3
				497.56	15	0.96	10
				504.7	5	0.10	3
				521.0	5	0.12	3
				540.9	5	0.16	3
				545.5	5	0.064	19
				551.8	5	0.11	3
				595.87	4	91.80	20
				604.21	10	2.85	19
				608.40	5	14.4	8
				639.00	10	0.83	5
				652.5	5	0.06	3
				701.52	10	0.77	11
				715.0	3	0.22	4
				733.9	4	0.110	19
				784.30	20	0.67	7
				809.3	3	0.29	7
				867.83	6	8.7	6
				886.71	15	0.34	8
				942.47	7	1.27	6

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{74}Ga	8.12	12	M	960.99	7	1.62	7
				975.1	3	0.27	3
				993.55	10	0.64	4
				999.90	20	0.13	13
				999.90	20	0.13	13
				1024.3	5	0.14	3
				1024.3	5	0.07	7
				1101.32	6	5.42	19
				1131.52	14	0.87	6
				1134.5	3	0.19	20
				1134.5	3	0.19	20
				1160.33	10	0.63	5
				1177.42	18	0.24	3
				1184.40	20	0.28	3
				1204.22	4	7.62	19
				1293.9	5	0.25	4
				1312.84	11	0.62	9
				1332.1	3	1.74	10
				1337.18	10	0.8	8
				1337.18	10	0.8	8
				1357.90	20	0.16	16
				1417.6	7	0.110	10
				1443.38	7	1.8	19
				1443.38	7	1.8	19
				1471.70	20	0.193	19
				1478.2	3	0.30	3
				1489.37	7	2.88	6
				1510.2	3	0.23	3
				1570.34	10	0.97	4
				1601.97	20	0.29	3
				1617.2	3	0.129	19
				1630.7	10	0.09	8
				1676.77	14	0.73	4
				1744.90	20	4.82	10
				1806.5	3	0.28	5
				1829.75	16	1.90	5
				1940.63	7	5.4	3
				1971.0	4	0.20	5
				1999.30	20	0.40	4
^{74}As	17.77	2	D	595.83	8	59	4
				608.43	8	0.552	21
				634.78	8	15.4	11
				635.0	20	0.0357	21
				887.00	10	0.0255	15
				993.46	8	0.0184	19
				1204.35	8	0.285	20
^{75}Ge	82.78	4	M	66.00	20	0.114	13
				198.60	10	1.19	12
				264.60	10	11.4	11
				353.0	5	0.021	3
				419.10	20	0.185	19
				468.80	20	0.223	24
				617.70	20	0.114	13
^{75m}Ge	47.7	5	S	61.92	10	0.0119	24
				136.01	8	0.020	6
				139.68	3	39.5	4
^{75}Se	119.78	5	D	24.38		0.0253	12
				66.0518	8	1.111	9
				96.7340	9	3.449	25
				121.1155	11	17.20	13

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{75}Se	119.78	5	D	136.0001	6	58.5	5
				198.6060	12	1.496	11
				264.6576	9	58.9	5
				279.5422	10	25.02	19
				303.9236	10	1.315	10
				400.6573	8	11.41	9
				419.08	4	0.01237	
				572.40	3	0.0362	4
^{76}As	26.24	9	H	358.4	7	0.0135	6
				403.20	20	0.0234	17
				456.90	10	0.036	3
				472.80	10	0.050	5
				559.10	5	45.0	20
				563.23	5	1.20	9
				571.50	10	0.140	11
				575.30	5	0.068	6
				657.05	5	6.2	5
				665.0	10	0.04	4
				665.34	5	0.36	4
				727.00	7	0.0185	16
				740.10	5	0.117	11
				771.74	5	0.122	11
				809.80	10	0.0171	12
				863.8	4	0.0113	11
				867.64	8	0.131	11
				882.13	5	0.059	6
				980.90	10	0.041	3
				1129.87	5	0.126	15
				1130.0	10	0.018	14
				1212.92	5	1.44	11
				1216.08	5	3.42	24
				1228.52	5	1.22	11
				1439.10	5	0.279	19
				1453.62	5	0.108	11
				1532.80	20	0.0243	18
				1787.66	8	0.293	23
				1870.00	5	0.054	6
^{77}Ge	11.211	3	H	150.46	15	0.042	9
				156.35	11	0.69	11
				159.3	3	0.043	16
				177.28	13	0.13	5
				194.74	10	1.67	9
				208.83	15	1.12	16
				211.03	4	30.0	8
				215.51	4	27.9	8
				219.1	4	0.14	15
				254.66	11	0.197	9
				264.45	3	53.3	5
				268.10	22	0.3	3
				313.4	10	0.021	6
				325.5	10	0.023	6
				337.53	15	0.21	3
				338.60	12	0.72	7
				339.6	4	0.07	6
				350.10	15	0.0165	6
				367.49	4	14.5	7
				398.97	11	0.105	11
				416.35	4	22.7	11
				419.73	11	1.22	5
				430.60	21	0.0101	6

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{77}Ge	11.211	3	H	439.46	11	0.207	9
				444.59	18	0.020	5
				461.37	10	1.33	8
				470.5	10	0.015	8
				475.46	10	1.07	10
				504.02	12	0.067	5
				520.6	10	0.28	14
				531.26	14	0.043	6
				534.99	15	0.037	6
				557.0	10	0.0426	4
				557.92	8	16.8	10
				569.39	16	0.15	7
				582.56	10	0.80	4
				610.88	14	0.068	8
				614.36	10	0.093	14
				614.36	10	0.53	8
				624.75	11	0.190	8
				631.85	10	7.4	5
				634.40	10	2.14	9
				639.12	15	0.034	6
				655.20	22	0.014	5
				659.99	15	0.031	5
				673.12	10	0.132	14
				673.12	10	0.53	6
				680.40	14	0.040	5
				685.31	11	0.066	7
				685.31	11	0.025	3
				698.57	11	0.231	10
				705.25	11	0.108	6
				712.34	11	0.86	5
				714.37	10	7.5	5
				730.53	18	0.021	4
				743.63	11	0.190	15
				745.77	10	1.03	7
				749.89	10	0.93	6
				766.75	10	0.83	5
				775.84	19	0.017	4
				781.29	10	1.07	7
				784.80	10	1.38	8
				788.96	11	0.101	6
				794.37	11	0.30	3
				798.82	12	0.053	6
				802.92	13	0.035	7
				810.38	10	2.38	14
				813.40	11	0.139	6
				823.25	12	0.63	4
				825.80	12	0.064	5
				843.22	11	0.216	11
				857.62	9	0.030	3
				875.23	10	0.82	5
				884.12	23	0.016	4
				889.3	6	0.010	4
				896.54	11	0.126	6
				900.74	13	0.107	13
				907.01	10	1.00	6
				913.85	11	0.39	3
				921.01	13	0.079	8
				923.14	11	0.74	6
				925.48	11	0.71	7
				925.48	11	0.063	7

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{77}Ge	11.211	3	H	928.89	10	1.09	6
				939.39	11	0.304	22
				945.65	18	0.022	23
				945.65	18	0.022	23
				959.26	11	0.078	9
				966.74	22	0.033	7
				970.34	19	0.026	5
				985.76	11	0.112	15
				996.56	11	0.109	6
				1007.5	3	0.014	4
				1021.9	3	0.010	4
				1052.56	13	0.038	7
				1061.77	12	0.161	13
				1080.84	11	0.27	3
				1085.23	10	6.4	4
				1104.26	13	0.038	5
				1114.85	11	0.111	9
				1125.02	11	0.126	11
				1134.76	14	0.033	5
				1151.90	11	0.201	9
				1155.5	3	0.017	4
				1164.72	15	0.039	10
				1186.52	13	0.043	6
				1193.30	10	2.68	15
				1201.43	14	0.076	7
				1215.43	11	0.134	9
				1234.60	15	0.028	4
				1242.23	11	0.42	3
				1263.91	10	0.90	6
				1279.99	11	0.183	12
				1295.61	11	0.059	6
				1295.61	11	0.088	9
				1309.32	11	0.51	4
				1312.84	11	0.373	17
				1319.71	11	0.295	10
				1323.25	23	0.017	3
				1326.07	13	0.043	5
				1339.28	11	0.075	7
				1354.29	17	0.019	5
				1358.4	3	0.023	6
				1368.45	10	3.19	11
				1452.67	11	0.127	7
				1454.93	20	0.036	4
				1465.4	3	0.059	6
				1465.4	3	0.059	6
				1476.56	11	0.253	14
				1479.03	11	0.084	9
				1479.03	11	0.126	14
				1495.64	11	0.53	4
				1528.33	13	0.050	4
				1538.83	11	0.150	10
				1557.03	22	0.0128	22
				1569.37	12	0.056	4
				1573.74	11	0.70	5
				1624.4	3	0.011	6
				1643.1	4	0.015	6
				1709.86	11	0.325	22
				1719.72	11	0.410	17
				1722.28	14	0.059	8
				1727.24	11	0.152	7

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{77}Ge	11.211	3	H	1735.80	14	0.034	4
				1759.7	4	0.011	8
				1792.48	24	0.032	16
				1810.29	14	0.038	3
				1831.5	3	0.019	9
				1846.50	11	0.177	9
				1878.76	18	0.040	4
				1881.57	24	0.016	4
				1911.93	14	0.026	3
				1929.43	14	0.027	3
^{78}As	90.7	2	M	156.6	3	0.092	24
				174.2	3	0.18	5
				351.10	20	0.162	25
				354.30	20	1.9	3
				391.0	3	0.124	22
				449.8	4	0.08	3
				462.20	20	0.59	9
				468.8	3	0.097	20
				497.0	3	0.18	3
				503.70	20	0.42	6
				545.30	10	3.0	4
				551.8	3	0.17	4
				613.80	10	54	6
				637.10	20	0.21	4
				657.90	20	0.27	4
				686.30	20	0.92	15
				687.5	4	0.65	13
				694.90	10	16.7	22
				722.40	20	0.146	23
				756.9	3	0.086	24
				828.10	10	8.1	11
				841.5	10	0.16	11
				842.60	10	1.08	17
				882.00	20	0.19	4
				884.90	20	0.46	7
				888.70	10	2.1	3
				903.6	4	0.08	3
				959.00	20	0.46	7
				968.2	4	0.16	6
				988.2	4	0.092	24
				1005.10	20	0.32	6
				1018.7	3	0.14	3
				1079.80	20	1.62	21
				1145.10	10	1.67	22
				1169.5	4	0.12	4
				1199.10	10	0.70	10
				1228.1	4	0.11	6
				1240.30	10	5.9	9
				1290.6	6	0.10	4
				1308.70	10	13.0	18
				1339.00	20	0.39	7
				1373.50	10	4.8	7
				1381.20	20	0.76	10
				1440.90	20	0.32	12
				1530.00	10	2.5	4
				1642.0	4	0.16	5
				1713.40	20	1.78	23
				1721.0	3	0.32	6
				1737.2	4	0.11	3
				1791.90	20	0.97	16

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{78}As	90.7	2	M	1835.70	20	1.46	20
				1894.00	20	0.29	5
				1921.00	20	0.81	14
				1923.50	20	0.76	14
				1995.60	20	1.35	19
^{82}Br	35.282	7	H	92.190	16	0.726	11
				100.89	8	0.068	5
				129.29	3	0.014	3
				137.40	5	0.090	3
				179.80	20	0.017	3
				214.80	10	0.011	5
				221.4800	20	2.26	4
				273.480	8	0.801	12
				280.30	10	0.024	7
				332.90	3	0.015	5
				401.16	6	0.089	5
				470.30	10	0.039	7
				554.3480	20	71.1	9
				599.5	3	0.017	5
				606.30	10	1.226	21
				619.106	4	43.5	6
				698.374	5	28.3	5
				735.64	7	0.068	7
				776.517	3	83.4	12
				827.828	6	24.0	4
				932.10	20	0.012	5
				952.02	3	0.367	9
				1007.59	3	1.276	21
				1044.002	5	28.3	5
				1072.90	10	0.075	9
				1081.29	5	0.66	6
				1174.0	4	0.068	5
				1180.10	20	0.108	5
				1317.473	10	26.8	5
				1395.10	10	0.0117	17
				1474.880	10	16.60	23
				1650.37	4	0.751	11
				1779.66	3	0.112	3
				1871.60	20	0.0492	18
				1956.80	10	0.0375	17
^{84}Br	31.76	8	M	230.20	20	0.30	5
				339.8	4	0.071	18
				354.70	20	0.30	5
				382.00	20	0.56	10
				447.7	8	0.042	13
				561.4	5	0.083	22
				604.8	3	1.7	3
				688.7	7	0.09	3
				736.5	3	1.29	23
				802.20	20	6.0	8
				881.60	10	42	4
				947.5	7	0.35	9
				955.7	20	0.06	3
				987.3	4	0.79	14
				1005.7	7	0.46	13
				1015.9	3	6.2	8
				1082.6	4	0.14	3
				1119.1	4	0.14	3
				1142.7	10	0.033	13
				1185.0	7	0.108	23

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{84}Br	31.76	8	M	1213.30	20	2.6	4
				1255.5	6	0.046	9
				1438.0	7	0.062	18
				1463.8	7	2.0	4
				1534.7	6	0.100	22
				1578.1	4	0.67	14
				1607.6	4	0.40	7
				1741.2	4	1.6	3
				1779.6	7	0.062	18
				1807.8	8	0.042	13
				1818.7	4	0.24	5
				1877.5	4	1.12	19
				1897.60	20	14.6	20
^{85}Kr	10.739	14	Y	513.997	5	0.434	10
^{85m}Kr	4.480	8	H	129.810	20	0.301	8
				151.195	6	75.2	10
				304.870	20	14.0	4
				451.00	10	0.011	4
^{86}Rb	18.642	18	D	1077.0	4	8.64	4
^{87}Kr	76.3	5	M	129.4	3	0.045	11
				402.588	12	50	4
				510.78	14	0.079	21
				582.32	21	0.035	10
				673.83	8	1.89	11
				814.25	6	0.164	13
				836.38	5	0.77	5
				845.44	4	7.3	4
				894.02	13	0.046	5
				901.5	3	0.026	5
				946.69	13	0.129	8
				976.14	12	0.056	5
				1063.2	4	0.027	6
				1175.41	7	1.11	7
				1338.00	7	0.63	5
				1382.55	7	0.288	17
				1389.87	12	0.119	8
				1461.3	7	0.050	6
				1531.2	4	0.36	6
				1578.03	14	0.129	12
				1611.18	14	0.114	16
				1740.51	7	2.04	11
				1842.61	23	0.139	12
^{88}Kr	2.825	19	H	27.513	14	1.94	17
				28.26	11	0.028	11
				122.27	6	0.197	12
				165.98	4	3.10	20
				176.71	17	0.024	7
				196.301	10	26.0	13
				240.71	4	0.253	14
				268.2		0.030	14
				311.69	3	0.107	9
				334.71	3	0.145	10
				350.04	19	0.017	7
				362.226	13	2.25	12
				363.5	5	0.05	4
				390.543	11	0.64	6
				391.20	10	0.08	5
				421.70	18	0.010	4
				471.80	3	0.73	4
				500.02	6	0.097	9

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{88}Kr	2.825	19	H	517.00	8	0.035	11
				570.57	7	0.062	8
				573.27	6	0.073	8
				579.04	14	0.024	11
				603.21	13	0.042	11
				665.94	6	0.087	15
				677.34	5	0.235	18
				731.01	9	0.035	11
				741.34	18	0.035	11
				774.14	6	0.097	15
				779.12	8	0.097	22
				788.28	4	0.53	3
				790.32	7	0.125	12
				798.65	21	0.028	11
				822.01	12	0.090	12
				834.830	10	13.0	7
				850.34	5	0.173	14
				862.327	19	0.67	4
				879.51	19	0.024	7
				883.06	14	0.042	8
				944.92	4	0.294	20
				950.49	12	0.038	11
				961.83	6	0.083	11
				985.780	16	1.31	7
				990.09	9	0.142	19
				1039.59	3	0.48	3
				1049.48	12	0.142	13
				1054.54	20	0.031	11
				1090.53	12	0.062	15
				1141.33	6	1.28	7
				1179.51	3	1.00	5
				1184.95	4	0.69	5
				1209.84	8	0.14	3
				1212.73	17	0.14	5
				1245.22	4	0.363	25
				1250.67	4	1.12	6
				1298.78	15	0.093	22
				1303.09	24	0.066	25
				1324.98	4	0.16	4
				1335.81	14	0.066	11
				1352.32	11	0.159	22
				1369.50	20	1.48	9
				1406.94	10	0.218	20
				1464.84	9	0.114	15
				1518.39	3	2.15	12
				1529.77	3	10.9	6
				1603.79	5	0.46	4
				1608.01	20	0.069	18
				1661.3	3	0.090	22
				1685.6	4	0.66	8
				1789.14	22	0.045	18
				1793.3	3	0.035	14
				1801.3	3	0.038	14
				1892.76	13	0.14	3
				1908.7	4	0.100	15
^{88}Rb	17.773	11	M	338.95	7	0.060	3
				439.2	3	0.015	4
				484.53	16	0.030	7
				891.3		0.022	4
				898.03	4	14.40	24

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{88}Rb	17.773	11	M	1027.3	3	0.011	5
				1217.97	18	0.052	4
				1366.26	12	0.113	9
				1382.45	5	0.784	9
				1679.6	3	0.050	6
				1687.		0.011	7
				1779.870	21	0.238	5
				1798.35	19	0.053	4
				1836.00	5	22.81	11
^{88}Y	106.627	21	D	850.6	8	0.065	13
				898.042	3	93.7	3
				1382.2	10	0.021	6
				1836.063	12	99.2	3
^{90m}Y	3.19	6	H	202.53	3	97.3	4
				479.51	5	90.74	5
				681.8	6	0.32	3
^{91}Sr	9.65	6	H	118.50	20	0.074	5
				261.20	20	0.449	17
				272.6	6	0.26	4
				274.70	20	1.04	5
				359.10	10	0.050	4
				379.90	10	0.147	6
				393.00	10	0.050	4
				486.50	20	0.080	5
				506.70	10	0.044	4
				520.8	3	0.034	4
				533.90	10	0.077	5
				593.10	10	0.094	5
				620.10	10	1.78	7
				626.80	10	0.044	4
				631.30	10	0.556	21
				652.3	3	2.98	20
				652.90	20	8.0	5
				653.0	20	0.37	14
				660.90	10	0.101	5
				749.80	10	23.7	8
				761.40	10	0.576	22
				793.60	10	0.064	4
				820.80	20	0.161	7
				823.70	10	0.067	4
				879.70	10	0.188	7
				892.90	10	0.070	4
				901.30	20	0.094	5
				925.80	20	3.85	13
				973.90	10	0.040	4
				992.20	10	0.044	4
				1024.30	10	33.5	11
				1054.60	10	0.224	8
				1140.80	10	0.127	6
				1280.9	5	0.93	4
				1305.30	10	0.017	4
				1327.40	10	0.040	4
				1353.50	20	0.023	4
				1413.40	10	0.98	4
				1473.80	10	0.168	7
				1486.40	10	0.013	4
				1545.90	10	0.067	4
				1553.6	3	0.017	4
				1626.8	3	0.013	4
				1651.4	5	0.291	11

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{91}Sr	9.65	6	H	1724.0	5	0.161	7
^{91}Y	58.51	6	D	1204.80	13	0.26	4
^{91m}Y	49.71	4	M	555.57	5	95.0	3
^{92}Sr	2.611	17	H	241.56	5	2.93	20
				352.50	20	0.054	10
				430.49	3	3.28	24
				491.27	17	0.27	3
				650.80	20	0.37	4
				892.68	24	0.080	16
				953.31	7	3.52	25
				1142.35	7	2.79	21
				1383.93	5	90	6
^{92}Y	3.54	1	H	448.50	10	2.3	3
				492.60	10	0.49	6
				561.10	10	2.4	3
				844.30	10	1.25	15
				912.8	3	0.63	8
				934.47	7	13.9	16
				972.30	20	0.068	10
				1132.40	10	0.24	3
				1405.40	10	4.8	6
				1847.30	10	0.36	4
				1885.1	3	0.028	5
^{93}Y	10.18	8	H	266.90	10	7.4	12
				273.0	10	0.072	19
				287.0	10	0.076	16
				341.5	5	0.045	7
				680.20	10	0.67	10
				714.40	20	0.017	4
				947.10	10	2.1	4
				962.30	20	0.0122	24
				987.7	3	0.011	3
				1158.50	20	0.030	6
				1168.61	20	0.011	5
				1183.50	10	0.049	9
				1184.7	6	0.020	5
				1203.30	10	0.109	17
				1237.40	10	0.030	8
				1425.40	10	0.25	4
				1450.50	10	0.33	5
				1470.10	10	0.066	16
				1642.70	10	0.052	9
				1651.70	20	0.024	5
				1827.80	20	0.024	5
				1917.80	10	1.57	23
^{95}Zr	64.032	6	D	235.690	20	0.270	20
				724.192	4	44.27	22
				756.725	12	54.38	22
^{95}Nb	34.991	6	D	204.1161	17	0.028	9
				561.9		0.015	3
				765.803	6	99.808	7
^{97}Zr	16.749	8	H	111.6	3	0.065	10
				182.9	5	0.032	7
				202.5	6	0.029	9
				218.90	20	0.168	19
				254.17	14	1.15	8
				272.40	16	0.23	3
				294.8	4	0.08	3
				297.2	3	0.066	12
				305.1	9	0.028	19

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{97}Zr	16.749	8	H	330.43	19	0.143	15
				355.40	9	2.09	10
				400.42	16	0.245	16
				410.0	10	0.07	5
				473.5	6	0.07	4
				507.64	8	5.03	19
				513.41	18	0.55	5
				558.0	10	0.028	19
				600.6	6	0.09	10
				602.37	14	1.38	8
				690.52	16	0.183	18
				699.2	3	0.101	20
				703.76	5	1.01	5
				707.4	6	0.032	17
				743.36	3	93.09	16
				772	3	0.24	13
				775.0	8	0.1862	4
				804.52	9	0.61	8
				805.6	8	0.2793	5
				829.79	9	0.239	18
				854.89	8	0.357	23
				971.34	15	0.278	17
				1018.1	8	0.3724	7
				1021.2	3	1.01	17
				1026.7	8	0.2793	5
				1110.44	19	0.093	19
				1147.97	8	2.62	11
				1276.07	9	0.94	6
				1361.0	8	0.6516	12
				1362.68	9	1.02	11
				1750.24	22	1.09	11
				1851.61	9	0.31	3
^{97}Nb	72.1	7	M	178.0	3	0.049	10
				238.4	3	0.049	10
				549.25	20	0.049	10
				657.94	9	98.23	8
				719.53	19	0.090	9
				857.46	21	0.045	7
				909.55	14	0.040	7
				1024.4	3	1.09	7
				1117.02	18	0.085	8
				1148.6	3	0.049	10
				1268.62	10	0.147	20
				1515.66	19	0.122	13
				1629.09	22	0.025	7
^{97m}Nb	58.7	18	S	743.36	3	97.90	6
^{99}Mo	65.924	6	H	40.58324	17	1.04	4
				158.782	15	0.0176	8
				162.370	15	0.0120	7
				181.068	8	6.05	12
				366.421	15	1.200	25
				380.13	8	0.0105	9
				411.491	15	0.0150	8
				528.788	15	0.0532	20
				620.03	4	0.0279	14
				621.771	24	0.018	4
				739.500	17	12.20	16
				777.921	20	4.31	9
				822.972	15	0.134	3
				960.754	20	0.095	3

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{99m}Tc	6.0072	9	H	140.5110	10	89	4
				142.63	3	0.0222	20
^{103}Ru	39.247	3	D	39.760	10	0.0692	12
				53.286	10	0.443	11
				241.875	10	0.0143	3
				294.964	10	0.288	4
				443.810	10	0.339	5
				497.085	10	91.0	13
				557.057	10	0.841	11
				610.333	10	5.76	7
				612.09	6	0.105	6
^{105}Ru	4.44	2	H	62.39	10	0.066	10
				81.20	10	0.052	10
				129.782	4	5.68	16
				139.33	10	0.047	10
				149.10	7	1.75	19
				163.46	10	0.156	19
				183.60	12	0.099	10
				225.08	12	0.123	10
				245.21	15	0.025	5
				254.88	12	0.066	10
				262.83	10	6.57	16
				286.30	20	0.028	5
				306.66	12	0.080	10
				316.44	15	11.1	4
				326.14	10	1.06	12
				330.85	10	0.67	8
				339.40	20	0.014	5
				343.30	20	0.028	5
				349.96	10	0.289	15
				350.18	10	1.02	12
				369.45	12	0.047	10
				393.36	10	3.77	7
				407.60	15	0.090	10
				413.53	10	2.27	24
				469.37	10	17.5	6
				470.1	4	0.184	24
				479.60	20	0.0279	10
				489.48	10	0.55	7
				499.3	4	2.0	3
				500.10	20	0.55	8
				513.73	10	0.20	5
				539.29	10	0.114	10
				559.24	10	0.109	10
				575.07	12	0.85	10
				577.0	4	0.019	5
				591.20	15	0.080	10
				597.10	15	0.030	8
				621.04	10	0.071	10
				632.34	10	0.151	15
				635.50	20	0.014	5
				638.66	10	0.222	24
				652.70	10	0.31	4
				656.21	10	2.1	3
				676.36	8	15.7	5
				701.00	20	0.019	5
				724.30	3	47.3	5
				738.27	10	0.076	10
				805.84	15	0.045	10
				820.00	20	0.014	5

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{105}Ru	4.44	2	H	821.98	12	0.21	5
				845.91	12	0.63	7
				846.90	20	0.028	5
				851.98	10	0.156	19
				875.85	15	2.50	10
				878.20	20	0.47	5
				907.64	10	0.53	6
				952.78	10	0.0151	15
				969.44	10	2.10	8
				984.60	20	0.0104	19
				1017.47	10	0.32	4
				1059.60	20	0.027	8
				1215.38	10	0.071	10
				1222.00	20	0.0184	24
				1251.89	15	0.0194	24
				1321.26	10	0.203	24
				1377.06	11	0.057	10
				1698.10	20	0.076	15
				1721.36	15	0.033	10
^{105}Rh	35.36	6	H	38.72	3	0.025	4
				280.10	20	0.166	15
				306.10	20	5.1	4
				318.90	10	19.1	6
				442.8	7	0.042	6
^{105m}Rh	40		S	129.57	8	20.00	
^{106}Rh	30.07	35	S	428.40	20	0.071	3
				434.25	21	0.0202	21
				439.2	3	0.0126	21
				511.861	4	20.4	4
				616.22	9	0.75	9
				621.93	6	9.93	23
				680.25	14	0.0110	7
				715.90	20	0.0100	5
				873.49	5	0.439	11
				1045.6	6	0.0133	17
				1050.41	6	1.56	5
				1062.14	5	0.0320	8
				1114.48	5	0.0118	19
				1128.07	5	0.404	10
				1180.73	8	0.0145	4
				1194.54	5	0.0573	12
				1496.33	13	0.0222	8
				1562.25	6	0.163	4
				1766.25	5	0.0343	9
				1796.94	9	0.0277	7
				1927.22	9	0.0153	5
				1988.44	8	0.0261	7
^{108m}Ag	438	9	Y	79.131	3	6.6	5
				433.937	4	90.5	6
				614.276	4	89.8	19
				722.907	10	90.8	19
^{110m}Ag	249.83	4	D	120.23	3	0.0171	9
				133.333	7	0.0746	16
				219.348	8	0.073	5
				221.078	10	0.0685	10
				229.420	22	0.0120	14
				266.914	12	0.041	4
				365.448	11	0.094	5
				387.075	9	0.0525	9
				396.894	22	0.037	4

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{110m}Ag	249.83	4	D	446.812	3	3.70	5
				467.01	4	0.0252	19
				544.56	4	0.018	3
				572.70	10	0.0175	13
				573.0	4	0.0172	10
				603.08	20	0.011	8
				620.3553	17	2.73	8
				626.256	10	0.217	17
				630.62	5	0.033	5
				647.9	4	0.0177	5
				657.7601	11	95.61	10
				666.90	9	0.029	14
				676.59	7	0.143	10
				677.6218	12	10.70	5
				687.0092	18	6.53	3
				706.6761	15	16.69	7
				708.133	20	0.23	5
				744.2756	18	4.77	3
				763.9425	17	22.60	7
				818.0245	18	7.43	4
				884.6782	13	75.0	12
				937.485	3	35.0	3
				997.246	14	0.130	4
				1018.94	4	0.0142	7
				1085.447	14	0.073	4
				1117.48	3	0.0494	9
				1125.709	20	0.0308	14
				1163.19	5	0.075	23
				1164.98	7	0.044	3
				1251.06	4	0.027	3
				1300.07	7	0.0191	7
				1334.348	16	0.143	5
				1384.2932	20	25.1	5
				1420.29	10	0.027	4
				1475.7794	23	4.08	5
				1505.0282	20	13.33	16
				1562.2942	18	1.22	3
				1592.77	6	0.0209	8
				1783.49	3	0.0102	5
				1903.53	3	0.0162	7
^{113}Ag	5.37	5	H	17.70	20	0.042	5
				96.20	20	0.0370	20
				133.50	20	0.0660	20
				206.40	20	0.0200	20
				217.20	10	0.0280	20
				258.80	10	1.64	3
				298.60	10	10.00	
				316.30	10	1.343	20
				333.10	10	0.598	9
				339.40	10	0.638	10
				364.40	10	0.140	3
				369.0	10	0.010	5
				374.30	20	0.0250	20
				382.10	10	0.145	3
				392.40	10	0.0200	20
				410.80	10	0.0120	20
				584.00	10	0.21	3
				585.0	10	0.010	5
				611.0	5	0.045	10
				624.00	10	0.0190	10

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{113}Ag	5.37	5	H	672.30	10	0.87	3
				672.30	10	0.030	10
				680.60	10	0.695	16
				734.0	10	0.010	5
				809.90	10	0.0150	20
				816.10	10	0.0110	20
				827.0	10	0.010	5
				878.50	10	0.0520	20
				883.60	10	0.282	7
				896.10	10	0.058	10
				988.40	10	0.423	9
				1049.90	10	0.045	3
				1084.50	10	0.016	3
				1126.10	10	0.061	3
				1180.80	10	0.037	3
				1194.60	10	0.378	10
				1479.20	10	0.068	4
^{113}Sn	115.09	3	D	255.134	10	2.11	8
				391.698	3	64.97	17
^{114m}In	49.51	1	D	190.27	3	15.56	16
				558.43	3	4.4	7
				725.24	3	4.4	7
^{115}Cd	53.46	5	H	35.57	6	0.0153	4
				231.443	3	0.740	18
				260.896	3	1.94	4
				266.985	10	0.092	4
				336.24	3	1.000	20
				492.351	4	8.03	19
				527.901	7	27.5	6
^{115m}In	4.486	4	H	336.24	3	45.8	4
				497.37	3	0.047	7
^{117}Cd	2.49	4	H	71.120	20	0.39	6
				89.730	10	3.26	22
				105.40	15	0.022	12
				131.40	20	0.011	6
				132.70	10	0.022	12
				160.8	3	0.25	12
				171.05	7	0.025	12
				179.35	8	0.10	3
				220.92	3	1.17	9
				221.0	4	0.06	6
				273.349	18	27.9	7
				279.80	10	0.11	6
				284.79	7	0.084	23
				292.05	3	0.64	9
				310.0	5	0.0698	18
				314.4	4	0.08	6
				344.459	10	17.9	6
				385.5	4	0.0363	10
				387.96	4	0.31	6
				397.20	10	0.20	6
				416.90	20	0.017	17
				419.79	4	0.18	4
				434.190	17	9.8	5
				439.39	7	0.11	6
				453.8	3	0.036	20
				463.04	3	0.75	6
				497.77	10	0.11	6
				500.60	20	0.014	14
				526.6	5	0.03	3

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{117}Cd	2.49	4	H	527.0	5	0.14	6
				597.6	3	0.014	14
				627.01	11	0.11	3
				644.50	20	0.017	17
				660.83	8	0.11	3
				688.0	3	0.011	12
				699.58	8	0.24	4
				712.71	5	0.56	17
				716.43	7	0.20	4
				728.64	7	0.24	4
				736.14	8	0.06	4
				748.05	4	0.56	20
				757.60	20	0.028	20
				787.4	5	0.0558	14
				831.80	3	2.26	11
				840.21	4	0.81	6
				850.72	8	0.12	4
				861.3	4	0.28	20
				862.60	5	0.61	6
				880.710	17	3.96	22
				945.67	3	1.53	10
				949.63	8	0.22	4
				952.33	8	0.14	4
				963.11	6	0.61	6
				965.80	20	0.08	6
				969.30	5	0.45	6
				970.4	3	0.06	6
				975.5	5	0.0725	19
				994.3	4	0.017	17
				1012.3	3	0.08	6
				1035.61	7	0.24	4
				1036.0	4	0.017	17
				1051.70	10	3.79	22
				1052.70	10	0.73	17
				1061.10	20	0.06	6
				1116.60	5	1.03	7
				1120.05	7	0.24	4
				1125.10	6	0.45	6
				1142.43	3	1.67	12
				1143.5	3	0.14	6
				1183.40	10	0.13	4
				1229.11	7	0.61	6
				1232.30	20	0.28	6
				1247.89	4	1.20	7
				1249.3	4	0.03	3
				1260.00	3	1.14	7
				1272.73	3	0.73	6
				1276.00	10	0.025	12
				1291.00	4	0.67	6
				1303.27	3	18.4	6
				1314.71	6	0.59	6
				1316.0	4	0.03	3
				1317.5	4	0.017	17
				1337.57	7	1.62	12
				1362.40	8	0.24	4
				1404.40	10	0.12	3
				1408.72	3	1.28	7
				1422.27	6	0.33	6
				1430.97	5	0.558	14
				1433.50	20	0.11	9

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{117}Cd	2.49	4	H	1450.15	7	0.61	6
				1468.90	20	0.039	12
				1475.46	7	0.42	6
				1511.90	20	0.07	4
				1521.00	12	0.09	3
				1562.24	4	1.42	7
				1563.6	4	0.08	6
				1576.62	3	11.2	4
				1578.4	3	0.14	6
				1583.10	10	0.05	3
				1596.0	4	0.03	3
				1597.3	4	0.06	6
				1652.10	20	0.28	12
				1682.07	5	0.70	6
				1685.8	3	0.039	17
				1706.93	4	1.00	7
				1723.06	3	2.01	10
				1739.13	9	0.13	4
				1748.70	20	0.08	4
				1756.80	20	0.045	23
				1856.40	10	0.25	6
				1867.30	10	0.11	3
^{117m}Cd	3.36	5	H	97.70	4	1.05	14
				99.40	10	0.10	6
				101.00	20	0.08	6
				168.63	5	0.29	6
				220.92	3	0.24	16
				292.05	3	0.10	11
				299.45	10	0.45	8
				310.26	15	0.50	11
				313.8	4	0.024	24
				325.30	20	0.13	6
				366.91	3	3.33	25
				381.2	4	0.024	24
				408.00	20	0.09	5
				439.39	7	0.18	8
				442.9	3	0.0262	5
				460.94	4	1.62	14
				484.79	3	1.02	14
				518.8	3	0.06	3
				545.0	4	0.16	8
				564.397	16	14.7	9
				597.34	20	0.131	3
				617.50	7	0.34	8
				627.26	15	0.236	5
				631.80	4	2.80	20
				663.50	6	0.68	8
				684.6	4	0.07	4
				712.71	5	1.00	14
				730.8	4	0.1048	20
				743.9	10	0.013	14
				748.06	3	4.5	11
				762.72	4	1.73	14
				788.16	13	0.50	11
				827.60	10	0.26	8
				860.41	4	7.9	4
				880.710	17	0.7	3
				886.00	10	0.39	8
				929.30	10	0.79	14
				931.37	4	3.64	25

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{117m}Cd	3.36	5	H	957.20	10	0.39	11
				995.0	5	0.0524	10
				1029.06	3	11.7	5
				1065.98	3	23.1	7
				1120.0	3	0.13	14
				1170.71	10	0.66	14
				1196.20	10	0.39	11
				1205.5	3	0.13	4
				1208.3	4	0.05	6
				1209.0	4	0.18	8
				1209.0	4	0.13	8
				1234.59	3	11.0	4
				1256.90	20	0.18	8
				1339.3	5	2.07	24
				1365.54	5	1.65	11
				1371.2	5	0.0314	6
				1432.91	3	13.4	4
				1442.1	3	0.0183	4
				1652.24	11	0.47	11
				1669.5	3	0.63	8
				1957.50	20	0.16	4
				1997.33	3	26.2	5
^{122}Sb	2.7238	2	D	564.24	4	70.67	18
				615.0	4	0.011	5
				692.65	4	3.85	13
				793.3	4	0.016	5
				1140.67	4	0.76	6
				1256.93	4	0.81	5
^{124}Sb	60.20	3	D	254.49	4	0.0161	10
				336.21	4	0.074	3
				371.00	11	0.038	5
				400.30	6	0.139	7
				444.09	3	0.1889	20
				469.06	7	0.050	3
				481.42	4	0.0237	19
				525.50	21	0.138	4
				530.45	3	0.0421	20
				572.06	6	0.0190	13
				602.7261	23	97.8	4
				632.489	19	0.1046	10
				645.8521	19	7.42	3
				662.42	3	0.029	4
				709.34	5	1.353	13
				713.776	4	2.276	18
				722.782	3	10.76	5
				735.7	7	0.056	6
				735.9	7	0.071	7
				766.32	4	0.01213	20
				790.706	7	0.739	6
				816.8	3	0.0729	18
				856.68	4	0.0238	10
				899.23	3	0.0172	14
				968.195	4	1.882	10
				976.62	5	0.0832	16
				1045.125	4	1.833	12
				1086.70	8	0.0378	18
				1263.45	7	0.0413	18
				1301.14	9	0.0343	10
				1325.504	4	1.580	15
				1355.20	5	1.038	13

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{124}Sb	60.20	3	D	1368.157	5	2.624	14
				1376.090	9	0.483	5
				1385.33	4	0.063	3
				1436.554	7	1.217	9
				1445.11	4	0.330	4
				1488.887	24	0.672	6
				1526.317	24	0.409	5
				1565.7	5	0.014	3
				1579.82	5	0.38	5
				1622.4	4	0.0409	10
				1690.971	4	47.57	19
				1720.72	3	0.0951	17
				1918.74	6	0.0545	16
^{125}Sn	9.64	3	D	234.70	10	0.035	10
				258.25	10	0.010	11
				258.25	10	0.010	11
				270.60	5	0.11	3
				282.45	5	0.018	6
				332.10	5	1.4	4
				350.95	5	0.26	7
				434.13	10	0.024	7
				469.85	5	1.5	4
				487.20	20	0.013	4
				524.30	5	0.010	3
				563.00	20	0.016	5
				652.60	10	0.041	11
				684.00	20	0.011	4
				800.28	5	1.1	3
				822.48	5	4.3	12
				893.40	5	0.29	8
				903.5	5	0.013	5
				915.55	5	4.1	12
				921.43	5	0.082	23
				934.63	5	0.21	6
				1017.40	5	0.32	9
				1067.10	5	10	3
				1087.70	10	1.2	4
				1089.15	10	4.6	13
				1111.40	10	0.014	5
				1151.23	5	0.11	3
				1163.84	5	0.031	9
				1173.30	5	0.18	5
				1198.70	15	0.016	5
				1220.88	10	0.27	8
				1259.35	10	0.031	9
				1349.42	10	0.059	16
				1419.70	5	0.49	13
				1591.40	20	0.025	7
				1806.690	16	0.15	4
				1889.884	16	0.074	21
^{125}Sb	2.75856	25	Y	19.80	6	0.0204	10
				35.489	5	4.37	5
				58.43	5	0.012	6
				116.955	11	0.263	4
				172.719	8	0.191	8
				176.3140	20	6.84	7
				178.842	5	0.0337	24
				198.654	11	0.0128	6
				204.138	10	0.317	7
				208.077	5	0.248	5

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{125}Sb	2.75856	25	Y	209.32	9	0.045	3
				227.891	10	0.1311	23
				321.04	4	0.416	5
				380.452	8	1.517	17
				408.065	10	0.184	3
				427.874	4	29.6	3
				443.555	9	0.306	4
				463.365	4	10.49	11
				600.5970	20	17.65	19
				606.713	3	4.98	6
				635.950	3	11.22	15
				671.441	6	1.791	19
^{127}Sb	3.85	5	D	61.10	10	1.44	14
				154.3	5	0.15	8
				252.4	3	8.5	6
				280.4	5	0.66	16
				290.8	5	2.02	16
				293.3	9	0.29	15
				310.0	7	0.26	12
				391.8	5	0.96	9
				412.1	5	3.8	5
				441.0	9	0.7	4
				445.1	5	4.3	3
				451.0	7	0.18	8
				456.0	10	0.11	8
				473.0	4	25.8	16
				502.8	6	0.8	3
				543.3	5	2.9	5
				584.2	11	0.33	19
				603.5	5	4.5	3
				624.0	10	0.066	23
				637.8	5	0.44	15
				652.3	9	0.37	8
				667.5	9	0.74	9
				682.3	10	0.6	3
				685.7	5	36.8	20
				698.5	5	3.64	22
				722.2	5	1.88	15
				745.9	5	0.15	8
				763.7	8	0.07	4
				783.7	5	15.1	9
				817.0	6	0.40	19
				820.6	6	0.22	12
				924.4	9	0.52	8
				1141.6	8	0.37	8
				1155.2	10	0.040	23
				1290.3	8	0.37	12
				1377.9	9	0.07	4
^{127}Te	9.35	7	H	57.63	8	0.030	5
				202.90	10	0.058	7
				215.10	10	0.039	5
				360.30	10	0.135	14
				417.90	10	0.99	14
^{128}Sb	9.05	4	H	102.8	3	0.40	11
				118.4	3	0.60	11
				152.6	3	0.50	11
				204.4	10	1.00	21
				214.80	20	1.00	21
				227.30	20	1.5	3
				235.00	10	0.30	11

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{128}Sb	9.05	4	H	249.70	20	0.60	11
				278.3	3	0.60	11
				314.10	10	61	5
				317.70	20	3.0	11
				322.30	20	3.0	11
				357.0	3	1.5	3
				366.1	3	1.5	3
				404.3	3	1.00	21
				445.7	3	1.5	3
				454.5	3	1.5	3
				459.5	3	1.5	3
				526.50	10	45	3
				582.9	3	1.00	21
				594.3	3	1.00	21
				603.0	3	1.7	4
				628.70	10	31	3
				636.20	10	36	3
				654.20	20	17.0	14
				667.1	3	2.5	4
				683.9	3	3.0	11
				692.9	3	2.0	10
				727.6	3	4.0	11
				743.30	10	100	7
				754.00	10	100	7
				773.7	3	1.5	3
				802.7	3	1.20	21
				813.60	20	13.0	21
				835.8	4	1.0	10
				845.8	4	2.5	4
				860.8	4	0.40	11
				878.0	4	3.5	5
				908.8	4	1.0	10
				972.3	4	1.0	10
				1047.5	4	3.5	5
				1078.6	4	2.0	10
				1112.7	4	2.0	10
				1129.6	4	0.80	21
				1158.2	4	1.5	3
				1181.6	4	4.5	6
				1250.5	4	1.0	10
				1259.5	4	1.0	10
				1339.8	4	1.0	10
				1378.0	4	1.8	5
				1593.2	5	0.50	11
				1685.7	5	0.50	11
				1707.9	5	0.30	11
				1785.5	5	0.40	11
^{129}Sb	4.366	26	H	95.42	3	0.0448	16
				115.84	4	0.087	3
				146.110	10	0.0906	19
				180.420	10	2.84	15
				244.530	10	0.403	7
				268.480	20	0.214	5
				290.48	4	0.060	3
				295.260	10	0.828	14
				314.400	20	0.123	3
				318.360	10	0.227	4
				330.33	4	0.073	4
				333.210	20	0.171	5
				351.46	11	0.075	9

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{129}Sb	4.366	26	H	354.13	8	0.097	10
				359.200	10	2.39	4
				364.21	3	0.305	9
				398.97	5	0.069	3
				404.640	10	1.172	19
				409.710	20	0.231	6
				415.17	4	0.096	4
				421.72	10	0.050	4
				434.7		0.1113	14
				435.04	9	0.212	15
				453.440	10	0.538	10
				471.54	9	0.045	4
				499.990	10	0.430	7
				505.330	10	0.518	9
				514.43	8	0.147	13
				523.13	12	1.55	4
				525.2		0.1644	21
				539.52	6	0.077	6
				544.560	10	15.42	24
				566.960	20	0.136	3
				590.0	3	0.022	7
				592.77	6	0.041	3
				606.22	4	0.146	5
				633.740	10	2.53	4
				647.940	20	0.124	4
				654.280	10	2.97	5
				670.31	4	0.96	4
				682.770	10	5.76	10
				684.180	10	0.622	10
				688.59	8	0.164	15
				694.77	3	0.403	11
				697.8		0.254	4
				703.36	5	0.095	4
				707.08	3	0.138	5
				715.49	14	0.051	9
				737.070	10	0.444	7
				761.120	10	4.32	7
				768.980	20	0.321	7
				773.370	10	2.82	5
				786.360	10	1.071	17
				787.160	10	1.74	3
				796.21	6	0.040	3
				812.970	10	48.2	8
				819.510	20	1.39	4
				826.75	16	0.067	20
				832.99	16	0.063	15
				840.17	22	0.027	10
				849.57	5	0.076	3
				861.00	3	0.0680	17
				874.89	3	0.534	9
				876.65	3	2.75	8
				903.19	8	0.140	8
				914.960	10	23.3	4
				939.5		0.1918	24
				940.51	12	0.77	4
				966.780	10	8.96	15
				992.70	4	0.105	4
				996.54	3	0.176	5
				1000.50	8	0.050	4
				1022.12	7	0.029	3

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{129}Sb	4.366	26	H	1030.650	10	15.13	24
				1037.29	4	0.307	11
				1042.30	6	0.042	3
				1053.02	5	0.053	3
				1087.98	3	0.411	10
				1104.520	10	0.341	6
				1122.48	3	0.092	4
				1126.57	3	0.120	4
				1147.59	3	0.089	3
				1167.950	20	0.253	5
				1179.63	4	0.0540	21
				1196.420	20	0.0853	18
				1209.03	3	0.940	19
				1211.89	17	0.38	7
				1233.2	6	0.053	25
				1237.81	12	0.241	6
				1258.440	10	0.402	7
				1263.300	10	0.910	15
				1273.100	20	0.164	4
				1276.13	7	0.103	10
				1281.720	10	0.559	9
				1287.45	3	0.100	3
				1298.7	4	0.12	4
				1301.45	5	0.202	9
				1318.300	10	0.462	8
				1326.980	10	0.695	11
				1384.98	3	0.100	3
				1419.40	12	0.394	7
				1421		0.0376	5
				1437.520	20	0.316	7
				1475.91	3	0.0699	17
				1480.94	12	0.373	7
				1483		0.0410	5
				1501.04	4	0.0598	21
				1526.840	10	0.548	9
				1541.47	3	0.0670	21
				1570.090	10	0.872	14
				1582.11	5	0.0337	15
				1600.130	10	0.579	10
				1606.720	10	0.0198	20
				1622.460	10	0.208	4
				1646.79	5	0.0270	11
				1656.100	10	1.311	22
				1669.16	7	0.0217	15
				1691.24	4	0.0424	16
				1724.310	20	0.133	3
				1727.770	20	0.029	7
				1738.160	10	7.45	12
				1762.42	5	0.0318	11
				1779.78	4	0.0781	22
				1843.490	10	0.021	6
				1871.580	10	0.356	6
				1891.10	7	0.0159	10
				1917.36	3	0.0540	16
				1934.24	3	0.0540	16
^{129}Te	69.6	3	M	27.81	5	16.3	20
				208.96	5	0.180	13
				250.62	5	0.38	3
				278.43	5	0.57	4
				281.26	5	0.165	12

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{129}Te	69.6	3	M	342.88	5	0.049	4
				459.60	5	7.7	6
				487.39	5	1.42	11
				531.83	5	0.088	7
				624.34	5	0.097	7
				740.96	5	0.037	3
				802.10	5	0.192	14
				804.60	13	0.022	3
				833.28	5	0.045	4
				982.27	5	0.0160	12
				1083.85	5	0.49	4
				1111.64	5	0.191	15
				1260.63	5	0.0112	9
^{129m}Te	33.6	1	D	27.81	5	0.027	6
				105.50	5	0.14	4
				556.65	5	0.118	24
				671.84	5	0.025	5
				695.88	6	3.0	6
				701.7	3	0.025	5
				729.57	5	0.70	14
				740.96	5	0.027	6
				817.04	5	0.091	18
				844.81	5	0.034	7
				1022.43	5	0.017	4
				1050.21	5	0.018	4
^{129}I	1.57E+7	4	Y	39.578	4	7.51	23
^{130}Sb	39.5	8	M	182.330	9	65	4
				258.00	20	3.9	4
				285.48	7	3.5	4
				303.30	20	5.8	6
				330.914	9	78	4
				455.40	20	4.8	5
				462.5	4	0.80	20
				468.00	10	18.0	10
				483.6	3	2.2	3
				506.7	3	2.0	4
				595.5	3	1.00	20
				626.7	3	2.8	3
				635.7	3	1.6	3
				654.7	3	2.00	20
				658.2	3	1.7	4
				669.2	3	1.10	20
				680.9	3	6.5	7
				686.6	3	3.2	4
				732.00	10	22.0	10
				793.40	10	100	5
				829.8	3	1.8	4
				839.52	6	100	5
				855.7	4	1.6	3
				883.3	4	1.2	3
				914.9	4	1.8	4
				926.0	5	0.40	20
				934.90	20	19.0	10
				992.1	4	1.9	4
				1000.2	4	2.3	5
				1030.7	4	1.5	3
				1075.5	5	0.40	20
				1089.5	4	3.7	4
				1096.5	5	0.80	20
				1134.2	5	0.40	20

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{130}Sb	39.5	8	M	1137.6	5	0.30	20
				1141.4	4	2.0	4
				1146.2	5	0.60	20
				1239.0	5	1.8	3
				1258.5	5	1.00	20
				1292.3	4	3.7	4
				1368.7	5	1.10	20
				1419.3	5	1.20	20
				1443.7	5	2.5	3
				1473.1	8	0.60	20
				1488.4	8	0.60	20
				1499.6	8	0.40	20
				1521.1	8	0.80	20
				1533.7	8	0.90	20
				1561.6	8	0.60	20
				1581.9	8	1.9	4
				1617.0	8	0.90	20
				1626.6	8	0.60	20
				1655.6	8	0.80	20
				1749.8	8	0.30	20
				1762.6	5	2.5	3
				1884.4	8	0.70	20
				1948.0	8	1.20	20
				1997.4	5	2.10	20
^{130}I	12.36	1	H	158.80	18	0.020	7
				227.55	16	0.012	5
				246.306	22	0.047	5
				280.09	11	0.024	7
				302.49	6	0.013	5
				363.467	15	0.089	20
				417.932	4	34.2	10
				427.94	4	0.083	11
				429.1		0.034	11
				457.758	21	0.237	15
				510.472	9	0.85	3
				536.066	6	99.00	
				539.053	8	1.40	4
				553.916	10	0.66	3
				586.049	8	1.69	6
				603.548	14	0.61	3
				623.0	3	0.017	11
				668.536	9	96	3
				686.060	14	1.07	4
				729.54	22	0.011	8
				739.512	10	82	3
				749.02	14	0.012	5
				800.23	4	0.101	5
				808.29	3	0.236	10
				814.15	11	0.025	5
				821.15	8	0.043	5
				854.99	10	0.035	5
				867.75	22	0.043	6
				877.35	4	0.191	10
				897.04	16	0.021	5
				944.21	8	0.062	14
				967.02	3	0.88	3
				996.80	16	0.028	5
				1060.07	17	0.017	5
				1094.29	20	0.028	8
				1096.48	4	0.552	20

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{130}I	12.36	1	H	1122.15	4	0.253	11
				1157.43	3	11.3	4
				1222.56	3	0.179	8
				1272.12	3	0.748	25
				1403.90	3	0.345	16
				1417.69	13	0.0119	20
				1424.73	15	0.0208	20
				1487.85	15	0.0119	20
				1500.20	9	0.0396	20
				1545.78	23	0.023	4
				1547.75	23	0.018	4
				1607.29	12	0.045	3
^{131}Sb	23.03	4	M	134.60	10	2.5	10
				159.9	5	0.47	15
				182.250	20	0.065	4
				274.3	3	1.2	13
				295.70	10	1.6	17
				301.3	3	2.4	5
				323.8	4	1.2	4
				326.2	4	1.2	7
				433.81	19	2.0	20
				456.7	5	0.7	7
				619.8	3	1.6	3
				625.7	3	2.4	5
				642.30	10	24	5
				657.9	3	4	4
				669.00	19	1.9	4
				726.30	10	4.1	5
				824.91	19	2.6	4
				854.60	20	3.3	5
				866.0	10	0.47	10
				911.0	4	0.71	4
				933.09	10	26.4	20
				943.41	10	47.1	24
				958.59	10	0.61	19
				991.5	5	1.4	5
				1050.4	4	0.7	4
				1123.63	19	8.9	9
				1191.9	6	0.6	6
				1191.9	6	0.6	6
				1207.40	10	4.1	4
				1233.76	19	2.3	5
				1249.10	20	0.52	24
				1267.57	19	3.0	3
				1284.7	5	0.3	3
				1284.7	8	0.3	3
				1331.8	3	0.85	11
				1360.3	3	0.9	5
				1392.0	4	0.8	3
				1398.90	20	1.37	16
				1455.10	10	0.47	24
				1470.30	20	1.55	17
				1517.2	3	1.22	16
				1538.0	4	0.5	3
				1544.2	3	0.9	4
				1553.5	4	0.6	3
				1559.0	4	0.42	19
				1573.50	20	1.04	25
				1608.80	20	1.4	3
				1721.8	5	2.45	19

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{131}Sb	23.03	4	M	1756.10	20	1.13	16
				1821.2	5	1.22	25
				1854.3	3	4.2	6
				1854.4	3	4.2	4
				1915.7	6	1.0	5
				1956.4	5	0.8	4
				1965.8	4	1.3	7
				1984.6	7	0.42	19
^{131m}Te	33.25	25	H	36.83	3	0.0116	15
				62.380	20	0.0351	24
				66.95	5	0.022	4
				73.32	5	0.026	3
				78.57	8	0.015	3
				79.19	3	0.123	5
				81.140	20	3.92	10
				86.430	20	0.142	5
				98.30	10	0.013	3
				100.00	10	0.071	4
				101.6	3	0.164	16
				102.060	10	7.66	20
				103.3	3	0.045	8
				105.00	20	0.026	4
				109.40	20	0.034	8
				111.90	20	0.030	8
				113.50	10	0.011	4
				127.4	4	0.022	8
				130.50	10	0.067	8
				134.860	20	0.68	3
				137.60	20	0.07	4
				149.3	3	0.075	19
				149.710	10	4.9	7
				151.20	20	0.07	3
				155.90	20	0.037	23
				159.66	4	0.123	15
				169.70	20	0.030	8
				172.00	20	0.011	4
				177.20	20	0.063	12
				182.250	20	0.992	20
				182.250	20	0.71	19
				183.11	8	0.149	19
				188.13	5	0.205	12
				189.76	4	0.49	4
				190.52	6	0.112	15
				200.630	20	7.28	17
				203.4	4	0.019	8
				207.50	10	0.037	12
				210.3	3	0.015	4
				211.9	4	0.011	4
				213.98	3	0.411	20
				227.7	4	0.015	12
				230.65	5	0.187	12
				232.30	10	0.090	12
				235.00	20	0.015	12
				240.930	10	7.32	15
				253.170	20	0.627	16
				255.44	7	0.299	13
				261.40	20	0.015	4
				267.2	3	0.015	12
				269.2	3	0.05	6
				269.2	3	0.05	6

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{131m}Te	33.25	25	H	278.560	20	1.72	5
				281.4	3	0.034	19
				283.20	20	0.37	4
				290.30	20	0.075	12
				296.8	3	0.049	8
				302.70	20	0.037	12
				303.90	20	0.037	8
				309.47	6	0.36	4
				323.7	4	0.015	8
				331.2	6	0.030	12
				334.270	10	9.22	20
				335.44	7	0.131	23
				342.92	5	0.37	12
				342.92	5	0.04	4
				345.9	3	0.09	3
				351.30	10	0.202	19
				353.5	3	0.07	4
				354.70	10	0.220	12
				357.4	3	0.019	8
				362.3	4	0.07	4
				364.98	10	1.16	15
				375.8	3	0.011	4
				377.8	3	0.019	19
				377.8	3	0.019	19
				379.3	3	0.019	8
				383.90	7	0.19	3
				403.3	4	0.030	12
				408.2	3	0.06	3
				417.40	20	0.269	20
				432.40	7	0.64	3
				452.30	4	1.5	4
				462.92	5	1.76	5
				468.16	9	0.30	3
				492.65	5	0.07	15
				506.80	20	0.086	15
				524.80	10	0.131	16
				530.70	10	0.101	19
				541.40	10	0.108	23
				546.70	20	0.037	8
				558.10	20	0.022	8
				572.70	20	0.041	23
				579.8	3	0.075	23
				586.30	3	1.90	9
				597.00	20	0.049	19
				602.09	4	0.30	12
				609.40	10	0.134	16
				637.3		0.015	15
				657.20	20	0.030	15
				665.05	3	4.18	11
				681.9	3	0.030	8
				685.90	10	0.149	12
				695.62	8	0.38	3
				702.50	7	0.377	20
				713.10	4	1.38	16
				738.80	20	0.063	12
				744.20	4	1.53	5
				749.0	8	0.015	8
				773.67	3	36.8	8
				774.10	10	0.52	8
				782.49	4	7.51	18

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{131m}Te	33.25	25	H	793.75	3	13.4	3
				801.60	20	0.019	8
				822.78	4	5.90	13
				844.90	20	0.15	4
				848.90	20	0.037	12
				852.21	3	0.37	19
				852.21	3	19.9	6
				856.05	6	0.60	4
				865.10	20	0.19	4
				872.3	3	0.097	12
				881.6	3	0.034	12
				910.00	3	3.17	10
				920.62	5	1.16	8
				923.40	20	0.112	23
				930.0	4	0.019	12
				941.27	5	0.75	3
				987.80	10	0.149	12
				995.1	3	0.086	15
				999.20	10	0.164	19
				1003.60	20	0.026	15
				1005.70	20	0.071	15
				1023.60	20	0.060	8
				1035.40	20	0.101	8
				1059.69	4	1.49	5
				1072.30	20	0.022	4
				1108.3	3	0.022	8
				1114.1	3	0.011	4
				1125.46	4	11.0	3
				1127.96	6	0.93	8
				1148.89	7	1.5	3
				1148.89	7	0.24	25
				1150.90	9	0.63	8
				1162.70	20	0.026	8
				1165.50	10	0.134	12
				1181.4	4	0.011	8
				1206.60	4	9.41	22
				1211.00	20	0.060	12
				1237.32	5	0.63	4
				1254.2	4	0.026	4
				1315.16	8	0.67	8
				1316.20	20	0.09	4
				1318.30	20	0.037	8
				1333.8	3	0.052	8
				1340.60	10	0.097	12
				1376.8	4	0.041	8
				1389.6	3	0.015	4
				1394.83	9	0.105	8
				1403.6	6	0.011	8
				1496.5	4	0.056	8
				1547.75	9	0.067	8
				1646.01	5	1.20	5
				1696.8	5	0.015	4
				1880.1	3	0.060	8
				1887.70	7	1.31	5
				1936.15	9	0.071	8
				1980.3	3	0.030	8
^{131}I	8.0252	6	D	80.1850	20	2.62	4
				163.930	8	0.0211	5
				177.2140	20	0.269	4
				272.498	17	0.0576	12

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{131}I	8.0252	6	D	284.305	5	6.12	7
				318.088	16	0.0774	17
				324.65	3	0.0212	25
				325.789	4	0.273	22
				358.40	20	0.016	6
				364.489	5	81.5	8
				404.814	4	0.0546	17
				503.004	4	0.359	4
				636.989	4	7.16	10
				642.719	5	0.217	5
				722.911	5	1.77	3
^{131m}Xe	11.84	4	D	163.930	8	1.95	6
^{132}Te	3.204	13	D	49.720	10	15.0	6
				111.76	8	1.74	8
				116.30	8	1.96	9
				228.16	6	88	4
^{132}I	2.295	13	H	136.7	4	0.04	5
				136.7	4	0.04	5
				147.40	10	0.237	20
				183.6	3	0.138	20
				194.3	5	0.089	
				234.3	6	0.030	10
				241.2	5	0.049	
				250.8	6	0.011	12
				250.8	6	0.011	12
				255.1	3	0.010	10
				255.10	20	0.237	20
				262.90	10	1.28	10
				278.4	4	0.025	25
				278.4	4	0.025	25
				284.90	10	0.71	7
				296.5	6	0.016	
				306.7	4	0.06	6
				306.7	4	0.06	6
				310.1	4	0.05	6
				310.1	4	0.05	6
				316.7	4	0.128	20
				343.7	4	0.089	20
				355.2	4	0.03	4
				355.2	4	0.03	4
				363.34	5	0.49	10
				376.6	4	0.010	5
				387.9	3	0.17	18
				387.9	3	0.17	18
				387.9	3	0.17	18
				402.6	6	0.023	
				416.8	3	0.47	5
				431.8	3	0.47	5
				445.0	6	0.099	
				446.2	3	0.60	5
				473.6	4	0.17	4
				478.2	4	0.17	4
				488.0	4	0.23	24
				488.0	4	0.23	24
				505.79	3	4.94	20
				522.65	9	16.0	5
				535.4	3	0.51	5
				539.7	4	0.06	7
				539.7	4	0.06	7
				547.20	20	1.14	8

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{132}I	2.295	13	H	559.7	4	0.089	20
				572.5	4	0.04	4
				572.5	4	0.04	4
				591.1	6	0.05	5
				591.1	6	0.05	5
				600.0	6	0.08	8
				600.0	6	0.08	8
				609.8	5	0.039	10
				620.90	20	0.39	20
				621.2	3	1.58	20
				630.190	20	13.3	4
				642.4	5	0.035	
				650.50	20	2.57	20
				659.0	7	0.10	10
				667.7141	20	98.70	
				669.80	20	4.6	6
				671.40	20	3.5	10
				684.40	20	0.039	10
				687.8	5	0.039	20
				706.4	7	0.020	
				727.0	3	2.2	6
				727.2	3	3.2	6
				728.40	20	1.6	4
				771.7		0.020	20
				772.600	10	75.6	13
				780.00	20	1.18	4
				784.4	4	0.38	4
				791.2	4	0.099	20
				809.50	20	2.6	3
				812.00	20	5.5	4
				831.3	5	0.025	10
				847.9	5	0.017	5
				863.00	20	0.56	5
				866.0	6	0.025	25
				866.0	6	0.025	25
				876.60	20	1.04	4
				886.1	5	0.025	8
				888.7	5	0.021	22
				888.7	5	0.021	22
				904.4	5	0.013	4
				910.10	20	0.93	3
				927.4	3	0.41	4
				947.2	6	0.044	14
				954.55	9	17.6	5
				965.8	5	0.035	8
				984.20	20	0.59	4
				995.8	5	0.030	10
				1002.5	6	0.016	17
				1002.5	6	0.016	17
				1005.4	6	0.016	5
				1009.0	4	0.046	7
				1035.00	20	0.51	5
				1049.6	4	0.046	12
				1081.8	4	0.021	22
				1081.8	4	0.021	22
				1086.2	4	0.079	20
				1096.9	4	0.044	8
				1112.4	4	0.065	15
				1126.5	4	0.03	4
				1126.5	4	0.03	4

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{132}I	2.295	13	H	1136.000	20	3.01	14
				1143.30	20	1.35	6
				1147.8	5	0.27	5
				1172.90	20	1.09	7
				1206.7	6	0.017	
				1212.3	4	0.012	3
				1242.6	7	0.012	
				1254.1	4	0.059	7
				1263.6	5	0.027	6
				1272.8	4	0.168	20
				1290.80	20	1.13	5
				1295.10	20	1.88	7
				1297.910	20	0.89	7
				1314.0	5	0.059	9
				1317.918	6	0.118	15
				1372.07	13	2.47	10
				1390.7	7	0.015	10
				1398.57	10	7.01	20
				1410.6	3	0.043	7
				1442.56	10	1.40	5
				1456.50	20	0.049	7
				1476.70	20	0.130	9
				1519.60	20	0.079	5
				1542.3	6	0.0158	20
				1592.9	3	0.047	4
				1617.90	20	0.010	5
				1644.0	6	0.013	4
				1661.4	5	0.016	3
				1671.3	4	0.022	4
				1715.4	4	0.055	4
				1720.6	5	0.054	4
				1727.2	4	0.067	6
				1752.3	7	0.025	8
				1757.40	20	0.30	3
				1760.4	6	0.059	20
				1768.5	8	0.025	8
				1778.5	4	0.079	8
				1814.0	5	0.016	4
				1830.1	5	0.028	5
				1879.2	5	0.014	3
				1913.7	5	0.030	10
				1921.08	12	1.23	6
				1985.625	6	0.0118	20
^{133m}Te	55.4	4	M	18.08		0.019	4
				20.860	10	0.32	4
				39.90	10	0.146	23
				39.90	10	0.089	24
				47.470	10	0.177	22
				50.00	20	0.07	5
				52.5	3	0.013	9
				74.050	10	0.30	4
				81.610	10	0.26	3
				86.9	5	0.035	6
				88.064	3	1.06	12
				92.33	3	0.16	4
				94.9890	20	2.30	23
				97.80	10	0.106	21
				110.2	5	0.066	19
				112.26	15	0.08	4
				116.44	9	0.22	10

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{133m}Te	55.4	4	M	119.58	15	0.09	5
				136.64	5	0.12	4
				150.800	20	0.27	10
				150.800	20	0.53	7
				157.60	10	0.089	24
				164.400	10	0.77	9
				169.025	6	4.2	5
				176.9	5	0.18	9
				177.19	14	0.18	5
				178.10	14	0.27	10
				184.61	16	0.13	5
				193.394	24	0.47	6
				198.18	7	0.13	9
				200.65	8	0.35	10
				201.00	10	0.13	5
				213.478	11	1.73	18
				214.00	10	0.18	5
				221.10	10	0.19	5
				224.17	7	0.13	5
				230.10	20	0.22	10
				235.00	10	0.13	5
				240.90	20	0.27	10
				244.38	5	0.27	6
				248.9	5	0.027	10
				251.51	7	0.22	5
				257.79	7	0.35	6
				261.626	7	6.3	7
				278.00	11	0.44	10
				281.2	5	0.09	5
				284.8	5	0.18	9
				294.82	13	0.18	5
				307.90	10	0.22	5
				312.072	3	1.77	22
				314.24	16	0.31	6
				318.8	5	0.18	9
				322.40	20	0.09	5
				326.0	4	0.22	10
				334.245	5	2.7	3
				334.26	4	6.8	9
				342.8	3	0.40	6
				344.40	5	0.58	11
				345.6	4	0.18	14
				347.30	4	0.53	7
				355.42	13	0.52	6
				360.8	6	0.04	3
				363.06	7	0.40	6
				367.90	20	0.18	5
				368.50	20	0.09	5
				369.30	20	0.09	5
				376.80	10	0.18	5
				384.0	7	0.13	9
				392.44	3	0.142	23
				396.97	4	0.58	8
				406.00	10	0.31	6
				413.20	20	0.53	7
				415.0		0.09	5
				429.03	5	1.77	20
				435.28	5	0.97	17
				444.940	20	1.64	19
				458.0	7	0.09	5

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{133m}Te	55.4	4	M	462.23	3	1.24	22
				464.0	5	0.22	14
				471.87	4	0.66	11
				474.7	4	0.09	5
				478.62	6	0.75	16
				487.40	6	0.44	10
				492.96	15	0.62	11
				495.00	10	0.155	24
				507.2	3	0.35	10
				519.70	10	0.22	10
				525.63	14	0.22	10
				532.40	5	0.71	9
				534.88	4	0.84	12
				540.30	20	0.22	10
				555.00	20	0.09	5
				565.3	5	0.053	23
				574.1	5	0.58	11
				574.11	3	0.97	11
				581.38	15	0.40	10
				586.4	3	0.22	10
				601.5	5	0.102	17
				602.10	20	0.013	5
				605.11	4	1.02	11
				607.3	8	0.13	9
				621.3	5	0.40	19
				623.30	20	0.22	10
				629.0	5	0.27	10
				632.0	4	0.22	10
				636.5	4	0.18	9
				642.33	9	0.71	12
				647.510	20	15.5	16
				653.3	6	0.49	19
				663.20	20	0.09	4
				681.00	10	0.09	5
				698.10	10	0.75	16
				702.91	4	1.95	24
				710.40	10	0.58	15
				718.90	20	0.66	19
				723.50	20	0.22	10
				724.0	10	0.09	5
				731.880	10	0.49	10
				734.00	4	1.42	17
				734.10	10	0.06	4
				739.79	15	0.49	14
				742.9	5	0.31	10
				753.30	20	0.27	10
				756.8	4	0.27	10
				779.67	4	1.42	20
				782.11	13	0.27	6
				789.7	3	0.35	10
				791.7	9	0.09	9
				792.6	9	0.09	9
				792.9	9	0.09	9
				794.7	9	0.84	24
				795.9	9	0.09	9
				800.54	5	0.89	24
				805.1	3	0.13	5
				816.34	8	0.62	8
				819.3	3	0.13	9
				827.05	9	0.44	10

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{133m}Te	55.4	4	M	851.7	5	0.09	5
				859.0	10	0.09	5
				863.955	9	12.5	13
				882.70	5	1.77	22
				884.80	6	0.80	16
				884.80	6	0.80	16
				888.53	15	0.66	15
				889.9	3	0.22	5
				891.40	10	0.84	16
				912.671	4	44	5
				914.774	12	8.8	9
				945.2	5	0.49	10
				949.2	3	0.53	15
				970.50	20	0.27	14
				972.64	11	0.44	14
				978.30	4	3.9	4
				980.26	5	1.19	18
				995.090	20	0.40	14
				996.1	3	0.31	23
				1007.5	5	0.53	15
				1015.1	3	0.09	5
				1029.88	6	0.97	17
				1035.50	10	0.09	5
				1053.7	3	0.13	5
				1059.8	5	0.04	5
				1061.89	6	1.33	19
				1078.13	15	0.13	9
				1079.63	14	0.44	10
				1090.50	20	0.09	5
				1098.4	5	0.71	19
				1103.9	3	0.09	5
				1134.88	15	0.27	10
				1137.3	5	0.22	14
				1142.74	9	1.06	21
				1174.0	5	0.31	10
				1198.0	10	0.18	9
				1204.20	20	0.18	5
				1227.5	8	0.13	9
				1229.6	3	0.18	9
				1252.00	20	0.27	10
				1299.20	20	0.13	9
				1307.20	20	0.31	6
				1334.0	10	0.22	18
				1348.87	5	1.19	13
				1372.3	5	0.22	10
				1392.3	5	0.09	5
				1405.0	9	0.09	5
				1455.00	10	0.58	15
				1456		0.09	9
				1458.90	20	0.13	5
				1506.2	8	0.22	10
				1516.26	8	1.02	17
				1537.0	8	0.071	24
				1552.0	10	0.13	9
				1570.0	3	0.09	5
				1573.50	20	0.22	10
				1581.0	8	0.13	9
				1587.66	6	1.15	18
				1643.6	5	0.27	10
				1646.2	3	0.22	10

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{133m}Te	55.4	4	M	1683.230	20	3.3	4
				1704.40	10	0.58	8
				1773.20	10	0.53	7
				1797.50	20	0.14	4
				1870.80	10	0.44	10
				1881.20	20	0.18	5
				1885.62	7	0.80	12
				1892.98	8	0.12	4
				1914.0	10	0.04	4
				1967.80	20	0.13	5
				1974.60	20	0.031	10
^{133}I	20.83	8	H	150.4		0.030	7
				176.97	7	0.078	18
				233.221	15	0.294	9
				245.95	8	0.035	9
				262.702	6	0.359	12
				267.173	19	0.117	7
				345.43	5	0.104	18
				361.09	5	0.11	4
				372.05	15	0.010	6
				381.59	7	0.045	5
				386.85	5	0.059	5
				417.6		0.154	11
				422.910	12	0.311	11
				438.87	8	0.040	5
				510.530	4	1.83	6
				522.4		0.04	5
				529.872	3	87.0	23
				537.73	10	0.036	7
				556.17	8	0.020	3
				617.974	14	0.544	16
				648.76	6	0.057	13
				670.10	8	0.043	6
				678.7	3	0.022	7
				680.247	11	0.650	20
				706.578	8	1.51	5
				768.382	15	0.460	15
				789.59	6	0.050	4
				820.506	22	0.155	6
				856.278	7	1.24	4
				875.329	5	4.51	13
				909.67	3	0.214	9
				911.49	5	0.046	7
				1052.296	18	0.556	17
				1060.07	6	0.138	7
				1087.71	10	0.0122	18
				1236.441	6	1.51	5
				1298.223	5	2.35	7
				1350.38	3	0.150	5
^{133}Xe	5.2475	5	D	79.6142	12	0.44	19
				80.9979	11	36.9	3
				160.6120	16	0.1066	13
^{133m}Xe	2.198	13	D	233.221	15	10.12	15
^{133}Ba	10.551	11	Y	53.1622	6	2.14	4
				79.6142	12	2.65	5
				80.9979	11	32.9	4
				160.6120	16	0.638	6
				223.2368	13	0.453	4
				276.3989	12	7.16	5
				302.8508	5	18.34	13

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{133}Ba	10.551	11	Y	356.0129	7	62.05	19
				383.8485	12	8.94	7
^{134}Te	41.8	8	M	29.60		0.015	15
				76.83	6	0.274	25
				79.445	12	20.9	9
				101.42	3	0.38	9
				131.05	20	0.18	6
				137.0	4	0.09	6
				180.891	15	18.3	8
				183.05	12	0.6	3
				201.235	15	8.9	4
				210.465	16	22.7	14
				259.8	3	0.44	9
				277.951	8	21.2	11
				435.06	4	18.9	11
				460.997	22	9.7	7
				464.64	5	4.7	4
				565.992	13	18.6	11
				636.26	10	1.68	22
				645.40	10	0.89	10
				665.85	10	1.18	18
				712.97	5	4.7	6
				742.586	18	15.3	8
				767.200	20	29.5	15
				844.06	5	1.2	3
				896.02	10	0.44	12
				925.55	7	1.48	16
				1027.00	10	0.44	12
^{134}I	52.5	2	M	135.399	22	4.3	3
				139.03	3	0.76	4
				151.98	15	0.106	12
				162.48	7	0.29	3
				188.47	4	0.77	6
				217.00	20	0.23	3
				235.47	3	2.13	16
				278.80	15	0.144	20
				319.81	6	0.46	3
				351.08	10	0.42	7
				405.451	20	7.37	24
				411.00	8	0.57	4
				433.35	3	4.15	17
				458.92	6	1.31	7
				465.50	10	0.36	4
				488.88	4	1.45	7
				514.40	3	2.24	10
				540.83	3	7.66	24
				565.52	4	0.95	7
				570.75	15	0.31	8
				595.362	20	11.1	5
				621.79	3	10.6	5
				627.96	3	2.22	14
				677.34	3	7.9	4
				706.65	10	0.83	6
				730.74	4	1.83	9
				739.18	8	0.69	5
				766.68	4	4.15	15
				816.38	7	0.62	7
				847.03	3	96	3
				857.29	3	6.70	23
				864.0	3	0.19	3

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{134}I	52.5	2	M	884.09	3	65.1	23
				922.6	3	0.14	3
				947.86	4	4.01	15
				966.90	5	0.39	4
				974.67	4	4.78	22
				1040.25	10	2.03	15
				1052.2	3	0.067	20
				1058.8	3	0.10	3
				1072.55	3	14.9	6
				1087.00	20	0.086	20
				1100.07	12	0.69	6
				1103.18	12	0.80	6
				1136.16	4	9.1	6
				1159.10	8	0.34	3
				1164.0	3	0.13	3
				1183.2	5	0.06	7
				1190.03	8	0.35	3
				1225.5	3	0.067	20
				1239.0	3	0.21	6
				1243.8	3	0.077	20
				1269.49	5	0.56	4
				1322.4	3	0.11	4
				1336.00	20	0.14	3
				1352.62	8	0.41	3
				1395.0	10	0.077	20
				1407.40	20	0.096	20
				1414.3	5	0.22	6
				1428.2	3	0.17	4
				1431.4	3	0.17	4
				1455.24	5	2.30	20
				1470.00	7	0.76	4
				1505.5	4	0.11	4
				1541.51	7	0.51	4
				1613.80	4	4.31	21
				1629.24	8	0.19	4
				1644.25	7	0.39	4
				1655.19	10	0.23	3
				1741.49	5	2.56	16
				1806.84	4	5.55	22
				1868.50	20	0.067	20
				1893.2	3	0.057	10
				1925.88	10	0.18	3
				1947.3	3	0.096	20
^{134}Cs	2.0652	4	Y	242.738	8	0.027	3
				326.589	13	0.0162	10
				475.3650	20	1.477	7
				563.246	5	8.338	14
				569.331	3	15.373	17
				604.7210	20	97.62	11
				795.864	4	85.46	6
				801.953	4	8.688	16
				1038.610	7	0.990	3
				1167.968	5	1.790	5
				1365.185	7	3.017	8
^{135}I	6.58	3	H	112.8		0.0126	4
				162.65	11	0.010	3
				165.74	6	0.031	3
				184.49	8	0.0235	25
				197.19	7	0.033	3
				220.502	15	1.75	7

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{135}I	6.58	3	H	229.72	3	0.241	8
				247.5	3	0.029	9
				254.74	13	0.023	9
				264.26	9	0.184	7
				288.451	16	3.10	12
				290.27	4	0.304	20
				304.91	13	0.032	3
				305.83	9	0.095	4
				333.60	20	0.037	3
				361.85	13	0.187	24
				403.03	4	0.232	8
				414.83	3	0.301	18
				417.633	22	3.53	12
				429.93	3	0.304	23
				433.741	19	0.554	23
				451.63	3	0.316	18
				530.8	4	0.032	15
				546.557	16	7.15	24
				575.97	8	0.129	24
				588.28	6	0.052	15
				616.90	20	0.037	18
				649.85	4	0.46	3
				656.09	10	0.075	15
				679.22	15	0.055	15
				684.60	20	0.023	9
				690.13	5	0.129	15
				707.92	4	0.66	4
				785.48	5	0.152	18
				795.5	4	0.023	23
				797.71	8	0.17	3
				807.2	3	0.046	18
				836.804	16	6.69	23
				960.3		0.03	3
				961.4		0.15	3
				972.0		0.89	4
				972.6		1.21	5
				995.09	10	0.15	3
				1038.760	21	7.9	3
				1096.86	10	0.089	15
				1101.58	3	1.61	6
				1124.00	3	3.62	12
				1131.511	18	22.6	8
				1159.90	20	0.103	24
				1169.04	4	0.88	4
				1180.46	9	0.063	9
				1225.6	3	0.043	18
				1240.47	3	0.90	4
				1260.409	17	28.7	10
				1277.83	12	0.057	4
				1308.70	15	0.034	9
				1315.77	11	0.066	18
				1334.80	20	0.032	9
				1343.66	9	0.077	12
				1367.89	4	0.61	3
				1416.3	4	0.032	9
				1441.8	5	0.017	12
				1448.35	10	0.32	3
				1457.56	3	8.7	3
				1502.79	4	1.08	5
				1521.99	13	0.037	18

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{135}I	6.58	3	H	1543.70	20	0.026	9
				1566.41	3	1.29	5
				1613.75	14	0.026	6
				1678.027	21	9.6	4
				1706.459	21	4.10	18
				1742.0	4	0.017	6
				1791.196	21	7.72	25
				1830.69	4	0.58	3
				1927.30	3	0.296	15
				1948.49	5	0.063	6
^{135}Xe	9.14	2	H	158.197	18	0.289	14
				200.19	10	0.012	5
				249.794	15	90	3
				358.39	3	0.221	11
				373.13	10	0.015	3
				407.990	20	0.358	17
				608.185	15	2.90	14
				654.432	16	0.0450	24
				731.520	20	0.055	4
				812.63	3	0.070	3
^{135m}Xe	15.29	5	M	526.561	17	80.6	6
^{136}Cs	13.16	3	D	66.881	17	4.79	20
				86.36	3	5.18	20
				109.681	7	0.21	3
				153.246	4	5.75	18
				163.9200	20	3.39	12
				166.576	6	0.37	4
				176.602	4	10.0	4
				187.285	6	0.36	4
				233.5	4	0.080	10
				273.646	8	11.1	4
				302.4	4	0.030	10
				315.5	5	0.020	18
				319.911	8	0.50	5
				340.547	8	42.2	13
				490.00	20	0.080	20
				507.188	10	0.97	3
				733.0	5	0.020	
				818.514	12	99.70	
				1048.073	20	80	3
				1235.362	23	20.0	7
				1321.6	4	0.050	20
				1538.09	20	0.100	20
				1551.30	20	0.015	5
^{137}Cs	30.08	9	Y	661.657	3	85.10	20
^{138}Cs	33.41	18	M	112.60	13	0.130	23
				138.10	6	1.49	9
				191.96	6	0.50	4
				193.89	8	0.328	23
				212.32	8	0.175	14
				227.76	6	1.51	4
				324.90	8	0.290	19
				333.86	16	0.089	16
				363.93	8	0.244	23
				365.29	13	0.191	23
				368.7	4	0.022	9
				408.98	6	4.66	10
				421.59	7	0.427	23
				462.796	5	30.7	7
				516.74	12	0.43	5

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{138}Cs	33.41	18	M	547.001	5	10.76	24
				575.7	4	0.021	9
				596.2	4	0.026	10
				683.59	15	0.108	14
				702.92	17	0.084	13
				717.7	3	0.040	13
				754.5	4	0.034	13
				766.10	12	0.146	15
				773.31	10	0.233	19
				782.08	9	0.33	3
				797.7	5	0.053	23
				802.6	3	0.038	23
				813.0	3	0.060	18
				842.21	16	0.082	12
				855.6	5	0.023	10
				871.80	8	5.11	14
				880.8	3	0.11	3
				935.03	12	0.181	16
				946.0	5	0.031	13
				953.0	3	0.053	15
				1009.78	8	29.8	7
				1041.4	3	0.063	17
				1054.32	15	0.159	19
				1147.22	9	1.24	7
				1199.15	24	0.17	3
				1203.69	13	0.40	4
				1264.94	16	0.137	17
				1343.59	9	1.14	6
				1359.1	5	0.048	19
				1386.39	21	0.076	12
				1415.68	13	0.37	3
				1435.86	9	76.3	16
				1445.0	3	0.97	19
				1495.63	23	0.18	4
				1555.31	10	0.366	23
				1614.09	20	0.137	23
				1717.1	3	0.107	23
				1727.68	18	0.111	13
				1748.7	5	0.07	3
				1778.25	23	0.137	23
				1806.65	18	0.092	11
				1821.7	3	0.045	10
				1903.2	4	0.046	14
				1941.0	3	0.079	16
^{139}Ba	82.93	9	M	165.8575	11	23.7	4
				1254.631	10	0.0300	5
				1310.617	10	0.0149	5
				1420.478	10	0.261	3
^{139}Ce	137.641	20	D	165.8575	11	79.90	
^{140}Ba	12.7527	23	D	13.846	15	1.22	18
				29.9660	10	14.1	5
				113.51	3	0.0161	13
				118.837	3	0.061	8
				132.6870	10	0.202	6
				162.6600	10	6.22	10
				304.849	3	4.29	7
				423.7220	10	3.15	5
				437.5750	20	1.929	20
				537.261	9	24.39	24
^{140}La	1.67855	12	D	64.135	10	0.0143	19

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{140}La	1.67855	12	D	68.916	6	0.0754	19
				109.422	11	0.219	4
				131.117	8	0.467	10
				173.543	9	0.127	4
				241.93	3	0.414	8
				266.543	12	0.466	8
				306.90	20	0.025	7
				328.762	8	20.3	3
				397.52	5	0.073	5
				432.493	12	2.90	3
				438.5	5	0.039	10
				487.021	12	45.5	6
				618.12	5	0.037	4
				751.637	18	4.33	4
				815.772	19	23.28	20
				867.846	20	5.50	7
				919.550	23	2.66	3
				925.189	21	6.90	7
				950.99	3	0.519	7
				992.9	5	0.013	5
				1045.05	24	0.025	15
				1097.20	23	0.023	5
				1303.5	4	0.042	7
				1405.20	17	0.059	7
				1596.21	4	95.4	15
				1877.29	19	0.041	4
				1924.62	13	0.0134	19
^{141}La	3.92	3	H	662.06	6	0.0259	23
				1354.52	9	1.64	15
				1497.00	10	0.0182	17
				1693.30	10	0.074	7
				1739.00	10	0.0156	15
^{141}Ce	32.511	13	D	145.4433	14	48.4	3
^{142}La	91.1	5	M	105.9	3	0.1422	15
				173.5	3	0.09	5
				178.3	3	0.19	5
				297.9	3	0.05	5
				318.0	3	0.05	5
				332.1	4	0.05	5
				339.5	4	0.09	5
				341.7	4	0.05	5
				350.3	3	0.024	24
				355.3	3	0.024	24
				361.1	3	0.0948	10
				367.30	20	0.1422	15
				393.60	20	0.1896	20
				420.20	20	0.237	3
				433.30	20	0.379	4
				439.0	5	0.05	5
				453.7	5	0.0948	10
				514.7	4	0.14	5
				529.4	6	0.05	5
				531.60	20	0.1422	15
				538.3	5	0.0474	5
				546.00	20	0.024	24
				570.6	5	0.05	5
				578.09	4	1.33	5
				639.5	4	0.09	5
				641.285	9	47.4	5
				646.2	7	0.14	10

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{142}La	91.1	5	M	677.0	6	0.05	5
				681.2	6	0.05	5
				692.4	6	0.0948	10
				793.1	4	0.05	5
				861.6	7	1.66	5
				878.2	4	0.1896	20
				894.9	4	8.34	17
				915.6	5	0.05	5
				946.9	4	0.0948	10
				962.2	4	0.38	5
				989.8	5	0.0948	10
				1006.70	20	0.237	3
				1011.4	3	3.93	11
				1020.8	4	0.024	24
				1039.4	3	0.0948	10
				1043.7	5	2.70	6
				1058.4	4	0.0948	10
				1069.4	5	0.09	5
				1072.2	8	0.09	5
				1089.9	7	0.1422	15
				1091.2	8	0.0948	10
				1104.8	8	0.0474	5
				1112.9	5	0.05	5
				1117.7	5	0.024	24
				1121.2	6	0.0474	5
				1130.6	5	0.47	5
				1144.2	4	0.024	24
				1160.2	5	1.71	5
				1176.4	4	0.1422	15
				1191.1	4	0.379	4
				1205.7	5	0.0474	5
				1214.0	5	0.05	5
				1231.3	5	0.05	5
				1233.1	6	1.90	6
				1242.0	4	0.237	3
				1264.7	4	0.0948	10
				1280.1	4	0.024	24
				1283.2	5	0.024	24
				1288.5	4	0.024	24
				1323.2	5	0.33	5
				1348.7	5	0.024	24
				1352.6	5	0.0948	10
				1363.0	5	2.13	6
				1372.9	7	0.05	5
				1389.3	8	0.43	5
				1393.0	8	0.1422	15
				1402.2	5	0.1422	15
				1445.5	5	0.1422	15
				1455.1	5	0.0948	10
				1461.2	5	0.95	5
				1494.1	7	0.1422	15
				1500.3	6	0.0948	10
				1516.3	6	0.43	5
				1524.6	7	0.47	5
				1540.2	7	0.47	10
				1545.8	5	2.99	15
				1618.2	7	0.284	3
				1628.5	7	0.024	24
				1644.3	7	0.237	3
				1688.6	8	0.237	3

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{142}La	91.1	5	M	1722.7	8	1.52	5
				1756.4	8	2.70	6
				1768.2	7	0.24	5
				1770.8	7	0.19	5
				1793.8	7	0.024	24
				1846.2	8	0.05	5
				1887.3	8	0.14	10
				1901.3	7	7.16	17
				1923.3	7	0.19	5
				1933.6	7	0.1422	15
				1949.4	9	0.38	5
				1961.5	9	0.1422	15
^{143}Ce	33.039	6	H	57.356	7	11.7	4
				139.742	17	0.077	5
				231.5500	20	2.05	5
				293.2660	20	42.8	5
				350.619	3	3.23	4
				371.29	3	0.025	3
				389.640	20	0.0364	18
				432.999	6	0.159	4
				446.02	9	0.015	3
				447.450	20	0.060	3
				490.368	5	2.16	3
				497.810	20	0.045	3
				556.870	10	0.0317	18
				587.200	20	0.267	4
				614.22	3	0.0120	13
				664.571	15	5.69	7
				721.929	13	5.39	7
				791.070	20	0.0133	5
				806.340	20	0.0287	9
				809.980	20	0.0312	9
				880.460	10	1.031	13
				937.820	10	0.0261	13
				1002.850	10	0.0753	19
				1031.22	3	0.0201	9
				1046.78	4	0.0120	9
				1060.220	20	0.0364	14
				1103.250	20	0.415	6
^{144}Ce	284.91	5	D	33.568	10	0.200	23
				40.98	10	0.257	16
				53.395	5	0.100	8
				80.120	5	1.36	6
				99.961	15	0.040	5
				133.5150	20	11.09	20
^{144}Pr	17.28	5	M	696.510	3	1.342	14
				1489.160	5	0.278	5
^{145}Pr	5.984	10	H	72.500	4	0.261	15
				318.666	6	0.0138	4
				352.481	5	0.0368	9
				492.624	5	0.0252	8
				623.502	6	0.0238	8
				657.668	5	0.0641	16
				675.795	5	0.514	12
				707.949	12	0.0100	5
				748.278	5	0.525	10
				848.237	17	0.0725	20
				920.710	5	0.146	4
				978.969	15	0.256	7
				1051.412	5	0.175	5

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{145}Pr	5.984	10	H	1150.258	3	0.194	6
				1161.04	4	0.0150	6
^{147}Nd	10.98	1	D	91.1050	20	28.1	8
				117.98	5	0.0160	14
				120.48	5	0.376	9
				196.64	4	0.190	4
				240.50	20	0.043	3
				271.87	6	0.0132	10
				275.374	15	0.910	19
				319.411	18	2.13	5
				398.155	20	0.912	19
				408.52	6	0.0187	14
				410.48	3	0.150	4
				439.895	22	1.28	3
				489.24	3	0.155	4
				531.016	22	13.4	3
				541.83	7	0.019	3
				589.35	4	0.039	3
				594.80	3	0.283	6
				680.52	15	0.0294	15
				685.90	4	0.886	18
^{149}Nd	1.728	1	H	30.00	3	0.017	5
				36.70		0.018	8
				58.526	11	1.42	6
				58.883	20	1.30	22
				65.23		0.016	6
				65.42		0.031	11
				67.20	19	0.044	11
				69.510	21	0.065	9
				72.753	12	0.60	3
				74.32	3	1.11	24
				74.66	10	0.98	16
				75.69	6	0.228	23
				77.097	10	0.61	3
				80.305	10	0.451	19
				90.12	5	0.052	4
				92.89	3	0.056	4
				94.88	10	0.041	13
				96.90		0.034	13
				97.001	12	1.45	12
				107.79	3	0.085	16
				112.52	4	0.119	17
				114.314	11	19.2	15
				116.930	24	0.11	4
				122.415	13	0.256	19
				126.630	18	0.111	9
				137.05	3	0.062	6
				139.210	12	0.51	3
				141.06	7	0.039	3
				155.1		0.034	16
				155.873	9	5.9	3
				171.17	10	0.032	6
				176.3		0.049	11
				177.818	18	0.155	17
				185.49	3	0.104	7
				188.640	8	1.79	11
				188.8		0.0104	4
				192.026	9	0.57	3
				197.4		0.0130	5
				198.0		0.049	6

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{149}Nd	1.728	1	H	198.928	8	1.39	7
				208.147	9	2.55	10
				211.309	7	25.9	15
				213.947	16	0.40	3
				224.49	6	0.024	3
				226.847	19	0.163	9
				229.566	9	0.482	23
				238.611	3	0.89	4
				239.6		0.0130	5
				240.220	7	3.94	22
				245.5		0.21	11
				245.72	5	0.80	21
				250.83	4	0.034	3
				254.228	22	0.085	5
				258.067	13	0.376	18
				263.4		0.0233	9
				267.693	8	6.0	3
				270.166	7	10.7	5
				273.24	4	0.18	8
				273.5		0.08	4
				275.437	11	0.65	3
				276.960	17	0.342	17
				282.4		0.017	7
				282.456	10	0.62	3
				287.7		0.013	6
				288.194	10	0.69	4
				290.374	20	0.063	3
				294.802	10	0.57	3
				301.128	14	0.376	18
				310.979	13	0.510	24
				326.554	10	4.56	21
				329.2		0.021	11
				332.167	18	0.0176	13
				342.81	10	0.083	19
				347.843	18	0.161	8
				349.231	9	1.38	7
				351.632	3	1.17	5
				352.78	3	0.054	4
				357.03	4	0.047	4
				358.49	10	0.010	6
				360.052	18	0.153	8
				366.634	14	0.54	3
				371.92	6	0.022	3
				380.8		0.052	4
				384.687	16	0.267	13
				396.76	4	0.073	4
				399.1		0.015	6
				413.69	3	0.0174	15
				423.553	10	7.4	5
				425.22	3	0.272	15
				432.7		0.013	6
				439.6		0.036	16
				441.47	13	0.032	3
				443.551	11	1.15	7
				443.7		0.0104	4
				462.34	10	0.041	21
				470.5		0.010	6
				480.32	5	0.041	3
				483.59	5	0.067	4
				493.85	5	0.060	6

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{149}Nd	1.728	1	H	498.1		0.010	3
				498.6		0.036	3
				510.30	5	0.062	16
				515.75	9	0.036	6
				527.6		0.012	4
				533.20	4	0.091	7
				536.6		0.047	21
				540.509	10	6.6	4
				547.1		0.016	8
				547.4		0.010	6
				555.88	9	0.59	4
				556.83	9	0.44	6
				558.0		0.0104	4
				567.6		0.017	4
				579.28	3	0.075	6
				582.9		0.018	8
				583.03	3	0.049	13
				594.40	5	0.028	3
				598.06	5	0.028	3
				606.67	16	0.010	6
				630.237	19	0.189	8
				635.7		0.067	14
				636.2		0.052	11
				651.0		0.06	3
				653.9		0.0181	7
				654.831	13	8.0	5
				657.2		0.018	8
				665.22	7	0.0153	12
				671.56	10	0.010	4
				673.58	7	0.011	3
				675.79	4	0.0254	21
				686.943	21	0.088	7
				696.264	21	0.171	13
				712.59	3	0.070	6
				718.43	4	0.049	6
				726.822	12	0.040	3
				727.88	5	0.0163	20
				736.18	11	0.018	5
				740.57	3	0.0142	6
				749.63	5	0.0135	17
				754.291	21	0.039	3
				761.46	5	0.028	3
				768.172	21	0.060	6
				786.73	4	0.0101	14
				793.43	3	0.0225	21
				806.10	8	0.025	3
				808.843	20	0.189	15
				809.6		0.0155	6
				813.19	8	0.0114	19
				832.09	5	0.023	3
				837.40	3	0.031	3
				839.24	5	0.0275	24
				842.847	23	0.052	6
				849.93	3	0.0218	20
				859.42	5	0.0197	20
				861.54	3	0.0176	20
				865.00	5	0.013	7
				871.375	23	0.034	3
				911.3		0.0155	6
				923.874	23	0.101	9

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{149}Nd	1.728	1	H	929.8	3	0.0109	14
				933.24	4	0.058	6
				945.80	3	0.0215	20
				963.95	3	0.025	3
				978.8		0.016	6
				979.013	23	0.078	11
				992.83	6	0.0148	17
				1022.78	3	0.104	9
				1041.95	3	0.028	3
				1075.95	4	0.021	3
				1078.76	3	0.063	8
				1100.77	3	0.049	6
				1123.47	8	0.0150	24
				1125.32	5	0.030	4
				1150.08	8	0.0231	25
				1172.76	19	0.037	5
				1180.5	3	0.040	4
				1234.12	4	0.026	4
				1293.4	4	0.018	8
				1367.96	13	0.016	13
				1407.26	6	0.0150	15
^{149}Pm	53.08	5	H	22.520	10	0.025	25
				277.090	20	0.0288	23
				285.950	10	3.10	20
				535.90	5	0.0115	10
				558.37	4	0.0152	14
				568.36	7	0.0186	18
				590.880	10	0.069	6
				613.92	6	0.0149	14
				808.11	5	0.0164	17
				830.53	7	0.033	4
				833.40	7	0.033	4
				859.46	6	0.109	8
				881.98	5	0.0239	18
^{151}Pm	28.40	4	H	4.821	3	0.061	16
				25.690	20	0.97	8
				35.2	3	0.034	25
				59.93	4	0.0248	25
				62.910	20	0.207	18
				64.880	10	1.89	18
				65.830	10	1.15	11
				69.700	20	0.47	5
				76.220	20	0.203	18
				88.80	9	0.0124	17
				92.97	4	0.034	3
				98.050	20	0.36	4
				98.74	8	0.059	10
				100.020	10	2.54	19
				100.6	3	0.012	4
				101.930	10	1.28	11
				102.7	5	0.032	16
				104.840	10	3.5	3
				109.560	20	0.086	8
				121.77	4	0.090	10
				125.2	3	0.0122	19
				130.430	20	0.068	6
				134.22	20	0.0203	22
				138.38	12	0.041	5
				138.9	3	0.027	7
				139.280	20	0.50	5

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{151}Pm	28.40	4	H	141.7	5	0.010	4
				143.17	3	0.214	16
				143.2	3	0.010	4
				146.2	4	0.017	3
				147.53	3	0.153	11
				148.50	12	0.054	5
				155.50	20	0.025	5
				156.18	5	0.149	15
				162.940	20	0.88	8
				163.580	20	1.55	13
				167.750	20	8.3	6
				168.39	5	0.92	10
				176.52	3	0.86	8
				177.160	10	3.8	3
				186.590	20	0.180	24
				195.50	20	0.027	7
				201.960	20	0.88	6
				204.17	3	0.131	13
				206.70	20	0.036	7
				209.000	10	1.73	14
				227.180	20	0.34	3
				227.81	15	0.050	16
				229.01	15	0.023	5
				232.430	20	1.03	10
				232.7	3	0.088	21
				236.20	20	0.095	17
				236.60	10	0.160	20
				236.70	20	0.19	5
				237.10	20	0.52	10
				240.090	10	3.8	3
				247.10	20	0.018	5
				247.80	20	0.029	5
				254.28	3	0.169	18
				258.110	20	0.56	5
				261.4	3	0.011	4
				270.72	3	0.068	8
				275.210	20	6.8	6
				277.62	10	0.061	14
				280.09	3	0.232	21
				290.750	10	0.83	8
				292.4	3	0.011	7
				294.8	3	0.014	5
				295.2	3	0.016	5
				297.80	5	0.038	5
				301.80	20	0.014	5
				302.5	3	0.027	7
				302.8	3	0.025	5
				306.74	6	0.239	17
				308.97	8	0.081	10
				310.80	20	0.017	5
				310.80	20	0.036	7
				314.92	10	0.063	8
				321.87	10	0.097	12
				323.940	10	1.22	11
				325.2	3	0.015	4
				325.80	10	0.106	15
				329.0	8	0.014	7
				329.750	20	0.221	17
				340.080	10	22.5	9
				341.0	3	0.074	19

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{151}Pm	28.40	4	H	344.900	10	2.12	14
				346.10	20	0.038	10
				349.81	3	0.142	15
				352.3	3	0.016	5
				353.32	10	0.106	12
				358.40	20	0.015	3
				360.9	3	0.011	3
				369.00	20	0.016	3
				374.20	20	0.022	5
				376.9	3	0.016	5
				378.5	3	0.010	5
				379.86	3	0.95	8
				381.2	3	0.020	7
				390.67	6	0.054	5
				395.63	10	0.043	5
				398.90	20	0.032	5
				404.74	6	0.065	8
				407.03	3	0.187	16
				410.75	7	0.063	8
				415.7	3	0.022	5
				416.8	4	0.016	5
				420.65	6	0.056	8
				424.55	6	0.050	7
				425.6	4	0.010	3
				427.25	4	0.063	8
				429.1	3	0.016	7
				440.850	20	1.51	11
				443.8	3	0.023	9
				445.680	20	4.0	3
				448.7	3	0.020	9
				451.400	20	0.29	3
				452.2	5	0.014	5
				454.4	4	0.014	5
				456.05	13	0.038	7
				462.24	13	0.036	5
				467.2	6	0.011	5
				470.5	3	0.018	7
				471.30	20	0.018	7
				471.4	5	0.014	5
				477.75	4	0.095	10
				487.10	20	0.017	5
				490.26	5	0.126	11
				494.9	4	0.011	5
				495.5	4	0.014	5
				507.27	14	0.047	7
				516.25	6	0.194	16
				521.10	20	0.032	5
				532.50	20	0.034	5
				537.65	11	0.045	7
				550.7	3	0.016	3
				554.2	3	0.016	3
				562.1	3	0.019	4
				565.00	4	0.353	25
				572.50	20	0.052	12
				573.20	20	0.029	7
				574.97	7	0.117	11
				583.10	20	0.026	4
				593.6	4	0.0101	21
				597.70	10	0.079	10
				603.0	6	0.011	4

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{151}Pm	28.40	4	H	605.9	5	0.010	3
				609.25	10	0.047	5
				620.60	20	0.072	8
				636.20	3	1.42	11
				654.25	6	0.241	19
				655.6	5	0.011	5
				661.55	15	0.023	9
				663.50	10	0.095	10
				668.70	20	0.36	5
				669.20	20	0.29	5
				671.28	3	0.90	8
				678.30	15	0.045	5
				699.0	8	0.019	6
				704.24	8	0.34	3
				709.25	6	0.137	13
				712.00	10	0.095	10
				717.72	8	4.1	3
				719.0	5	0.011	4
				736.12	10	0.47	5
				740.80	20	0.023	5
				752.82	8	1.28	11
				769.10	8	0.106	10
				772.76	8	0.90	8
				785.10	7	0.221	18
				795.74	9	0.059	5
				807.90	6	0.56	5
				811.80	10	0.068	8
				817.70	20	0.17	4
				817.70	20	0.09	4
				822.45	11	0.034	10
				848.65	7	0.281	24
				877.70	10	0.101	10
				883.68	13	0.045	5
				898.58	12	0.0248	25
				911.25	15	0.026	3
				948.72	7	0.35	3
				953.41	11	0.097	10
				959.7	3	0.063	8
				968.90	20	0.0146	17
^{152}Eu	13.517	14	Y	121.7817	3	28.53	16
				148.00	5	0.0205	11
				212.43	11	0.0207	6
				244.6974	8	7.55	5
				251.633	9	0.0670	19
				271.08	4	0.0715	19
				275.42	4	0.0346	9
				295.9387	17	0.440	5
				315.10	3	0.0399	11
				316.13	13	0.0101	5
				324.83	3	0.0681	19
				329.41	5	0.1213	25
				340.46	10	0.0266	8
				344.2785	12	26.59	21
				351.66	5	0.0106	8
				367.7892	20	0.859	6
				411.1165	12	2.237	13
				416.02	3	0.1088	20
				443.9607	16	2.827	15
				444.01	17	0.298	11
				482.33	5	0.0247	8

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{152}Eu	13.517	14	Y	488.6793	20	0.414	4
				493.54	4	0.0303	14
				503.467	9	0.1524	20
				520.24	4	0.0534	17
				523.13	5	0.0153	7
				526.88	5	0.0120	8
				534.25	5	0.0410	11
				556.48	10	0.0177	7
				562.98	14	0.0202	19
				563.986	5	0.494	5
				566.438	6	0.131	4
				586.265	3	0.455	4
				595.61	12	0.032	11
				656.489	5	0.1441	23
				671.155	14	0.024	5
				674.64	14	0.169	4
				675.0		0.0213	8
				678.623	5	0.473	4
				686.60	5	0.0203	7
				688.670	5	0.856	7
				696.87	19	0.016	8
				712.83	5	0.0955	25
				719.346	7	0.250	8
				719.36	14	0.095	4
				728.04	4	0.0111	4
				764.88	4	0.189	5
				768.96	4	0.082	5
				778.9046	24	12.93	9
				794.78	5	0.0263	16
				805.71	9	0.0152	6
				810.451	5	0.317	3
				839.36	4	0.0177	6
				841.574	5	0.168	3
				867.380	3	4.23	3
				896.59	9	0.0670	22
				901.19	5	0.0854	25
				919.337	4	0.419	5
				926.31	5	0.272	4
				930.59	5	0.0729	19
				958.63	5	0.0197	11
				963.367	7	0.140	7
				964.057	5	14.51	7
				974.09	5	0.0136	8
				990.18	5	0.0314	14
				1005.27	5	0.659	11
				1084.0	10	0.245	8
				1084.38	11	0.0106	8
				1085.837	10	10.11	5
				1089.737	5	1.734	12
				1109.18	5	0.189	7
				1112.076	3	13.67	9
				1170.97	9	0.0372	16
				1206.09	16	0.0130	14
				1212.948	11	1.415	9
				1249.94	5	0.187	3
				1261.35	5	0.0335	14
				1292.78	5	0.101	3
				1299.142	8	1.633	11
				1348.10	7	0.0173	8
				1363.78	5	0.0258	6

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{152}Eu	13.517	14	Y	1408.013	3	20.87	10
				1457.643	11	0.497	5
				1528.10	4	0.279	4
^{153}Sm	46.50	21	H	69.67301	13	4.73	5
				75.42214	23	0.19	3
				83.36718	21	0.192	8
				89.48596	22	0.158	15
				97.43102	21	0.772	19
				103.18014	17	29.25	22
				151.6245	12	0.0106	5
				172.85310	21	0.0737	22
				463.60	20	0.0136	6
				531.40	15	0.0547	10
				533.20	20	0.0299	7
				539.10	20	0.0211	6
				596.70	20	0.0109	4
^{154}Eu	8.601	10	Y	123.0706	9	40.4	5
				131.56	7	0.0131	5
				188.22	7	0.2400	24
				232.12	7	0.0218	5
				247.9290	7	6.89	7
				269.65	8	0.0115	6
				301.38	7	0.0124	4
				305.2		0.0205	4
				312.32	7	0.0182	4
				322.07	7	0.0619	8
				346.70	7	0.0260	5
				397.07	7	0.0276	7
				401.26	7	0.188	3
				403.49	7	0.0223	18
				444.4925	19	0.547	6
				467.92	7	0.0626	9
				478.24	7	0.2250	23
				517.98	7	0.0498	15
				533.03	8	0.0185	11
				534.86	7	0.017	7
				557.53	7	0.269	3
				569.50	7	0.0139	21
				581.97	7	0.893	9
				591.755	3	4.95	5
				598.30	7	0.0105	14
				602.68	7	0.0293	11
				613.24	7	0.0931	12
				625.2557	24	0.316	4
				649.52	7	0.0874	19
				664.74	8	0.0261	11
				669.14	8	0.0160	8
				676.60	7	0.1672	18
				692.4206	18	1.777	19
				715.76	7	0.187	6
				723.3015	22	20.06	20
				756.8021	23	4.52	5
				800.61	8	0.0212	11
				815.51	7	0.511	6
				845.416	7	0.568	12
				850.67	7	0.243	3
				873.1835	23	12.08	12
				880.65	7	0.084	6
				892.775	6	0.521	6
				904.064	3	0.889	10

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{154}Eu	8.601	10	Y	924.57	7	0.0649	10
				996.29	7	10.48	10
				1004.76	7	18.01	19
				1047.18	18	0.0613	15
				1118.27	7	0.113	4
				1128.552	7	0.300	4
				1140.702	6	0.237	4
				1160.31	7	0.0462	6
				1188.14	7	0.0876	9
				1241.34	7	0.1226	17
				1246.121	4	0.856	11
				1274.429	4	34.8	4
				1289.88	11	0.0210	8
				1291.36	8	0.022	8
				1294.99	8	0.0116	6
				1408.28	7	0.0247	11
				1494.048	4	0.698	8
				1537.81	7	0.0575	12
				1596.481	3	1.797	24
^{156}Eu	15.19	8	D	88.970	10	8.4	12
				160.20	20	0.0103	14
				190.16	8	0.0165	21
				199.214	12	0.74	8
				215.70	20	0.013	3
				317.30	9	0.060	8
				335.69	11	0.0102	16
				348.27	9	0.0136	23
				354.20	9	0.0146	23
				434.40	9	0.209	18
				472.70	6	0.145	13
				490.34	6	0.160	14
				494.90	15	0.015	4
				498.88	6	0.066	7
				554.66	6	0.017	5
				585.90	6	0.052	13
				599.47	5	2.08	18
				626.0		0.022	5
				632.79	8	0.039	6
				646.29	5	6.3	6
				660.0		0.014	4
				707.10	20	0.065	8
				709.86	5	0.88	8
				723.47	5	5.4	5
				768.56	7	0.087	9
				778.0		0.026	5
				784.14	10	0.049	6
				797.73	6	0.109	11
				811.77	5	9.7	8
				820.36	7	0.169	15
				836.52	7	0.081	9
				839.00	20	0.030	6
				841.16	10	0.208	18
				858.36	12	0.205	18
				865.8	3	0.188	19
				867.01	8	1.33	11
				872.39	9	0.040	6
				903.62	10	0.040	6
				916.4	4	0.032	7
				928.8	4	0.028	6
				944.35	7	1.33	11

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{156}Eu	15.19	8	D	947.46	15	0.292	25
				960.50	8	1.45	13
				961.0	6	0.15	4
				963.0		0.034	6
				969.83	6	0.37	4
				1011.87	5	0.31	3
				1018.50	10	0.084	9
				1027.39	8	0.128	12
				1037		0.053	7
				1040.44	7	0.50	5
				1065.14	5	4.9	4
				1076		0.34	3
				1079.16	5	4.6	4
				1101.80	11	0.042	7
				1115.78	7	0.050	7
				1129.47	7	0.135	13
				1140.51	5	0.283	24
				1153.67	10	6.8	6
				1154.08	10	4.7	4
				1156		0.131	23
				1164.2	3	0.065	8
				1169.12	5	0.266	23
				1187.3	5	0.015	7
				1220.50	11	0.019	6
				1230.71	6	8.0	7
				1242.42	5	6.6	6
				1258.03	7	0.095	9
				1277.43	5	2.89	24
				1366.41	5	1.57	13
				1626.29	14	0.046	7
				1682.10	12	0.272	24
				1857.42	11	0.240	21
				1873		0.059	13
				1877.03	15	1.51	13
				1937.71	11	1.94	16
				1946.34	13	0.165	16
				1965.95	12	3.9	4
^{157}Eu	15.18	3	H	9.365	12	1.7	3
				51.834	14	0.76	10
				54.548	8	3.8	5
				63.929	8	23	3
				64.40	20	0.13	7
				76.925	14	0.20	4
				95.60	20	0.011	6
				116.31	3	0.040	11
				129.50	20	0.012	7
				131.438	16	0.057	16
				158.41	3	0.025	7
				161.820	13	0.086	18
				208.621	11	0.150	18
				209.00	20	0.017	9
				212.05	3	0.062	10
				226.63	3	0.038	9
				237.90	20	0.016	8
				252.30	20	0.045	23
				276.86	5	0.041	9
				288.023	19	0.097	17
				291.69	7	0.022	6
				302.99	3	0.068	12
				318.710	8	2.9	3

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{157}Eu	15.18	3	H	328.30	20	0.022	12
				334.441	10	0.84	9
				339.30	20	0.017	9
				344.61	6	0.036	8
				358.931	10	0.31	4
				370.509	8	11.2	10
				379.905	9	0.27	4
				383.17	3	0.072	13
				393.408	20	0.124	16
				398.953	9	1.34	12
				409.135	10	2.72	24
				410.723	9	17.8	16
				420.090	9	0.94	10
				427.355	15	0.162	20
				434.388	13	0.36	5
				450.761	10	1.24	13
				460.923	9	0.99	10
				470.39	3	0.202	25
				474.625	11	2.56	22
				491.89	3	0.092	15
				506.43	3	0.083	14
				524.835	18	0.31	4
				543.93	6	0.020	21
				543.93	6	0.020	21
				553.02	7	0.036	8
				555.23	12	0.035	8
				567.58	4	0.148	18
				570.937	13	1.59	14
				585.46	20	0.018	6
				591.097	19	0.160	20
				607.10	20	0.047	24
				613.73	14	0.017	6
				619.303	12	3.6	4
				622.751	13	0.99	10
				625.60	20	0.015	5
				628.70	3	0.101	18
				632.23	5	0.047	10
				635.75	9	0.047	10
				655.59	3	0.188	24
				668.50	20	0.012	4
				674.59	18	0.017	6
				682.60	6	0.078	23
				683.16	3	0.24	5
				685.20	20	0.048	25
				687.502	13	1.20	15
				696.94	4	0.073	10
				698.62	5	0.064	9
				700.856	19	0.30	4
				707.46	9	0.047	8
				716.92	10	0.028	7
				728.5	4	0.022	6
				739.34	12	0.018	6
				750.8	6	0.07	8
				750.8	6	0.07	8
				752.61	4	0.26	4
				754.8	3	0.025	8
				762.69	3	0.37	7
				762.69	3	0.0336	24
				803.65	20	0.018	6
				814.17	12	0.022	7

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{157}Eu	15.18	3	H	816.64	4	0.072	13
				836.23	14	0.013	5
				846.78	15	0.034	12
				865.05	20	0.020	6
				932.6	4	0.020	6
				934.24	8	0.039	11
				944.21	10	0.032	11
				969.19	9	0.011	5
				985.69	4	0.146	18
				996.38	12	0.030	10
				1051.57	15	0.026	8
				1060.06	10	0.028	10
				1115.53	15	0.019	6
				1167.38	12	0.047	12
^{181}Hf	42.39	6	D	6.3	3	0.0115	4
				133.021	19	43.3	6
				136.260	18	5.85	19
				136.86	4	0.86	19
				345.93	6	15.12	13
				475.99	9	0.703	7
				482.18	9	80.5	5
				615.17	11	0.233	18
				618.66	8	0.0250	13
^{182}Ta	114.74	12	D	31.7377	5	0.874	22
				42.7148	4	0.268	6
				44.66	11	0.030	6
				65.72216	15	3.01	4
				67.74971	10	42.9	4
				84.6803	3	2.654	19
				100.10596	7	14.20	11
				110.393	12	0.107	4
				113.67171	22	1.871	10
				116.4179	6	0.444	4
				152.4299	3	7.02	4
				156.3864	3	2.671	13
				179.3938	3	3.119	16
				198.3519	3	1.465	7
				222.1085	3	7.57	3
				229.3207	6	3.644	17
				264.0740	3	3.612	17
				351.02	6	0.0113	9
				829.9	4	0.014	3
				891.70	10	0.0574	25
				928.00	4	0.614	6
				959.73	3	0.350	4
				1001.700	18	2.086	12
				1044.42	5	0.239	5
				1113.410	18	0.445	6
				1121.290	3	35.24	8
				1157		0.73	4
				1158.10	20	0.29	4
				1180.85	14	0.087	3
				1189.040	3	16.49	6
				1221.395	3	27.23	10
				1223.60	9	0.24	3
				1231.004	3	11.62	4
				1257.407	3	1.509	6
				1273.719	3	0.660	4
				1289.145	3	1.372	8
				1342.730	15	0.2565	16

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{182}Ta	114.74	12	D	1373.824	3	0.2224	22
				1387.390	3	0.0729	11
				1410.13	8	0.0396	8
				1453.120	6	0.0307	11
^{187}W	24.000	4	H	72.002	4	13.55	21
				100.38	24	0.0106	10
				103.8		0.0106	4
				106.596	13	0.0309	9
				106.596	13	0.016	16
				113.746	8	0.0920	20
				134.247	7	10.36	21
				154.4		0.0166	7
				178.8		0.013	7
				206.247	19	0.153	17
				239.13	8	0.100	4
				246.20	4	0.136	11
				261.0		0.013	4
				262.7		0.013	4
				454.920	20	0.0362	18
				479.530	10	26.6	5
				484.15	3	0.0209	11
				491.2		0.030	10
				511.760	10	0.807	18
				551.550	10	6.14	10
				564.62	19	0.015	6
				582.0		0.1308	20
				589.06	5	0.150	3
				618.370	10	7.57	12
				625.520	10	1.314	21
				641.1		0.037	14
				685.810	10	33.2	5
				727.2		0.0432	7
				730.3		0.010	10
				745.210	20	0.368	7
				772.870	20	5.02	8
				794.8		0.0266	4
				816.560	20	0.015	3
				864.550	10	0.409	7
				879.44	5	0.171	3
				933.8		0.01332	
				968.8		0.0465	7
^{192}Ir	73.829	11	D	110.33	17	0.0127	8
				136.39	3	0.199	25
				201.3112	7	0.471	7
				205.79433	9	3.31	3
				283.2668	8	0.266	4
				295.95654	15	28.71	7
				308.45514	17	29.70	7
				316.50623	17	82.86	4
				329.09	15	0.0173	6
				374.4853	8	0.727	8
				416.4688	7	0.670	21
				420.51	6	0.069	8
				468.0689	3	47.84	3
				484.5752	4	3.19	3
				489.06	3	0.438	16
				588.5811	7	4.522	11
				593.63	19	0.0420	10
				604.4111	3	8.216	20
				612.4623	3	5.34	8

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{192}Ir	73.829	11	D	884.5366	7	0.292	7
				1061.49	4	0.0531	6
^{198}Au	2.6941	2	D	411.80209	17	95.62	6
				675.8837	7	0.805	5
				1087.6843	7	0.1589	19
^{203}Hg	46.594	12	D	279.1952	10	81.56	5
^{203}Pb	51.92	3	H	279.1952	10	80.9	19
				401.320	3	3.35	11
				680.515	3	0.75	3
^{206}Tl	4.202	11	M	803.06	3	0.0050	5
^{207}Bi	31.55	4	Y	569.6980	20	97.75	3
				897.77	12	0.128	5
				1063.656	3	74.5	3
				1442.20	20	0.1310	20
				1460.0	15	1.61	6
				1770.228	9	6.87	3
^{208}Tl	3.053	4	M	211.40	15	0.180	10
				233.36	15	0.310	10
				252.61	10	0.780	20
				277.371	5	6.6	3
				485.95	15	0.049	4
				510.77	10	22.60	20
				583.1870	20	85.0	3
				587.7		0.060	20
				650.1	3	0.050	20
				705.2	3	0.022	4
				722.04	12	0.24	4
				748.70	20	0.046	3
				763.13	8	1.79	3
				808.30	20	0.030	7
				821.20	20	0.041	4
				835.90	20	0.076	11
				860.557	4	12.50	10
				883.30	20	0.031	3
				927.60	20	0.125	11
				982.70	20	0.205	8
				1093.90	20	0.430	20
				1160.8	3	0.011	3
				1185.2	3	0.017	5
				1282.8	3	0.052	5
^{210}Pb	22.20	22	Y	46.5390	10	4.25	4
^{210}Po	138.376	2	D	803.06	3	0.00103	
^{211}Pb	36.1	2	M	65.420	14	0.077	6
				81.00	20	0.045	12
				83.80	10	0.058	9
				88.20	20	0.017	4
				94.3	3	0.012	3
				95.00	20	0.018	3
				97.30	20	0.0116	13
				244.0		0.039	13
				313.59	9	0.031	4
				342.91	4	0.035	6
				362.072	17	0.043	3
				404.853	10	3.78	6
				427.088	10	1.76	5
				478.0	4	0.013	3
				481.1	4	0.026	6
				481.92	12	0.0103	13
				500.4	5	0.012	3
				609.38	4	0.043	7

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{211}Pb	36.1	2	M	676.69	7	0.013	4
				704.64	3	0.462	11
				766.51	3	0.617	17
				832.01	3	3.52	6
				951.0		0.022	13
				1014.64	5	0.0173	6
				1080.16	6	0.0123	7
				1109.48	5	0.115	4
				1196.33	5	0.0102	4
^{211}Bi	2.14	2	M	351.07	5	13.02	12
^{212}Pb	10.64	1	H	115.183	5	0.596	10
				176.68	5	0.052	7
				238.6320	20	43.6	6
				300.087	10	3.30	5
				415.2		0.0131	22
^{212}Bi	60.55	6	M	39.857	4	1.06	9
				288.20	4	0.337	3
				328.03	4	0.125	7
				433.7	5	0.017	4
				452.98	5	0.363	4
				473.0	7	0.050	4
				727.330	9	6.67	9
				785.37	8	1.102	13
				893.408	5	0.378	20
				952.120	11	0.17	4
				1073.60	20	0.0160	20
				1078.62	10	0.564	20
				1512.7	3	0.29	4
				1620.50	10	1.47	4
				1679.7	5	0.058	13
				1806.0	5	0.090	20
^{214}Pb	26.8	9	M	53.2284	18	1.075	7
				118.2		0.094	21
				137.5	3	0.053	14
				141.3	6	0.058	18
				170.07	6	0.015	3
				196.19	5	0.067	8
				205.68	9	0.0114	13
				216.47	7	0.0100	23
				241.9950	23	7.251	16
				258.86	3	0.531	4
				274.80	4	0.355	10
				295.2228	18	18.42	4
				298.8		0.026	5
				305.26	3	0.0312	21
				314.33	7	0.078	6
				323.84	4	0.029	3
				351.9321	18	35.60	7
				462.02	6	0.212	5
				470.6	8	0.011	3
				480.432	20	0.337	4
				487.14	6	0.432	5
				511.00	9	0.033	9
				533.660	20	0.181	6
				538.42	8	0.020	3
				543.83	7	0.044	4
				580.14	3	0.370	4
				765.97	19	0.053	4
				785.96	8	1.06	3
				839.07	8	0.583	8

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{214}Bi	19.9	4	M	268.80	20	0.0170	20
				273.80	5	0.128	7
				280.97	4	0.067	7
				304.20	20	0.019	19
				304.20	20	0.019	19
				333.37	5	0.065	4
				334.78	8	0.019	19
				334.78	8	0.019	19
				338.5	6	0.11	4
				348.92	6	0.104	12
				351.9	5	0.070	10
				386.78	5	0.295	5
				388.89	5	0.402	10
				394.05	8	0.0126	9
				396.02	6	0.026	4
				405.720	20	0.169	6
				426.5	5	0.012	4
				452.92	10	0.030	4
				454.790	20	0.292	4
				461.08	11	0.051	6
				469.77	4	0.132	5
				474.44	4	0.099	6
				485.92	11	0.022	4
				487.95	13	0.028	9
				494.20	9	0.0104	10
				501.99	14	0.0180	20
				519.90	5	0.0165	17
				524.60	8	0.0168	17
				536.78	4	0.065	6
				542.83	7	0.077	6
				572.78	6	0.078	5
				595.24	7	0.0170	20
				609.320	5	45.49	16
				615.77	5	0.054	7
				617.10	20	0.034	4
				633.10	4	0.056	3
				639.62	8	0.033	3
				649.22	5	0.057	5
				658.70	20	0.0140	20
				660.94	13	0.053	4
				665.447	9	1.531	6
				683.23	5	0.082	5
				697.93	8	0.067	4
				699.82	13	0.016	5
				703.11	4	0.472	9
				704.96	22	0.047	7
				708.87	21	0.0121	12
				710.71	8	0.0740	20
				719.87	3	0.392	8
				723.08	10	0.037	3
				727.0	10	0.036	14
				733.81	7	0.041	3
				740.76	13	0.0430	20
				752.85	3	0.128	7
				768.360	5	4.894	11
				769.7	5	0.030	10
				786.35	14	0.32	4
				788.6	4	0.0130	20
				799.3	3	0.036	7
				806.180	9	1.264	5

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{214}Bi	19.9	4	M	814.96	9	0.039	3
				821.18	3	0.161	8
				826.45	10	0.117	13
				832.36	9	0.0280	20
				840.4	5	0.0100	20
				847.16	11	0.024	3
				873.06	18	0.018	3
				878.03	12	0.012	3
				904.31	8	0.076	7
				915.75	13	0.0230	20
				930.20	20	0.026	4
				934.056	6	3.107	10
				934.10	20	0.050	10
				934.5	5	0.010	3
				938.65	16	0.013	4
				939.6	5	0.017	6
				943.33	11	0.0170	20
				961.62	17	0.0101	13
				964.08	3	0.365	10
				965.00	10	0.011	3
				976.18	12	0.0154	21
				989.34	17	0.010	3
				991.49	19	0.0110	20
				1013.4	7	0.013	4
				1021.36	17	0.0150	23
				1032.38	7	0.063	4
				1033.30	20	0.020	3
				1045.70	20	0.0230	20
				1051.96	3	0.313	7
				1062		0.013	8
				1067.39	24	0.025	6
				1069.96	7	0.272	9
				1087		0.015	7
				1103.70	13	0.098	12
				1104.71	13	0.078	4
				1109		0.015	5
				1118.9	5	0.040	10
				1120.294	6	14.92	3
				1130.45	16	0.036	3
				1133.66	3	0.2512	10
				1155.210	8	1.633	6
				1155.6	5	0.016	4
				1167.30	20	0.0120	20
				1173.00	8	0.055	3
				1207.68	3	0.451	10
				1238.122	7	5.834	15
				1279.0	7	0.0130	20
				1280.976	10	1.434	6
				1284.0	10	0.0110	10
				1285.1	5	0.016	3
				1303.75	7	0.107	5
				1316.99	9	0.081	6
				1329.94	16	0.081	6
				1341.49	13	0.021	3
				1371		0.0100	20
				1377.669	8	3.988	11
				1385.310	13	0.793	5
				1401.515	12	1.330	5
				1407.988	11	2.394	7
				1449		0.018	9

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{214}Bi	19.9	4	M	1479.17	9	0.055	4
				1484		0.013	5
				1509.210	10	2.130	10
				1538.53	5	0.398	11
				1543.34	5	0.303	10
				1583.204	15	0.705	5
				1594.75	7	0.267	12
				1599.37	5	0.324	12
				1636.36	16	0.0115	13
				1657.07	17	0.048	4
				1661.274	16	1.047	6
				1684.012	20	0.214	5
				1729.595	11	2.878	8
				1764.491	10	15.30	3
				1813.72	13	0.0110	10
				1838.36	4	0.350	10
				1847.429	13	2.025	9
				1873.16	5	0.214	8
				1890.32	9	0.084	8
				1896.05	12	0.149	8
				1898.68	14	0.050	7
				1935.62	16	0.032	3
^{219}Rn	3.96	1	S	130.60	3	0.13	9
				221.5	3	0.030	5
				271.230	10	10.8	7
				293.56	4	0.073	6
				401.810	10	6.6	5
				438.2	6	0.015	16
				517.60	6	0.044	4
				676.66	7	0.0173	24
^{223}Ra	11.43	5	D	10.0	10	0.0139	14
				14.40	10	0.0167	15
				33.6	5	0.10	4
				63.2	5	0.056	16
				104.23	8	0.019	3
				106.78	3	0.0236	15
				110.856	10	0.058	5
				114.70	20	0.010	5
				122.319	10	1.209	23
				136.10	20	0.028	3
				144.235	10	3.27	9
				154.208	10	5.70	17
				158.635	10	0.695	18
				175.65	15	0.019	5
				177.30	10	0.047	5
				179.54	6	0.153	14
				219.0	8	0.014	6
				221.32	24	0.036	6
				247.2	5	0.010	3
				249.30	10	0.039	10
				251.6	3	0.042	14
				255.20	20	0.053	7
				269.463	10	13.9	4
				288.18	3	0.160	5
				293.80	20	0.0667	10
				323.871	10	3.99	9
				328.38	3	0.209	8
				334.01	6	0.101	6
				338.282	10	2.84	7
				342.87	4	0.222	15

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{223}Ra	11.43	5	D	346.8	3	0.181	3
				362.052	17	0.046	3
				362.90	20	0.015	7
				369.5		0.0209	3
				371.676	15	0.487	16
				372.90	10	0.0500	8
				373.3		0.0500	8
				376.0	3	0.012	4
				376.10	20	0.013	5
				382.8	3	0.014	5
				387.70	20	0.015	6
				393.5	5	0.011	4
				430.6	3	0.019	6
				432.12	10	0.035	3
				439.3		0.082	14
				445.033	12	1.29	5
				481.6	5	0.021	6
				487.50	20	0.0111	14
				527.611	13	0.071	5
				598.721	24	0.095	5
				609.31	4	0.057	3
				632.0	10	0.031	10
^{224}Ra	3.66	4	D	240.986	6	4.10	5
^{226}Ra	1600	7	Y	186.211	13	3.64	4
^{227}Th	18.68	9	D	6.5	3	0.09	3
				20.25	5	0.24	4
				24.13	5	0.088	10
				27.41	9	0.030	6
				29.860	10	0.076	13
				31.580	10	0.068	12
				40.20	3	0.015	4
				41.93	5	0.028	14
				43.77	5	0.213	23
				43.8	5	0.055	23
				44.22	12	0.053	14
				44.40	5	0.013	9
				48.30	3	0.014	6
				49.82	5	0.43	10
				50.130	10	8.4	9
				50.85	5	0.015	7
				59.6	5	0.010	4
				61.441	20	0.090	13
				62.45	5	0.11	12
				62.45	5	0.11	12
				64.35	10	0.026	5
				68.74	3	0.03	4
				68.74	3	0.03	4
				69.8	3	0.010	4
				72.85	5	0.025	20
				73.63	5	0.014	6
				75.01	5	0.027	11
				77.4	4	0.0103	9
				79.690	20	1.95	18
				93.88	5	1.51	14
				94.97	5	0.019	20
				94.97	5	0.019	20
				96.03	5	0.070	15
				99.58	10	0.026	7
				99.60	20	0.0129	11
				100.27	3	0.084	17

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{227}Th	18.68	9	D	113.11	5	0.54	5
				113.11	5	0.155	14
				117.20	5	0.199	22
				117.5	5	0.013	4
				123.58	10	0.014	6
				134.60	10	0.034	7
				138.40	10	0.014	3
				140.6	3	0.022	16
				141.42	5	0.07	8
				141.42	5	0.07	8
				150.14	20	0.011	4
				164.52	10	0.015	3
				168.36	10	0.015	3
				173.45	3	0.017	3
				175.8	3	0.021	6
				184.65	5	0.036	5
				197.56	10	0.013	4
				200.50	10	0.013	9
				201.64	10	0.024	4
				204.14	10	0.23	4
				204.98	10	0.16	3
				206.08	5	0.25	4
				210.62	5	1.25	14
				212.7	3	0.019	6
				212.70	4	0.079	12
				218.90	5	0.06	6
				218.90	5	0.06	6
				219.0	3	0.050	13
				234.76	10	0.45	7
				235.960	20	12.9	12
				246.12	10	0.0123	14
				248.10	10	0.025	6
				250.27	8	0.45	6
				252.50	5	0.111	19
				254.63	3	0.71	15
				256.230	20	7.0	7
				262.87	5	0.107	12
				267.05	20	0.010	3
				270.56	20	0.028	10
				272.91	5	0.51	5
				279.80	5	0.054	14
				281.42	5	0.09	10
				281.42	5	0.09	10
				284.24	10	0.040	14
				285.52	10	0.044	13
				286.09	20	1.74	22
				289.59	10	1.9	5
				289.77	10	0.019	5
				292.41	5	0.066	10
				296.50	5	0.44	6
				299.98	3	2.21	20
				300.50	16	0.014	3
				304.500	20	1.15	17
				306.1	3	0.010	4
				308.40	3	0.017	3
				312.69	3	0.52	6
				314.75	10	0.035	3
				314.85	4	0.3	3
				314.85	4	0.3	3
				319.24	5	0.032	7

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{227}Th	18.68	9	D	324.88	20	0.010	3
				329.850	20	2.9	3
				334.370	20	1.14	13
				342.55	4	0.35	10
				346.450	10	0.0120	17
				350.54	7	0.110	21
				352.61	10	0.0101	24
				362.63	10	0.051	5
				379.40	10	0.010	3
				383.51	4	0.025	24
				392.4	5	0.010	3
^{228}Ac	6.15	2	H	18.40		0.014	4
				56.96	5	0.019	4
				57.766	5	0.47	3
				77.34	3	0.026	5
				99.509	6	1.26	7
				100.41	3	0.093	13
				129.0650	10	2.42	9
				135.54	5	0.018	4
				137.91	5	0.024	5
				141.02	3	0.050	8
				145.849	10	0.158	8
				153.977	10	0.722	21
				168.65	10	0.010	3
				173.964	13	0.035	5
				184.540	20	0.070	8
				191.353	10	0.123	8
				199.407	10	0.315	5
				204.026	10	0.112	15
				209.253	6	3.89	7
				214.85	5	0.76	11
				214.85	10	0.029	4
				223.85	10	0.054	5
				231.42	10	0.025	4
				257.52	10	0.030	3
				263.58	10	0.040	4
				270.2450	20	3.46	6
				278.95	5	0.160	21
				278.95	5	0.031	5
				282.00	3	0.072	19
				321.646	8	0.226	11
				326.04	20	0.033	5
				327.4		0.12	4
				328.000	6	2.95	12
				332.370	4	0.40	4
				338.320	3	11.27	19
				340.96	5	0.369	21
				356.94	10	0.0170	18
				377.99	10	0.025	3
				389.12	15	0.0103	15
				397.94	10	0.027	3
				399.62	10	0.029	3
				409.462	6	1.92	4
				416.30	20	0.0132	21
				419.42	10	0.021	3
				440.44	5	0.121	8
				449.15	5	0.048	5
				452.47	10	0.015	5
				457.17	15	0.0150	23
				463.004	6	4.40	7

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{228}Ac	6.15	2	H	466.40	10	0.029	3
				470.25	20	0.013	3
				471.76	15	0.033	3
				474.75	10	0.022	3
				478.33	5	0.209	15
				480.94	20	0.023	5
				490.33	15	0.0111	23
				492.37	10	0.0235	23
				503.823	13	0.182	12
				508.959	17	0.45	5
				515.06	10	0.049	5
				520.151	16	0.067	5
				523.131	16	0.103	8
				540.76	10	0.026	3
				546.47	5	0.201	13
				548.73	15	0.023	3
				555.12	10	0.046	5
				562.500	4	0.87	3
				570.91	10	0.182	24
				572.14	8	0.150	16
				583.41	5	0.111	10
				590.4		0.017	3
				610.64	10	0.023	5
				616.22	3	0.080	5
				620.38	5	0.080	5
				623.27	20	0.011	3
				627.23	20	0.014	3
				629.40	5	0.045	5
				634.18	10	0.0106	21
				640.34	3	0.054	5
				648.84	10	0.022	22
				648.84	10	0.022	22
				651.51	3	0.090	8
				663.82	10	0.028	6
				666.45	10	0.057	6
				672.00	15	0.026	8
				674.2		0.05	6
				674.8		2.1	7
				677.11	10	0.062	5
				684.0		0.019	5
				688.10	5	0.067	5
				688.10	5	0.067	5
				699.08	15	0.037	5
				701.747	14	0.173	10
				707.41	5	0.155	15
				718.48	15	0.019	4
				726.863	15	0.62	8
				737.72	5	0.037	4
				755.315	4	1.00	3
				772.291	5	1.49	3
				774.10	20	0.06000	
				776.56	10	0.019	6
				778.2		0.022	6
				782.142	5	0.485	19
				791.5	3	0.013	3
				791.5	3	0.010	3
				792.8		0.08000	
				794.947	5	4.25	7
				816.71	10	0.030	3
				824.934	23	0.050	5

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{228}Ac	6.15	2	H	830.486	8	0.540	21
				835.710	6	1.61	6
				840.377	7	0.91	4
				870.46	4	0.044	4
				873.17	15	0.031	6
				874.44	7	0.047	10
				877.46	10	0.014	3
				887.33	10	0.027	3
				901.23	15	0.016	3
				904.20	4	0.77	3
				911.204	4	25.8	4
				918.97	10	0.027	3
				944.196	14	0.095	8
				947.982	11	0.106	8
				958.61	4	0.28	4
				964.766	10	4.99	9
				968.971	17	15.8	3
				975.96	5	0.050	5
				979.48	10	0.026	3
				987.71	20	0.077	13
				988.63	20	0.077	13
				1016.44	15	0.011	11
				1016.44	15	0.011	11
				1019.86	10	0.021	4
				1033.248	9	0.201	13
				1039.65	15	0.044	9
				1040.92	15	0.044	9
				1053.09	20	0.013	4
				1054.11	20	0.018	5
				1062.55	15	0.010	3
				1065.18	4	0.132	10
				1074.71	15	0.010	3
				1095.679	20	0.129	10
				1103.41	10	0.0150	23
				1110.610	10	0.285	23
				1110.610	10	0.019	10
				1117.63	10	0.054	8
				1142.85	15	0.0103	21
				1153.52	4	0.139	10
				1164.50	8	0.065	5
				1175.31	10	0.024	3
				1217.03	10	0.021	3
				1245.05	20	0.095	18
				1247.08	4	0.50	3
				1250.04	10	0.062	5
				1276.69	10	0.014	3
				1286.27	20	0.050	10
				1287.68	20	0.080	15
				1309.71	20	0.019	6
				1315.34	10	0.015	3
				1347.50	15	0.015	3
				1357.78	15	0.020	4
				1365.70	15	0.014	3
				1374.19	10	0.014	4
				1385.39	10	0.0106	21
				1401.49	10	0.012	3
				1415.66	10	0.021	4
				1430.95	10	0.035	7
				1451.40	15	0.0106	21
				1459.138	15	0.83	8

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{228}Ac	6.15	2	H	1469.71	15	0.020	4
				1480.37	15	0.016	3
				1495.910	20	0.86	4
				1501.57	5	0.46	3
				1529.05	10	0.057	6
				1537.89	10	0.047	5
				1548.65	4	0.038	4
				1557.11	4	0.178	13
				1559.85	20	0.020	4
				1573.26	5	0.033	3
				1580.53	3	0.60	4
				1588.20	3	3.22	8
				1625.06	5	0.255	18
				1630.627	10	1.51	4
				1638.281	10	0.47	3
				1666.523	13	0.178	13
				1677.67	3	0.054	5
				1684.01	20	0.015	5
				1686.09	7	0.095	8
				1700.59	20	0.0101	23
				1702.43	5	0.048	5
				1724.21	4	0.029	3
				1738.2	3	0.018	4
				1740.4	3	0.011	3
				1758.11	10	0.035	4
				1823.22	10	0.044	4
				1835.43	10	0.038	4
				1842.13	10	0.042	4
				1870.83	10	0.0243	23
				1887.10	5	0.090	8
				1907.18	20	0.0119	10
				1929.78	20	0.0199	21
				1952.33	15	0.059	5
				1965.24	20	0.0204	18
^{228}Th	1.9125	9	Y	84.373	3	1.19	4
				131.613	4	0.127	4
				166.410	4	0.101	4
				205.93	5	0.0191	8
				215.983	5	0.247	8
^{231}Th	25.52	1	H	9.200		0.0330	15
				10.25		0.0502	23
				17.20		0.23	8
				18.07		0.011	11
				19.10		0.244	12
				25.640	20	14.1	10
				42.86	7	0.059	3
				58.5700	24	0.462	25
				63.86	3	0.023	4
				72.751	3	0.252	14
				81.2280	14	0.90	6
				82.0870	14	0.42	3
				84.2140	13	6.6	4
				89.950	20	1.00	6
				93.02	4	0.047	6
				99.278	3	0.131	9
				102.2700	13	0.436	24
				106.61	3	0.0176	11
				116.820	20	0.0222	17
				124.914	17	0.058	3
				134.030	20	0.0250	14

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{231}Th	25.52	1	H	135.664	11	0.079	5
				145.940	20	0.0317	20
				163.101	5	0.154	9
				174.150	20	0.0178	11
				183.500	20	0.0330	20
				217.94	3	0.0396	20
^{231}Pa	3.276E+4	11	Y	16.50	10	0.221	9
				19.60		0.35	10
				25.48	6	0.119	14
				27.360	20	10.5	5
				29.970	20	0.097	6
				35.83	3	0.0162	11
				38.200	20	0.145	6
				39.980	20	0.016	4
				44.140	20	0.055	5
				46.340	20	0.186	11
				52.71	3	0.077	5
				54.600	20	0.070	5
				57.19	3	0.0328	23
				63.64	3	0.0445	17
				74.15	4	0.0223	9
				77.34	3	0.0572	19
				96.84	3	0.084	3
				100.85	6	0.0228	9
				144.40	8	0.0115	10
				243.08	9	0.0336	24
				246.04	9	0.012	4
				255.78	7	0.1059	20
				260.19	8	0.182	4
				273.15	6	0.0577	13
				277.22	7	0.0679	15
				283.682	16	1.65	3
				286.58	10	0.0104	6
				300.066	10	2.41	5
				302.667	9	2.3	4
				302.667	9	0.17	5
				312.92	5	0.0986	20
				327.14	7	0.0359	9
				330.055	15	1.36	3
				340.71	6	0.177	4
				354.48	5	0.0961	21
				357.11	8	0.168	4
				379.35	7	0.0496	12
				407.81	3	0.0355	8
^{234}Th	24.10	3	D	62.860	20	0.016	3
				63.290	20	3.7	4
				73.920	20	0.0130	15
				83.30	5	0.060	6
				87.02	6	0.015	3
				92.380	10	2.13	21
				92.800	20	2.10	20
				112.81	5	0.210	23
				184.8		0.010	5
^{234m}Pa	1.159	16	M	73.920	20	0.013	4
		11		258.227	3	0.0764	22
				740.10	8	0.0109	17
				742.813	5	0.1066	23
				766.42	10	0.317	5
				786.28	10	0.0544	9
				921.72	10	0.01278	16

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{234m}Pa	1.159	11	M	945.940	20	0.0101	9
				1001.03	10	0.842	9
				1193.73	12	0.01358	17
				1510.21	10	0.01305	21
				1737.75	10	0.0213	3
				1831.36	10	0.01742	24
^{235}U	703.8E+6	5	Y	19.55	5	63	3
				31.60	5	0.017	6
				34.70	10	0.0370	4
				41.4	3	0.030	10
				41.96	15	0.060	10
				51.21	5	0.034	7
				54.25	5	0.015	15
				64.45	5	0.013	12
				72.70	20	0.1200	12
				73.72	5	0.01000	10
				74.94	3	0.051	6
				96.090	20	0.091	12
				109.19	7	1.66	14
				115.45	5	0.030	10
				120.35	5	0.0260	3
				136.55	5	0.01200	12
				140.760	20	0.200	20
				143.760	20	10.96	14
				150.930	20	0.090	10
				163.356	3	5.08	7
				182.62	5	0.39	5
				185.715	5	57.0	7
				194.940	10	0.630	12
				198.900	20	0.036	6
				202.120	10	1.080	23
				205.316	10	5.02	6
				215.28	4	0.029	3
				221.386	14	0.118	7
				233.50	3	0.038	4
				240.88	4	0.074	6
				246.830	20	0.055	3
				251.50	10	0.020	20
				275.35	15	0.051	6
				275.49	6	0.0320	4
				279.50	5	0.270	3
				291.65	3	0.040	6
				345.92	3	0.040	6
				387.84	3	0.040	6
^{237}U	6.75	1	D	13.810	20	0.099	4
				26.34460	20	2.43	6
				33.1960	10	0.130	5
				38.54	3	0.011	11
				43.420	3	0.0240	20
				51.01	3	0.340	10
				59.54091	10	34.5	8
				64.830	20	1.282	17
				164.610	20	1.86	3
				208.005	23	21.2	3
				221.80	4	0.0212	7
				234.40	4	0.0205	7
				267.54	4	0.712	10
				332.35	3	1.200	16
				335.37	3	0.0951	22
				368.62	3	0.0392	17

Name of nuclide	Half-life	Half-life uncertainty	Half-life unit	Gamma-ray energy (keV)	Gamma-ray energy uncertainty (keV)	Emission rate (%)	Emission rate uncertainty (%)
^{237}U	6.75	1	D	370.94	3	0.1073	17
^{239}Np	2.356	3	D	4.200		2.600	
				44.660	20	0.130	10
				49.410	20	0.120	20
				57.28		0.036	
				57.30		0.090	
				61.4600	20	1.300	20
				67.860	20	0.10	3
				106.1230	20	25.34	17
				106.47	4	0.049	8
				124.4		0.010	
				166.39	6	0.016	7
				181.70	3	0.082	3
				209.7530	20	3.363	20
				226.380	20	0.259	16
				227.8		0.5100	
				228.1830	10	10.73	9
				254.40	3	0.1092	22
				272.84	3	0.0766	19
				277.5990	10	14.51	8
				285.4600	20	0.794	7
				315.880	3	1.600	12
				334.3100	20	2.056	13
				434.7	5	0.013	
^{241}Am	432.6	6	Y	26.34460	20	2.27	13
				32.18		0.0174	5
				33.1960	10	0.126	4
				43.420	3	0.073	8
				55.560	20	0.0181	18
				59.54091	10	35.9	4
				98.970	20	0.0203	5
				102.980	20	0.0195	5

Table 2.2 Nuclear data in the order of energies

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
4.2	^{239}Np	2.356	D	2.600	62.9	^{151}Pm	28.40	H	0.207
9.4	^{157}Eu	15.18	H	1.7	63.3	^{234}Th	24.10	D	3.7
13.8	^{140}Ba	12.7527	D	1.22	63.9	^{157}Eu	15.18	H	23
14.4	^{57}Co	271.74	D	9.16	64.4	^{157}Eu	15.18	H	0.13
16.5	^{231}Pa	3.276E+4	Y	0.221	64.8	^{237}U	6.75	D	1.282
17.2	^{231}Th	25.52	H	0.23	64.9	^{151}Pm	28.40	H	1.89
19.1	^{231}Th	25.52	H	0.244	65.7	^{182}Ta	114.74	D	3.01
19.6	^{235}U	703.8E+6	Y	63	65.8	^{151}Pm	28.40	H	1.15
19.6	^{231}Pa	3.276E+4	Y	0.35	66.0	^{75}Ge	82.78	M	0.114
20.3	^{227}Th	18.68	D	0.24	66.1	^{75}Se	119.78	D	1.111
20.9	^{133m}Te	55.4	M	0.32	66.9	^{136}Cs	13.16	D	4.79
25.5	^{231}Pa	3.276E+4	Y	0.119	67.7	^{182}Ta	114.74	D	42.9
25.6	^{231}Th	25.52	H	14.1	67.9	^{239}Np	2.356	D	0.10
25.7	^{151}Pm	28.40	H	0.97	69.7	^{153}Sm	46.50	H	4.73
26.3	^{237}U	6.75	D	2.43	69.7	^{151}Pm	28.40	H	0.47
26.3	^{241}Am	432.6	Y	2.27	71.1	^{117}Cd	2.49	H	0.39
27.4	^{231}Pa	3.276E+4	Y	10.5	72.0	^{187}W	24.000	H	13.55
27.5	^{88}Kr	2.825	H	1.94	72.5	^{145}Pr	5.984	H	0.261
27.8	^{129}Te	69.6	M	16.3	72.7	^{235}U	703.8E+6	Y	0.1200
30.0	^{140}Ba	12.7527	D	14.1	72.8	^{231}Th	25.52	H	0.252
31.7	^{182}Ta	114.74	D	0.874	72.8	^{149}Nd	1.728	H	0.60
33.2	^{237}U	6.75	D	0.130	74.1	^{133m}Te	55.4	M	0.30
33.2	^{241}Am	432.6	Y	0.126	74.3	^{149}Nd	1.728	H	1.11
33.6	^{144}Ce	284.91	D	0.200	74.7	^{149}Nd	1.728	H	0.98
33.6	^{223}Ra	11.43	D	0.10	75.4	^{153}Sm	46.50	H	0.19
35.5	^{125}Sb	2.75856	Y	4.37	75.7	^{149}Nd	1.728	H	0.228
38.2	^{231}Pa	3.276E+4	Y	0.145	76.2	^{151}Pm	28.40	H	0.203
39.6	^{129}I	1.57E+7	Y	7.51	76.8	^{134}Te	41.8	M	0.274
39.9	^{212}Bi	60.55	M	1.06	76.9	^{157}Eu	15.18	H	0.20
39.9	^{133m}Te	55.4	M	0.146	77.1	^{149}Nd	1.728	H	0.61
40.6	^{99}Mo	65.924	H	1.04	79.1	^{108m}Ag	438	Y	6.6
41.0	^{144}Ce	284.91	D	0.257	79.2	^{131m}Te	33.25	H	0.123
42.7	^{182}Ta	114.74	D	0.268	79.4	^{134}Te	41.8	M	20.9
43.8	^{227}Th	18.68	D	0.213	79.6	^{133}Xe	5.2475	D	0.44
44.7	^{239}Np	2.356	D	0.130	79.6	^{133}Ba	10.551	Y	2.65
46.3	^{231}Pa	3.276E+4	Y	0.186	79.7	^{227}Th	18.68	D	1.95
46.5	^{210}Pb	22.20	Y	4.25	80.1	^{144}Ce	284.91	D	1.36
47.5	^{133m}Te	55.4	M	0.177	80.2	^{131}I	8.0252	D	2.62
49.4	^{239}Np	2.356	D	0.120	80.3	^{149}Nd	1.728	H	0.451
49.7	^{132}Te	3.204	D	15.0	81.0	^{133}Xe	5.2475	D	36.9
49.8	^{227}Th	18.68	D	0.43	81.0	^{133}Ba	10.551	Y	32.9
50.1	^{227}Th	18.68	D	8.4	81.1	^{131m}Te	33.25	H	3.92
51.0	^{237}U	6.75	D	0.340	81.2	^{231}Th	25.52	H	0.90
51.8	^{157}Eu	15.18	H	0.76	81.6	^{133m}Te	55.4	M	0.26
53.2	^{133}Ba	10.551	Y	2.14	82.1	^{231}Th	25.52	H	0.42
53.2	^{214}Pb	26.8	M	1.075	83.4	^{153}Sm	46.50	H	0.192
53.3	^{103}Ru	39.247	D	0.443	84.2	^{231}Th	25.52	H	6.6
53.4	^{144}Ce	284.91	D	0.100	84.4	^{228}Th	1.9125	Y	1.19
54.5	^{157}Eu	15.18	H	3.8	84.7	^{182}Ta	114.74	D	2.654
57.4	^{143}Ce	33.039	H	11.7	86.4	^{136}Cs	13.16	D	5.18
57.8	^{228}Ac	6.15	H	0.47	86.4	^{131m}Te	33.25	H	0.142
58.5	^{149}Nd	1.728	H	1.42	88.1	^{133m}Te	55.4	M	1.06
58.6	^{231}Th	25.52	H	0.462	89.0	^{156}Eu	15.19	D	8.4
58.9	^{149}Nd	1.728	H	1.30	89.5	^{153}Sm	46.50	H	0.158
59.5	^{237}U	6.75	D	34.5	89.7	^{117}Cd	2.49	H	3.26
59.5	^{241}Am	432.6	Y	35.9	90.0	^{231}Th	25.52	H	1.00
61.1	^{127}Sb	3.85	D	1.44	91.1	^{147}Nd	10.98	D	28.1
61.5	^{239}Np	2.356	D	1.300	92.2	^{82}Br	35.282	H	0.726
62.5	^{227}Th	18.68	D	0.11	92.3	^{133m}Te	55.4	M	0.16
62.5	^{227}Th	18.68	D	0.11	92.4	^{234}Th	24.10	D	2.13

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
92.8	^{234}Th	24.10	D	2.10	131.1	^{140}La	1.67855	D	0.467
93.9	^{227}Th	18.68	D	1.51	131.6	^{228}Th	1.9125	Y	0.127
95.0	^{133m}Te	55.4	M	2.30	132.7	^{140}Ba	12.7527	D	0.202
96.7	^{75}Se	119.78	D	3.449	133.0	^{181}Hf	42.39	D	43.3
97.0	^{149}Nd	1.728	H	1.45	133.5	^{144}Ce	284.91	D	11.09
97.4	^{153}Sm	46.50	H	0.772	134.2	^{187}W	24.000	H	10.36
97.7	^{117m}Cd	3.36	H	1.05	134.6	^{131}Sb	23.03	M	2.5
97.8	^{133m}Te	55.4	M	0.106	134.9	^{131m}Te	33.25	H	0.68
98.1	^{151}Pm	28.40	H	0.36	135.4	^{134}I	52.5	M	4.3
99.3	^{231}Th	25.52	H	0.131	136.0	^{75}Se	119.78	D	58.5
99.4	^{117m}Cd	3.36	H	0.10	136.3	^{181}Hf	42.39	D	5.85
99.5	^{228}Ac	6.15	H	1.26	136.4	^{192}Ir	73.829	D	0.199
100.0	^{151}Pm	28.40	H	2.54	136.5	^{57}Co	271.74	D	10.68
100.1	^{182}Ta	114.74	D	14.20	136.6	^{133m}Te	55.4	M	0.12
101.4	^{134}Te	41.8	M	0.38	136.9	^{181}Hf	42.39	D	0.86
101.6	^{131m}Te	33.25	H	0.164	138.1	^{138}Cs	33.41	M	1.49
101.9	^{151}Pm	28.40	H	1.28	139.0	^{134}I	52.5	M	0.76
102.1	^{131m}Te	33.25	H	7.66	139.2	^{149}Nd	1.728	H	0.51
102.3	^{231}Th	25.52	H	0.436	139.3	^{151}Pm	28.40	H	0.50
102.8	^{128}Sb	9.05	H	0.40	139.7	^{75m}Ge	47.7	S	39.5
103.2	^{153}Sm	46.50	H	29.25	140.5	^{99m}Tc	6.0072	H	89
104.8	^{151}Pm	28.40	H	3.5	140.8	^{235}U	703.8E+6	Y	0.200
105.5	^{129m}Te	33.6	D	0.14	142.7	^{59}Fe	44.495	D	1.02
105.9	^{142}La	91.1	M	0.1422	143.2	^{151}Pm	28.40	H	0.214
106.1	^{239}Np	2.356	D	25.34	143.8	^{235}U	703.8E+6	Y	10.96
109.2	^{235}U	703.8E+6	Y	1.66	144.2	^{223}Ra	11.43	D	3.27
109.4	^{140}La	1.67855	D	0.219	145.4	^{141}Ce	32.511	D	48.4
109.7	^{136}Cs	13.16	D	0.21	145.8	^{228}Ac	6.15	H	0.158
110.4	^{182}Ta	114.74	D	0.107	147.4	^{132}I	2.295	H	0.237
111.8	^{132}Te	3.204	D	1.74	147.5	^{151}Pm	28.40	H	0.153
112.5	^{149}Nd	1.728	H	0.119	149.1	^{105}Ru	4.44	H	1.75
112.6	^{138}Cs	33.41	M	0.130	149.7	^{131m}Te	33.25	H	4.9
112.8	^{234}Th	24.10	D	0.210	150.8	^{133m}Te	55.4	M	0.27
113.1	^{227}Th	18.68	D	0.54	150.8	^{133m}Te	55.4	M	0.53
113.1	^{227}Th	18.68	D	0.155	151.2	^{85m}Kr	4.480	H	75.2
113.7	^{182}Ta	114.74	D	1.871	152.0	^{134}I	52.5	M	0.106
114.3	^{149}Nd	1.728	H	19.2	152.4	^{182}Ta	114.74	D	7.02
115.2	^{212}Pb	10.64	H	0.596	152.6	^{128}Sb	9.05	H	0.50
116.3	^{132}Te	3.204	D	1.96	153.2	^{136}Cs	13.16	D	5.75
116.4	^{182}Ta	114.74	D	0.444	154.0	^{228}Ac	6.15	H	0.722
116.4	^{133m}Te	55.4	M	0.22	154.2	^{223}Ra	11.43	D	5.70
116.9	^{149}Nd	1.728	H	0.11	154.3	^{127}Sb	3.85	D	0.15
117.0	^{125}Sb	2.75856	Y	0.263	155.9	^{149}Nd	1.728	H	5.9
117.2	^{227}Th	18.68	D	0.199	156.2	^{151}Pm	28.40	H	0.149
118.4	^{128}Sb	9.05	H	0.60	156.4	^{77}Ge	11.211	H	0.69
120.5	^{147}Nd	10.98	D	0.376	156.4	^{182}Ta	114.74	D	2.671
121.1	^{75}Se	119.78	D	17.20	158.2	^{135}Xe	9.14	H	0.289
121.8	^{152}Eu	13.517	Y	28.53	158.6	^{223}Ra	11.43	D	0.695
122.1	^{57}Co	271.74	D	85.60	159.7	^{131m}Te	33.25	H	0.123
122.3	^{88}Kr	2.825	H	0.197	159.9	^{131}Sb	23.03	M	0.47
122.3	^{223}Ra	11.43	D	1.209	160.6	^{133}Xe	5.2475	D	0.1066
122.4	^{149}Nd	1.728	H	0.256	160.6	^{133}Ba	10.551	Y	0.638
123.1	^{154}Eu	8.601	Y	40.4	160.8	^{117}Cd	2.49	H	0.25
126.6	^{149}Nd	1.728	H	0.111	162.5	^{134}I	52.5	M	0.29
129.1	^{228}Ac	6.15	H	2.42	162.7	^{140}Ba	12.7527	D	6.22
129.6	^{105m}Rh	40	S	20.00	162.9	^{151}Pm	28.40	H	0.88
129.8	^{105}Ru	4.44	H	5.68	163.1	^{231}Th	25.52	H	0.154
129.8	^{85m}Kr	4.480	H	0.301	163.4	^{235}U	703.8E+6	Y	5.08
130.6	^{219}Rn	3.96	S	0.13	163.5	^{105}Ru	4.44	H	0.156
131.1	^{134}Te	41.8	M	0.18	163.6	^{151}Pm	28.40	H	1.55

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
163.9	^{136}Cs	13.16	D	3.39	194.9	^{235}U	703.8E+6	Y	0.630
163.9	^{131m}Xe	11.84	D	1.95	196.3	^{88}Kr	2.825	H	26.0
164.4	^{133m}Te	55.4	M	0.77	196.6	^{147}Nd	10.98	D	0.190
164.6	^{237}U	6.75	D	1.86	198.2	^{133m}Te	55.4	M	0.13
165.9	^{139}Ba	82.93	M	23.7	198.4	^{182}Ta	114.74	D	1.465
165.9	^{139}Ce	137.641	D	79.90	198.6	^{75}Ge	82.78	M	1.19
166.0	^{88}Kr	2.825	H	3.10	198.6	^{75}Se	119.78	D	1.496
166.4	^{228}Th	1.9125	Y	0.101	198.9	^{149}Nd	1.728	H	1.39
166.6	^{136}Cs	13.16	D	0.37	199.2	^{156}Eu	15.19	D	0.74
167.8	^{151}Pm	28.40	H	8.3	199.4	^{228}Ac	6.15	H	0.315
168.4	^{151}Pm	28.40	H	0.92	200.6	^{131m}Te	33.25	H	7.28
168.6	^{117m}Cd	3.36	H	0.29	200.7	^{133m}Te	55.4	M	0.35
169.0	^{133m}Te	55.4	M	4.2	201.0	^{133m}Te	55.4	M	0.13
172.7	^{125}Sb	2.75856	Y	0.191	201.2	^{134}Te	41.8	M	8.9
173.5	^{140}La	1.67855	D	0.127	201.3	^{192}Ir	73.829	D	0.471
174.2	^{78}As	90.7	M	0.18	202.0	^{151}Pm	28.40	H	0.88
176.3	^{125}Sb	2.75856	Y	6.84	202.1	^{235}U	703.8E+6	Y	1.080
176.5	^{151}Pm	28.40	H	0.86	202.5	^{90m}Y	3.19	H	97.3
176.6	^{136}Cs	13.16	D	10.0	204.0	^{228}Ac	6.15	H	0.112
176.9	^{133m}Te	55.4	M	0.18	204.1	^{125}Sb	2.75856	Y	0.317
177.2	^{151}Pm	28.40	H	3.8	204.1	^{227}Th	18.68	D	0.23
177.2	^{133m}Te	55.4	M	0.18	204.2	^{151}Pm	28.40	H	0.131
177.2	^{131}I	8.0252	D	0.269	204.4	^{128}Sb	9.05	H	1.00
177.3	^{77}Ge	11.211	H	0.13	205.0	^{227}Th	18.68	D	0.16
177.8	^{149}Nd	1.728	H	0.155	205.3	^{235}U	703.8E+6	Y	5.02
178.1	^{133m}Te	55.4	M	0.27	205.8	^{192}Ir	73.829	D	3.31
178.3	^{142}La	91.1	M	0.19	206.1	^{227}Th	18.68	D	0.25
179.4	^{117}Cd	2.49	H	0.10	206.2	^{187}W	24.000	H	0.153
179.4	^{182}Ta	114.74	D	3.119	208.0	^{237}U	6.75	D	21.2
179.5	^{223}Ra	11.43	D	0.153	208.1	^{125}Sb	2.75856	Y	0.248
180.4	^{129}Sb	4.366	H	2.84	208.1	^{149}Nd	1.728	H	2.55
180.9	^{134}Te	41.8	M	18.3	208.6	^{157}Eu	15.18	H	0.150
181.1	^{99}Mo	65.924	H	6.05	208.8	^{77}Ge	11.211	H	1.12
182.3	^{131m}Te	33.25	H	0.992	209.0	^{129}Te	69.6	M	0.180
182.3	^{131m}Te	33.25	H	0.71	209.0	^{151}Pm	28.40	H	1.73
182.3	^{130}Sb	39.5	M	65	209.3	^{228}Ac	6.15	H	3.89
182.6	^{235}U	703.8E+6	Y	0.39	209.8	^{239}Np	2.356	D	3.363
183.1	^{134}Te	41.8	M	0.6	210.5	^{134}Te	41.8	M	22.7
183.1	^{131m}Te	33.25	H	0.149	210.6	^{227}Th	18.68	D	1.25
183.6	^{132}I	2.295	H	0.138	211.0	^{77}Ge	11.211	H	30.0
184.6	^{133m}Te	55.4	M	0.13	211.3	^{149}Nd	1.728	H	25.9
185.5	^{149}Nd	1.728	H	0.104	211.4	^{208}Tl	3.053	M	0.180
185.7	^{235}U	703.8E+6	Y	57.0	212.3	^{138}Cs	33.41	M	0.175
186.2	^{226}Ra	1600	Y	3.64	213.5	^{133m}Te	55.4	M	1.73
186.6	^{151}Pm	28.40	H	0.180	213.9	^{149}Nd	1.728	H	0.40
187.3	^{136}Cs	13.16	D	0.36	214.0	^{131m}Te	33.25	H	0.411
188.1	^{131m}Te	33.25	H	0.205	214.0	^{133m}Te	55.4	M	0.18
188.2	^{154}Eu	8.601	Y	0.2400	214.8	^{128}Sb	9.05	H	1.00
188.5	^{134}I	52.5	M	0.77	214.9	^{228}Ac	6.15	H	0.76
188.6	^{149}Nd	1.728	H	1.79	215.5	^{77}Ge	11.211	H	27.9
189.8	^{131m}Te	33.25	H	0.49	216.0	^{228}Th	1.9125	Y	0.247
190.3	^{114m}In	49.51	D	15.56	217.0	^{134}I	52.5	M	0.23
190.5	^{131m}Te	33.25	H	0.112	218.9	^{97}Zr	16.749	H	0.168
191.4	^{228}Ac	6.15	H	0.123	219.1	^{77}Ge	11.211	H	0.14
192.0	^{138}Cs	33.41	M	0.50	220.5	^{135}I	6.58	H	1.75
192.0	^{149}Nd	1.728	H	0.57	220.9	^{117}Cd	2.49	H	1.17
192.3	^{59}Fe	44.495	D	3.08	220.9	^{117m}Cd	3.36	H	0.24
193.4	^{133m}Te	55.4	M	0.47	221.1	^{133m}Te	55.4	M	0.19
193.9	^{138}Cs	33.41	M	0.328	221.4	^{235}U	703.8E+6	Y	0.118
194.7	^{77}Ge	11.211	H	1.67	221.5	^{82}Br	35.282	H	2.26

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
222.1	^{182}Ta	114.74	D	7.57	252.5	^{227}Th	18.68	D	0.111
223.2	^{133}Ba	10.551	Y	0.453	252.6	^{208}Tl	3.053	M	0.780
224.2	^{133m}Te	55.4	M	0.13	253.2	^{131m}Te	33.25	H	0.627
225.1	^{105}Ru	4.44	H	0.123	254.2	^{97}Zr	16.749	H	1.15
226.4	^{239}Np	2.356	D	0.259	254.3	^{151}Pm	28.40	H	0.169
226.8	^{149}Nd	1.728	H	0.163	254.4	^{239}Np	2.356	D	0.1092
227.2	^{151}Pm	28.40	H	0.34	254.6	^{227}Th	18.68	D	0.71
227.3	^{128}Sb	9.05	H	1.5	254.7	^{77}Ge	11.211	H	0.197
227.8	^{138}Cs	33.41	M	1.51	255.1	^{132}I	2.295	H	0.237
227.8	^{239}Np	2.356	D	0.5100	255.1	^{113}Sn	115.09	D	2.11
227.9	^{125}Sb	2.75856	Y	0.1311	255.4	^{131m}Te	33.25	H	0.299
228.2	^{132}Te	3.204	D	88	255.8	^{231}Pa	3.276E+4	Y	0.1059
228.2	^{239}Np	2.356	D	10.73	256.2	^{227}Th	18.68	D	7.0
229.3	^{182}Ta	114.74	D	3.644	257.8	^{133m}Te	55.4	M	0.35
229.6	^{149}Nd	1.728	H	0.482	258.0	^{130}Sb	39.5	M	3.9
229.7	^{135}I	6.58	H	0.241	258.1	^{149}Nd	1.728	H	0.376
230.1	^{133m}Te	55.4	M	0.22	258.1	^{151}Pm	28.40	H	0.56
230.2	^{84}Br	31.76	M	0.30	258.8	^{74}Ga	8.12	M	0.11
230.7	^{131m}Te	33.25	H	0.187	258.8	^{113}Ag	5.37	H	1.64
231.4	^{115}Cd	53.46	H	0.740	258.9	^{214}Pb	26.8	M	0.531
231.6	^{143}Ce	33.039	H	2.05	259.8	^{134}Te	41.8	M	0.44
232.4	^{151}Pm	28.40	H	1.03	260.2	^{231}Pa	3.276E+4	Y	0.182
233.2	^{74}Ga	8.12	M	0.16	260.9	^{115}Cd	53.46	H	1.94
233.2	^{133}I	20.83	H	0.294	261.2	^{91}Sr	9.65	H	0.449
233.2	^{133m}Xe	2.198	D	10.12	261.6	^{133m}Te	55.4	M	6.3
233.4	^{208}Tl	3.053	M	0.310	262.7	^{133}I	20.83	H	0.359
234.8	^{227}Th	18.68	D	0.45	262.8	^{105}Ru	4.44	H	6.57
235.0	^{128}Sb	9.05	H	0.30	262.9	^{227}Th	18.68	D	0.107
235.0	^{133m}Te	55.4	M	0.13	262.9	^{132}I	2.295	H	1.28
235.5	^{134}I	52.5	M	2.13	264.1	^{182}Ta	114.74	D	3.612
235.7	^{95}Zr	64.032	D	0.270	264.3	^{135}I	6.58	H	0.184
236.0	^{227}Th	18.68	D	12.9	264.5	^{77}Ge	11.211	H	53.3
236.6	^{151}Pm	28.40	H	0.160	264.6	^{75}Ge	82.78	M	11.4
236.7	^{151}Pm	28.40	H	0.19	264.7	^{75}Se	119.78	D	58.9
237.1	^{151}Pm	28.40	H	0.52	266.5	^{140}La	1.67855	D	0.466
238.6	^{149}Nd	1.728	H	0.89	266.9	^{93}Y	10.18	H	7.4
238.6	^{212}Pb	10.64	H	43.6	267.2	^{133}I	20.83	H	0.117
239.1	^{187}W	24.000	H	0.100	267.5	^{237}U	6.75	D	0.712
240.1	^{151}Pm	28.40	H	3.8	267.7	^{149}Nd	1.728	H	6.0
240.2	^{149}Nd	1.728	H	3.94	268.1	^{77}Ge	11.211	H	0.3
240.7	^{88}Kr	2.825	H	0.253	268.5	^{129}Sb	4.366	H	0.214
240.9	^{133m}Te	55.4	M	0.27	269.5	^{223}Ra	11.43	D	13.9
240.9	^{131m}Te	33.25	H	7.32	270.2	^{149}Nd	1.728	H	10.7
241.0	^{224}Ra	3.66	D	4.10	270.2	^{228}Ac	6.15	H	3.46
241.6	^{92}Sr	2.611	H	2.93	270.6	^{125}Sn	9.64	D	0.11
241.9	^{140}La	1.67855	D	0.414	271.2	^{219}Rn	3.96	S	10.8
242.0	^{214}Pb	26.8	M	7.251	272.4	^{97}Zr	16.749	H	0.23
244.4	^{133m}Te	55.4	M	0.27	272.6	^{91}Sr	9.65	H	0.26
244.5	^{129}Sb	4.366	H	0.403	272.9	^{227}Th	18.68	D	0.51
244.7	^{152}Eu	13.517	Y	7.55	273.2	^{149}Nd	1.728	H	0.18
245.5	^{149}Nd	1.728	H	0.21	273.3	^{117}Cd	2.49	H	27.9
245.7	^{149}Nd	1.728	H	0.80	273.5	^{82}Br	35.282	H	0.801
246.2	^{187}W	24.000	H	0.136	273.6	^{136}Cs	13.16	D	11.1
247.9	^{154}Eu	8.601	Y	6.89	273.8	^{214}Bi	19.9	M	0.128
249.7	^{128}Sb	9.05	H	0.60	274.3	^{131}Sb	23.03	M	1.2
249.8	^{135}Xe	9.14	H	90	274.7	^{91}Sr	9.65	H	1.04
250.3	^{227}Th	18.68	D	0.45	274.8	^{214}Pb	26.8	M	0.355
250.6	^{129}Te	69.6	M	0.38	275.2	^{151}Pm	28.40	H	6.8
251.5	^{133m}Te	55.4	M	0.22	275.4	^{147}Nd	10.98	D	0.910
252.4	^{127}Sb	3.85	D	8.5	275.4	^{149}Nd	1.728	H	0.65

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
276.4	^{133}Ba	10.551	Y	7.16	302.7	^{231}Pa	3.276E+4	Y	2.3
277.0	^{149}Nd	1.728	H	0.342	302.7	^{231}Pa	3.276E+4	Y	0.17
277.4	^{208}Tl	3.053	M	6.6	302.9	^{133}Ba	10.551	Y	18.34
277.6	^{239}Np	2.356	D	14.51	303.3	^{130}Sb	39.5	M	5.8
278.0	^{134}Te	41.8	M	21.2	303.9	^{75}Se	119.78	D	1.315
278.0	^{133m}Te	55.4	M	0.44	304.5	^{227}Th	18.68	D	1.15
278.3	^{128}Sb	9.05	H	0.60	304.8	^{140}Ba	12.7527	D	4.29
278.4	^{129}Te	69.6	M	0.57	304.9	^{85m}Kr	4.480	H	14.0
278.6	^{131m}Te	33.25	H	1.72	306.1	^{105}Rh	35.36	H	5.1
278.8	^{134}I	52.5	M	0.144	306.7	^{151}Pm	28.40	H	0.239
279.0	^{228}Ac	6.15	H	0.160	307.9	^{133m}Te	55.4	M	0.22
279.2	^{203}Hg	46.594	D	81.56	308.5	^{192}Ir	73.829	D	29.70
279.2	^{203}Pb	51.92	H	80.9	309.5	^{131m}Te	33.25	H	0.36
279.5	^{235}U	703.8E+6	Y	0.270	310.0	^{127}Sb	3.85	D	0.26
279.5	^{75}Se	119.78	D	25.02	310.3	^{117m}Cd	3.36	H	0.50
279.8	^{117}Cd	2.49	H	0.11	311.0	^{149}Nd	1.728	H	0.510
280.1	^{151}Pm	28.40	H	0.232	311.7	^{88}Kr	2.825	H	0.107
280.1	^{105}Rh	35.36	H	0.166	312.1	^{133m}Te	55.4	M	1.77
280.4	^{127}Sb	3.85	D	0.66	312.7	^{227}Th	18.68	D	0.52
281.3	^{129}Te	69.6	M	0.165	314.1	^{128}Sb	9.05	H	61
282.5	^{149}Nd	1.728	H	0.62	314.2	^{133m}Te	55.4	M	0.31
283.2	^{131m}Te	33.25	H	0.37	314.4	^{129}Sb	4.366	H	0.123
283.3	^{192}Ir	73.829	D	0.266	314.9	^{227}Th	18.68	D	0.3
283.7	^{231}Pa	3.276E+4	Y	1.65	314.9	^{227}Th	18.68	D	0.3
284.3	^{131}I	8.0252	D	6.12	315.9	^{239}Np	2.356	D	1.600
284.8	^{133m}Te	55.4	M	0.18	316.3	^{113}Ag	5.37	H	1.343
284.9	^{132}I	2.295	H	0.71	316.4	^{105}Ru	4.44	H	11.1
285.5	^{239}Np	2.356	D	0.794	316.5	^{192}Ir	73.829	D	82.86
285.5	^{130}Sb	39.5	M	3.5	316.7	^{132}I	2.295	H	0.128
286.0	^{149}Pm	53.08	H	3.10	317.7	^{128}Sb	9.05	H	3.0
286.1	^{227}Th	18.68	D	1.74	318.4	^{129}Sb	4.366	H	0.227
288.2	^{223}Ra	11.43	D	0.160	318.7	^{157}Eu	15.18	H	2.9
288.2	^{149}Nd	1.728	H	0.69	318.8	^{133m}Te	55.4	M	0.18
288.2	^{212}Bi	60.55	M	0.337	318.9	^{105}Rh	35.36	H	19.1
288.5	^{135}I	6.58	H	3.10	319.4	^{147}Nd	10.98	D	2.13
289.6	^{227}Th	18.68	D	1.9	319.8	^{134}I	52.5	M	0.46
290.3	^{135}I	6.58	H	0.304	319.9	^{136}Cs	13.16	D	0.50
290.8	^{151}Pm	28.40	H	0.83	320.1	^{51}Cr	27.704	D	9.910
290.8	^{127}Sb	3.85	D	2.02	321.0	^{125}Sb	2.75856	Y	0.416
292.1	^{117}Cd	2.49	H	0.64	321.6	^{228}Ac	6.15	H	0.226
292.1	^{117m}Cd	3.36	H	0.10	322.3	^{128}Sb	9.05	H	3.0
293.3	^{143}Ce	33.039	H	42.8	323.8	^{131}Sb	23.03	M	1.2
293.3	^{127}Sb	3.85	D	0.29	323.9	^{223}Ra	11.43	D	3.99
294.8	^{149}Nd	1.728	H	0.57	323.9	^{151}Pm	28.40	H	1.22
294.8	^{133m}Te	55.4	M	0.18	324.9	^{138}Cs	33.41	M	0.290
295.0	^{103}Ru	39.247	D	0.288	325.3	^{117m}Cd	3.36	H	0.13
295.2	^{214}Pb	26.8	M	18.42	325.8	^{131}I	8.0252	D	0.273
295.3	^{129}Sb	4.366	H	0.828	325.8	^{151}Pm	28.40	H	0.106
295.7	^{131}Sb	23.03	M	1.6	326.0	^{133m}Te	55.4	M	0.22
295.9	^{152}Eu	13.517	Y	0.440	326.1	^{105}Ru	4.44	H	1.06
296.0	^{192}Ir	73.829	D	28.71	326.2	^{131}Sb	23.03	M	1.2
296.5	^{227}Th	18.68	D	0.44	326.6	^{149}Nd	1.728	H	4.56
298.6	^{113}Ag	5.37	H	10.00	327.4	^{228}Ac	6.15	H	0.12
299.5	^{117m}Cd	3.36	H	0.45	328.0	^{228}Ac	6.15	H	2.95
300.0	^{227}Th	18.68	D	2.21	328.0	^{212}Bi	60.55	M	0.125
300.1	^{231}Pa	3.276E+4	Y	2.41	328.4	^{223}Ra	11.43	D	0.209
300.1	^{212}Pb	10.64	H	3.30	328.8	^{140}La	1.67855	D	20.3
301.1	^{149}Nd	1.728	H	0.376	329.4	^{152}Eu	13.517	Y	0.1213
301.3	^{131}Sb	23.03	M	2.4	329.8	^{151}Pm	28.40	H	0.221
302.0	^{74}Ga	8.12	M	0.11	329.9	^{227}Th	18.68	D	2.9

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
330.1	^{231}Pa	3.276E+4	Y	1.36	354.3	^{78}As	90.7	M	1.9
330.4	^{97}Zr	16.749	H	0.143	354.7	^{84}Br	31.76	M	0.30
330.9	^{105}Ru	4.44	H	0.67	354.7	^{131m}Te	33.25	H	0.220
330.9	^{130}Sb	39.5	M	78	355.4	^{97}Zr	16.749	H	2.09
332.1	^{125}Sn	9.64	D	1.4	355.4	^{133m}Te	55.4	M	0.52
332.4	^{237}U	6.75	D	1.200	356.0	^{133}Ba	10.551	Y	62.05
332.4	^{228}Ac	6.15	H	0.40	357.0	^{128}Sb	9.05	H	1.5
333.1	^{113}Ag	5.37	H	0.598	357.1	^{231}Pa	3.276E+4	Y	0.168
333.2	^{129}Sb	4.366	H	0.171	358.4	^{135}Xe	9.14	H	0.221
334.0	^{223}Ra	11.43	D	0.101	358.9	^{157}Eu	15.18	H	0.31
334.2	^{133m}Te	55.4	M	2.7	359.2	^{129}Sb	4.366	H	2.39
334.3	^{133m}Te	55.4	M	6.8	360.1	^{149}Nd	1.728	H	0.153
334.3	^{131m}Te	33.25	H	9.22	360.3	^{127}Te	9.35	H	0.135
334.3	^{239}Np	2.356	D	2.056	361.1	^{133}I	20.83	H	0.11
334.4	^{227}Th	18.68	D	1.14	361.9	^{135}I	6.58	H	0.187
334.4	^{157}Eu	15.18	H	0.84	362.2	^{88}Kr	2.825	H	2.25
334.7	^{88}Kr	2.825	H	0.145	363.1	^{133m}Te	55.4	M	0.40
334.8	^{59}Fe	44.495	D	0.270	363.3	^{132}I	2.295	H	0.49
335.4	^{131m}Te	33.25	H	0.131	363.9	^{138}Cs	33.41	M	0.244
336.2	^{115}Cd	53.46	H	1.000	364.2	^{129}Sb	4.366	H	0.305
336.2	^{115m}In	4.486	H	45.8	364.4	^{113}Ag	5.37	H	0.140
337.5	^{77}Ge	11.211	H	0.21	364.5	^{131}I	8.0252	D	81.5
338.3	^{223}Ra	11.43	D	2.84	365.0	^{131m}Te	33.25	H	1.16
338.3	^{228}Ac	6.15	H	11.27	365.3	^{138}Cs	33.41	M	0.191
338.5	^{214}Bi	19.9	M	0.11	366.1	^{128}Sb	9.05	H	1.5
338.6	^{77}Ge	11.211	H	0.72	366.3	^{65}Ni	2.51719	H	4.81
339.4	^{113}Ag	5.37	H	0.638	366.4	^{99}Mo	65.924	H	1.200
340.1	^{151}Pm	28.40	H	22.5	366.6	^{149}Nd	1.728	H	0.54
340.5	^{136}Cs	13.16	D	42.2	366.9	^{117m}Cd	3.36	H	3.33
340.7	^{231}Pa	3.276E+4	Y	0.177	367.3	^{142}La	91.1	M	0.1422
341.0	^{228}Ac	6.15	H	0.369	367.5	^{77}Ge	11.211	H	14.5
342.6	^{227}Th	18.68	D	0.35	367.8	^{152}Eu	13.517	Y	0.859
342.8	^{133m}Te	55.4	M	0.40	367.9	^{133m}Te	55.4	M	0.18
342.9	^{223}Ra	11.43	D	0.222	370.5	^{157}Eu	15.18	H	11.2
342.9	^{131m}Te	33.25	H	0.37	370.9	^{237}U	6.75	D	0.1073
344.3	^{152}Eu	13.517	Y	26.59	371.7	^{223}Ra	11.43	D	0.487
344.4	^{133m}Te	55.4	M	0.58	374.5	^{192}Ir	73.829	D	0.727
344.5	^{117}Cd	2.49	H	17.9	376.8	^{133m}Te	55.4	M	0.18
344.9	^{151}Pm	28.40	H	2.12	379.9	^{151}Pm	28.40	H	0.95
345.4	^{133}I	20.83	H	0.104	379.9	^{91}Sr	9.65	H	0.147
345.6	^{133m}Te	55.4	M	0.18	379.9	^{157}Eu	15.18	H	0.27
345.9	^{181}Hf	42.39	D	15.12	380.5	^{125}Sb	2.75856	Y	1.517
346.8	^{223}Ra	11.43	D	0.181	382.0	^{84}Br	31.76	M	0.56
347.3	^{133m}Te	55.4	M	0.53	382.1	^{113}Ag	5.37	H	0.145
347.8	^{149}Nd	1.728	H	0.161	383.8	^{133}Ba	10.551	Y	8.94
348.9	^{214}Bi	19.9	M	0.104	383.9	^{131m}Te	33.25	H	0.19
349.2	^{149}Nd	1.728	H	1.38	384.0	^{133m}Te	55.4	M	0.13
349.8	^{151}Pm	28.40	H	0.142	384.7	^{149}Nd	1.728	H	0.267
350.0	^{105}Ru	4.44	H	0.289	386.8	^{214}Bi	19.9	M	0.295
350.2	^{105}Ru	4.44	H	1.02	387.9	^{132}I	2.295	H	0.17
350.5	^{227}Th	18.68	D	0.110	387.9	^{132}I	2.295	H	0.17
350.6	^{143}Ce	33.039	H	3.23	387.9	^{132}I	2.295	H	0.17
351.0	^{125}Sn	9.64	D	0.26	388.0	^{117}Cd	2.49	H	0.31
351.1	^{211}Bi	2.14	M	13.02	388.9	^{214}Bi	19.9	M	0.402
351.1	^{134}I	52.5	M	0.42	390.5	^{88}Kr	2.825	H	0.64
351.1	^{78}As	90.7	M	0.162	391.0	^{78}As	90.7	M	0.124
351.3	^{131m}Te	33.25	H	0.202	391.7	^{113}Sn	115.09	D	64.97
351.6	^{149}Nd	1.728	H	1.17	391.8	^{127}Sb	3.85	D	0.96
351.9	^{214}Pb	26.8	M	35.60	392.4	^{133m}Te	55.4	M	0.142
353.3	^{151}Pm	28.40	H	0.106	393.4	^{105}Ru	4.44	H	3.77

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
393.4	^{157}Eu	15.18	H	0.124	429.9	^{135}I	6.58	H	0.304
393.6	^{142}La	91.1	M	0.1896	430.5	^{92}Sr	2.611	H	3.28
397.0	^{133m}Te	55.4	M	0.58	431.8	^{132}I	2.295	H	0.47
397.2	^{117}Cd	2.49	H	0.20	432.4	^{131m}Te	33.25	H	0.64
398.2	^{147}Nd	10.98	D	0.912	432.5	^{140}La	1.67855	D	2.90
399.0	^{157}Eu	15.18	H	1.34	433.0	^{143}Ce	33.039	H	0.159
399.0	^{77}Ge	11.211	H	0.105	433.3	^{142}La	91.1	M	0.379
400.3	^{124}Sb	60.20	D	0.139	433.4	^{134}I	52.5	M	4.15
400.4	^{97}Zr	16.749	H	0.245	433.7	^{135}I	6.58	H	0.554
400.7	^{75}Se	119.78	D	11.41	433.8	^{131}Sb	23.03	M	2.0
401.3	^{154}Eu	8.601	Y	0.188	433.9	^{108m}Ag	438	Y	90.5
401.3	^{203}Pb	51.92	H	3.35	434.2	^{117}Cd	2.49	H	9.8
401.8	^{219}Rn	3.96	S	6.6	434.4	^{157}Eu	15.18	H	0.36
402.6	^{87}Kr	76.3	M	50	434.4	^{156}Eu	15.19	D	0.209
403.0	^{135}I	6.58	H	0.232	434.7	^{129}Sb	4.366	H	0.1113
404.3	^{128}Sb	9.05	H	1.00	435.0	^{129}Sb	4.366	H	0.212
404.6	^{129}Sb	4.366	H	1.172	435.1	^{134}Te	41.8	M	18.9
404.9	^{211}Pb	36.1	M	3.78	435.3	^{133m}Te	55.4	M	0.97
405.5	^{134}I	52.5	M	7.37	437.6	^{140}Ba	12.7527	D	1.929
405.7	^{214}Bi	19.9	M	0.169	439.4	^{117}Cd	2.49	H	0.11
406.0	^{133m}Te	55.4	M	0.31	439.4	^{117m}Cd	3.36	H	0.18
407.0	^{151}Pm	28.40	H	0.187	439.5	^{77}Ge	11.211	H	0.207
408.0	^{135}Xe	9.14	H	0.358	439.9	^{147}Nd	10.98	D	1.28
408.1	^{125}Sb	2.75856	Y	0.184	440.4	^{228}Ac	6.15	H	0.121
409.0	^{138}Cs	33.41	M	4.66	440.9	^{151}Pm	28.40	H	1.51
409.1	^{157}Eu	15.18	H	2.72	441.0	^{127}Sb	3.85	D	0.7
409.5	^{228}Ac	6.15	H	1.92	443.6	^{149}Nd	1.728	H	1.15
409.7	^{129}Sb	4.366	H	0.231	443.6	^{125}Sb	2.75856	Y	0.306
410.5	^{147}Nd	10.98	D	0.150	443.8	^{103}Ru	39.247	D	0.339
410.7	^{157}Eu	15.18	H	17.8	444.0	^{152}Eu	13.517	Y	2.827
411.0	^{134}I	52.5	M	0.57	444.0	^{152}Eu	13.517	Y	0.298
411.1	^{152}Eu	13.517	Y	2.237	444.1	^{124}Sb	60.20	D	0.1889
411.8	^{198}Au	2.6941	D	95.62	444.5	^{154}Eu	8.601	Y	0.547
412.1	^{127}Sb	3.85	D	3.8	444.9	^{133m}Te	55.4	M	1.64
413.2	^{133m}Te	55.4	M	0.53	445.0	^{223}Ra	11.43	D	1.29
413.5	^{105}Ru	4.44	H	2.27	445.1	^{127}Sb	3.85	D	4.3
414.8	^{135}I	6.58	H	0.301	445.7	^{151}Pm	28.40	H	4.0
416.0	^{152}Eu	13.517	Y	0.1088	445.7	^{128}Sb	9.05	H	1.5
416.4	^{77}Ge	11.211	H	22.7	446.2	^{132}I	2.295	H	0.60
416.5	^{192}Ir	73.829	D	0.670	446.8	^{110m}Ag	249.83	D	3.70
416.8	^{132}I	2.295	H	0.47	448.5	^{92}Y	3.54	H	2.3
417.4	^{131m}Te	33.25	H	0.269	449.9	^{63}Zn	38.47	M	0.236
417.6	^{133}I	20.83	H	0.154	450.8	^{157}Eu	15.18	H	1.24
417.6	^{135}I	6.58	H	3.53	451.0	^{127}Sb	3.85	D	0.18
417.9	^{127}Te	9.35	H	0.99	451.4	^{151}Pm	28.40	H	0.29
417.9	^{130}I	12.36	H	34.2	451.6	^{135}I	6.58	H	0.316
419.1	^{75}Ge	82.78	M	0.185	452.3	^{131m}Te	33.25	H	1.5
419.7	^{77}Ge	11.211	H	1.22	453.0	^{212}Bi	60.55	M	0.363
419.8	^{117}Cd	2.49	H	0.18	453.4	^{129}Sb	4.366	H	0.538
420.1	^{157}Eu	15.18	H	0.94	454.5	^{128}Sb	9.05	H	1.5
420.2	^{142}La	91.1	M	0.237	454.8	^{214}Bi	19.9	M	0.292
421.6	^{138}Cs	33.41	M	0.427	455.4	^{130}Sb	39.5	M	4.8
422.9	^{133}I	20.83	H	0.311	456.0	^{127}Sb	3.85	D	0.11
423.6	^{149}Nd	1.728	H	7.4	456.7	^{131}Sb	23.03	M	0.7
423.7	^{140}Ba	12.7527	D	3.15	457.8	^{130}I	12.36	H	0.237
425.2	^{149}Nd	1.728	H	0.272	458.9	^{134}I	52.5	M	1.31
427.1	^{211}Pb	36.1	M	1.76	459.5	^{128}Sb	9.05	H	1.5
427.4	^{157}Eu	15.18	H	0.162	459.6	^{129}Te	69.6	M	7.7
427.9	^{125}Sb	2.75856	Y	29.6	460.9	^{157}Eu	15.18	H	0.99
429.0	^{133m}Te	55.4	M	1.77	460.9	^{117m}Cd	3.36	H	1.62

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
461.0	^{134}Te	41.8	M	9.7	491.3	^{92}Sr	2.611	H	0.27
461.4	^{77}Ge	11.211	H	1.33	492.4	^{115}Cd	53.46	H	8.03
462.0	^{214}Pb	26.8	M	0.212	492.6	^{92}Y	3.54	H	0.49
462.2	^{78}As	90.7	M	0.59	493.0	^{133m}Te	55.4	M	0.62
462.2	^{133m}Te	55.4	M	1.24	493.0	^{74}Ga	8.12	M	5.0
462.5	^{130}Sb	39.5	M	0.80	495.0	^{133m}Te	55.4	M	0.155
462.8	^{138}Cs	33.41	M	30.7	497.0	^{78}As	90.7	M	0.18
462.9	^{131m}Te	33.25	H	1.76	497.1	^{103}Ru	39.247	D	91.0
463.0	^{228}Ac	6.15	H	4.40	497.6	^{74}Ga	8.12	M	0.96
463.0	^{117}Cd	2.49	H	0.75	497.8	^{117}Cd	2.49	H	0.11
463.4	^{125}Sb	2.75856	Y	10.49	499.3	^{105}Ru	4.44	H	2.0
464.0	^{133m}Te	55.4	M	0.22	500.0	^{129}Sb	4.366	H	0.430
464.6	^{134}Te	41.8	M	4.7	500.1	^{105}Ru	4.44	H	0.55
465.5	^{134}I	52.5	M	0.36	502.8	^{127}Sb	3.85	D	0.8
468.0	^{130}Sb	39.5	M	18.0	503.0	^{131}I	8.0252	D	0.359
468.1	^{192}Ir	73.829	D	47.84	503.5	^{152}Eu	13.517	Y	0.1524
468.2	^{131m}Te	33.25	H	0.30	503.7	^{78}As	90.7	M	0.42
468.8	^{75}Ge	82.78	M	0.223	503.8	^{228}Ac	6.15	H	0.182
469.4	^{105}Ru	4.44	H	17.5	504.7	^{74}Ga	8.12	M	0.10
469.8	^{214}Bi	19.9	M	0.132	505.3	^{129}Sb	4.366	H	0.518
469.9	^{125}Sn	9.64	D	1.5	505.8	^{132}I	2.295	H	4.94
470.1	^{105}Ru	4.44	H	0.184	506.7	^{130}Sb	39.5	M	2.0
470.4	^{157}Eu	15.18	H	0.202	507.2	^{136}Cs	13.16	D	0.97
471.1	^{74}Ga	8.12	M	0.39	507.2	^{133m}Te	55.4	M	0.35
471.8	^{88}Kr	2.825	H	0.73	507.6	^{97}Zr	16.749	H	5.03
471.9	^{133m}Te	55.4	M	0.66	507.9	^{65}Ni	2.51719	H	0.293
472.7	^{156}Eu	15.19	D	0.145	509.0	^{228}Ac	6.15	H	0.45
473.0	^{127}Sb	3.85	D	25.8	510.5	^{130}I	12.36	H	0.85
473.6	^{132}I	2.295	H	0.17	510.5	^{133}I	20.83	H	1.83
474.6	^{157}Eu	15.18	H	2.56	510.8	^{208}Tl	3.053	M	22.60
475.4	^{134}Cs	2.0652	Y	1.477	511.8	^{187}W	24.000	H	0.807
475.5	^{77}Ge	11.211	H	1.07	511.9	^{106}Rh	30.07	S	20.4
476.0	^{181}Hf	42.39	D	0.703	513.4	^{97}Zr	16.749	H	0.55
477.6	^{7}Be	53.22	D	10.44	513.7	^{105}Ru	4.44	H	0.20
478.2	^{132}I	2.295	H	0.17	514.0	^{85}Kr	10.739	Y	0.434
478.2	^{154}Eu	8.601	Y	0.2250	514.4	^{134}I	52.5	M	2.24
478.3	^{228}Ac	6.15	H	0.209	514.4	^{129}Sb	4.366	H	0.147
478.6	^{133m}Te	55.4	M	0.75	514.7	^{142}La	91.1	M	0.14
479.5	^{90m}Y	3.19	H	90.74	516.3	^{151}Pm	28.40	H	0.194
479.5	^{187}W	24.000	H	26.6	516.7	^{138}Cs	33.41	M	0.43
480.4	^{214}Pb	26.8	M	0.337	519.7	^{133m}Te	55.4	M	0.22
482.2	^{181}Hf	42.39	D	80.5	520.6	^{77}Ge	11.211	H	0.28
483.6	^{130}Sb	39.5	M	2.2	521.0	^{74}Ga	8.12	M	0.12
484.6	^{192}Ir	73.829	D	3.19	522.7	^{132}I	2.295	H	16.0
484.8	^{117m}Cd	3.36	H	1.02	523.1	^{129}Sb	4.366	H	1.55
484.9	^{74}Ga	8.12	M	1.06	523.1	^{228}Ac	6.15	H	0.103
487.0	^{140}La	1.67855	D	45.5	524.8	^{131m}Te	33.25	H	0.131
487.1	^{214}Pb	26.8	M	0.432	524.8	^{157}Eu	15.18	H	0.31
487.4	^{129}Te	69.6	M	1.42	525.2	^{129}Sb	4.366	H	0.1644
487.4	^{133m}Te	55.4	M	0.44	525.5	^{124}Sb	60.20	D	0.138
488.0	^{132}I	2.295	H	0.23	525.6	^{133m}Te	55.4	M	0.22
488.0	^{132}I	2.295	H	0.23	526.5	^{128}Sb	9.05	H	45
488.7	^{152}Eu	13.517	Y	0.414	526.6	^{135m}Xe	15.29	M	80.6
488.9	^{134}I	52.5	M	1.45	527.0	^{117}Cd	2.49	H	0.14
489.1	^{192}Ir	73.829	D	0.438	527.9	^{115}Cd	53.46	H	27.5
489.2	^{147}Nd	10.98	D	0.155	529.9	^{133}I	20.83	H	87.0
489.5	^{105}Ru	4.44	H	0.55	530.7	^{131m}Te	33.25	H	0.101
490.3	^{151}Pm	28.40	H	0.126	531.0	^{147}Nd	10.98	D	13.4
490.3	^{156}Eu	15.19	D	0.160	531.6	^{142}La	91.1	M	0.1422
490.4	^{143}Ce	33.039	H	2.16	532.4	^{133m}Te	55.4	M	0.71

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
533.7	^{214}Pb	26.8	M	0.181	576.0	^{135}I	6.58	H	0.129
534.9	^{133m}Te	55.4	M	0.84	578.1	^{142}La	91.1	M	1.33
535.4	^{132}I	2.295	H	0.51	580.1	^{214}Pb	26.8	M	0.370
536.1	^{130}I	12.36	H	99.00	581.4	^{133m}Te	55.4	M	0.40
537.3	^{140}Ba	12.7527	D	24.39	582.0	^{154}Eu	8.601	Y	0.893
539.1	^{130}I	12.36	H	1.40	582.0	^{187}W	24.000	H	0.1308
539.3	^{105}Ru	4.44	H	0.114	582.6	^{77}Ge	11.211	H	0.80
540.3	^{133m}Te	55.4	M	0.22	582.9	^{128}Sb	9.05	H	1.00
540.5	^{149}Nd	1.728	H	6.6	583.2	^{208}Tl	3.053	M	85.0
540.8	^{134}I	52.5	M	7.66	583.4	^{228}Ac	6.15	H	0.111
540.9	^{74}Ga	8.12	M	0.16	584.0	^{113}Ag	5.37	H	0.21
541.4	^{131m}Te	33.25	H	0.108	584.2	^{127}Sb	3.85	D	0.33
543.3	^{127}Sb	3.85	D	2.9	586.0	^{130}I	12.36	H	1.69
544.6	^{129}Sb	4.366	H	15.42	586.3	^{152}Eu	13.517	Y	0.455
545.0	^{117m}Cd	3.36	H	0.16	586.3	^{131m}Te	33.25	H	1.90
545.3	^{78}As	90.7	M	3.0	586.4	^{133m}Te	55.4	M	0.22
546.5	^{228}Ac	6.15	H	0.201	587.2	^{143}Ce	33.039	H	0.267
546.6	^{135}I	6.58	H	7.15	588.6	^{192}Ir	73.829	D	4.522
547.0	^{138}Cs	33.41	M	10.76	589.1	^{187}W	24.000	H	0.150
547.2	^{132}I	2.295	H	1.14	591.1	^{157}Eu	15.18	H	0.160
551.6	^{187}W	24.000	H	6.14	591.8	^{154}Eu	8.601	Y	4.95
551.8	^{74}Ga	8.12	M	0.11	594.3	^{128}Sb	9.05	H	1.00
551.8	^{78}As	90.7	M	0.17	594.8	^{147}Nd	10.98	D	0.283
553.9	^{130}I	12.36	H	0.66	595.4	^{134}I	52.5	M	11.1
554.3	^{82}Br	35.282	H	71.1	595.5	^{130}Sb	39.5	M	1.00
555.6	^{91m}Y	49.71	M	95.0	595.8	^{74}As	17.77	D	59
555.9	^{149}Nd	1.728	H	0.59	595.9	^{74}Ga	8.12	M	91.80
556.7	^{129m}Te	33.6	D	0.118	597.3	^{117m}Cd	3.36	H	0.131
556.8	^{149}Nd	1.728	H	0.44	599.5	^{156}Eu	15.19	D	2.08
557.1	^{103}Ru	39.247	D	0.841	600.6	^{125}Sb	2.75856	Y	17.65
557.5	^{154}Eu	8.601	Y	0.269	601.5	^{133m}Te	55.4	M	0.102
557.9	^{77}Ge	11.211	H	16.8	602.1	^{131m}Te	33.25	H	0.30
558.4	^{114m}In	49.51	D	4.4	602.4	^{97}Zr	16.749	H	1.38
559.1	^{76}As	26.24	H	45.0	602.7	^{124}Sb	60.20	D	97.8
559.2	^{105}Ru	4.44	H	0.109	603.0	^{128}Sb	9.05	H	1.7
561.1	^{92}Y	3.54	H	2.4	603.5	^{127}Sb	3.85	D	4.5
562.5	^{228}Ac	6.15	H	0.87	603.5	^{130}I	12.36	H	0.61
563.2	^{76}As	26.24	H	1.20	604.2	^{74}Ga	8.12	M	2.85
563.2	^{134}Cs	2.0652	Y	8.338	604.4	^{192}Ir	73.829	D	8.216
564.0	^{152}Eu	13.517	Y	0.494	604.7	^{134}Cs	2.0652	Y	97.62
564.2	^{122}Sb	2.7238	D	70.67	604.8	^{84}Br	31.76	M	1.7
564.4	^{117m}Cd	3.36	H	14.7	605.1	^{133m}Te	55.4	M	1.02
565.0	^{151}Pm	28.40	H	0.353	606.2	^{129}Sb	4.366	H	0.146
565.5	^{134}I	52.5	M	0.95	606.3	^{82}Br	35.282	H	1.226
566.0	^{134}Te	41.8	M	18.6	606.7	^{125}Sb	2.75856	Y	4.98
566.4	^{152}Eu	13.517	Y	0.131	607.3	^{133m}Te	55.4	M	0.13
567.0	^{129}Sb	4.366	H	0.136	608.2	^{135}Xe	9.14	H	2.90
567.6	^{157}Eu	15.18	H	0.148	608.4	^{74}Ga	8.12	M	14.4
569.3	^{134}Cs	2.0652	Y	15.373	608.4	^{74}As	17.77	D	0.552
569.4	^{77}Ge	11.211	H	0.15	609.3	^{214}Bi	19.9	M	45.49
569.7	^{207}Bi	31.55	Y	97.75	609.4	^{131m}Te	33.25	H	0.134
570.8	^{134}I	52.5	M	0.31	609.5	^{65}Ni	2.51719	H	0.155
570.9	^{228}Ac	6.15	H	0.182	610.3	^{103}Ru	39.247	D	5.76
570.9	^{157}Eu	15.18	H	1.59	612.1	^{103}Ru	39.247	D	0.105
571.5	^{76}As	26.24	H	0.140	612.5	^{192}Ir	73.829	D	5.34
572.1	^{228}Ac	6.15	H	0.150	613.8	^{78}As	90.7	M	54
574.1	^{133m}Te	55.4	M	0.58	614.3	^{108m}Ag	438	Y	89.8
574.1	^{133m}Te	55.4	M	0.97	614.4	^{77}Ge	11.211	H	0.53
575.0	^{151}Pm	28.40	H	0.117	615.2	^{181}Hf	42.39	D	0.233
575.1	^{105}Ru	4.44	H	0.85	616.2	^{106}Rh	30.07	S	0.75

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
617.5	^{117m}Cd	3.36	H	0.34	649.9	^{135}I	6.58	H	0.46
617.7	^{75}Ge	82.78	M	0.114	650.5	^{132}I	2.295	H	2.57
618.0	^{133}I	20.83	H	0.544	650.8	^{92}Sr	2.611	H	0.37
618.4	^{187}W	24.000	H	7.57	652.3	^{91}Sr	9.65	H	2.98
619.1	^{82}Br	35.282	H	43.5	652.3	^{127}Sb	3.85	D	0.37
619.3	^{157}Eu	15.18	H	3.6	652.7	^{105}Ru	4.44	H	0.31
619.8	^{131}Sb	23.03	M	1.6	652.9	^{91}Sr	9.65	H	8.0
620.1	^{91}Sr	9.65	H	1.78	653.0	^{91}Sr	9.65	H	0.37
620.4	^{110m}Ag	249.83	D	2.73	653.3	^{133m}Te	55.4	M	0.49
620.9	^{132}I	2.295	H	0.39	654.2	^{128}Sb	9.05	H	17.0
621.2	^{132}I	2.295	H	1.58	654.3	^{151}Pm	28.40	H	0.241
621.3	^{133m}Te	55.4	M	0.40	654.3	^{129}Sb	4.366	H	2.97
621.8	^{134}I	52.5	M	10.6	654.7	^{130}Sb	39.5	M	2.00
621.9	^{106}Rh	30.07	S	9.93	654.8	^{149}Nd	1.728	H	8.0
622.8	^{157}Eu	15.18	H	0.99	655.6	^{157}Eu	15.18	H	0.188
623.3	^{133m}Te	55.4	M	0.22	656.2	^{105}Ru	4.44	H	2.1
624.8	^{77}Ge	11.211	H	0.190	656.5	^{152}Eu	13.517	Y	0.1441
625.3	^{154}Eu	8.601	Y	0.316	657.1	^{76}As	26.24	H	6.2
625.5	^{187}W	24.000	H	1.314	657.8	^{110m}Ag	249.83	D	95.61
625.7	^{131}Sb	23.03	M	2.4	657.9	^{78}As	90.7	M	0.27
626.3	^{110m}Ag	249.83	D	0.217	657.9	^{131}Sb	23.03	M	4
626.7	^{130}Sb	39.5	M	2.8	657.9	^{97}Nb	72.1	M	98.23
627.0	^{117}Cd	2.49	H	0.11	658.2	^{130}Sb	39.5	M	1.7
627.3	^{117m}Cd	3.36	H	0.236	659.0	^{132}I	2.295	H	0.10
628.0	^{134}I	52.5	M	2.22	660.8	^{117}Cd	2.49	H	0.11
628.7	^{128}Sb	9.05	H	31	660.9	^{91}Sr	9.65	H	0.101
628.7	^{157}Eu	15.18	H	0.101	661.7	^{137}Cs	30.08	Y	85.10
629.0	^{133m}Te	55.4	M	0.27	663.5	^{117m}Cd	3.36	H	0.68
630.2	^{132}I	2.295	H	13.3	664.6	^{143}Ce	33.039	H	5.69
630.2	^{149}Nd	1.728	H	0.189	665.1	^{131m}Te	33.25	H	4.18
631.3	^{91}Sr	9.65	H	0.556	665.3	^{76}As	26.24	H	0.36
631.8	^{117m}Cd	3.36	H	2.80	665.4	^{214}Bi	19.9	M	1.531
631.9	^{77}Ge	11.211	H	7.4	665.9	^{134}Te	41.8	M	1.18
632.0	^{133m}Te	55.4	M	0.22	667.1	^{128}Sb	9.05	H	2.5
632.3	^{105}Ru	4.44	H	0.151	667.5	^{127}Sb	3.85	D	0.74
632.5	^{124}Sb	60.20	D	0.1046	667.7	^{132}I	2.295	H	98.70
633.7	^{129}Sb	4.366	H	2.53	668.5	^{130}I	12.36	H	96
634.4	^{77}Ge	11.211	H	2.14	668.7	^{151}Pm	28.40	H	0.36
634.8	^{74}As	17.77	D	15.4	669.0	^{131}Sb	23.03	M	1.9
635.7	^{130}Sb	39.5	M	1.6	669.2	^{130}Sb	39.5	M	1.10
636.0	^{125}Sb	2.75856	Y	11.22	669.2	^{151}Pm	28.40	H	0.29
636.2	^{128}Sb	9.05	H	36	669.6	^{63}Zn	38.47	M	8.2
636.2	^{151}Pm	28.40	H	1.42	669.8	^{132}I	2.295	H	4.6
636.3	^{134}Te	41.8	M	1.68	670.3	^{129}Sb	4.366	H	0.96
636.5	^{133m}Te	55.4	M	0.18	671.3	^{151}Pm	28.40	H	0.90
637.0	^{131}I	8.0252	D	7.16	671.4	^{132}I	2.295	H	3.5
637.1	^{78}As	90.7	M	0.21	671.4	^{125}Sb	2.75856	Y	1.791
637.8	^{127}Sb	3.85	D	0.44	672.3	^{113}Ag	5.37	H	0.87
638.7	^{105}Ru	4.44	H	0.222	673.1	^{77}Ge	11.211	H	0.132
639.0	^{74}Ga	8.12	M	0.83	673.1	^{77}Ge	11.211	H	0.53
641.3	^{142}La	91.1	M	47.4	673.8	^{87}Kr	76.3	M	1.89
642.3	^{131}Sb	23.03	M	24	674.6	^{152}Eu	13.517	Y	0.169
642.3	^{133m}Te	55.4	M	0.71	674.8	^{228}Ac	6.15	H	2.1
642.7	^{131}I	8.0252	D	0.217	675.8	^{145}Pr	5.984	H	0.514
645.4	^{134}Te	41.8	M	0.89	675.9	^{198}Au	2.6941	D	0.805
645.9	^{124}Sb	60.20	D	7.42	676.4	^{105}Ru	4.44	H	15.7
646.2	^{142}La	91.1	M	0.14	676.6	^{110m}Ag	249.83	D	0.143
646.3	^{156}Eu	15.19	D	6.3	676.6	^{154}Eu	8.601	Y	0.1672
647.5	^{133m}Te	55.4	M	15.5	677.3	^{88}Kr	2.825	H	0.235
647.9	^{129}Sb	4.366	H	0.124	677.3	^{134}I	52.5	M	7.9

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
677.6	^{110m}Ag	249.83	D	10.70	707.9	^{135}I	6.58	H	0.66
678.6	^{152}Eu	13.517	Y	0.473	708.1	^{110m}Ag	249.83	D	0.23
680.2	^{93}Y	10.18	H	0.67	709.3	^{151}Pm	28.40	H	0.137
680.2	^{133}I	20.83	H	0.650	709.3	^{124}Sb	60.20	D	1.353
680.5	^{203}Pb	51.92	H	0.75	709.9	^{156}Eu	15.19	D	0.88
680.6	^{113}Ag	5.37	H	0.695	710.4	^{133m}Te	55.4	M	0.58
680.9	^{130}Sb	39.5	M	6.5	712.3	^{77}Ge	11.211	H	0.86
681.8	^{90m}Y	3.19	H	0.32	712.7	^{117}Cd	2.49	H	0.56
682.3	^{127}Sb	3.85	D	0.6	712.7	^{117m}Cd	3.36	H	1.00
682.8	^{129}Sb	4.366	H	5.76	713.0	^{134}Te	41.8	M	4.7
683.2	^{157}Eu	15.18	H	0.24	713.1	^{131m}Te	33.25	H	1.38
683.6	^{138}Cs	33.41	M	0.108	713.8	^{124}Sb	60.20	D	2.276
683.9	^{128}Sb	9.05	H	3.0	714.4	^{77}Ge	11.211	H	7.5
684.2	^{129}Sb	4.366	H	0.622	715.0	^{74}Ga	8.12	M	0.22
685.7	^{127}Sb	3.85	D	36.8	715.8	^{154}Eu	8.601	Y	0.187
685.8	^{187}W	24.000	H	33.2	716.4	^{117}Cd	2.49	H	0.20
685.9	^{131m}Te	33.25	H	0.149	717.7	^{151}Pm	28.40	H	4.1
685.9	^{147}Nd	10.98	D	0.886	718.9	^{133m}Te	55.4	M	0.66
686.1	^{130}I	12.36	H	1.07	719.3	^{152}Eu	13.517	Y	0.250
686.3	^{78}As	90.7	M	0.92	719.9	^{214}Bi	19.9	M	0.392
686.6	^{130}Sb	39.5	M	3.2	721.9	^{143}Ce	33.039	H	5.39
687.0	^{110m}Ag	249.83	D	6.53	722.0	^{208}Tl	3.053	M	0.24
687.5	^{78}As	90.7	M	0.65	722.2	^{127}Sb	3.85	D	1.88
687.5	^{157}Eu	15.18	H	1.20	722.4	^{78}As	90.7	M	0.146
688.6	^{129}Sb	4.366	H	0.164	722.8	^{124}Sb	60.20	D	10.76
688.7	^{152}Eu	13.517	Y	0.856	722.9	^{108m}Ag	438	Y	90.8
690.1	^{135}I	6.58	H	0.129	722.9	^{131}I	8.0252	D	1.77
690.5	^{97}Zr	16.749	H	0.183	723.3	^{154}Eu	8.601	Y	20.06
692.4	^{57}Co	271.74	D	0.149	723.5	^{156}Eu	15.19	D	5.4
692.4	^{154}Eu	8.601	Y	1.777	723.5	^{133m}Te	55.4	M	0.22
692.7	^{122}Sb	2.7238	D	3.85	724.2	^{95}Zr	64.032	D	44.27
692.9	^{128}Sb	9.05	H	2.0	724.3	^{105}Ru	4.44	H	47.3
694.8	^{129}Sb	4.366	H	0.403	725.2	^{114m}In	49.51	D	4.4
694.9	^{78}As	90.7	M	16.7	726.3	^{131}Sb	23.03	M	4.1
695.6	^{131m}Te	33.25	H	0.38	726.9	^{228}Ac	6.15	H	0.62
695.9	^{129m}Te	33.6	D	3.0	727.0	^{132}I	2.295	H	2.2
696.3	^{149}Nd	1.728	H	0.171	727.2	^{132}I	2.295	H	3.2
696.5	^{144}Pr	17.28	M	1.342	727.3	^{212}Bi	60.55	M	6.67
697.8	^{129}Sb	4.366	H	0.254	727.6	^{128}Sb	9.05	H	4.0
698.1	^{133m}Te	55.4	M	0.75	728.4	^{132}I	2.295	H	1.6
698.4	^{82}Br	35.282	H	28.3	728.6	^{117}Cd	2.49	H	0.24
698.5	^{127}Sb	3.85	D	3.64	729.6	^{129m}Te	33.6	D	0.70
698.6	^{77}Ge	11.211	H	0.231	730.7	^{134}I	52.5	M	1.83
699.2	^{97}Zr	16.749	H	0.101	730.8	^{117m}Cd	3.36	H	0.1048
699.6	^{117}Cd	2.49	H	0.24	731.9	^{133m}Te	55.4	M	0.49
700.9	^{157}Eu	15.18	H	0.30	732.0	^{130}Sb	39.5	M	22.0
701.5	^{74}Ga	8.12	M	0.77	733.5	^{56}Co	77.236	D	0.191
701.7	^{228}Ac	6.15	H	0.173	733.9	^{74}Ga	8.12	M	0.110
702.5	^{131m}Te	33.25	H	0.377	734.0	^{133m}Te	55.4	M	1.42
702.9	^{133m}Te	55.4	M	1.95	736.1	^{151}Pm	28.40	H	0.47
703.1	^{214}Bi	19.9	M	0.472	736.5	^{84}Br	31.76	M	1.29
703.8	^{97}Zr	16.749	H	1.01	737.1	^{129}Sb	4.366	H	0.444
704.2	^{151}Pm	28.40	H	0.34	739.2	^{134}I	52.5	M	0.69
704.6	^{211}Pb	36.1	M	0.462	739.5	^{99}Mo	65.924	H	12.20
705.3	^{77}Ge	11.211	H	0.108	739.5	^{130}I	12.36	H	82
706.6	^{133}I	20.83	H	1.51	739.8	^{133m}Te	55.4	M	0.49
706.7	^{134}I	52.5	M	0.83	740.1	^{76}As	26.24	H	0.117
706.7	^{110m}Ag	249.83	D	16.69	742.6	^{134}Te	41.8	M	15.3
707.1	^{129}Sb	4.366	H	0.138	742.8	^{234m}Pa	1.159	M	0.1066
707.4	^{228}Ac	6.15	H	0.155	742.9	^{133m}Te	55.4	M	0.31

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
743.3	^{128}Sb	9.05	H	100	781.3	^{77}Ge	11.211	H	1.07
743.4	^{97}Zr	16.749	H	93.09	782.1	^{138}Cs	33.41	M	0.33
743.4	^{97m}Nb	58.7	S	97.90	782.1	^{133m}Te	55.4	M	0.27
743.6	^{77}Ge	11.211	H	0.190	782.1	^{228}Ac	6.15	H	0.485
744.2	^{131m}Te	33.25	H	1.53	782.5	^{131m}Te	33.25	H	7.51
744.3	^{110m}Ag	249.83	D	4.77	783.7	^{127}Sb	3.85	D	15.1
745.2	^{187}W	24.000	H	0.368	784.3	^{74}Ga	8.12	M	0.67
745.8	^{77}Ge	11.211	H	1.03	784.4	^{132}I	2.295	H	0.38
745.9	^{127}Sb	3.85	D	0.15	784.8	^{77}Ge	11.211	H	1.38
748.1	^{117}Cd	2.49	H	0.56	785.1	^{151}Pm	28.40	H	0.221
748.1	^{117m}Cd	3.36	H	4.5	785.4	^{212}Bi	60.55	M	1.102
748.3	^{145}Pr	5.984	H	0.525	785.5	^{135}I	6.58	H	0.152
749.8	^{91}Sr	9.65	H	23.7	786.0	^{214}Pb	26.8	M	1.06
749.9	^{77}Ge	11.211	H	0.93	786.4	^{214}Bi	19.9	M	0.32
751.6	^{140}La	1.67855	D	4.33	786.4	^{129}Sb	4.366	H	1.071
752.6	^{157}Eu	15.18	H	0.26	787.2	^{129}Sb	4.366	H	1.74
752.8	^{151}Pm	28.40	H	1.28	787.7	^{56}Co	77.236	D	0.311
752.9	^{214}Bi	19.9	M	0.128	788.2	^{117m}Cd	3.36	H	0.50
753.3	^{133m}Te	55.4	M	0.27	788.3	^{88}Kr	2.825	H	0.53
754.0	^{128}Sb	9.05	H	100	789.0	^{77}Ge	11.211	H	0.101
755.3	^{228}Ac	6.15	H	1.00	789.7	^{133m}Te	55.4	M	0.35
756.7	^{95}Zr	64.032	D	54.38	790.3	^{88}Kr	2.825	H	0.125
756.8	^{133m}Te	55.4	M	0.27	790.7	^{124}Sb	60.20	D	0.739
756.8	^{154}Eu	8.601	Y	4.52	793.4	^{130}Sb	39.5	M	100
761.1	^{129}Sb	4.366	H	4.32	793.8	^{131m}Te	33.25	H	13.4
761.4	^{91}Sr	9.65	H	0.576	794.4	^{77}Ge	11.211	H	0.30
762.7	^{157}Eu	15.18	H	0.37	794.7	^{133m}Te	55.4	M	0.84
762.7	^{117m}Cd	3.36	H	1.73	794.9	^{228}Ac	6.15	H	4.25
763.1	^{208}Tl	3.053	M	1.79	795.9	^{134}Cs	2.0652	Y	85.46
763.9	^{110m}Ag	249.83	D	22.60	797.7	^{135}I	6.58	H	0.17
764.9	^{152}Eu	13.517	Y	0.189	797.7	^{156}Eu	15.19	D	0.109
765.8	^{95}Nb	34.991	D	99.808	800.2	^{130}I	12.36	H	0.101
766.1	^{138}Cs	33.41	M	0.146	800.3	^{125}Sn	9.64	D	1.1
766.4	^{234m}Pa	1.159	M	0.317	800.5	^{133m}Te	55.4	M	0.89
766.5	^{211}Pb	36.1	M	0.617	802.0	^{134}Cs	2.0652	Y	8.688
766.7	^{134}I	52.5	M	4.15	802.1	^{129}Te	69.6	M	0.192
766.8	^{77}Ge	11.211	H	0.83	802.2	^{84}Br	31.76	M	6.0
767.2	^{134}Te	41.8	M	29.5	802.7	^{128}Sb	9.05	H	1.20
768.4	^{214}Bi	19.9	M	4.894	804.5	^{97}Zr	16.749	H	0.61
768.4	^{133}I	20.83	H	0.460	805.1	^{133m}Te	55.4	M	0.13
769.0	^{129}Sb	4.366	H	0.321	805.6	^{97}Zr	16.749	H	0.2793
769.1	^{151}Pm	28.40	H	0.106	806.2	^{214}Bi	19.9	M	1.264
770.6	^{65}Ni	2.51719	H	0.104	807.9	^{151}Pm	28.40	H	0.56
771.7	^{76}As	26.24	H	0.122	808.3	^{130}I	12.36	H	0.236
772.0	^{97}Zr	16.749	H	0.24	808.8	^{149}Nd	1.728	H	0.189
772.3	^{228}Ac	6.15	H	1.49	809.3	^{74}Ga	8.12	M	0.29
772.6	^{132}I	2.295	H	75.6	809.5	^{132}I	2.295	H	2.6
772.8	^{151}Pm	28.40	H	0.90	810.4	^{77}Ge	11.211	H	2.38
772.9	^{187}W	24.000	H	5.02	810.5	^{152}Eu	13.517	Y	0.317
773.3	^{138}Cs	33.41	M	0.233	810.8	^{58}Co	70.86	D	99.450
773.4	^{129}Sb	4.366	H	2.82	811.8	^{156}Eu	15.19	D	9.7
773.7	^{131m}Te	33.25	H	36.8	812.0	^{132}I	2.295	H	5.5
773.7	^{128}Sb	9.05	H	1.5	813.0	^{129}Sb	4.366	H	48.2
774.1	^{131m}Te	33.25	H	0.52	813.4	^{77}Ge	11.211	H	0.139
775.0	^{97}Zr	16.749	H	0.1862	813.6	^{128}Sb	9.05	H	13.0
776.5	^{82}Br	35.282	H	83.4	814.3	^{87}Kr	76.3	M	0.164
777.9	^{99}Mo	65.924	H	4.31	815.5	^{154}Eu	8.601	Y	0.511
778.9	^{152}Eu	13.517	Y	12.93	815.8	^{140}La	1.67855	D	23.28
779.7	^{133m}Te	55.4	M	1.42	816.3	^{133m}Te	55.4	M	0.62
780.0	^{132}I	2.295	H	1.18	816.4	^{134}I	52.5	M	0.62

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
817.0	^{127}Sb	3.85	D	0.40	854.9	^{97}Zr	16.749	H	0.357
817.7	^{151}Pm	28.40	H	0.17	855.7	^{130}Sb	39.5	M	1.6
818.0	^{110m}Ag	249.83	D	7.43	856.1	^{131m}Te	33.25	H	0.60
818.5	^{136}Cs	13.16	D	99.70	856.3	^{133}I	20.83	H	1.24
819.3	^{133m}Te	55.4	M	0.13	857.3	^{134}I	52.5	M	6.70
819.5	^{129}Sb	4.366	H	1.39	858.4	^{156}Eu	15.19	D	0.205
820.4	^{156}Eu	15.19	D	0.169	859.5	^{149}Pm	53.08	H	0.109
820.5	^{133}I	20.83	H	0.155	860.4	^{117m}Cd	3.36	H	7.9
820.6	^{127}Sb	3.85	D	0.22	860.6	^{208}Tl	3.053	M	12.50
820.8	^{91}Sr	9.65	H	0.161	860.8	^{128}Sb	9.05	H	0.40
821.2	^{214}Bi	19.9	M	0.161	861.3	^{117}Cd	2.49	H	0.28
822.0	^{105}Ru	4.44	H	0.21	861.6	^{142}La	91.1	M	1.66
822.5	^{125}Sn	9.64	D	4.3	862.3	^{88}Kr	2.825	H	0.67
822.8	^{131m}Te	33.25	H	5.90	862.6	^{117}Cd	2.49	H	0.61
823.0	^{99}Mo	65.924	H	0.134	863.0	^{132}I	2.295	H	0.56
823.3	^{77}Ge	11.211	H	0.63	864.0	^{58}Co	70.86	D	0.686
824.9	^{131}Sb	23.03	M	2.6	864.0	^{133m}Te	55.4	M	12.5
826.5	^{214}Bi	19.9	M	0.117	864.0	^{134}I	52.5	M	0.19
827.1	^{133m}Te	55.4	M	0.44	864.6	^{187}W	24.000	H	0.409
827.6	^{117m}Cd	3.36	H	0.26	865.1	^{131m}Te	33.25	H	0.19
827.8	^{82}Br	35.282	H	24.0	865.8	^{156}Eu	15.19	D	0.188
828.1	^{78}As	90.7	M	8.1	866.0	^{131}Sb	23.03	M	0.47
829.8	^{97}Zr	16.749	H	0.239	867.0	^{156}Eu	15.19	D	1.33
829.8	^{130}Sb	39.5	M	1.8	867.4	^{152}Eu	13.517	Y	4.23
830.5	^{228}Ac	6.15	H	0.540	867.6	^{76}As	26.24	H	0.131
831.8	^{117}Cd	2.49	H	2.26	867.8	^{74}Ga	8.12	M	8.7
832.0	^{211}Pb	36.1	M	3.52	867.8	^{140}La	1.67855	D	5.50
834.8	^{88}Kr	2.825	H	13.0	871.8	^{138}Cs	33.41	M	5.11
834.8	^{54}Mn	312.20	D	99.9760	873.2	^{154}Eu	8.601	Y	12.08
835.7	^{228}Ac	6.15	H	1.61	873.5	^{106}Rh	30.07	S	0.439
835.8	^{128}Sb	9.05	H	1.0	874.9	^{129}Sb	4.366	H	0.534
836.4	^{87}Kr	76.3	M	0.77	875.2	^{77}Ge	11.211	H	0.82
836.8	^{135}I	6.58	H	6.69	875.3	^{133}I	20.83	H	4.51
839.1	^{214}Pb	26.8	M	0.583	875.9	^{105}Ru	4.44	H	2.50
839.5	^{130}Sb	39.5	M	100	876.6	^{132}I	2.295	H	1.04
840.2	^{117}Cd	2.49	H	0.81	876.7	^{129}Sb	4.366	H	2.75
840.4	^{228}Ac	6.15	H	0.91	877.4	^{130}I	12.36	H	0.191
841.2	^{156}Eu	15.19	D	0.208	877.7	^{151}Pm	28.40	H	0.101
841.5	^{78}As	90.7	M	0.16	878.0	^{128}Sb	9.05	H	3.5
841.6	^{152}Eu	13.517	Y	0.168	878.2	^{105}Ru	4.44	H	0.47
842.6	^{78}As	90.7	M	1.08	878.2	^{142}La	91.1	M	0.1896
843.2	^{77}Ge	11.211	H	0.216	879.4	^{187}W	24.000	H	0.171
844.1	^{134}Te	41.8	M	1.2	879.7	^{91}Sr	9.65	H	0.188
844.3	^{92}Y	3.54	H	1.25	880.5	^{143}Ce	33.039	H	1.031
844.9	^{131m}Te	33.25	H	0.15	880.7	^{117}Cd	2.49	H	3.96
845.4	^{154}Eu	8.601	Y	0.568	880.7	^{117m}Cd	3.36	H	0.7
845.4	^{87}Kr	76.3	M	7.3	880.8	^{138}Cs	33.41	M	0.11
845.8	^{128}Sb	9.05	H	2.5	881.6	^{84}Br	31.76	M	42
845.9	^{105}Ru	4.44	H	0.63	882.0	^{78}As	90.7	M	0.19
846.8	^{56}Mn	2.5789	H	98.85	882.7	^{133m}Te	55.4	M	1.77
846.8	^{56}Co	77.236	D	99.9399	883.3	^{130}Sb	39.5	M	1.2
847.0	^{134}I	52.5	M	96	883.6	^{113}Ag	5.37	H	0.282
848.7	^{151}Pm	28.40	H	0.281	884.1	^{134}I	52.5	M	65.1
850.3	^{88}Kr	2.825	H	0.173	884.5	^{192}Ir	73.829	D	0.292
850.7	^{154}Eu	8.601	Y	0.243	884.7	^{110m}Ag	249.83	D	75.0
850.7	^{117}Cd	2.49	H	0.12	884.8	^{133m}Te	55.4	M	0.80
852.0	^{105}Ru	4.44	H	0.156	884.8	^{133m}Te	55.4	M	0.80
852.2	^{131m}Te	33.25	H	0.37	884.9	^{78}As	90.7	M	0.46
852.2	^{131m}Te	33.25	H	19.9	886.0	^{117m}Cd	3.36	H	0.39
854.6	^{131}Sb	23.03	M	3.3	886.7	^{74}Ga	8.12	M	0.34

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
888.5	^{133m}Te	55.4	M	0.66	937.5	^{110m}Ag	249.83	D	35.0
888.7	^{78}As	90.7	M	2.1	939.4	^{77}Ge	11.211	H	0.304
889.3	^{46}Sc	83.79	D	99.9840	939.5	^{129}Sb	4.366	H	0.1918
889.9	^{133m}Te	55.4	M	0.22	940.5	^{129}Sb	4.366	H	0.77
891.4	^{133m}Te	55.4	M	0.84	941.3	^{131m}Te	33.25	H	0.75
892.8	^{154}Eu	8.601	Y	0.521	942.5	^{74}Ga	8.12	M	1.27
893.4	^{125}Sn	9.64	D	0.29	943.4	^{131}Sb	23.03	M	47.1
893.4	^{212}Bi	60.55	M	0.378	944.4	^{156}Eu	15.19	D	1.33
894.9	^{142}La	91.1	M	8.34	944.9	^{88}Kr	2.825	H	0.294
896.0	^{134}Te	41.8	M	0.44	945.2	^{133m}Te	55.4	M	0.49
896.5	^{77}Ge	11.211	H	0.126	945.7	^{117}Cd	2.49	H	1.53
897.8	^{207}Bi	31.55	Y	0.128	946.7	^{87}Kr	76.3	M	0.129
898.0	^{88}Rb	17.773	M	14.40	947.1	^{93}Y	10.18	H	2.1
898.0	^{88}Y	106.627	D	93.7	947.5	^{156}Eu	15.19	D	0.292
900.7	^{77}Ge	11.211	H	0.107	947.5	^{84}Br	31.76	M	0.35
903.2	^{129}Sb	4.366	H	0.140	947.9	^{134}I	52.5	M	4.01
904.1	^{154}Eu	8.601	Y	0.889	948.0	^{228}Ac	6.15	H	0.106
904.2	^{228}Ac	6.15	H	0.77	948.7	^{151}Pm	28.40	H	0.35
907.0	^{77}Ge	11.211	H	1.00	949.2	^{133m}Te	55.4	M	0.53
907.6	^{105}Ru	4.44	H	0.53	949.6	^{117}Cd	2.49	H	0.22
908.8	^{128}Sb	9.05	H	1.0	951.0	^{140}La	1.67855	D	0.519
909.7	^{133}I	20.83	H	0.214	952.0	^{82}Br	35.282	H	0.367
910.0	^{131m}Te	33.25	H	3.17	952.1	^{212}Bi	60.55	M	0.17
910.1	^{132}I	2.295	H	0.93	952.3	^{117}Cd	2.49	H	0.14
911.0	^{131}Sb	23.03	M	0.71	953.3	^{92}Sr	2.611	H	3.52
911.2	^{228}Ac	6.15	H	25.8	954.6	^{132}I	2.295	H	17.6
912.7	^{133m}Te	55.4	M	44	957.2	^{117m}Cd	3.36	H	0.39
912.8	^{92}Y	3.54	H	0.63	958.6	^{131}Sb	23.03	M	0.61
913.9	^{77}Ge	11.211	H	0.39	958.6	^{228}Ac	6.15	H	0.28
914.8	^{133m}Te	55.4	M	8.8	959.0	^{78}As	90.7	M	0.46
914.9	^{130}Sb	39.5	M	1.8	959.7	^{182}Ta	114.74	D	0.350
915.0	^{129}Sb	4.366	H	23.3	960.5	^{156}Eu	15.19	D	1.45
915.6	^{125}Sn	9.64	D	4.1	961.0	^{74}Ga	8.12	M	1.62
919.3	^{152}Eu	13.517	Y	0.419	961.0	^{156}Eu	15.19	D	0.15
919.6	^{140}La	1.67855	D	2.66	961.4	^{135}I	6.58	H	0.15
920.6	^{131m}Te	33.25	H	1.16	962.1	^{63}Zn	38.47	M	6.5
920.7	^{145}Pr	5.984	H	0.146	962.2	^{142}La	91.1	M	0.38
922.6	^{134}I	52.5	M	0.14	963.1	^{117}Cd	2.49	H	0.61
923.1	^{77}Ge	11.211	H	0.74	963.4	^{152}Eu	13.517	Y	0.140
923.4	^{131m}Te	33.25	H	0.112	964.1	^{152}Eu	13.517	Y	14.51
923.9	^{149}Nd	1.728	H	0.101	964.1	^{214}Bi	19.9	M	0.365
924.4	^{127}Sb	3.85	D	0.52	964.8	^{228}Ac	6.15	H	4.99
925.2	^{140}La	1.67855	D	6.90	966.8	^{129}Sb	4.366	H	8.96
925.5	^{77}Ge	11.211	H	0.71	966.9	^{134}I	52.5	M	0.39
925.6	^{134}Te	41.8	M	1.48	967.0	^{130}I	12.36	H	0.88
925.8	^{91}Sr	9.65	H	3.85	968.2	^{124}Sb	60.20	D	1.882
926.0	^{130}Sb	39.5	M	0.40	968.2	^{78}As	90.7	M	0.16
926.3	^{152}Eu	13.517	Y	0.272	969.0	^{228}Ac	6.15	H	15.8
927.4	^{132}I	2.295	H	0.41	969.3	^{117}Cd	2.49	H	0.45
927.6	^{208}Tl	3.053	M	0.125	969.4	^{105}Ru	4.44	H	2.10
928.0	^{182}Ta	114.74	D	0.614	969.8	^{156}Eu	15.19	D	0.37
928.9	^{77}Ge	11.211	H	1.09	970.5	^{133m}Te	55.4	M	0.27
929.3	^{117m}Cd	3.36	H	0.79	971.3	^{97}Zr	16.749	H	0.278
931.4	^{117m}Cd	3.36	H	3.64	972.0	^{135}I	6.58	H	0.89
933.1	^{131}Sb	23.03	M	26.4	972.3	^{128}Sb	9.05	H	1.0
934.1	^{214}Bi	19.9	M	3.107	972.6	^{135}I	6.58	H	1.21
934.5	^{92}Y	3.54	H	13.9	972.6	^{133m}Te	55.4	M	0.44
934.6	^{125}Sn	9.64	D	0.21	974.7	^{134}I	52.5	M	4.78
934.9	^{130}Sb	39.5	M	19.0	975.1	^{74}Ga	8.12	M	0.27
935.0	^{138}Cs	33.41	M	0.181	977.4	^{56}Co	77.236	D	1.421

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
978.3	^{133m}Te	55.4	M	3.9	1035.6	^{117}Cd	2.49	H	0.24
979.0	^{145}Pr	5.984	H	0.256	1037.3	^{129}Sb	4.366	H	0.307
980.3	^{133m}Te	55.4	M	1.19	1037.8	^{56}Co	77.236	D	14.05
982.7	^{208}Tl	3.053	M	0.205	1038.6	^{134}Cs	2.0652	Y	0.990
984.2	^{132}I	2.295	H	0.59	1038.8	^{135}I	6.58	H	7.9
985.7	^{157}Eu	15.18	H	0.146	1039.6	^{88}Kr	2.825	H	0.48
985.8	^{77}Ge	11.211	H	0.112	1040.3	^{134}I	52.5	M	2.03
985.8	^{88}Kr	2.825	H	1.31	1040.4	^{156}Eu	15.19	D	0.50
987.3	^{84}Br	31.76	M	0.79	1043.7	^{142}La	91.1	M	2.70
987.8	^{131m}Te	33.25	H	0.149	1044.0	^{82}Br	35.282	H	28.3
988.4	^{113}Ag	5.37	H	0.423	1044.4	^{182}Ta	114.74	D	0.239
990.1	^{88}Kr	2.825	H	0.142	1045.1	^{124}Sb	60.20	D	1.833
991.5	^{131}Sb	23.03	M	1.4	1047.5	^{128}Sb	9.05	H	3.5
992.1	^{130}Sb	39.5	M	1.9	1048.1	^{136}Cs	13.16	D	80
992.7	^{129}Sb	4.366	H	0.105	1049.5	^{88}Kr	2.825	H	0.142
993.6	^{74}Ga	8.12	M	0.64	1050.4	^{131}Sb	23.03	M	0.7
995.1	^{133m}Te	55.4	M	0.40	1050.4	^{106}Rh	30.07	S	1.56
995.1	^{135}I	6.58	H	0.15	1051.4	^{145}Pr	5.984	H	0.175
996.1	^{133m}Te	55.4	M	0.31	1051.7	^{117}Cd	2.49	H	3.79
996.3	^{154}Eu	8.601	Y	10.48	1052.0	^{214}Bi	19.9	M	0.313
996.5	^{129}Sb	4.366	H	0.176	1052.3	^{133}I	20.83	H	0.556
996.6	^{77}Ge	11.211	H	0.109	1052.7	^{117}Cd	2.49	H	0.73
996.9	^{56}Co	77.236	D	0.111	1053.7	^{133m}Te	55.4	M	0.13
997.2	^{110m}Ag	249.83	D	0.130	1054.3	^{138}Cs	33.41	M	0.159
999.2	^{131m}Te	33.25	H	0.164	1054.6	^{91}Sr	9.65	H	0.224
999.9	^{74}Ga	8.12	M	0.13	1058.8	^{134}I	52.5	M	0.10
999.9	^{74}Ga	8.12	M	0.13	1059.7	^{131m}Te	33.25	H	1.49
1000.2	^{130}Sb	39.5	M	2.3	1060.1	^{133}I	20.83	H	0.138
1001.0	^{234m}Pa	1.159	M	0.842	1061.8	^{77}Ge	11.211	H	0.161
1001.7	^{182}Ta	114.74	D	2.086	1061.9	^{133m}Te	55.4	M	1.33
1004.8	^{154}Eu	8.601	Y	18.01	1063.7	^{207}Bi	31.55	Y	74.5
1005.1	^{78}As	90.7	M	0.32	1065.1	^{156}Eu	15.19	D	4.9
1005.3	^{152}Eu	13.517	Y	0.659	1065.2	^{228}Ac	6.15	H	0.132
1005.7	^{84}Br	31.76	M	0.46	1066.0	^{117m}Cd	3.36	H	23.1
1006.7	^{142}La	91.1	M	0.237	1067.1	^{125}Sn	9.64	D	10
1007.5	^{133m}Te	55.4	M	0.53	1070.0	^{214}Bi	19.9	M	0.272
1007.6	^{82}Br	35.282	H	1.276	1072.6	^{134}I	52.5	M	14.9
1009.8	^{138}Cs	33.41	M	29.8	1075.5	^{130}Sb	39.5	M	0.40
1011.4	^{142}La	91.1	M	3.93	1076.0	^{156}Eu	15.19	D	0.34
1011.9	^{156}Eu	15.19	D	0.31	1077.0	^{86}Rb	18.642	D	8.64
1015.9	^{84}Br	31.76	M	6.2	1078.1	^{133m}Te	55.4	M	0.13
1017.4	^{125}Sn	9.64	D	0.32	1078.6	^{128}Sb	9.05	H	2.0
1017.5	^{105}Ru	4.44	H	0.32	1078.6	^{212}Bi	60.55	M	0.564
1018.1	^{97}Zr	16.749	H	0.3724	1079.2	^{156}Eu	15.19	D	4.6
1018.7	^{78}As	90.7	M	0.14	1079.6	^{133m}Te	55.4	M	0.44
1021.2	^{97}Zr	16.749	H	1.01	1079.8	^{78}As	90.7	M	1.62
1022.8	^{149}Nd	1.728	H	0.104	1080.8	^{77}Ge	11.211	H	0.27
1024.3	^{74}Ga	8.12	M	0.14	1081.3	^{82}Br	35.282	H	0.66
1024.3	^{91}Sr	9.65	H	33.5	1082.6	^{84}Br	31.76	M	0.14
1024.4	^{97}Nb	72.1	M	1.09	1083.9	^{129}Te	69.6	M	0.49
1026.7	^{97}Zr	16.749	H	0.2793	1084.0	^{152}Eu	13.517	Y	0.245
1027.0	^{134}Te	41.8	M	0.44	1085.2	^{77}Ge	11.211	H	6.4
1027.4	^{156}Eu	15.19	D	0.128	1085.8	^{152}Eu	13.517	Y	10.11
1029.1	^{117m}Cd	3.36	H	11.7	1087.7	^{198}Au	2.6941	D	0.1589
1029.9	^{133m}Te	55.4	M	0.97	1087.7	^{125}Sn	9.64	D	1.2
1030.7	^{129}Sb	4.366	H	15.13	1088.0	^{129}Sb	4.366	H	0.411
1030.7	^{130}Sb	39.5	M	1.5	1089.2	^{125}Sn	9.64	D	4.6
1033.2	^{228}Ac	6.15	H	0.201	1089.5	^{130}Sb	39.5	M	3.7
1035.0	^{132}I	2.295	H	0.51	1089.7	^{152}Eu	13.517	Y	1.734
1035.4	^{131m}Te	33.25	H	0.101	1089.9	^{142}La	91.1	M	0.1422

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
1093.9	^{208}Tl	3.053	M	0.430	1140.7	^{154}Eu	8.601	Y	0.237
1095.7	^{228}Ac	6.15	H	0.129	1140.8	^{91}Sr	9.65	H	0.127
1096.5	^{130}I	12.36	H	0.552	1141.3	^{88}Kr	2.825	H	1.28
1096.5	^{130}Sb	39.5	M	0.80	1141.4	^{130}Sb	39.5	M	2.0
1098.4	^{133m}Te	55.4	M	0.71	1141.6	^{127}Sb	3.85	D	0.37
1099.2	^{59}Fe	44.495	D	56.5	1142.4	^{92}Sr	2.611	H	2.79
1100.1	^{134}I	52.5	M	0.69	1142.4	^{117}Cd	2.49	H	1.67
1101.3	^{74}Ga	8.12	M	5.42	1142.7	^{133m}Te	55.4	M	1.06
1101.6	^{135}I	6.58	H	1.61	1143.3	^{132}I	2.295	H	1.35
1103.2	^{134}I	52.5	M	0.80	1143.5	^{117}Cd	2.49	H	0.14
1103.3	^{143}Ce	33.039	H	0.415	1145.1	^{78}As	90.7	M	1.67
1104.5	^{129}Sb	4.366	H	0.341	1146.2	^{130}Sb	39.5	M	0.60
1109.2	^{152}Eu	13.517	Y	0.189	1147.2	^{138}Cs	33.41	M	1.24
1109.5	^{211}Pb	36.1	M	0.115	1147.8	^{132}I	2.295	H	0.27
1110.6	^{228}Ac	6.15	H	0.285	1148.0	^{97}Zr	16.749	H	2.62
1111.6	^{129}Te	69.6	M	0.191	1148.9	^{131m}Te	33.25	H	1.5
1112.1	^{152}Eu	13.517	Y	13.67	1148.9	^{131m}Te	33.25	H	0.24
1112.7	^{128}Sb	9.05	H	2.0	1150.3	^{145}Pr	5.984	H	0.194
1113.4	^{182}Ta	114.74	D	0.445	1150.9	^{131m}Te	33.25	H	0.63
1114.9	^{77}Ge	11.211	H	0.111	1151.2	^{125}Sn	9.64	D	0.11
1115.5	^{65}Ni	2.51719	H	15.43	1151.9	^{77}Ge	11.211	H	0.201
1115.5	^{65}Zn	243.93	D	50.04	1153.5	^{228}Ac	6.15	H	0.139
1116.6	^{117}Cd	2.49	H	1.03	1153.7	^{156}Eu	15.19	D	6.8
1118.3	^{154}Eu	8.601	Y	0.113	1154.1	^{156}Eu	15.19	D	4.7
1119.1	^{84}Br	31.76	M	0.14	1155.2	^{214}Bi	19.9	M	1.633
1120.0	^{117m}Cd	3.36	H	0.13	1156.0	^{156}Eu	15.19	D	0.131
1120.1	^{117}Cd	2.49	H	0.24	1157.0	^{182}Ta	114.74	D	0.73
1120.3	^{214}Bi	19.9	M	14.92	1157.4	^{130}I	12.36	H	11.3
1120.5	^{46}Sc	83.79	D	99.9870	1158.1	^{182}Ta	114.74	D	0.29
1121.3	^{182}Ta	114.74	D	35.24	1158.2	^{128}Sb	9.05	H	1.5
1122.2	^{130}I	12.36	H	0.253	1159.1	^{136}Cs s			
1123.6	^{131}Sb	23.03	M	8.9	1159.1	^{134}I	52.5	M	0.34
1123.7	^{63}Zn	38.47	M	0.111	1159.9	^{135}I	6.58	H	0.103
1124.0	^{135}I	6.58	H	3.62	1160.2	^{142}La	91.1	M	1.71
1125.0	^{77}Ge	11.211	H	0.126	1160.3	^{74}Ga	8.12	M	0.63
1125.1	^{117}Cd	2.49	H	0.45	1164.0	^{134}I	52.5	M	0.13
1125.5	^{131m}Te	33.25	H	11.0	1165.5	^{131m}Te	33.25	H	0.134
1126.6	^{129}Sb	4.366	H	0.120	1168.0	^{129}Sb	4.366	H	0.253
1128.0	^{131m}Te	33.25	H	0.93	1168.0	^{134}Cs	2.0652	Y	1.790
1128.1	^{106}Rh	30.07	S	0.404	1169.0	^{135}I	6.58	H	0.88
1128.6	^{154}Eu	8.601	Y	0.300	1169.1	^{156}Eu	15.19	D	0.266
1129.5	^{156}Eu	15.19	D	0.135	1169.5	^{78}As	90.7	M	0.12
1129.6	^{128}Sb	9.05	H	0.80	1170.7	^{117m}Cd	3.36	H	0.66
1129.9	^{76}As	26.24	H	0.126	1172.9	^{132}I	2.295	H	1.09
1130.6	^{142}La	91.1	M	0.47	1173.2	^{60}Co	1925.28	D	99.85
1131.5	^{135}I	6.58	H	22.6	1173.3	^{125}Sn	9.64	D	0.18
1131.5	^{74}Ga	8.12	M	0.87	1174.0	^{133m}Te	55.4	M	0.31
1132.4	^{92}Y	3.54	H	0.24	1174.1	^{134}Cs s			
1133.7	^{214}Bi	19.9	M	0.2512	1175.1	^{56}Co	77.236	D	2.252
1134.2	^{130}Sb	39.5	M	0.40	1175.4	^{87}Kr	76.3	M	1.11
1134.5	^{74}Ga	8.12	M	0.19	1176.4	^{142}La	91.1	M	0.1422
1134.5	^{74}Ga	8.12	M	0.19	1177.4	^{74}Ga	8.12	M	0.24
1134.9	^{133m}Te	55.4	M	0.27	1179.5	^{88}Kr	2.825	H	1.00
1136.0	^{132}I	2.295	H	3.01	1180.1	^{82}Br	35.282	H	0.108
1136.2	^{134}I	52.5	M	9.1	1181.6	^{128}Sb	9.05	H	4.5
1137.3	^{133m}Te	55.4	M	0.22	1183.4	^{117}Cd	2.49	H	0.13
1137.6	^{130}Sb	39.5	M	0.30	1184.4	^{74}Ga	8.12	M	0.28
1140.4	^{56}Co	77.236	D	0.132	1185.0	^{88}Kr	2.825	H	0.69
1140.5	^{156}Eu	15.19	D	0.283	1185.0	^{84}Br	31.76	M	0.108
1140.7	^{122}Sb	2.7238	D	0.76	1189.0	^{182}Ta	114.74	D	16.49

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
1190.0	^{134}I	52.5	M	0.35	1242.4	^{156}Eu	15.19	D	6.6
1190.4	^{132}I s				1245.2	^{88}Kr	2.825	H	0.363
1191.1	^{142}La	91.1	M	0.379	1246.1	^{154}Eu	8.601	Y	0.856
1191.9	^{131}Sb	23.03	M	0.6	1247.1	^{228}Ac	6.15	H	0.50
1191.9	^{131}Sb	23.03	M	0.6	1247.9	^{117}Cd	2.49	H	1.20
1193.3	^{77}Ge	11.211	H	2.68	1249.1	^{131}Sb	23.03	M	0.52
1194.6	^{113}Ag	5.37	H	0.378	1249.9	^{152}Eu	13.517	Y	0.187
1196.2	^{117m}Cd	3.36	H	0.39	1250.5	^{128}Sb	9.05	H	1.0
1198.0	^{133m}Te	55.4	M	0.18	1250.7	^{88}Kr	2.825	H	1.12
1199.1	^{78}As	90.7	M	0.70	1252.0	^{133m}Te	55.4	M	0.27
1199.2	^{138}Cs	33.41	M	0.17	1256.9	^{117m}Cd	3.36	H	0.18
1203.3	^{93}Y	10.18	H	0.109	1256.9	^{122}Sb	2.7238	D	0.81
1203.7	^{138}Cs	33.41	M	0.40	1257.4	^{182}Ta	114.74	D	1.509
1204.2	^{133m}Te	55.4	M	0.18	1258.4	^{129}Sb	4.366	H	0.402
1204.2	^{74}Ga	8.12	M	7.62	1258.5	^{130}Sb	39.5	M	1.00
1204.4	^{74}As	17.77	D	0.285	1259.5	^{128}Sb	9.05	H	1.0
1204.8	^{91}Y	58.51	D	0.26	1260.0	^{117}Cd	2.49	H	1.14
1205.5	^{117m}Cd	3.36	H	0.13	1260.4	^{135}I	6.58	H	28.7
1206.6	^{131m}Te	33.25	H	9.41	1263.3	^{129}Sb	4.366	H	0.910
1207.4	^{131}Sb	23.03	M	4.1	1263.9	^{77}Ge	11.211	H	0.90
1207.7	^{214}Bi	19.9	M	0.451	1264.9	^{138}Cs	33.41	M	0.137
1209.0	^{117m}Cd	3.36	H	0.18	1267.6	^{131}Sb	23.03	M	3.0
1209.0	^{117m}Cd	3.36	H	0.13	1268.6	^{97}Nb	72.1	M	0.147
1209.0	^{129}Sb	4.366	H	0.940	1269.5	^{134}I	52.5	M	0.56
1209.8	^{88}Kr	2.825	H	0.14	1272.1	^{130}I	12.36	H	0.748
1211.9	^{129}Sb	4.366	H	0.38	1272.7	^{117}Cd	2.49	H	0.73
1212.7	^{88}Kr	2.825	H	0.14	1272.8	^{132}I	2.295	H	0.168
1212.9	^{76}As	26.24	H	1.44	1273.1	^{129}Sb	4.366	H	0.164
1212.9	^{152}Eu	13.517	Y	1.415	1273.7	^{182}Ta	114.74	D	0.660
1213.3	^{84}Br	31.76	M	2.6	1274.4	^{154}Eu	8.601	Y	34.8
1215.4	^{77}Ge	11.211	H	0.134	1274.5	^{22}Na	2.6018	Y	99.940
1216.1	^{76}As	26.24	H	3.42	1276.1	^{97}Zr	16.749	H	0.94
1220.9	^{125}Sn	9.64	D	0.27	1276.1	^{129}Sb	4.366	H	0.103
1221.4	^{182}Ta	114.74	D	27.23	1277.4	^{156}Eu	15.19	D	2.89
1222.6	^{130}I	12.36	H	0.179	1280.0	^{77}Ge	11.211	H	0.183
1223.6	^{182}Ta	114.74	D	0.24	1280.9	^{91}Sr	9.65	H	0.93
1227.5	^{133m}Te	55.4	M	0.13	1281.0	^{214}Bi	19.9	M	1.434
1228.1	^{78}As	90.7	M	0.11	1281.7	^{129}Sb	4.366	H	0.559
1228.5	^{76}As	26.24	H	1.22	1284.7	^{131}Sb	23.03	M	0.3
1229.1	^{117}Cd	2.49	H	0.61	1284.7	^{131}Sb	23.03	M	0.3
1229.6	^{133m}Te	55.4	M	0.18	1287.5	^{129}Sb	4.366	H	0.100
1230.7	^{156}Eu	15.19	D	8.0	1289.1	^{182}Ta	114.74	D	1.372
1231.0	^{182}Ta	114.74	D	11.62	1290.3	^{127}Sb	3.85	D	0.37
1232.3	^{117}Cd	2.49	H	0.28	1290.6	^{78}As	90.7	M	0.10
1233.1	^{142}La	91.1	M	1.90	1290.8	^{132}I	2.295	H	1.13
1233.8	^{131}Sb	23.03	M	2.3	1291.0	^{117}Cd	2.49	H	0.67
1234.6	^{117m}Cd	3.36	H	11.0	1291.6	^{59}Fe	44.495	D	43.2
1235.4	^{136}Cs	13.16	D	20.0	1292.3	^{130}Sb	39.5	M	3.7
1236.4	^{133}I	20.83	H	1.51	1292.8	^{152}Eu	13.517	Y	0.101
1237.3	^{131m}Te	33.25	H	0.63	1293.6	^{41}Ar	109.61	M	99.160
1237.8	^{129}Sb	4.366	H	0.241	1293.9	^{74}Ga	8.12	M	0.25
1238.1	^{214}Bi	19.9	M	5.834	1295.1	^{132}I	2.295	H	1.88
1238.3	^{56}Co	77.236	D	66.46	1297.9	^{132}I	2.295	H	0.89
1239.0	^{130}Sb	39.5	M	1.8	1298.2	^{133}I	20.83	H	2.35
1239.0	^{134}I	52.5	M	0.21	1298.7	^{129}Sb	4.366	H	0.12
1240.3	^{78}As	90.7	M	5.9	1299.1	^{152}Eu	13.517	Y	1.633
1240.5	^{135}I	6.58	H	0.90	1299.2	^{133m}Te	55.4	M	0.13
1241.3	^{154}Eu	8.601	Y	0.1226	1301.5	^{129}Sb	4.366	H	0.202
1242.0	^{142}La	91.1	M	0.237	1303.3	^{117}Cd	2.49	H	18.4
1242.2	^{77}Ge	11.211	H	0.42	1303.8	^{214}Bi	19.9	M	0.107

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
1307.2	^{133m}Te	55.4	M	0.31	1372.3	^{133m}Te	55.4	M	0.22
1308.7	^{78}As	90.7	M	13.0	1373.5	^{78}As	90.7	M	4.8
1309.3	^{77}Ge	11.211	H	0.51	1373.8	^{182}Ta	114.74	D	0.2224
1312.8	^{74}Ga	8.12	M	0.62	1376.1	^{124}Sb	60.20	D	0.483
1312.8	^{77}Ge	11.211	H	0.373	1377.7	^{214}Bi	19.9	M	3.988
1314.7	^{117}Cd	2.49	H	0.59	1378.0	^{128}Sb	9.05	H	1.8
1315.2	^{131m}Te	33.25	H	0.67	1381.2	^{78}As	90.7	M	0.76
1317.5	^{82}Br	35.282	H	26.8	1382.5	^{88}Rb	17.773	M	0.784
1317.9	^{132}I	2.295	H	0.118	1382.6	^{87}Kr	76.3	M	0.288
1318.2	^{132}I s				1383.9	^{92}Sr	2.611	H	90
1318.3	^{129}Sb	4.366	H	0.462	1384.3	^{110m}Ag	249.83	D	25.1
1319.7	^{77}Ge	11.211	H	0.295	1385.0	^{129}Sb	4.366	H	0.100
1321.3	^{105}Ru	4.44	H	0.203	1385.3	^{214}Bi	19.9	M	0.793
1322.4	^{134}I	52.5	M	0.11	1388.6	^{136}Cs s			
1323.2	^{142}La	91.1	M	0.33	1389.3	^{142}La	91.1	M	0.43
1325.0	^{88}Kr	2.825	H	0.16	1389.9	^{87}Kr	76.3	M	0.119
1325.5	^{124}Sb	60.20	D	1.580	1392.0	^{131}Sb	23.03	M	0.8
1327.0	^{129}Sb	4.366	H	0.695	1393.0	^{142}La	91.1	M	0.1422
1331.8	^{131}Sb	23.03	M	0.85	1394.8	^{131m}Te	33.25	H	0.105
1332.1	^{74}Ga	8.12	M	1.74	1394.9	^{132}I s			
1332.5	^{60}Co	1925.28	D	99.9826	1398.6	^{132}I	2.295	H	7.01
1334.0	^{133m}Te	55.4	M	0.22	1398.9	^{131}Sb	23.03	M	1.37
1334.3	^{110m}Ag	249.83	D	0.143	1400.6	^{134}Cs s			
1335.4	^{56}Co	77.236	D	0.1224	1401.5	^{214}Bi	19.9	M	1.330
1336.0	^{134}I	52.5	M	0.14	1402.2	^{142}La	91.1	M	0.1422
1337.2	^{74}Ga	8.12	M	0.8	1403.9	^{130}I	12.36	H	0.345
1337.2	^{74}Ga	8.12	M	0.8	1404.4	^{117}Cd	2.49	H	0.12
1337.5	^{132}I s				1405.4	^{92}Y	3.54	H	4.8
1337.6	^{117}Cd	2.49	H	1.62	1406.7	^{134}Cs s			
1338.0	^{87}Kr	76.3	M	0.63	1406.9	^{88}Kr	2.825	H	0.218
1339.0	^{78}As	90.7	M	0.39	1408.0	^{214}Bi	19.9	M	2.394
1339.1	^{132}I s				1408.0	^{152}Eu	13.517	Y	20.87
1339.3	^{117m}Cd	3.36	H	2.07	1408.7	^{117}Cd	2.49	H	1.28
1339.8	^{128}Sb	9.05	H	1.0	1412.1	^{63}Zn	38.47	M	0.75
1342.7	^{182}Ta	114.74	D	0.2565	1413.4	^{91}Sr	9.65	H	0.98
1343.6	^{138}Cs	33.41	M	1.14	1414.3	^{134}I	52.5	M	0.22
1348.9	^{133m}Te	55.4	M	1.19	1415.7	^{138}Cs	33.41	M	0.37
1350.4	^{133}I	20.83	H	0.150	1417.6	^{74}Ga	8.12	M	0.110
1352.3	^{88}Kr	2.825	H	0.159	1419.3	^{130}Sb	39.5	M	1.20
1352.6	^{134}I	52.5	M	0.41	1419.4	^{129}Sb	4.366	H	0.394
1354.5	^{141}La	3.92	H	1.64	1419.7	^{125}Sn	9.64	D	0.49
1355.2	^{124}Sb	60.20	D	1.038	1420.5	^{139}Ba	82.93	M	0.261
1357.9	^{74}Ga	8.12	M	0.16	1421.7	^{110m}Ag s			
1360.2	^{56}Co	77.236	D	4.283	1422.3	^{117}Cd	2.49	H	0.33
1360.3	^{131}Sb	23.03	M	0.9	1425.4	^{93}Y	10.18	H	0.25
1361.0	^{97}Zr	16.749	H	0.6516	1428.2	^{134}I	52.5	M	0.17
1362.4	^{117}Cd	2.49	H	0.24	1431.0	^{117}Cd	2.49	H	0.558
1362.7	^{97}Zr	16.749	H	1.02	1431.4	^{134}I	52.5	M	0.17
1363.0	^{142}La	91.1	M	2.13	1432.9	^{117m}Cd	3.36	H	13.4
1365.2	^{134}Cs	2.0652	Y	3.017	1433.5	^{117}Cd	2.49	H	0.11
1365.5	^{117m}Cd	3.36	H	1.65	1435.9	^{138}Cs	33.41	M	76.3
1366.3	^{88}Rb	17.773	M	0.113	1436.6	^{124}Sb	60.20	D	1.217
1366.4	^{156}Eu	15.19	D	1.57	1437.5	^{129}Sb	4.366	H	0.316
1367.9	^{135}I	6.58	H	0.61	1439.1	^{76}As	26.24	H	0.279
1368.2	^{124}Sb	60.20	D	2.624	1440.3	^{132}I s			
1368.5	^{77}Ge	11.211	H	3.19	1440.9	^{78}As	90.7	M	0.32
1368.6	^{24}Na	14.997	H	99.9936	1442.2	^{207}Bi	31.55	Y	0.1310
1368.7	^{130}Sb	39.5	M	1.10	1442.6	^{132}I	2.295	H	1.40
1369.5	^{88}Kr	2.825	H	1.48	1442.7	^{56}Co	77.236	D	0.180
1372.1	^{132}I	2.295	H	2.47	1443.4	^{74}Ga	8.12	M	1.8

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
1443.4	^{74}Ga	8.12	M	1.8	1518.4	^{88}Kr	2.825	H	2.15
1443.7	^{130}Sb	39.5	M	2.5	1521.1	^{130}Sb	39.5	M	0.80
1445.0	^{138}Cs	33.41	M	0.97	1524.6	^{142}La	91.1	M	0.47
1445.1	^{124}Sb	60.20	D	0.330	1526.3	^{124}Sb	60.20	D	0.409
1445.5	^{142}La	91.1	M	0.1422	1526.8	^{129}Sb	4.366	H	0.548
1448.4	^{135}I	6.58	H	0.32	1528.1	^{152}Eu	13.517	Y	0.279
1450.2	^{117}Cd	2.49	H	0.61	1529.8	^{88}Kr	2.825	H	10.9
1450.5	^{93}Y	10.18	H	0.33	1530.0	^{78}As	90.7	M	2.5
1452.7	^{77}Ge	11.211	H	0.127	1531.2	^{87}Kr	76.3	M	0.36
1453.6	^{76}As	26.24	H	0.108	1533.7	^{130}Sb	39.5	M	0.90
1455.0	^{133m}Te	55.4	M	0.58	1534.7	^{84}Br	31.76	M	0.100
1455.1	^{131}Sb	23.03	M	0.47	1538.0	^{131}Sb	23.03	M	0.5
1455.2	^{134}I	52.5	M	2.30	1538.1	^{136}Cs	13.16	D	0.100
1457.6	^{135}I	6.58	H	8.7	1538.5	^{214}Bi	19.9	M	0.398
1457.6	^{152}Eu	13.517	Y	0.497	1538.8	^{77}Ge	11.211	H	0.150
1458.9	^{133m}Te	55.4	M	0.13	1540.2	^{142}La	91.1	M	0.47
1459.1	^{228}Ac	6.15	H	0.83	1541.5	^{134}I	52.5	M	0.51
1460.0	^{207}Bi	31.55	Y	1.61	1542.4	^{110m}Ag s			
1460.8	^{40}K	1.248E+9	Y	10.66	1543.3	^{214}Bi	19.9	M	0.303
1461.2	^{142}La	91.1	M	0.95	1544.2	^{131}Sb	23.03	M	0.9
1463.8	^{84}Br	31.76	M	2.0	1545.8	^{142}La	91.1	M	2.99
1464.8	^{88}Kr	2.825	H	0.114	1547.0	^{63}Zn	38.47	M	0.122
1470.0	^{134}I	52.5	M	0.76	1552.0	^{133m}Te	55.4	M	0.13
1470.3	^{131}Sb	23.03	M	1.55	1553.5	^{131}Sb	23.03	M	0.6
1471.7	^{74}Ga	8.12	M	0.193	1555.3	^{138}Cs	33.41	M	0.366
1473.1	^{130}Sb	39.5	M	0.60	1557.1	^{228}Ac	6.15	H	0.178
1473.8	^{91}Sr	9.65	H	0.168	1559.0	^{131}Sb	23.03	M	0.42
1474.9	^{82}Br	35.282	H	16.60	1561.6	^{130}Sb	39.5	M	0.60
1475.5	^{117}Cd	2.49	H	0.42	1562.2	^{117}Cd	2.49	H	1.42
1475.8	^{110m}Ag	249.83	D	4.08	1562.3	^{106}Rh	30.07	S	0.163
1476.6	^{77}Ge	11.211	H	0.253	1562.3	^{110m}Ag	249.83	D	1.22
1476.7	^{132}I	2.295	H	0.130	1566.4	^{135}I	6.58	H	1.29
1478.2	^{74}Ga	8.12	M	0.30	1570.1	^{129}Sb	4.366	H	0.872
1479.0	^{77}Ge	11.211	H	0.126	1570.3	^{74}Ga	8.12	M	0.97
1479.7	^{132}I s				1573.5	^{131}Sb	23.03	M	1.04
1480.9	^{129}Sb	4.366	H	0.373	1573.5	^{133m}Te	55.4	M	0.22
1481.8	^{65}Ni	2.51719	H	23.59	1573.7	^{77}Ge	11.211	H	0.70
1488.4	^{130}Sb	39.5	M	0.60	1576.6	^{117}Cd	2.49	H	11.2
1488.9	^{124}Sb	60.20	D	0.672	1578.0	^{87}Kr	76.3	M	0.129
1489.2	^{144}Pr	17.28	M	0.278	1578.1	^{84}Br	31.76	M	0.67
1489.4	^{74}Ga	8.12	M	2.88	1578.4	^{117}Cd	2.49	H	0.14
1494.0	^{154}Eu	8.601	Y	0.698	1579.8	^{124}Sb	60.20	D	0.38
1494.1	^{142}La	91.1	M	0.1422	1580.5	^{228}Ac	6.15	H	0.60
1495.6	^{138}Cs	33.41	M	0.18	1581.0	^{133m}Te	55.4	M	0.13
1495.6	^{77}Ge	11.211	H	0.53	1581.9	^{130}Sb	39.5	M	1.9
1495.9	^{228}Ac	6.15	H	0.86	1583.2	^{214}Bi	19.9	M	0.705
1499.6	^{130}Sb	39.5	M	0.40	1587.7	^{133m}Te	55.4	M	1.15
1499.8	^{132}I s				1588.2	^{228}Ac	6.15	H	3.22
1501.6	^{228}Ac	6.15	H	0.46	1591.4	^{110m}Ag s			
1502.8	^{135}I	6.58	H	1.08	1593.2	^{128}Sb	9.05	H	0.50
1505.0	^{110m}Ag	249.83	D	13.33	1594.8	^{214}Bi	19.9	M	0.267
1505.5	^{134}I	52.5	M	0.11	1595.2	^{110m}Ag s			
1506.2	^{133m}Te	55.4	M	0.22	1596.2	^{140}La	1.67855	D	95.4
1509.2	^{214}Bi	19.9	M	2.130	1596.5	^{154}Eu	8.601	Y	1.797
1510.2	^{74}Ga	8.12	M	0.23	1599.4	^{214}Bi	19.9	M	0.324
1512.7	^{212}Bi	60.55	M	0.29	1600.1	^{129}Sb	4.366	H	0.579
1515.7	^{97}Nb	72.1	M	0.122	1602.0	^{74}Ga	8.12	M	0.29
1516.3	^{133m}Te	55.4	M	1.02	1603.8	^{88}Kr	2.825	H	0.46
1516.3	^{142}La	91.1	M	0.43	1607.6	^{84}Br	31.76	M	0.40
1517.2	^{131}Sb	23.03	M	1.22	1608.8	^{131}Sb	23.03	M	1.4

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)	Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
1611.2	^{87}Kr	76.3	M	0.114	1727.7	^{138}Cs	33.41	M	0.111
1613.8	^{134}I	52.5	M	4.31	1729.6	^{214}Bi	19.9	M	2.878
1614.1	^{138}Cs	33.41	M	0.137	1737.2	^{78}As	90.7	M	0.11
1617.0	^{130}Sb	39.5	M	0.90	1738.2	^{129}Sb	4.366	H	7.45
1617.2	^{74}Ga	8.12	M	0.129	1739.1	^{117}Cd	2.49	H	0.13
1618.2	^{142}La	91.1	M	0.284	1740.5	^{87}Kr	76.3	M	2.04
1620.5	^{212}Bi	60.55	M	1.47	1741.2	^{84}Br	31.76	M	1.6
1622.3	^{132}I s				1741.5	^{134}I	52.5	M	2.56
1622.5	^{129}Sb	4.366	H	0.208	1744.9	^{74}Ga	8.12	M	4.82
1623.4	^{65}Ni	2.51719	H	0.498	1749.8	^{130}Sb	39.5	M	0.30
1625.1	^{228}Ac	6.15	H	0.255	1750.2	^{97}Zr	16.749	H	1.09
1626.6	^{130}Sb	39.5	M	0.60	1756.1	^{131}Sb	23.03	M	1.13
1629.2	^{134}I	52.5	M	0.19	1756.4	^{142}La	91.1	M	2.70
1630.6	^{228}Ac	6.15	H	1.51	1757.4	^{132}I	2.295	H	0.30
1638.3	^{228}Ac	6.15	H	0.47	1762.6	^{130}Sb	39.5	M	2.5
1642.0	^{78}As	90.7	M	0.16	1764.5	^{214}Bi	19.9	M	15.30
1643.3	^{134}Cs s				1768.2	^{142}La	91.1	M	0.24
1643.6	^{133m}Te	55.4	M	0.27	1770.2	^{207}Bi	31.55	Y	6.87
1644.3	^{134}I	52.5	M	0.39	1770.8	^{142}La	91.1	M	0.19
1644.3	^{142}La	91.1	M	0.237	1771.4	^{56}Co	77.236	D	15.41
1646.0	^{131m}Te	33.25	H	1.20	1773.2	^{133m}Te	55.4	M	0.53
1646.2	^{133m}Te	55.4	M	0.22	1778.3	^{138}Cs	33.41	M	0.137
1650.4	^{82}Br	35.282	H	0.751	1779.7	^{82}Br	35.282	H	0.112
1651.4	^{91}Sr	9.65	H	0.291	1779.9	^{88}Rb	17.773	M	0.238
1652.1	^{117}Cd	2.49	H	0.28	1785.5	^{128}Sb	9.05	H	0.40
1652.2	^{117m}Cd	3.36	H	0.47	1787.7	^{76}As	26.24	H	0.293
1655.2	^{134}I	52.5	M	0.23	1791.2	^{135}I	6.58	H	7.72
1655.6	^{130}Sb	39.5	M	0.80	1791.9	^{78}As	90.7	M	0.97
1656.1	^{129}Sb	4.366	H	1.311	1797.5	^{133m}Te	55.4	M	0.14
1661.3	^{214}Bi	19.9	M	1.047	1803.7	^{132}I s			
1666.5	^{228}Ac	6.15	H	0.178	1806.5	^{74}Ga	8.12	M	0.28
1669.5	^{117m}Cd	3.36	H	0.63	1806.7	^{125}Sn	9.64	D	0.15
1674.7	^{58}Co	70.86	D	0.517	1806.8	^{134}I	52.5	M	5.55
1676.8	^{74}Ga	8.12	M	0.73	1810.7	^{56}Mn	2.5789	H	26.9
1678.0	^{135}I	6.58	H	9.6	1810.8	^{56}Co	77.236	D	0.640
1682.1	^{117}Cd	2.49	H	0.70	1811.0	^{132}I s			
1682.1	^{156}Eu	15.19	D	0.272	1818.7	^{84}Br	31.76	M	0.24
1683.2	^{133m}Te	55.4	M	3.3	1821.2	^{131}Sb	23.03	M	1.22
1684.0	^{214}Bi	19.9	M	0.214	1822.2	^{110m}Ag s			
1685.6	^{88}Kr	2.825	H	0.66	1829.8	^{74}Ga	8.12	M	1.90
1685.7	^{128}Sb	9.05	H	0.50	1830.7	^{135}I	6.58	H	0.58
1688.6	^{142}La	91.1	M	0.237	1835.7	^{78}As	90.7	M	1.46
1691.0	^{124}Sb	60.20	D	47.57	1836.0	^{88}Rb	17.773	M	22.81
1704.4	^{133m}Te	55.4	M	0.58	1836.1	^{88}Y	106.627	D	99.2
1706.5	^{135}I	6.58	H	4.10	1838.4	^{214}Bi	19.9	M	0.350
1706.9	^{117}Cd	2.49	H	1.00	1840.6	^{132}I s			
1707.9	^{128}Sb	9.05	H	0.30	1842.6	^{87}Kr	76.3	M	0.139
1709.9	^{77}Ge	11.211	H	0.325	1846.5	^{77}Ge	11.211	H	0.177
1713.4	^{78}As	90.7	M	1.78	1847.3	^{92}Y	3.54	H	0.36
1717.1	^{138}Cs	33.41	M	0.107	1847.4	^{214}Bi	19.9	M	2.025
1719.7	^{77}Ge	11.211	H	0.410	1851.6	^{97}Zr	16.749	H	0.31
1721.0	^{78}As	90.7	M	0.32	1854.3	^{131}Sb	23.03	M	4.2
1721.8	^{131}Sb	23.03	M	2.45	1854.4	^{131}Sb	23.03	M	4.2
1722.7	^{142}La	91.1	M	1.52	1856.4	^{117}Cd	2.49	H	0.25
1723.1	^{117}Cd	2.49	H	2.01	1857.4	^{156}Eu	15.19	D	0.240
1724.0	^{91}Sr	9.65	H	0.161	1866.6	^{136}Cs s			
1724.3	^{129}Sb	4.366	H	0.133	1867.3	^{117}Cd	2.49	H	0.11
1724.9	^{65}Ni	2.51719	H	0.399	1870.8	^{133m}Te	55.4	M	0.44
1727.2	^{132}I s				1871.6	^{129}Sb	4.366	H	0.356
1727.2	^{77}Ge	11.211	H	0.152	1873.2	^{214}Bi	19.9	M	0.214

Gamma-ray energy (keV)	Name of nuclide	Half-life	Half-life unit	Emission rate (%)
1877.0	^{156}Eu	15.19	D	1.51
1877.5	^{84}Br	31.76	M	1.12
1881.2	^{133m}Te	55.4	M	0.18
1884.4	^{130}Sb	39.5	M	0.70
1885.6	^{133m}Te	55.4	M	0.80
1887.3	^{142}La	91.1	M	0.14
1887.7	^{131m}Te	33.25	H	1.31
1892.8	^{88}Kr	2.825	H	0.14
1893.0	^{133m}Te	55.4	M	0.12
1894.0	^{78}As	90.7	M	0.29
1896.1	^{214}Bi	19.9	M	0.149
1897.6	^{84}Br	31.76	M	14.6
1901.3	^{142}La	91.1	M	7.16
1908.7	^{88}Kr	2.825	H	0.100
1915.7	^{131}Sb	23.03	M	1.0
1917.8	^{93}Y	10.18	H	1.57
1921.0	^{78}As	90.7	M	0.81
1921.1	^{132}I	2.295	H	1.23
1923.3	^{142}La	91.1	M	0.19
1923.5	^{78}As	90.7	M	0.76
1925.9	^{134}I	52.5	M	0.18
1927.3	^{135}I	6.58	H	0.296
1933.6	^{142}La	91.1	M	0.1422
1937.7	^{156}Eu	15.19	D	1.94
1940.6	^{74}Ga	8.12	M	5.4
1945.5	^{132}I s			
1946.3	^{156}Eu	15.19	D	0.165
1948.0	^{130}Sb	39.5	M	1.20
1949.4	^{142}La	91.1	M	0.38
1956.4	^{131}Sb	23.03	M	0.8
1957.5	^{117m}Cd	3.36	H	0.16
1961.5	^{142}La	91.1	M	0.1422
1962.8	^{132}I s			
1963.7	^{56}Co	77.236	D	0.707
1965.8	^{131}Sb	23.03	M	1.3
1966.0	^{156}Eu	15.19	D	3.9
1967.8	^{133m}Te	55.4	M	0.13
1969.9	^{134}Cs s			
1971.0	^{74}Ga	8.12	M	0.20
1984.6	^{131}Sb	23.03	M	0.42
1995.6	^{78}As	90.7	M	1.35
1997.3	^{117m}Cd	3.36	H	26.2
1997.4	^{130}Sb	39.5	M	2.10
1999.3	^{74}Ga	8.12	M	0.40

Appendix 3　References

1) 放射能測定法シリーズ 7「ゲルマニウム半導体検出器によるガンマ線スペクトロメトリー（平成 4 年改訂）」, 文部科学省
2) Gordon Gilmore, John D. Hemingway （米沢仲四朗, 松江秀明, 宮本ユタカ, 鈴木大輔, 安田健一郎, 伊奈川潤, 齋藤陽子 共訳）, 実用ガンマ線測定ハンドブック, 日刊工業新聞社 (2002)
3) 水本良彦, 日下部俊男, 岩田志郎, ゲルマニウム検出器のピーク対トータル効率比, RADIOISOTOPES, 36, 20–23 (1987)
4) 日本食品標準成分表 2015 年版（七訂）, 文部科学省 科学技術・学術審議会 資源調査分科会 報告：http://www.mext.go.jp/a_menu/syokuhinseibun/1365295.htm
5) 大野峻史, 鈴木直樹, 土田智宏, 春日俊信, 黒崎裕人, 霜鳥達雄, 丸田文之, 山﨑興樹, 福島第一原子力発電所事故の影響により新潟県において検出された人工放射性核種について, 新潟県放射線監視センター年報, 9 (2011)
6) 古田定昭, 住谷秀一, 渡辺均, 中野政尚, 今泉謙二, 竹安正則, 中田陽, 藤田博喜, 水谷朋子, 森澤正人, 國分祐司, 河野恭彦, 永岡美佳, 横山裕也, 外間智規, 磯崎徳重, 根本正史, 檜山佳典, 小沼利光, 加藤千明, 倉知保, 福島第一原子力発電所事故に係る特別環境放射線モニタリング結果　－中間報告（空間線量率、空気中放射性物質濃度、降下じん中放射性物質濃度）－, JAEA-Review 2011-035 (2011)
7) 原子力規制委員会 web ページ, 放射線モニタリング情報　モニタリング結果, http://radioactivity.nsr.go.jp/ja/list/512/list-1.html
8) Hikaru Amano, Masakazu Akiyama, Bi Chunlei, Takao Kawamura, Takeshi Kishimoto, Tomotaka Kuroda, Takahiko Muroi, Tomoaki Odaira, Yuji Ohta, Kenji Takeda, Yushu Watanabe, Takao Morimoto, Radiation measurements in the Chiba Metropolitan Area and Radiological aspects of fallout from the Fukushima Dai-ichi Nuclear Power Plants accident, Journal of Environmental Radioactivity, 111, 42–52 (2012)
9) Katsumi Shozugawa, Norio Nogawa, Motoyuki Matsuo, Deposition of fission and activation products after the Fukushima Dai-ichi nuclear power plant accident, Environmental Pollution, 163, 243–247 (2012)
10) P. Thakur, S. Ballard, R. Nelson, An overview of Fukushima radionuclides measured in the northern hemisphere, Science of the Total Environment, 458-460, 577–613 (2013)

11) S. Endo, S. Kimura, T. Takatsuji, K. Nanasawa, T. Imanaka, K. Shizuma, Measurement of soil contamination by radionuclides due to the Fukushima Daiichi Nuclear Power Plant accident and associated estimated cumulative external dose estimation, Journal of Environmental Radioactivity, 111, 18–27 (2012)
12) Takehisa OHKURA, Tetsuya OISHI, Mitsumasa TAKI, Yukio SHIBANUMA, Masamitsu KIKUCHI, Hitoshi AKINO, Yasuaki KIKUTA, Masatsugu KAWASAKI, Jun SAEGUSA, Masahiro TSUTSUMI, Hitoshi OGOSE, Shunsuke TAMURA and Tadahiro SAWAHATA, Emergency Monitoring of Environmental Radiation and Atmospheric Radionuclides at Nuclear Science Research Institute, JAEA Following the Accident of Fukushima Daiichi Nuclear Power Plant, JAEA-Data/Code 2012–010 (2012)
13) 米沢仲四郎, 山本洋一, 核実験監視用放射性核種観測網による大気中の人工放射性核種の測定, ぶんせき, 8, 451–458 (2011)
14) H. Koide, T. Imanaka, K. Kobayashi, K. Ogino, Radioactive contamination from the JCO criticality accident, Journal of Environmental Radioactivity, 50,123–130（2000）
15) IAEA, Report on the preliminary fact finding mission following the accident at the nuclear fuel processing facility in Tokaimura, Japan, IAEA-TOAC, International Atomic Energy Agency, Vienna (1999)
16) JCO 臨界事故調査支援原研タスクグループ, JCO 臨界事故における原研の活動, JAERI-Tech 2000-074 (2000)
17) J. Gasparro, M. Hult, K. Komura, D. Arnold, L. Holmes, P.N. Johnston, M. Laubenstein, S. Neumaier, J.-L. Reyss, P. Schillebeeckx, H. Tagziria, G. Van Britsom, R. Vasselli, Measurements of ^{60}Co in spoons activated by neutrons during the JCO criticality accident at Tokai-mura in 1999, Journal of Environmental Radioactivity, 73, 307–321 (2004)
18) 核燃料サイクル開発機構　東海事業所, JCO 臨界事故に係る環境モニタリング結果（1999 年 9 月 30 日～11 月 2 日) (業務報告), JNC TN8440 2001-004 (2001)
19) Kazuhisa Komura, Ahmed M Yousef, Yoshimasa Murata, Toshiaki Mitsugashira, Riki Seki, Tetsuji Imanaka, Activation of gold by the neutrons from the JCO accident, Journal of Environmental Radioactivity, 50, 77–82 (2000)
20) Mikael Hult, María José Martínez Canet, Peter N. Johnston, Kazuhisa Komura, Thermal neutron fluence from ultra low-level γ -ray spectrometry of spoons activated during the JCO criticality accident at Tokaimura in 1999, Journal of Environmental Radioactivity, 60, 307–318 (2002)

21) S. Endo, N. Tosaki, K. Shizuma, M. Ishikawa, J. Takada, S. Suga, K. Kitagawa, M. Hoshi, Radioactivity of ^{51}Cr in stainless steel collected from residences in the JCO neighborhood, Journal of Environmental Radioactivity, 50, 83–88 (2000)

22) Takashi Nakanishi, Risa Hosotani, Kazuhisa Komura, Toshiharu Muroyama, Hisaki Kofuji, Yoshimasa Murata, Shinzo Kimura, Sarata Kumar Sahoo, Hidenori Yonehara, Yoshito Watanabe, Tada-aki Ban-nai, Residual neutron-induced radionuclides in a soil sample collected in the vicinity of the criticality accident site in Tokai-mura, Japan: A Progress Report, Journal of Environmental Radioactivity, 50, 61–68 (2000)

23) Toshiaki Mitsugashira, Mitsuo Hara, Takashi Nakanishi, Tsutomu Sekine, Riki Seki, Sadao Kojima, Passive gamma-ray spectrometry for the determination of total fission events in the JCO criticality accident '99 in Tokai, Journal of Environmental Radioactivity, 50, 21-26 (2000)

24) Y. Murata, T. Muroyama, H. Kofuji, M. Yamamoto, K. Komura, Neutron-induced radionuclides in soil from the JCO campus by non-destructive γ -ray spectrometry, Journal of Environmental Radioactivity, 50, 69–76 (2000)

25) 動力炉・核燃料開発事業団　東海事業所, 再処理施設周辺環境放射線監視年報 1986 年（1 月～12 月）, PNC SN8440 87-08 (1987)

26) 動力炉・核燃料開発事業団　東海事業所, ソ連チェルノブイル原子力発電所事故に伴う特別環境放射能調査, PNCT N8420 86-10 (1986)

27) Hikaru Amano and Kimiaki Saito, Proceeding of the Workshop on the Results of the Cooperative Research Between JAERI and CHESCIR Concerning the Study on Assessment and Analysis of Environmental Radiological Consequences and Verification of an Assessment System November 16–17, 1999, Tokyo, JAERI-Conf 2000-016 (2001)

28) Toshi Nagaoka, Orihiko Togawa, Shigeru Moriuchi, S.I. Rybalko, A.K. Sukhoruchkin and S.V. Kazakov, Proceeding of the Second Steering Conference Relating to the “Agreement on the Implementation of Research at the Chernobyl Center for International Research” Between CHECIR and JAERI, JAERI-Conf 94-005 (1994)

29) 放射能測定法シリーズ No.33「ゲルマニウム半導体検出器を用いた in-situ 測定法（平成 29 年 3 月改訂）」, 原子力規制庁監視情報課

30) G. Heusser, Cosmic ray-induced background in Ge-spectrometry, Nuclear Instruments and Methods in Physics Research B, 83, 223–228 (1993)

31) Ari-Pekka Leppänen, Aleksi Mattila, Markku Kettunen, Riitta Kontro, Artificial radionuclides in surface air in Finland following the Fukushima Daiichi nuclear power plant accident, Journal of Environmental Radioactivity, 126, 273–283 (2013)

32) A. Bolsunovsky, D. Dementyev, Evidence of the radioactive fallout in the center of Asia (Russia) following the Fukushima Nuclear Accident, Journal of Environmental Radioactivity, 102, 1062–1064 (2011)

33) A. Ioannidou, E. Giannakaki, M. Manolopoulou, S. Stoulos, E. Vagena, C. Papastefanou, L. Gini, S. Manenti, F. Groppi, An air-mass trajectory study of the transport of radioactivity from Fukushima to Thessaloniki, Greece and Milan, Italy, Atmospheric Environment, 75, 163–170 (2013)

34) Daisuke Tsumune, Takaki Tsubono, Michio Aoyama, Katsumi Hirose, Distribution of oceanic ^{137}Cs from the Fukushima Dai-ichi Nuclear Power Plant simulated numerically by a regional ocean model, Journal of Environmental Radioactivity, 111, 100–108 (2012)

35) 遠藤暁, 今中哲二, 林剛平, 菅井益郎, 小澤祥司, 梶本剛, 福島原発事故に伴う飯舘村の放射能汚染調査, 放射化学, 29, 15–25 (2014)

36) Georg Steinhauser, Alexander Brandl, Thomas E. Johnson, Comparison of the Chernobyl and Fukushima nuclear accidents: A review of the environmental impacts, Science of the Total Environment, 470–471, 800–817 (2014)

37) Hugo Lepage, Olivier Evrard, Yuichi Onda, Jeremy Patin, Caroline Chartin, Irène Lefèvre, Philippe Bonté, Sophie Ayrault, Environmental mobility of ^{110m}Ag: lessons learnt from Fukushima accident (Japan) and potential use for tracking the dispersion of contamination within coastal catchments, Journal of Environmental Radioactivity, 130, 44–55 (2014)

38) Hyoe Takata, Kazuyuki Hasegawa, Shinji Oikawa, Natsumi Kudo, Takahito Ikenoue, Ryosuke S. Isono, Masashi Kusakabe, Remobilization of radiocesium on riverine particles in seawater: The contribution of desorption to the export flux to the marine environment, Marine Chemistry, 176, 51–63 (2015)

39) J. Diaz Leon, D.A. Jaffe, J. Kaspar, A. Knecht, M.L. Miller, R.G.H. Robertson, A.G. Schubert, Arrival time and magnitude of airborne fission products from the Fukushima, Japan, reactor incident as measured in Seattle, WA, USA, Journal of Environmental Radioactivity, 102, 1032–1038 (2011)

40) Katsumi Hirose, 2011 Fukushima Dai-ichi nuclear power plant accident: summary of regional radioactive deposition monitoring results, Journal of Environmental Radioactivity, 111, 13–17 (2012)

41) Keiko Tagami, Shigeo Uchida, Yukio Uchihori, Nobuyoshi Ishii, Hisashi Kitamura, Yoshiyuki Shirakawa, Specific activity and activity ratios of radionuclides in soil collected about 20 km from the Fukushima Daiichi Nuclear Power Plant: Radionuclide release to the south and southwest, Science of the Total Environment, 409, 4885–4888 (2011)
42) Kimiaki Saito, Isao Tanihata, Mamoru Fujiwara, Takashi Saito, Susumu Shimoura, Takaharu Otsuka, Yuichi Onda, Masaharu Hoshi, Yoshihiro Ikeuchi, Fumiaki Takahashi, Nobuyuki Kinouchi, Jun Saegusa, Akiyuki Seki, Hiroshi Takemiya, Tokushi Shibata, Detailed deposition density maps constructed by large-scale soil sampling for gamma-ray emitting radioactive nuclides from the Fukushima Dai-ichi Nuclear Power Plant accident, Journal of Environmental Radioactivity, 139, 308–319 (2015)
43) Kimiaki Saito, Yuichi Onda, Outline of the national mapping projects implemented after the Fukushima accident, Journal of Environmental Radioactivity, 139, 240–249 (2015)
44) Laura Tositti, Erika Brattich, Giorgia Cinelli, Alberto Previti, Domiziano Mostacci, Comparison of radioactivity data measured in PM_{10} aerosol samples at two elevated stations in northern Italy during the Fukushima event, Journal of Environmental Radioactivity, 114, 105–112 (2012)
45) Nobuyuki Hamada, Haruyuki Ogino, Food safety regulations: what we learned from the Fukushima nuclear accident, Journal of Environmental Radioactivity, 111, 83–99 (2012)
46) N. Momoshima, S. Sugihara, R. Ichikawa, H. Yokoyama, Atmospheric radionuclides transported to Fukuoka, Japan remote from the Fukushima Daiichi nuclear power complex following the nuclear accident, Journal of Environmental Radioactivity, 111, 28–32 (2012)
47) P. Bailly du Bois, P. Laguionie, D. Boust, I. Korsakissok, D. Didier, B. Fiévet, Estimation of marine source-term following Fukushima Dai-ichi accident, Journal of Environmental Radioactivity, 114, 2–9 (2012)
48) Taeko Doi, Kazuyoshi Masumoto, Akihiro Toyoda, Atsushi Tanaka, Yasuyuki Shibata, Katsumi Hirose, Anthropogenic radionuclides in the atmosphere observed at Tsukuba: characteristics of the radionuclides derived from Fukushima, Journal of Environmental Radioactivity, 122, 55–62 (2013)
49) Yutaka Kanai, Monitoring of aerosols in Tsukuba after Fukushima Nuclear Power Plant incident in 2011, Journal of Environmental Radioactivity, 111, 33–37 (2012)

50) Tadaaki Ban-nai, Yasuyuki Muramatsu, Keiko Tagami, Shigeo Uchida, Satoshi Yoshida, Shinzo Kimura, Yoshito Watanabe, Levels of radionuclides in plant samples collected around the uranium conversion facility following the criticality accident in Tokai-mura, Journal of Environmental Radioactivity, 50, 131–143 (2000)
51) 栗田義幸, 三枝純, 前田智史, 放射能分析建屋内への放射性セシウムの混入状況及び混入低減策, 日本放射線安全管理学会誌, 15(2) , 180–185 (2016)
52) IAEA, Environmental Consequences of the Chernobyl Accident and their Remediation: Twenty Years of Experience（チェルノブイリ原発事故による環境への影響とその修復 : 20 年の経験（日本学術会議訳））, International Atomic Energy Agency, Vienna (2006)
53) Kazunori Nagaoka, Shoji Sato, Shigeru Araki, Yuji Ohta, Yoshihiro Ikeuchi, Changes of Radionuclides in the Environment in Chiba, Japan, After the Fukushima Nuclear Power Plant Accident, Health Physics, 102(4), 437–442 (2012)

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