Library of uranium and plutonium reference spectra

Introduction

Due to the difficulties in procuring and circulating certified uranium or plutonium samples, the ESARDA Working Group on Techniques and Standards for Non-Destructive Assay decided to create a uranium and plutonium reference spectra library in order to help users and programmers of uranium enrichment or plutonium analysis codes to test and perfect their processes.

For the main part, the uranium spectra were obtained in the context of the ESARDA international uranium enrichment exercise organized in 1997 and 1998 and the plutonium spectra in the context of the ESARDA Pu-2000 exercise organized in 2000. Several uranium samples characterized by a known enrichment and plutonium samples characterized by a known isotopic composition were measured using germanium and CZT detectors. The main characteristics of this reference spectrum library are presented here.

Uranium reference spectra

The uranium reference spectra were provided by LLNL [Lawrence Livermore National Laboratory] and LNHB [Laboratoire National Henri Becquerel] in the context of the international ESARDA uranium exercise*.

(: J. Morel, C. Hill, M. Bickel, A. Alonso-Munoz, S. Napier, B. Thaurel and ESARDA NDA-WG Members. Results from the uranium enrichment measurement exercise, final report. Note Technique LPRI/98/23, CEA Saclay, France (1998). J. Morel, C. Hill, M. Bickel, A. Alonso-Munoz, S. Napier, B. Thaurel, ESARDA NDA-WG Members. Results from the international evaluation exercise for uranium enrichment measurements, Appl. Radiat. Isot. 52 (2000)).*

These spectra were obtained by counting several samples prepared and characterized by IRMM [Institute for Reference Materials and Measurements] and BNFL [British Nuclear Fuels Ltd], namely two LE UO_2 pellet samples with ^{235}U abundances of 3.1 and 1.5 %, two LE UO_2 powder samples with ^{235}U abundances of 2.0 and 2.9 %, two LE UO_2 freshly converted powder samples with ^{235}U abundances of 3.4 and 2.7 %, one HEU metal sample with a ^{235}U abundance of 93.2 %. Other reference spectra were obtained from five U_3O_8 samples in cylindrical aluminium cans proposed as reference materials (EC-NRM171**)** and having the following ^{235}U abundances: 0.32 %, 0.71 %, 1.9 %, 2.9 %, 4.5 %. Other uranium reference spectra obtained by LLNL using their certified samples were also added; they correspond to the following ^{235}U concentrations: 0.017, 0.48, 0.72, 0.99, 1.9, 2.0, 3.0, 4.5, 4.9, 10.1, 49.4, 75.1, 93.1, 93.2 and 99.1 %. The list of reference spectra appears in Table U-1. Most of the LLNL spectra were obtained by using a planar HPGe detector with an area of 8.0 cm² and 1.3 cm thick having an energy resolution of 0.61 keV at 186 keV. The LNHB spectra were obtained by using two different HPGe detectors and one CZT detector with the following characteristics:

HPGe planar type	2.0 cm² x 1.0 cm	FWHM (at 186 keV): 0.65 keV
HPGe coaxial type	21 cm² x 5.7 cm	FWHM (at 186 keV): 1.0 keV
CZT detector	9.0 mm² x 2 mm	FWHM (at 186 keV): 2.2 keV

As a general rule, these spectra were coded in 4000 channels using an analysis range of about 0.05 to 0.08 keV/channel, so that the region of interest from 0 to 220 keV could be taken into account. As a general rule, the count rates were limited so that the peak widths at half, tenth and fifth peak heights did not increase by more than 10 % with respect to the usual values. These reference spectra were recorded in 8I10 format ASCII files and also in binary

".chn" for spectra provided by LNHB. As shown in Tables U-2 and U-3, each ASCII file contains the following information:

- file name, origin and date,
- sample name and origin,
- declared enrichment value (with uncertainty if given and estimated for 1 σ confidence level) and origin of the certification,
- sample description,
- main characteristics of the detector used i.e. type, crystal area, crystal thickness and FWHM at 185 keV,
- number of channels, live and real count times(s),
- energy of the first and last channels corresponding to the file,
- data corresponding to the channel contents.

For the spectra corresponding to the freshly converted samples, ^{238}U is not in equilibrium with its daughter ^{234}Th. Thus, in this case, the value of the correction decay factor is also quoted with the sample description.

The previous characteristics for all the uranium spectra are collated in the appended file "U ref spectra". The spectra files are available in the "Spectra from LNHB" and "Spectra from LLNL" subdirectories of the directory called "U spectra".

Table U-1 – List of uranium reference spectra

Origin of spectrum	Enrichment value %	Origin of sample	Number of spectra
LLNL	0.017	LLNL	1
LNHB	0.317	ESARDA U-exercise	1 (CZT)
LNHB	0.317	ESARDA U-exercise	1 (HPGe plan.)
LNHB	0.317	ESARDA U-exercise	1 (HPGe coax.)
LLNL	0.483	LLNL	1
LNHB	0.712	ESARDA U-exercise	1 (CZT)
LNHB	0.712	ESARDA U-exercise	1 (HPGe plan.)
LNHB	0.712	ESARDA U-exercise	1 (HPGe coax.)
LLNL	0.717	LLNL	1
LLNL	0.991	LLNL	1
LLNL	1.497	ESARDA U-exercise	3
LNHB	1.497	ESARDA U-exercise	1 (CZT)
LNHB	1.497	ESARDA U-exercise	3 (HPGe plan.)
LNHB	1.497	ESARDA U-exercise	3 (HPGe coax.)
LLNL	1.942	LLNL	9
LNHB	1.942	ESARDA U-exercise	1 (CZT)
LNHB	1.942	ESARDA U-exercise	1 (HPGe plan.)
LNHB	1.942	ESARDA U-exercise	1 (HPGe coax.)
LLNL	1.950	LLNL	1
LLNL	1.995	ESARDA U-exercise	4
LNHB	1.995	ESARDA U-exercise	1 (CZT)
LNHB	1.995	ESARDA U-exercise	3 (HPGe plan.)
LNHB	1.995	ESARDA U-exercise	3 (HPGe coax.)
LLNL	2.013	LLNL	1
LLNL	2.685	ESARDA U-exercise (decay cor.)	3
LNHB	2.685	ESARDA U-exercise (decay cor.)	1 (CZT)
LNHB	2.685	ESARDA U-exercise (decay cor.)	6 (HPGe plan.)
LNHB	2.685	ESARDA U-exercise (decay cor.)	6 (HPGe coax.)
LLNL	2.877	ESARDA U-exercise	10
LNHB	2.877	ESARDA U-exercise	1 (CZT)
LNHB	2.877	ESARDA U-exercise	3 (HPGe plan.)
LNHB	2.877	ESARDA U-exercise	3 (HPGe coax.)
LLNL	2.949	LLNL	15
LNHB	2.949	ESARDA U-exercise	1 (CZT)
LNHB	2.949	ESARDA U-exercise	1 (HPGe plan.)
LNHB	2.949	ESARDA U-exercise	1 (HPGe coax.)
LLNL	3.009	LLNL	1
LLNL	3.109	ESARDA U-exercise	3
LNHB	3.109	ESARDA U-exercise	1 (CZT)
LNHB	3.109	ESARDA U-exercise	3 (HPGe plan.)
LNHB	3.109	ESARDA U-exercise	3 (HPGe coax.)
LLNL	3.432	ESARDA U-exercise (decay cor.)	3
LNHB	3.432	ESARDA U-exercise (decay cor.)	1 (CZT)
LNHB	3.432	ESARDA U-exercise (decay cor.)	6 (HPGe plan.)
LNHB	3.432	ESARDA U-exercise (decay cor.)	6 (HPGe coax.)
LLNL	4.460	LLNL	5
LNHB	4.462	ESARDA U-exercise	1 (CZT)
LNHB	4.462	ESARDA U-exercise	1 (HPGe plan.)
LNHB	4.462	ESARDA U-exercise	1 (HPGe coax.)
LLNL	4.949	LLNL	1
LLNL	10.079	LLNL	1
LLNL	49.380	LLNL	1
LLNL	75.130	LLNL	1
LLNL	93.076	LLNL	1
LLNL	93.156	ESARDA U-exercise	2
LNHB	93.156	ESARDA U-exercise	1 (CZT)
LNHB	93.156	ESARDA U-exercise	2 (HPGe plan.)
LNHB	93.156	ESARDA U-exercise	3 (HPGe coax.)
LLNL	93.170	LLNL	1
LLNL	99.100	LLNL	1

Table U-2 – Example of data corresponding to the spectrum of a HEU metal sample

File name: 125v003 Origin and date: LLNL - 1997
Sample: 125v Origin: IRMM
Declared enrichment:93.156 ± 0.023 Origin: IRMM (mass spec.)
Description: HEU metal sample
Detector: HP Ge plan Crystal area (cm²): 8.0
FWHM at 185 keV (keV): 0.61 Crystal thickness (cm): 1.3
Number of channels: 4096 Live/real counting times(s): 6131/7070

Energy first channel(keV): -9 Energy of last channel (keV): 319

Data:

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	4	71	255	5073	7934	8033
7871	7723	7685	7632	7635	7565	7382	7313
7313	7243	7112	7179	7105	6816	6809	6722
6653	6712	6632	6484	6426	6485	6315	6384
6290	6289	6306	6146	5987	5915	5926	5994
5979	5995	5958	5694	5717	5673	5649	5668

.....etc.....

Table U-3 – Example of data corresponding to the spectrum of a freshly converted UO2 sample

File name: X-X3e Origin and date: LNHB 1997
Sample: X-3 Origin: IRMM
Declared enrichment: 3.4317 ± 0.0016 Origin: IRMM (mass spec.)
Description: Freshly converted UO2 powder sample (Equilibrium factor: 0.639)
Detector: HP Ge plan Crystal area (cm²): 2.0
FWHM at 185 keV (keV): 0.65 Crystal thickness (cm): 1.0
Number of channels: 4096 Live/real counting times (s): 1800/1848
Energy first channel (keV): 0 Energy last channel (keV): 214
Data:

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	13	124	249	463
472	484	440	450	432	433	428	412
408	412	389	376	394	388	395	362
366	368	351	383	329	333	314	316
349	336	324	273	314	300	296	322
298	302	306	308	297	281	271	253.

.....**etc**.....

Plutonium reference spectra

The plutonium reference spectra were provided by LNHB [Laboratoire National Henri Becquerel] in the context of the international ESARDA Pu-2000 exercise [*]. They were obtained by using three different HPGe detectors with the following characteristics:

- HPGe planar type: 2.0 cm² x 1.0 cm, FWHM (at 208 keV): 0.63 keV
- HPGe coaxial type: 21 cm² x 5.7 cm, FWHM (at 208 keV): 0.88 keV
- HPGe detector semi-planar type for safeguards: 30 cm² x 3.0 cm, FWHM (at 208 keV): 0.67 keV.

(J. Morel , M. Bickel , C. Hill , A. Verbruggen and ESARDA NDA-WG Members. Results from the international evaluation "Pu-2000 exercise" for plutonium isotopic composition measurements; Note Technique DIMRI/LNHB/02-07, CEA-Saclay, France (2002))*

The samples used for the Pu-2000 exercise were prepared by IRMM (Institute for Reference Materials and Measurements); their main characteristics in terms of type, packaging and plutonium mass are given in Table Pu-1. Their plutonium isotopic compositions are given in mass %, i.e. the ratio of the mass of a particular isotope to the total plutonium mass, for the reference date 2000-01-01 and their associated uncertainties are assessed for a 1 σ confidence level (68 %). Four other certified samples were also used as quality control samples. Their main characteristics and certified isotopic abundances are given in Table Pu-2 for the same reference date; the corresponding uncertainties are quoted for 1 σ confidence level. Detailed information on the samples can be found in the relevant IRMM internal report**.

*(** C. Hill, A. Verbruggen, M. Bickel. Pu-2000: description of the samples used for the exercise; report GE/R/25/01, European Commission, JRC, Geel, Belgium (2001))*

Table Pu-1 – Plutonium samples prepared for the Pu-2000 exercise

Sample	Description	^{238}Pu mass %		^{239}Pu mass %		^{240}Pu mass %		^{241}Pu mass %		^{242}Pu mass %		^{241}Am mass %	
		Value	Unc%	Value	Unc%	Value	Unc%	Value	Unc%	Value	Unc%	Value	Unc%
A	PuO_2 canned in stainless steel container Bottom thickness container: 0.50 ± 0.01 mm. Total PuO_2 mass: 4.23 ± 0.01 g	0.1170	3.9	79.490	0.1	18.99	0.3	0.741	0.85	0.664	1.3	1.100	-
B	PuO_2 canned in stainless steel container Container bottom thickness: 0.49 ± 0.01 mm. Total PuO_2 mass: 4.66 ± 0.01 g	1.44	0.55	61.300	1.15	26.90	0.25	4.390	0.35	6.06	0.4	6.500	-
C	PuO_2 canned in stainless steel container Total PuO_2 mass: > 4.0 g	0.0105	0.5	93.520	0.005	6.314	0.04	0.1161	0.10	0.0396	0.4	1.190	1.0
D	PuO_2 canned in stainless steel container Total PuO_2 mass: > 4.0 g	0.0105	0.5	93.520	0.005	6.314	0.04	0.1161	0.10	0.0396	0.4	1.170	1.0
E	PuO_2 pellet sealed in a stainless steel container. Window: 0.3-0.5 mm, height of the pellet: 2 mm. Pu mass: 0.45 g	0.0100	2.0	93.850	0.03	5.989	0.05	0.1120	0.7	0.034	2.4	0.310	1.6
F	PuO_2 pellet sealed in a stainless steel container. Window: 0.3-0.5 mm, height of the pellet: 2 mm. Pu mass: 0.45 g	0.0206	1.4	89.530	0.04	10.111	0.02	0.2500	0.25	0.094	1.1	0.456	0.7
G	PuO_2 pellet sealed in a stainless steel container. Window: 0.3-0.5 mm, height of the pellet: 2 mm. Pu mass: 0.45 g	0.0431	0.5	84.970	0.02	14.196	0.03	0.559	0.4	0.235	1.7	1.060	1.1
H	PuO_2 pellet sealed in a stainless steel container. Window: 0.3-0.5 mm, height of the pellet: 2 mm. Pu mass: 0.45 g	0.1000	1	78.390	0.01	19.917	0.02	1.036	0.20	0.568	0.4	2.370	0.9
I	PuO_2 pellet sealed in a stainless steel container. Window: 0.3-0.5 mm, height of the pellet: 2 mm. Pu mass: 0.45 g	0.121	0.5	76.610	0.02	21.40	0.03	1.164	0.2	0.700	1.1	2.643	0.1
J	PuO_2 pellet sealed in a stainless steel container. Window: 0.3-0.5 mm, height of the pellet: 2 mm. Pu mass: 0.45 g	0.869	0.4	68.090	0.01	24.49	0.02	3.027	0.1	3.521	0.1	6.100	1.7
K	PuO_2 pellet sealed in a stainless steel container. Window: 0.3-0.5 mm, height of the pellet: 2 mm. Pu mass: 0.45 g	1.18	0.6	64.150	0.03	26.46	0.04	3.753	0.1	4.617	0.1	6.500	1.5
L	PuO_2 canned in stainless steel container	0.01	5	98.300	0.15	1.630	0.3	0.048	1.1	0.0230	2.6	1.200	25
M	PuO_2 powder, low burn-up PuO_2 mass: 5 g	0.0109	1	93.540	0.01	6.292	0.02	0.1149	0.25	0.0385	0.4	0.2009	-
N	PuO_2 powder, high burn-up	1.303	0.15	64.990	0.01	24.02	0.025	5.041	0.1	4.642	0.1	4.950	0.6
O	Pu metal, low burn-up Pu mass: 1 g	0.00630	0.8	95.420	0.025	4.501	0.1	0.0604	0.45	0.0073	2.1	0.1635	-
P	MOX pellet. Total mass: 2 g U mass %: 83.58, Pu mass %: 4.44	1.110	0.5	64.720	0.02	26.24	0.02	3.59	0.15	4.34	0.15	1.380	0.85
Q	MOX solution. Volume: 10 ml, U mass %: 83.58, Pu mass %: 4.44	1.110	0.5	64.720	0.02	26.24	0.02	3.59	0.15	4.34	0.14	1.380	0.85
R	Pure ^{239}Pu. PuO_2 canned in stainless steel container. Container bottom thickness: 0.78mm. Total PuO_2 mass: 3.85 ± 0.05 g	0	-	99.980	0.005	0.021	-	0.0001	-	0	-	0.0003	-
S	Pure ^{240}Pu. PuO_2 canned in stainless steel container. Container bottom thickness: 0.40 mm. Total PuO_2 mass: 5.62 ± 0.05 g	0.012	-	0.023	-	99.94	0.005	0.001	-	0.029	-	0.002	-

Table Pu-2 – Reference CBNM samples proposed for the Pu-2000 exercise

Sample	Isotopic composition [Mass %]	Description
CBNM 93	Pu-238: 0.01050± 0.0001 Pu-239: 93.5201 ± 0.0044 Pu-240: 6.3138 ± 0.0020 Pu-241: 0.1161 ± 0.0001 Pu-242: 0.0396 ± 0.0002 Am-241: 0.2091 ± 0.0021	PuO_2 powder sealed in stainless steel container PuO_2 mass: 6.65 ± 0.06 g Window thickness: 0.780 ± 0.002 mm
CBNM 84	Pu-238: 0.0635 ± 0.0003 Pu-239: 84.7755 ± 0.0058 Pu-240: 14.2657 ± 0.0043 Pu-241: 0.5357 ± 0.0005 Pu-242: 0.3596 ± 0.0005 Am-241: 0.7054 ± 0.0036	PuO_2 powder sealed in stainless steel container PuO_2 mass: 6.65 ± 0.06 g Window thickness: 0.780 ± 0.002 mm
CBNM 70	Pu-238: 0.7816 ± 0.0009 Pu-239: 75.3797 ± 0.0052 Pu-240: 18.7890 ± 0.0045 Pu-241: 2.9133 ± 0.0010 Pu-242: 2.1364 ± 0.0012 Am-241: 3.852 ± 0.019	PuO_2 powder sealed in stainless steel container PuO_2 mass: 6.65 ± 0.06 g Window thickness: 0.780 ± 0.002 mm
CBNM 61	Pu-238: 1.1133 ± 0.0012 Pu-239: 64.700 ± 0.015 Pu-240: 26.262 ± 0.012 Pu-241: 3.5848 ± 0.0024 Pu-242: 4.3399 ± 0.0033 Am-241: 4.754 ± 0.024	PuO_2 powder sealed in stainless steel container PuO_2 mass: 6.65 ± 0.06 g Window thickness: 0.780 ± 0.002 mm

The plutonium reference spectra were coded in 8192 channels using an analysis range of 0.075 keV/channel, so that the region of interest from 0 to 614 keV could be taken into account. These spectra were recorded in 8I10 format ASCII files and also in binary ".chn" format. As shown in Table Pu-3, each ASCII file contains the following information:

- file name, origin and date,
- sample name and origin,
- declared isotopic composition (at the reference date of 1 January 2000) for each plutonium isotope and Am-241 with the corresponding uncertainty estimated for a 1 σ confidence level,
- sample description,
- main characteristics of the detector used i.e. type, crystal diameter, crystal thickness and FWHM at 208 keV,
- number of channels, live and real count times(s),
- energy of the first and last channels corresponding to the file,
- data corresponding to the channel contents.

The previous characteristics for all the plutonium spectra are collated in the appended file "Pu ref spectra". The spectrum files are available in the "Spectra from coaxial detector", "Spectra from planar detector" and "Spectra from safeguards detector" subdirectories of the directory called "Pu spectra".

Table Pu 3 - Example of data corresponding to a reference plutonium spectrum

Example for PuO_2 pellet sample

File name : P-J-1 Origin and date : CEA-DAMRI 2000, October 11
Sample : J - 1484 Origin : IRMM, Pu-2000 exercise
Declared isotopic composition (from Pu-2000 exercise) at the reference date of 2000, January 1
Pu-238/Pu : 0.869 ± 0.003 Pu-239/Pu : 68.09 ± 0.01
Pu-240/Pu : 24.490 ± 0.005 Pu-241/Pu : 3.027 ± 0.003
Pu-242/Pu : 3.521 ± 0.003 Am-241/Pu : 6.10 ± 0.10
Detector : HPGe planar Crystal diameter (cm) : 1.6
FWHM at 208 keV (keV) : 0.65 Crystal thickness (cm) : 1.0
Number of channels : 8192 Live/real counting times (s) : 1200/1483
Energy first channel (keV) : 0 Energy last channel (keV) : 614

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	2	4	6	127	4477	1700	245
488	1602	2431	2759	3179	3395	3408	3426
3348	3201	3201	3216	3135	3109	3084	3087
3023	2986	3063	2940	3023	2917	2927	2892

……etc……

Introduction of other reference spectra

This library could be supplemented by the introduction of other reference spectra. A standard form is proposed here for all other possible contributions; please complete the corresponding documents.

Preliminary sheet

1 – Laboratory:

Address:

Person(s) for correspondence:

Phone number: Fax number: E-mail:

2 – Recommendations

The following conditions shall be complied with as far as possible, when acquiring these spectra:

- When determining uranium enrichment by methods based on analysis of the XK region, the uranium spectrum energy range of interest extends from 0 to 250 keV. It is thus recommended that a sensitivity of about 0.06 keV/channel for spectra coded over 4096 channels be used or 0.03 keV/channel for 8192 channels.
- When determining the isotopic composition of plutonium, use a ~1 mm thick cadmium screen to highly attenuate the 59.5 keV gamma-ray of ^{241}Am, without eliminating it altogether, if possible. The effect of this is to limit the count rates in the low energy range and suppress the sum-peaks due to this ray. For most applications, it is recommended to use an analysis range of ~ 0.075 keV/channel for spectra coded over 8000 channels. A number of applications are characterised by appreciable matrix effects and require analysis of the 500 to 1000 keV region. Thus, for this type of application, in addition to the spectra obtained under the above conditions, supplementary spectra must be acquired by doubling the gain.
- Conventional acquisition systems cannot operate at the high count rates of highly active samples without considerable degradation of the peak shapes. Thus with these systems, the count rates must be limited to less than 5000 pulses/second. For other systems capable of operating at high count rates, these rates must be limited to 50,000 pulses/second to ensure that the peak widths at half, tenth and fifth peak heights do not increase by more than 10 % with respect to the usual values.
- If collimation is used, make measurements with and without the collimator, if possible, to determine the influence of the latter.
- If possible, please send the spectra as ASCII files, preferably 8I10 in format; if not, specify the format.

Reference uranium spectrum identification sheet

1 – General characteristics

Spectrum file name:

Format ASCII - I8: format “yes” or “no”? , if no, specify:

Acquisition date: / /

Count time: seconds

Analysis range: keV/channel; number of channels used: channels

Region of interest: keV to keV

2 – Experimental acquisition conditions

2.1 – Detector

Type (Si-Li or HP Ge ‘n’ or ‘p’, planar or coaxial):

Dimensions - diameter: mm, thickness: mm

FWHM (in keV) at 122 keV (^{57}Co): , at 186 keV (^{235}U):

2.2 – Screen(s) (if used)

Type of material: , thickness: mm

Type of material: , thickness: mm

2.3 – Geometry

Sample to detector distance: mm

Collimator (if used):

Type of material: thickness: mm

Inside diameter: mm

Collimator to detector distance: ... mm

2.4 – Other details

Count rate: counts/second

3 – Sample

3.1 – Nuclear material characteristics

Chemical form: physical form: ..

Approximate amount of U: grams

Sample age: years

If ^{234}Th is not in equilibrium with ^{238}U (case of freshly converted samples), give the number of days between separation time and the start of the spectrum acquisition: days

3.2 – Container description

Composition and thickness of first envelope: / cm

Composition and thickness of second envelope: / cm

3.3 – Description of any matrix material

Composition and thickness of materials making up the matrix other than the nuclear material

Composition and thickness of first material: / cm

Composition and thickness of second material: / cm

4 – Uranium enrichment value

4.1 – Certification

Certification origin: ...

Method(s) used: .

Reference date: / /

4.2 – Isotope ratios obtained on spectrum acquisition date

^{235}U/total U ratio: ± (1 σ)

^{234}U/total U ratio: ± (1 σ)

4.3 – Radioactive impurities

Method used for analysing impurities:

Nuclide 1: , activity: MBq

Nuclide 2: , activity: MBq

5 – Comments

Reference plutonium spectrum identification sheet

1 – General characteristics

Spectrum file name:

Format ASCII - I8: "yes" or "no"?, if no, specify:

Acquisition date: / /

Count time: seconds

Analysis range: keV/channel; number of channels used: channels

Region of interest: keV to keV

2 – Experimental acquisition conditions

2.1 – Detector

Type(Si-Li or HP Ge 'n' or 'p', planar or coaxial):

Dimensions - diameter: mm, thickness: mm

FWHM (in keV) at 122 keV (^{57}Co): , at 208 keV (^{237}U):

2.2 – Screen(s) (if used)

Type of material: , thickness: mm

Type of material: , thickness: mm

2.3 – Geometry

Sample to detector distance: mm

Collimator (if used):

Type of material: thickness: mm

Inside diameter: mm

Collimator to detector distance: ... mm

2.4 – Other details

Count rate: counts/second.

3 – Sample

3.1 – Nuclear material characteristics

Chemical form: .. physical form: .

Ratio U/Pu:

Approximate amount of Pu: grams

Sample age: years

If ^{237}U is not in equilibrium with ^{241}Pu (case of freshly converted samples), give the number of days between the separation time and the start of the spectrum acquisition: days

3.2 – Container description

Composition and thickness of first envelope: / cm

Composition and thickness of second envelope: / cm

3.3 – Description of any matrix material

Composition and thickness of materials making up the matrix other than the nuclear material

Composition and thickness of first material: / cm

Composition and thickness of second material: / cm

4 – Isotopic composition values

4.1 – Certification

Certification origin: ...

Method(s) used: ...

Reference date: / /

4.2 – Isotopic ratios obtained on the spectrum acquisition date

$^{238}Pu/Pu_{total}$ ratio: ± (1 σ)

$^{239}Pu/Pu_{total}$ ratio: ± (1 σ)

$^{240}Pu/Pu_{total}$ ratio: ± (1 σ)

$^{241}Pu/Pu_{total}$ ratio: ± (1 σ)

$^{242}Pu/Pu_{total}$ ratio: ± (1 σ)

$^{241}Am/Pu_{total}$ ratio: ± (1 σ)

4.3 – Radioactive impurities

Method used for analysing impurities:

Nuclide 1: , activity: MBq

Nuclide 2: , activity: MBq

5 – Comments