European Commission

JRC REFERENCE MATERIALS REPORT

CERTIFICATION REPORT

Preparation and certification of ^{243}Am spike reference material: IRMM-0243

Certified reference material for the amount content of ^{243}Am and $n(^{241}Am)/n(^{243}Am)$ isotope amount ratio

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Abstract

This report describes the preparation and certification of IRMM-0243, a ^{243}Am spike reference material. It is certified for the amount content of ^{243}Am and the $n(^{241}Am)/n(^{243}Am)$ isotope amount ratio. Furthermore, the material is certified for the amount contents of ^{241}Am and total Am, the mass fractions of ^{243}Am, ^{241}Am and total Am, the isotope amount and mass fractions (e.g. isotopic composition) and the molar mass of Am. The material was produced in compliance with ISO/IEC 17034:2016 [1] and certified in accordance with ISO Guide 35:2006 [2].

The material was prepared by dilution of an americium starting solution in nitric acid and dispensing of the solution into glass ampoules. In total 587 units were produced.

Between-unit homogeneity was quantified and stability during dispatch and storage were assessed in accordance with ISO Guide 35:2006 [2].

The characterisation of the amount content of ^{243}Am was performed by Isotope Dilution Mass Spectrometry (IDMS) using a ^{241}Am spike, produced from highly enriched ^{241}Pu material. The $n(^{241}Am)/n(^{243}Am)$ isotope amount ratio was measured by Thermal Ionisation Mass Spectrometry (TIMS).

The certified values were verified by alpha particle spectrometry, alpha particle counting at a defined solid angle (DSA) and high-resolution gamma-ray spectrometry as independent verification methods.

The uncertainties of the certified values were estimated in compliance with the Guide to the Expression of Uncertainty in Measurement (GUM) [3] and include uncertainties related to possible inhomogeneity, instability and characterisation.

The indicative value for the $n(^{242m}Am)/n(^{243}Am)$ isotope amount ratio and its uncertainty were derived from the inter-laboratory comparison (ILC) organised by CEA/CETAMA using IRMM-0243 as the test sample.

The main purpose of this material is for use as a spike isotopic reference material for the quantification of americium by IDMS in unknown samples. A unit of IRMM-0243 consists of a glass ampoule with a screw cap containing about 3.5 mL nitric acid solution (c = 1 mol/L) with an americium mass fraction of about 1.5 μg/g solution.

The material is a true solution; therefore there is no recommended minimum sample intake[1] to be taken into account.

The following values were assigned:

[1] Size of aliquot for analysis

IRMM-0243	AMERICIUM IN NITRIC ACID SOLUTION		
		Certified value [1]	Uncertainty [2]
Amount contents [nmol/g (solution)]	^{241}Am [3]	0.7754	0.0015
	^{243}Am	5.696	0.011
	Am [3]	6.472	0.012
Isotope amount ratios [mol/mol]	$n(^{241}\text{Am})/n(^{243}\text{Am})$	0.136138	0.000054
Mass fractions [3] [μg/g (solution)]	^{241}Am	0.18692	0.00036
	^{243}Am	1.3845	0.0026
	Am	1.5716	0.0030
Isotope amount fractions (·100) [3] [mol/mol]	$n(^{241}\text{Am})/n(\text{Am})$	11.9810	0.0042
	$n(^{243}\text{Am})/n(\text{Am})$	88.0069	0.0042
Isotope mass fractions (·100) [3] [g/g]	$m(^{241}\text{Am})/m(\text{Am})$	11.8940	0.0042
	$m(^{243}\text{Am})/m(\text{Am})$	88.0940	0.0042
Molar mass [3] [g/mol]	$M(\text{Am})$	242.821094	0.000085
		Indicative value [4]	Uncertainty [2]
Isotope amount ratios [mol/mol]	$n(^{242m}\text{Am})/n(^{243}\text{Am})$	0.0001373	0.0000024
Isotope amount fractions (·100) [mol/mol]	$n(^{242m}\text{Am})/n(\text{Am})$	0.01208	0.00021
Isotope mass fractions (·100) [g/g]	$m(^{242m}\text{Am})/m(\text{Am})$	0.01205	0.00021

[1] The certified values are traceable to the International System of units (SI) via the values on the respective certificates of IRMM-049d and IRMM-290b-A3 and via the half-life of ^{241}Pu. The reference date for the certified values is January 1, 2017.

[2] The uncertainty is the expanded uncertainty with a coverage factor k = 2 corresponding to a level of confidence of about 95 % estimated in accordance with ISO/IEC Guide 98-3, Guide to the Expression of Uncertainty in Measurement (GUM:1995), ISO, 2008.

[3] The derived certified values are calculated from the certified amount content of ^{243}Am, certified $n(^{241}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio and the atomic masses according to Wang et al. (The AME 2012 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 36, No. 12, 1603-2014, 2012).

[4] The indicative value for the $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio was derived from the ^{243}Am inter-laboratory comparison (ILC) organised by CEA/CETAMA using IRMM-0243 as the test sample. It represents the DerSimonian-Laird weighted mean of the results from nine participating laboratories. The indicative values for the $m(^{242m}\text{Am})/m(\text{Am})$ mass and $n(^{242m}\text{Am})/n(\text{Am})$ amount fractions were calculated using the indicative value of $n(^{242m}\text{Am})/n(^{243}\text{Am})$ and the certified values. The reference date for the indicative values is January 1, 2017.

The half-lives of radionuclides were obtained from DDEP-BIPM (Table of radionuclides) and R. Wellum et al. (A new evaluation of the half-life of ^{241}Pu, J. Anal. At. Spectrom., 24, 801-807, 2009).

1. Introduction

1.1 Background

In nuclear safeguards and security, accurate isotopic measurements are required in order to draw correct conclusions. The accuracy, reliability and traceability of such measurements depend heavily on suitable isotopic reference materials. There is a wide range of uranium and plutonium Certified Reference Materials (CRMs) for quality control, method validation and instrument calibration in mass spectrometry. On the contrary, the availability of americium reference materials is limited. Currently, there is no ^{243}Am spike CRM available, although it is indispensable for accurate mass spectrometry measurements of ^{241}Am in nuclear materials. Such material can be used in nuclear forensics to determine the 'model age' of a (seized) plutonium material, i.e. the time elapsed since its last chemical purification (via ^{241}Am/^{241}Pu chronometer), in radiation waste management for characterisation of irradiated nuclear fuel/waste for long-term disposal at geological repositories and in nuclear data applications for determination of radionuclide half-lives [4].

The provision of nuclear reference materials is regularly addressed among reference materials providers and users, e.g. in the frame of the Working Group on Techniques and Standards for Destructive Analysis (WGDA) of the European Safeguards and Research Association (ESARDA), the International Atomic Energy Agency (IAEA), and the Nuclear Forensics International Technical Working Group (ITWG). The need for an americium spike CRM was expressed at the 2014 IAEA Technical Meeting on Reference Materials for Destructive Analysis in the Nuclear Fuel Cycle as well as at the 2016 Nuclear Security Summit: Certified Reference Material Fact Sheet [5].

To fill this gap, a novel ^{243}Am spike (IRMM-0243) has been prepared and certified for the amount content and isotopic composition in collaboration with the French Nuclear and Alternative Energies Commission (CEA), Nuclear Energy Division – CEA, Marcoule.

1.2 Choice of the material

The IRMM-0243 reference material was prepared from an americium starting solution, containing ^{243}Am and ^{241}Am isotopes with relative isotope mass fractions $m(^{243}\text{Am})/m(\text{Am})$ and $m(^{241}\text{Am})/m(\text{Am})$ of about 88 % and 12 %, respectively. The solution was diluted in nitric acid to achieve an Am mass fraction of 1.5 μg/g and dispensed into individual glass ampoules. This concentration of americium is considered suitable for various mass spectrometry measurements (e.g. TIMS, ICP-MS).

1.3 Design of the project

IRMM-0243 was characterised for the amount contents of ^{243}Am, ^{241}Am and total Am, the mass fractions of ^{243}Am, ^{241}Am and total Am, the isotope amount ratios of $n(^{241}\text{Am})/n(^{243}\text{Am})$ and $n(^{242\text{m}}\text{Am})/n(^{243}\text{Am})$, the isotope amount and mass fractions (e.g. isotopic composition) and the molar mass of Am.

Characterisation measurements, homogeneity and stability studies were performed on one set of randomly selected ampoules.

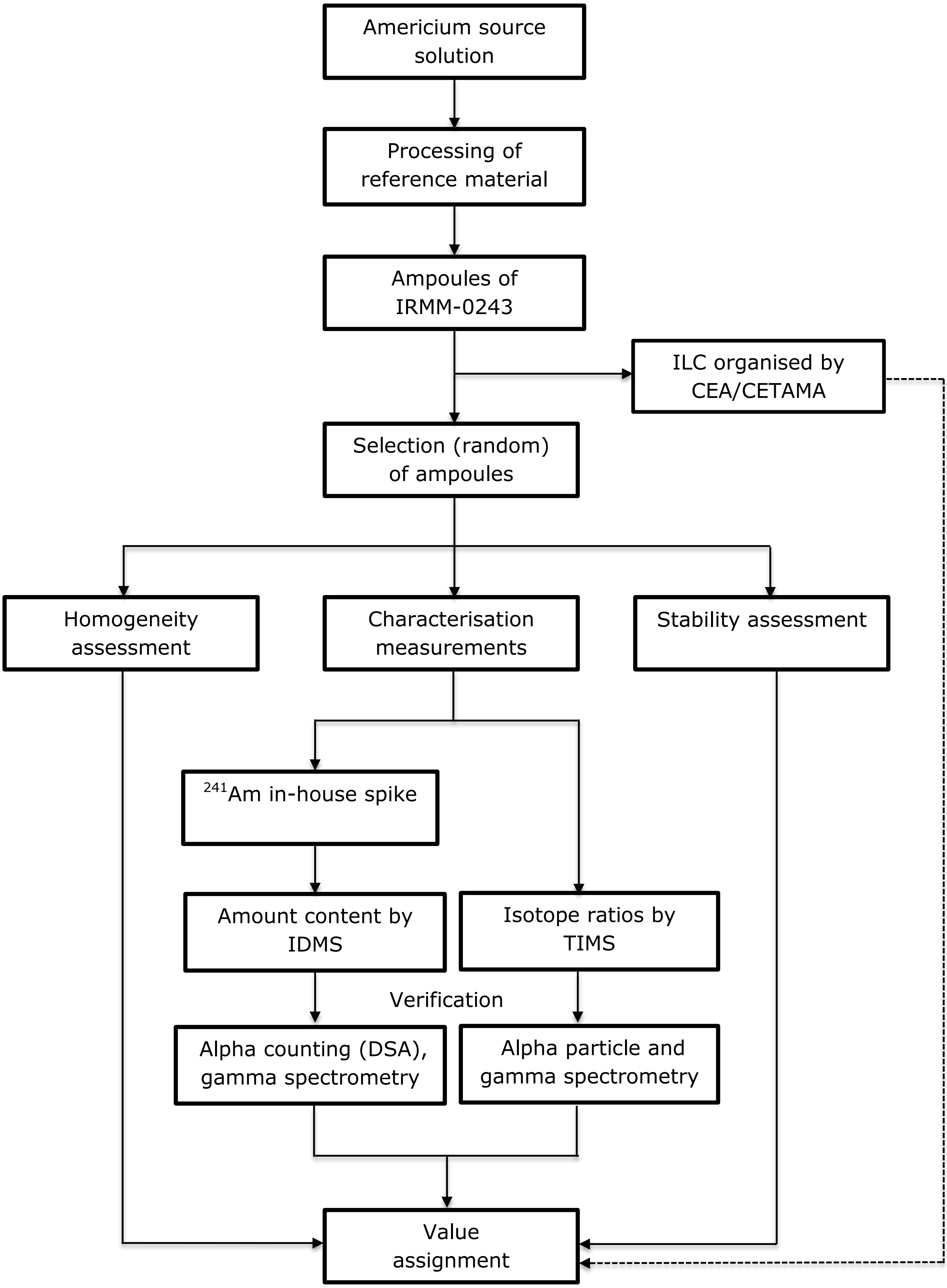
The characterisation of the amount content of ^{243}Am was performed by Isotope Dilution Mass Spectrometry (IDMS) [6]. In IDMS, the amount of an element in the sample is determined on the basis of additions of known amounts of the same element (called spike) whose isotopic composition differs from that of the unknown sample. By measuring the change in isotopic composition of the blend (sample-spike mixture) by mass spectrometry, the unknown amount of the element in the sample can be calculated. In absence of a suitable ^{241}Am spike CRM for IDMS measurements, an alternative approach was applied. The ^{241}Am spike was produced from highly enriched ^{241}Pu ($m(^{241}\text{Pu})/m(\text{Pu})$ = 0.993) material available at JRC-Geel. After the initial purification of the ^{241}Pu material, the ingrown ^{241}Am, produced by beta-decay of ^{241}Pu, was used as spike for the measurement of the amount content of ^{243}Am by IDMS (see Section 6.1). The isotope amount ratios of $n(^{241}\text{Am})/n(^{243}\text{Am})$ and $n(^{242m}\text{Am})/n(^{243}\text{Am})$ were measured by Thermal Ionisation Mass Spectrometry (TIMS). All isotope ratio measurements were performed using the total evaporation method on a multi-collector Triton TIMS.

Independent verification measurements were performed by alpha particle spectrometry, alpha particle counting at a defined solid angle (DSA) and high-resolution gamma-ray spectrometry.

Prior to release of this ^{243}Am spike CRM, that same material was used in an inter-laboratory comparison (ILC) organised by CEA/CETAMA. The purpose of this exercise was to assess the measurement performance of participating laboratories. It also served as an external verification of the certified values.

Figure 1 shows all the steps in the preparation and certification of the IRMM-0243 material in a flow chart.

Figure 1 Flow chart for the preparation and certification of IRMM-0243



2. Participants

The americium starting solution, the purification and the impurity analysis were provided by the CEA/L2AT (ATalante Analysis Laboratory, Marcoule, France).

Value assignment, homogeneity and stability studies, including data evaluation and the overall project management have been performed at the European Commission`s Joint Research Centre, Directorate G - Nuclear Safety and Security, G.2 - Standards for Nuclear Safety, Security and Safeguards, Geel, Belgium.

3. Material processing and process control

3.1 Origin of the starting material

About 4 mg of americium starting material was made available by the CEA/L2AT (ATalante Analysis Laboratory, Marcoule, France).

3.2 Processing

The processing of IRMM-0243 material included the purification of the americium starting solution, dilution, and subsequent dispensing into glass ampoules.

Purification of Am solution

The americium starting solution was purified by extraction chromatography to remove the impurities (Ca, Al, Fe, Co, Ni, etc.). The americium solution was loaded on a pre-conditioned TRU-Spec column (Triskem International, Bruz, France) and the impurities washed through the column with 20 mL of nitric acid solution (c = 1 mol/L). Americium (and the lanthanides) was then eluted with 5 mL dilute nitric acid solution (c = 0.01 mol/L).

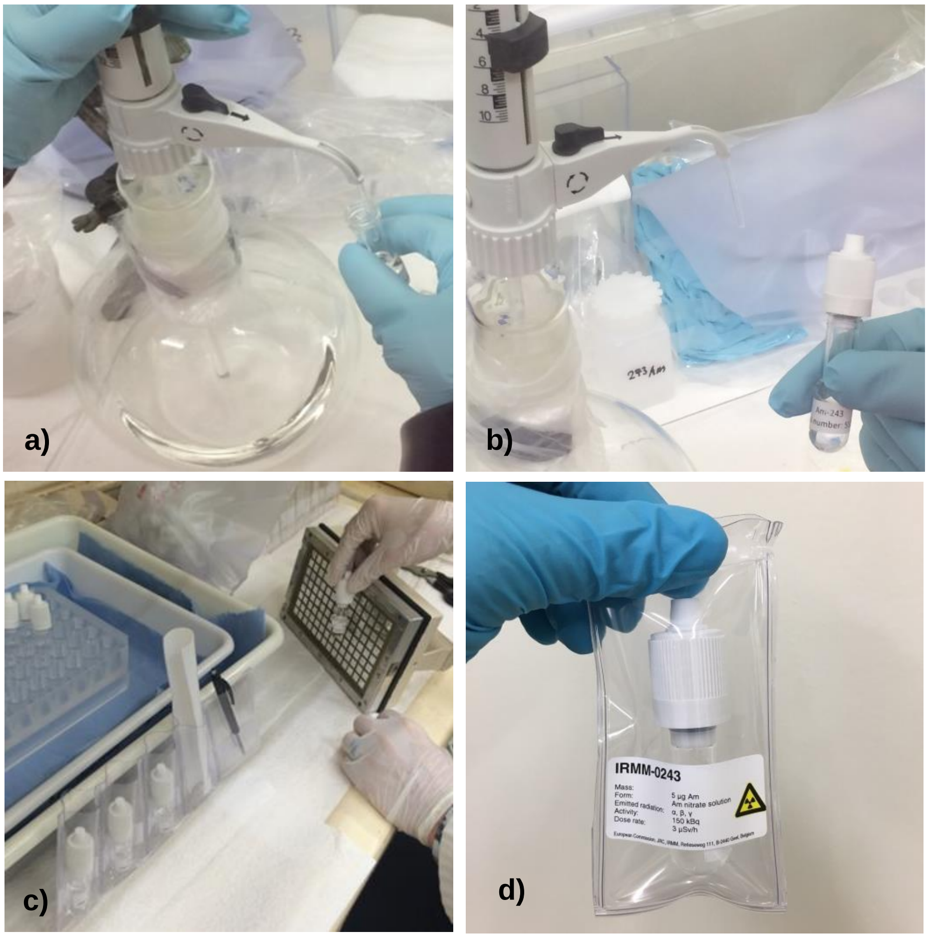
Cleaning

The glass ampoules, the flask for the dilution and the dispenser were cleaned prior to use with ultra-pure Milli Q water (18.2 MΩ cm at 25 ^{o}C, Millipore, Belgium) and in 10 % (m/m) nitric acid solution (p.a., Merck, Darmstadt, Germany) for 24 hours. The flask and the ampoules were dried in an oven at 60 ^{o}C.

Dilution and dispensing

The purified americium solution (about 1 g/L) was diluted with 2400 mL nitric acid solution (c = 1 mol/L, p.a., Merck, Darmstadt, Germany) in a 3 L glass flask to obtain an americium mass fraction of 1.5 μg/g. The solution was allowed to homogenise for a week with occasional stirring by hand. Aliquots of 3.5 mL of the mother solution were dispensed into glass ampoules with screw-caps. The ampoules were closed immediately after the dispensing to minimise the evaporation of the solution. The dispensing of all 587 units was completed within a week. The dilution of the americium starting solution and the dispensing into ampoules were carried out in a dedicated glove box. Finally, the ampoules were taken out of the glove box, checked individually for surface contamination, sealed in PVC bags and labelled. The major processing steps are depicted in Figure 2.

Figure 2 Processing steps of the americium reference material: a) dispensing of a solution, b) closing of an ampoule with a screw-cap, c) contamination check and PVC sealing and d) a unit of IRMM-0243



3.3 Process control

The results of the impurity analysis after purification of the americium source solution are summarised in Annex A.

4. Homogeneity

A key requirement for any reference material is the equivalence between the various units. In this respect, it is relevant whether the variation between units is significant compared to the uncertainty of the certified value. In contrast to that it is not relevant if this variation between units is significant compared to the analytical variation. Consequently, ISO 17034:2016 [1] requires RM producers to quantify the between-unit variation. This aspect is covered in between-unit homogeneity studies.

The within-unit inhomogeneity does not influence the uncertainty of the certified value when the minimum sample intake is respected, but determines the minimum size of an aliquot that is representative for the whole unit.

4.1 Between-unit homogeneity for the amount content of ^{243}Am

The between-unit homogeneity was evaluated to ensure that the certified values of the CRM are valid for all units of the material, within the stated uncertainty.

The number of selected units (18 units in total) is greater than the cubic root of the total number of the produced units (587). The eighteen units were selected using a random stratified sampling scheme covering the whole batch for the between-unit homogeneity test.

For this project, the homogeneity, stability and characterisation studies were performed on the same units. The data obtained from the between-unit homogeneity assessment were also used to assign the certified values of the material (see Section 6 and 7).

A chemical purification was carried out prior to isotope ratio measurements on each unit. The measurements were carried on sets of two units over the period from January to July 2016. This allowed enough time for the weighing, chemical preparation and isotope measurements on each set. It also gave rise to sets with slightly increased amounts of ingrown ^{241}Am over time. Details are described in section 6 (Characterisation) of this report.

Using this approach, the measurements were performed under intermediate precision conditions rather than repeatability conditions within short intervals of time. Consequently, significant day-to-day effects occurred (confirmed by analysis of variance, ANOVA) that could mask the between-unit variation. The correction of the data for day-to-day variations was deemed not necessary since the uncertainty from the homogeneity study (see Table 2) was three times smaller compared to the uncertainty from the characterisation (see Section 6) and, therefore contributed only to a small extent to the overall uncertainty of this reference material.

The respective samples of each unit of IRMM-0243 were measured in a randomised manner to be able to separate a potential analytical drift from a trend in the filling sequence. The measurement results of the unit No. 240 and 437 had to be excluded from the evaluation due to technical reasons, such as e.g. loss of sample prior to measurement, high background from the filament due to unusual high filament temperatures or very low signal intensity.

Regression analyses were performed to evaluate potential trends in the analytical sequence as well as trends in the filling sequence. A trend in the analytical sequence was observed at the 95 % confidence level. The analytical trend arose from the data points at the beginning of the analytical sequence (see Annex B). Since no technical reason was found to exclude these data points, they were all retained for statistical evaluation. Correction of this trend is therefore expected to improve the sensitivity of the subsequent statistical analysis through a reduction in analytical variation without masking potential between-unit heterogeneities. As the analytical sequence and the unit numbers were not correlated, the analytical trend was corrected as shown below (Equation 1):

$$\boldsymbol{x_{i-corr}} = \boldsymbol{x_i} - \boldsymbol{b} \cdot \boldsymbol{i} \qquad \text{Equation 1}$$

i	position of the result in the analytical sequence
b	slope of the linear regression for the analytical run

No trend in the filling sequence was visible. The trend corrected data were tested for consistency using Grubbs outlier test on a confidence level of 99 % on the individual results and on the unit means. No outlying individual result or outlying unit means were detected.

The results of the homogeneity study are shown in Annex B

Quantification of between-unit inhomogeneity was accomplished by analysis of variance (ANOVA), which can separate the between-unit standard deviation (s_{bb}) from the within-unit standard deviation (s_{wb}). The latter is equivalent to the method intermediate precision if the individual samples are representative for the whole unit.

Evaluation by ANOVA requires unit means that follow at least a unimodal distribution and results for each unit that follow unimodal distributions with approximately the same standard deviations (homoscedasticity). Distribution of the unit means was visually tested using histograms and normal probability plots. Minor deviations from unimodality of the individual values do not significantly affect the estimate of between-ampoule standard deviations. Results of the statistical evaluation are given in Table 1.

Table 1 Results of the statistical evaluation of the homogeneity study for the amount content of ^{243}Am

	Trends (before correction) [1)]		Outliers [2)]		Distribution	
	Analytical sequence	Filling sequence	Individual results	Unit means	Individual results	Unit means
Amount content of ^{243}Am	yes	no	none	none	unimodal	unimodal

[1)] at 95 % confidence level

[2)] at 99 % confidence level

It should be noted that $s_{bb,rel}$ (between-unit relative standard deviation) and $s_{wb,rel}$ (within-unit relative standard deviation) are estimates of the true standard deviations and therefore subject to random fluctuations. Therefore, the mean square between groups ($MS_{between}$) can be smaller than the mean squares within groups (MS_{within}), resulting in negative arguments under the square root used for the estimation of the between-unit variation, whereas the true variation cannot be lower than zero. In this case, the maximum inhomogeneity, u^*_{bb}, that could be hidden by method repeatability (in our case intermediate precision) was calculated as described by Linsinger *et al.* [7]. u^*_{bb} is comparable to the limit of detection of an analytical method, yielding the maximum inhomogeneity that might be undetected by the given study setup (alpha risk).

Relative within-unit standard deviation of method intermediate precision ($s_{wb,rel}$), relative between–unit standard deviation ($s_{bb,rel}$) and relative maximum inhomogeneity ($u^*_{bb,rel}$) were calculated as:

$$s_{wb,rel} = \frac{\sqrt{MS_{within}}}{\bar{y}} \qquad \text{Equation 2}$$

$$s_{bb,rel} = \frac{\sqrt{\frac{MS_{between} - MS_{within}}{N}}}{\bar{y}} \qquad \text{Equation 3}$$

$$u^*_{bb,rel} = \frac{\sqrt{\frac{MS_{within}}{N}}\sqrt[4]{\frac{2}{\nu_{MSwithin}}}}{\bar{y}} \qquad \text{Equation 4}$$

MS_{within}	mean square within-unit from an ANOVA
$MS_{between}$	mean squares between-unit from an ANOVA
$\bar{y}$	mean of all results of the homogeneity study
N	mean number of replicates per unit
$\nu_{MSwithin}$	degrees of freedom of MS_{within}

The uncertainty contribution for homogeneity was determined under intermediate precision conditions as described earlier in this section. The results of the evaluation of the between-unit variation are summarised in Table 2.

Table 2 Results of the homogeneity study for the amount content of ^{243}Am

	$s_{wb,rel}$ [%]	$s_{bb,rel}$ [1)] [%]	$u^{*}_{bb,rel}$ [%]
Amount content of ^{243}Am	0.038	0.029	0.0081

1) Dataset without trend correction

Therefore, the between-unit standard deviation (s_{bb}) can be used as estimate of u_{bb}. As u^{*}_{bb} sets the limits of the study to detect inhomogeneity, the larger value of s_{bb} and u^{*}_{bb} is adopted as uncertainty contribution to account for potential inhomogeneity.

The correction of the data for the analytical trend as described earlier in this section (Equation 1) was applied solely for the purpose of the homogeneity evaluation. It was not applied for the value assignment (Sections 6 and 7) since its influence on the mean value for the amount content of ^{243}Am was negligible and is included in the uncertainty contribution ($s_{bb, rel}$).

4.2 Homogeneity of the Am isotope ratios

The IRMM-0243 reference material was prepared by dilution of an americium starting solution in nitric acid and dispensing into ampoules. Any differences in the isotope amount ratios could only stem from a contamination with americium of a different isotopic composition during processing. A dedicated glove box was used for the dilution and dispensing, in which no other americium source was kept. Therefore any contamination originating from another americium source can be excluded. This was confirmed by the characterisation study on randomly selected units where no heterogeneity in the isotope ratios was observed.

From these studies and considerations it is concluded that the homogeneity contribution to the uncertainty of the isotope ratios is negligible and therefore, no additional uncertainty component ($u_{bb,rel}$ = 0) was applied.

4.3 Within-unit homogeneity and minimum sample intake

The within-unit homogeneity is closely related to the minimum sample intake. The minimum sample intake is the minimum amount of sample that is representative for the whole unit and thus should be used in an analysis. Using sample sizes equal to or above the minimum sample intake guarantee the certified value within its stated uncertainty.

Quantification of within-unit inhomogeneity was not necessary for IRMM-0243 because the material is a true solution and as such can be regarded as completely homogeneous. Therefore, no minimum sample intake needs to be taken into account for analysis.

5. Stability

Contamination, evaporation of solvent and adsorption on glass walls are considered as the most relevant factors that could affect the stability of both the isotope ratios and the amount content of americium in IRMM-0243. Contamination prior to use (opening of the ampoules) is excluded since the IRMM-0243 reference material is supplied in glass ampoules with a screw-cap and sealed in PVC bags. Therefore only the influence of evaporation (temperature) and adsorption needed to be investigated.

Stability testing is necessary to establish conditions for storage (long-term stability) as well as conditions for dispatch to the customers (short-term stability). During transport, especially in summer time, temperatures up to 60 °C could be reached and stability under these conditions must be demonstrated. It should be noted that the term stability in this context does not refer to radioactive decay. It is self-evident that the radionuclides are decaying according to their half-lives, a process which is quantitatively predictable using the decay data [8, 9].

5.1 Short-term stability

The shipment of nuclear materials follows the legal requirements related to radioprotection measures for transport of radioactive materials. The packaging of IRMM-0243 consists of two parts: an inner and an outer container according to regulations and respective procedures [10]. Units of IRMM-0243 are double sealed in PVC bags and put into a Type A inner container for radioactive materials. The inner container is then placed in a larger outer container, sealed and finally shipped to customers. From the package material specification and the fact that the transport does not take longer than one week, the ampoules of IRMM-0243 packed as described above are not exposed to temperatures outside the range of 4 to 60 °C.

No measurable evaporation or adsorption on the walls that would affect the concentration of americium in the solution is expected to occur during shipment. The isotope ratios are not affected by evaporation or adsorption. Taking this into account, the IRMM-0243 is considered stable regarding its isotopic composition and the amount content during dispatch and can be shipped to customers under normal temperature conditions. No additional uncertainty component ($u_{\text{sts, rel}}$ = 0) was applied.

5.2 Long-term stability

No dedicated long-term stability study has been conducted for IRMM-0243. Experience acquired over the years with various nuclear CRMs at JRC-Geel has demonstrated that nitric acid solutions containing radioactive materials at various concentration levels can be stored at room temperature for long period with no measurable change in isotopic composition or in amount contents. In addition the measurements for the characterisation and homogeneity study (carried out between January and July 2016) were also used to demonstrate the stability of IRMM-0243 during the certification campaign. No significant change in the amount content of ^{243}Am was observed in the selected units of IRMM-0243 (Annex C). Taking these considerations into account, no additional uncertainty component ($u_{\text{lts, rel}}$ = 0) was applied.

Nevertheless, the IRMM-0243 will be subjected to post-certification monitoring to control its stability. Two units of IRMM-0243 will be analysed every year to verify the certified values. The validity of the material certificate is 3 years and may be extended after further stability test are carried out.

6. Characterisation

The material characterisation is the process of determining the property values of a reference material. The material characterisation was based on a primary method of measurement [6, 11], confirmed by an independent method.

A primary method is *"a method having the highest metrological qualities, whose operation(s) can be completely described and understood and for which a complete uncertainty statement can be written in terms of SI units. A primary ratio method measures the value of a ratio of an unknown to a standard of the same quantity; its operation must be completely described by a measurement equation [2, 11]".*

The material characterisation for the amount content ^{243}Am was based on IDMS using ^{241}Am spike produced in-house (see Section 6.1) and for the $n(^{241}\text{Am})/n(^{243}\text{Am})$ and $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratios on TIMS. Independent verification measurements were carried out by alpha particle spectrometry, alpha particle counting at DSA and high-resolution gamma-ray spectrometry at the JRC.G.2 Laboratory for Radionuclide Metrology.

The measurements for the characterisation and homogeneity assessment were carried out together on the same selected ampoules (see Section 4).

6.1 ^{241}Am in-house spike

A ^{241}Am spike material is required in order to determine the amount content of ^{243}Am in selected ampoules of IRMM-0243 by IDMS. For that reason a ^{241}Am spike was produced from highly enriched ^{241}Pu material (mass fraction $m(^{241}\text{Pu})/m(\text{Pu})$ = 0.993) available at JRC-Geel. The ingrown ^{241}Am, which is produced by beta-decay of ^{241}Pu after purification of the material, is used as a spike for the measurements of the ^{243}Am.

The purification of about 2 mg ^{241}Pu material was accomplished by anion exchange separations (Bio Rad AG® 1-X4 resin, 100-200 mesh, Hercules, USA) [12]. The purification procedure was performed three times in order to remove all the decay products that had been growing in since the production of the material in 1991. The final purification was carried out on June 10, 2014 at 15:10 CET, which marked the start of the ^{241}Am in-growth (time zero). The completeness of the purification of ^{241}Pu from ^{241}Am was confirmed by high-resolution gamma-ray spectrometry.

The purified plutonium material was diluted with 100 mL nitric acid solution (c = 1 mol/L) and characterised for the amount content of ^{241}Pu and isotopic composition by IDMS (using a ^{242}Pu spike CRM, IRMM-049d) and TIMS, respectively.

The value for the amount content of ^{241}Pu was calculated from the mean of the 10 blends measured by IDMS. Each blend was measured in replicates on the Triton TIMS (ThermoFischer Scientific, Bremen, Germany). The mass fractionation correction was based on the measurement of the IRMM-290b-A3 Pu isotopic standard. The results of the characterisation measurement of ^{241}Pu solution are shown in Table 3.

Table 3 The amount content of ^{241}Pu and the isotope amount fractions in the ^{241}Pu solution after purification. The reference date of the values is June 10, 2014 15:10 CET (time zero)

		Value	Uncertainty [1)]
Amount content [nmol/g (solution)]	^{241}Pu	81.394	0.053
Isotope amount fractions (·100) [mol/mol]	$n(^{238}\text{Pu})/n(\text{Pu})$	0.00097	0.00034
	$n(^{239}\text{Pu})/n(\text{Pu})$	0.00053	0.00018
	$n(^{240}\text{Pu})/n(\text{Pu})$	0.25741	0.00029
	$n(^{241}\text{Pu})/n(\text{Pu})$	99.29993	0.00052
	$n(^{242}\text{Pu})/n(\text{Pu})$	0.44116	0.00025

1) Expanded (k = 2) uncertainty

6.2 Chemical purification and isotope measurements

Spiking was carried out about one and a half years after the purification of the ^{241}Pu material. During this period a sufficient amount of ^{241}Am spike had been produced for IDMS analysis. From each of the eighteen selected units, an aliquot (2.5-2.7 g) was taken and mixed with an aliquot (about 1.0 g) of the ^{241}Pu spike solution with the in-grown ^{241}Am for determination of the amount content of ^{243}Am by IDMS, and another aliquot (un-spiked, about 0.7 g) for determination of the isotopic composition (e.g.

isotope amount ratios) by TIMS. Spiking was done by accurate weighing using the substitution method. The mass of the ^{241}Pu spike solution was monitored to account for evaporation losses before each weighing.

In substitution weighing, the mass of a sample is determined through a series of mass determinations of an unknown (U) and a reference weight (S). The so called "SUUS" method was applied. The uncertainty contributions in substitution weighing are the uncertainties associated with the calibrated reference weights, air buoyancy correction and the variability of the balance used in "SUUS" method.

Prior to the isotope measurements, two purification steps were carried out to remove the ^{241}Pu from the in-grown ^{241}Am in the blends by means of UTEVA-spec and DGA extraction resins (Triskem International, Bruz, France), respectively [13]. The un-spiked samples underwent the same purification protocol as the blends.

Isotope ratio measurements were performed on the multi-collector Triton Thermal Ionisation Mass Spectrometer (ThermoFisher Scientific, Bremen, Germany) using the total evaporation (TE) method.

The measurements were carried out in a similar manner as routinely performed for uranium and plutonium samples of similar size. In the TE method, the evaporation filament is heated up to maintain a steady intensity and measured until the whole sample is consumed. In this way, the fractionation effects in the ion source are minimized [14, 15, 16, 17]. Degassed zone refined rhenium was used as ionization and evaporation filaments (double filament configuration). About 20 ng of americium nitrate solution was deposited on an evaporation filament, evaporated and mounted on a sample turret. All ion currents were measured simultaneously on Faraday cups.

For uranium and plutonium a mass fractionation correction by measurement of a CRM on the same magazine is recommended following ASTM C1672-17 [18]. According to ASTM C1672-17, the bias for uncorrected $n(^{235}\text{U})/n(^{238}\text{U})$ and $n(^{242}\text{Pu})/n(^{239}\text{Pu})$ ratios is below 0.05 % within 2 standard deviations (2σ) for ratios spanning 3 mass units. In the absence of a suitable Am isotopic standard, it was not possible to perform a correction for mass fractionation during isotope ratio measurements for this project. Due to similar chemical behaviour and similar ionization energies, it can be assumed that americium behaves similar to uranium and plutonium during the TE measurement and that the bias statements for uranium and plutonium can equally be applied to americium. For the $n(^{243}\text{Am})/n(^{241}\text{Am})$ ratio this maximum expected bias was applied as an additional uncertainty component and set to 0.033 % (2σ, for ratios spanning 2 mass units) and for the $n(^{242m}\text{Am})/n(^{243}\text{Am})$ ratio to 0.017 % (2σ, for ratios spanning 1 mass unit), marked as "K-TE" in Figure 3.

In addition, an uncertainty of 0.020 % (2σ, for ratios spanning 3 mass units) derived from isotope measurements of the U and Pu quality control samples (gravimetrically prepared CRMs IRMM-074/2,3 for U and IRMM-290-G3 for Pu) was added as a conservative contribution to the uncertainty budget for Am, marked as "K-QC" in Figure 3.

6.4 The amount content of ^{243}Am and its uncertainty

The amount content of ^{243}Am ($c_{243\text{Am}}$) in the selected units was calculated using the equations below:

$$\boldsymbol{c_{243_{Am}} = \frac{R_y - R_b}{R_b - R_x} \cdot R_x \cdot \frac{m_y}{m_x} \cdot c_{241_{Am}}} \qquad \text{Equation 5}$$

$$\boldsymbol{c_{241_{Am}} = c^{o}_{241_{Pu}} \frac{\lambda_{241_{Pu}}}{\lambda_{241_{Am}} - \lambda_{241_{Pu}}} \left(e^{-\lambda_{241_{Pu}}\Delta t} - e^{-\lambda_{241_{Am}}\Delta t}\right) + c^{o}_{241_{Am}} e^{-\lambda_{241_{Am}}\Delta t}} \qquad \text{Equation 6}$$

R_x	isotope amount ratio $n(^{243}Am)/n(^{241}Am)$ in the un-spiked sample [mol/mol]
R_y	isotope amount ratio $n(^{243}Am)/n(^{241}Am)$ in the spike [mol/mol]
R_b	isotope amount ratio $n(^{243}Am)/n(^{241}Am)$ in the blend [mol/mol]
m_x	mass of the sample [g]
m_y	mass of the spike [g]
c_{241Am}	amount content of the in-grown ^{241}Am spike [mol/g]
c^0_{241Pu}	amount content of ^{241}Pu spike solution at the time of purification [mol/g]
c^0_{241Am}	(residual) amount content of ^{241}Am in ^{241}Pu spike solution after purification [mol/g]
Δt	time for the ingrowth of ^{241}Am [a]
λ_{241Am}	decay constants of ^{241}Am [a^{-1}]
λ_{241Pu}	decay constants ^{241}Pu [a^{-1}]

The half-lives and associated uncertainties (k = 1) used for the calculations of the respective decay constants ($\lambda = \ln 2/T_{1/2}$) were 14.325 ± 0.012 a [8] for ^{241}Pu and 432.6 ± 0.6 a [9] for ^{241}Am. The residual amount of ^{241}Am in the ^{241}Pu spike solution after the purification (June 10, 2014 15:10 CET) was found negligible (c^0_{241Am} = 0, Equation 6). This was confirmed by high-resolution gamma-ray spectrometry (see Section 6.1)

The amount content of ^{243}Am and its associated expanded uncertainty was calculated according to the Guide to the Expression of Uncertainty in Measurement (GUM) [3] using the GUM Workbench Software. Detailed calculations and associated uncertainty budgets are given in Annex D.

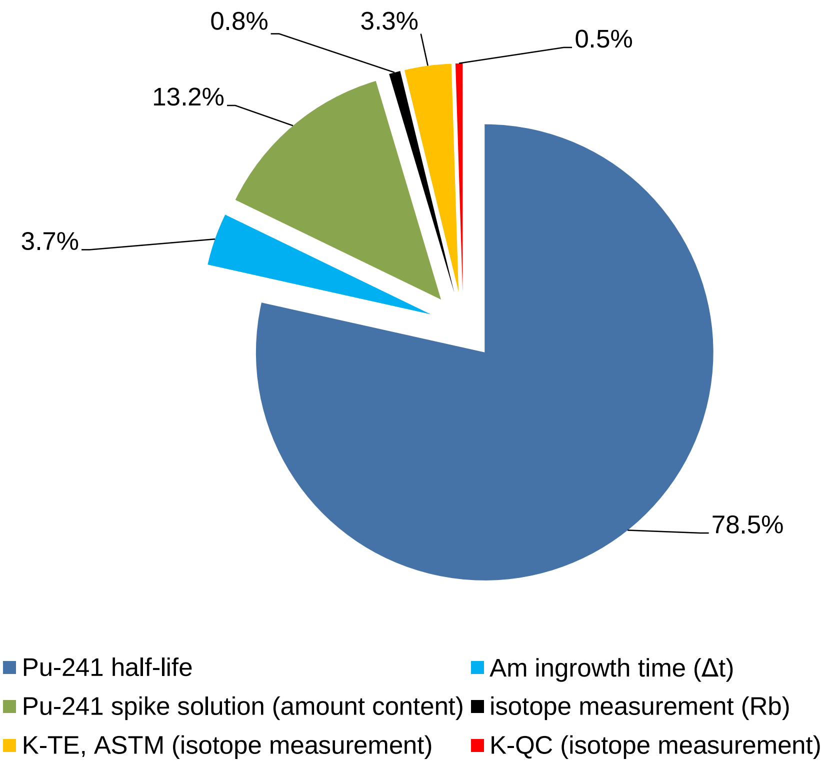
The amount content of ^{243}Am and its standard uncertainty from characterisation are given in Table 4.

Table 4 The amount content of ^{243}Am and its standard uncertainty from characterisation in IRMM-0243

	Mean [nmol/g (solution)]	u_{char} [nmol/g (solution)]	$u_{char, rel}$ [%]
Amount content of ^{243}Am	5.6960	0.0052	0.091

The uncertainty from characterisation of the amount content of ^{243}Am is dominated by the uncertainties associated with the half-life of ^{241}Pu and the amount content of the ^{241}Pu spike solution. Relative contributions of various uncertainty components from characterisation are shown in Figure 3.

Figure 3 Uncertainty contributions from characterisation of the amount content of ^{243}Am



6.5 The amount ratios of $n(^{241}Am)/n(^{243}Am)$ and $n(^{242m}Am)/n(^{243}Am)$ and their uncertaities

The Am isotope amount ratios and their standard uncertainties from characterisation are given in Table 5.

Table 5 The $n(^{241}Am)/n(^{243}Am)$ and $n(^{242m}Am)/n(^{243}Am)$ isotope amount ratios and their standard uncertainties from characterisation in IRMM-0243

	Mean [mol/mol]	u_{char} [mol/mol]	$u_{char, rel}$ [%]
$n(^{241}Am)/n(^{243}Am)$	0.136138	0.000027	0.020
$n(^{242m}Am)/n(^{243}Am)$ [1)]	0.00015063	0.00000077	0.51

[1)] See section 6.7

The uncertainty from characterisation of the $n(^{241}Am)/n(^{243}Am)$ and $n(^{242m}Am)/n(^{243}Am)$ isotope amount ratios consists of the standard deviation of the replicate measurements, the variability between selected ampoules, an uncertainty component [18] from the potential bias during the isotope ratio measurement (see Section 6.2) and an uncertainty component from the quality control measurements. In the case of $n(^{242m}Am)/n(^{243}Am)$ amount ratio, an additional source of uncertainty was added to account for the ^{242}Cm impurity in the IRMM-0243 material (see Annex A).

Results from the characterisation measurements for the amount content of ^{243}Am and $n(^{241}Am)/n(^{243}Am)$ and $n(^{242m}Am)/n(^{243}Am)$ amount ratios are shown in Annex E.

6.6 Verification measurements

Independent verification measurement for the amount content of ^{243}Am and ^{241}Am and for the $n(^{241}\text{Am})/n(^{243}\text{Am})$ amount ratios were performed applying radiometric methods at the JRC.G.2 Laboratory for Radionuclide Metrology.

High-resolution alpha particle spectrometry was performed to determine the $A(^{243}\text{Am})/A(^{241}\text{Am})$ activity ratio of the Am reference solution [19, 20, 21]. The alpha source was prepared from the Am CRM solution by electrodeposition on a polished stainless steel disk with an active diameter of 18.6 mm. The measurement was performed using a passivated ion-implanted planar silicon detector (PIPS®, 150 mm^2 active area, Mirion Technologies (MGPI) SA, France). The total activity per unit mass was determined by means of alpha-particle counting at a defined solid angle (DSA) [19, 22]. Gravimetrically quantified drops of americium solution were deposited on 34 mm glass plates and covered with 20 µg/cm^2 VYNS foils to prevent material loss.

Two gamma measurement campaigns were carried out, one in the underground laboratory "HADES" [23] and one above ground in the radionuclide metrology laboratory at JRC-Geel. Point-like sources for gamma measurements were prepared gravimetrically by drop deposition on laminated plastic foils with a diameter of 34 mm. They were measured above ground using two coaxial HPGe gamma-ray spectrometers, one of 35 % and the other of 90 % relative efficiency (Mirion Technologies (MGPI) SA, France). One gamma source was selected for ultra-low-level gamma-ray spectrometry measurements (ULGS) in HADES laboratory using the Ge-8 detector. The Ge-8 is a HPGe detector of type Broad Energy Germanium Detector (BEGe) with a relative efficiency of 20 % (Canberra, U.S.A). The activities of ^{241}Am and ^{243}Am were calculated based on the main gamma-ray peaks of the nuclides, i.e. the 59.54 keV line for ^{241}Am and the 74.66 keV line for ^{243}Am, respectively [23, 24, 25].

The measurement results from the three independent methods confirmed the certified values of the ^{243}Am and ^{241}Am amount contents and $n(^{241}\text{Am})/n(^{243}\text{Am})$ amount ratio within measurement uncertainties. Measurement uncertainties were estimated according to GUM [3] and mean values calculated by means of the power-moderated mean formalism [26]. The results of the verification measurements are shown in Annex F.

6.7 Inter-laboratory comparison

The IRMM-0243 certification project provided a unique opportunity for the measurement community to assess the current state of practice for americium measurements. To this end, the ^{243}Am inter-laboratory comparison (ILC) was organised by CEA/CETAMA. This ILC also constitutes an efficient external control of the reference values certified by the JRC-Geel and consolidates the characterisation measurement data.

An ampoule of IRMM-0243 material with undisclosed values was distributed to the participants. The laboratories were asked to measure the amount content of ^{241}Am, ^{243}Am and total Am and the $n(^{241}\text{Am})/n(^{243}\text{Am})$ and $n(^{242\text{m}}\text{Am})/n(^{243}\text{Am})$ isotope amount ratios using their analytical procedures. A detailed ILC report will be published in due time.

In this certification report, we compared the certified values (x_{CRM}) with the weighted mean (x_{ILC}) of the participants using the compatibility equation [27] below:

$$\boldsymbol{compatibility} = \frac{|X_{ILC} - X_{CRM}|}{\sqrt{u_{ILC}^2 + u_{CRM}^2}} \qquad \text{Equation 7}$$

X_{ILC} weighted mean of the participant results (ILC)

X_{CRM} certified value

u_{ILC} standard uncertainty of the weighted mean (ILC)

u_{CRM} standard uncertainty of the certified value

The results of the compatibility evaluation are shown in Table 6.

Table 6 Results of the compatibility evaluation

Measurand	Compatibility
Amount content of ^{243}Am	0.3
Amount content of ^{241}Am	0.1
Amount content of Am	0.3
$n(^{241}\text{Am})/n(^{243}\text{Am})$	0.8
$n(^{242m}\text{Am})/n(^{243}\text{Am})$	9.4

It can be concluded from Table 6 that there is a good agreement between the certified values and the weighted mean values of the participants` results (compatibility ≤ 2 at a 95 % CI) [27] for all the measurands, except for the $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio. For the $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio, a lower value (0.0001373 ± 0.0000024) was obtained from the participants (ILC) compared to the characterised value by TIMS (0.0001506 ± 0.0000015, see Section 6.5). Additional measurements of the procedural blank at JRC-Geel showed several hundred cps at masses 238, 239 and 242. This may explain the higher value of the $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio. It is very likely that these interferences come from reagents and resins used in the chemical purification since they were not observed in the ion source (TIMS) or on the rhenium filaments. The $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio could not be corrected quantitatively for this effect and, therefore, only an indicative value based on the ILC results has been assigned to the $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio (see Section 7.2).

The results of the CEA/CETAMA ^{243}Am ILC provided a valuable external verification for IRMM-0243 and underpinned confidence in the certified values.

7. Value Assignment

Certified values were assigned.

Certified values are values that fulfil the highest standards of accuracy. Certified values for IRMM-0243 were assigned on the basis of IDMS and TIMS and verified by independent measurement methods. Full uncertainty budgets in accordance with the GUM [3] were established.

7.1 Certified values and their uncertainties

The certified value for each parameter was assigned as the unweighted mean of the nine individual values from characterisation (Annex E).

The uncertainty of the assigned values consists of uncertainties related to characterisation, u_{char} (Section 6), potential between-ampoule inhomogeneity, u_{bb} (Section 4), and potential degradation during transport, u_{sts} and long-term storage, u_{lts} (Section 5). As described in Section 5 no additional uncertainty from stability (short- and long-term) was applied. These different contributions were combined to estimate the expanded, uncertainty of the certified value (U_{CRM}) with a coverage factor k as:

$$U_{CRM} = k \cdot \sqrt{u_{char}^2 + u_{bb}^2}$$ Equation 8

- u_{char} was estimated as described in Section 6
- u_{bb} was estimated as described in Section 4.

Because of sufficient degrees of freedom of the different uncertainty contributions**,** a coverage factor *k* of 2, corresponding to a level of confidence of about 95 %, was applied to obtain the expanded uncertainties for all certified properties. The certified values and their uncertainties are summarised in Table 7 and Table 8.

Table 7 Certified amount content of ^{243}Am and its uncertainty in IRMM-0243

IRMM-0243	Certified value [1)] [nmol/g (solution)]	$u_{char, rel}$ [%]	$u_{bb, rel}$ [%]	$U_{CRM, rel}$ [2)] [%]	U_{CRM} [2)] [nmol/g (solution)]
Amount content of ^{243}Am	5.696	0.091	0.029	0.19	0.011

1) The reference date for the certified value is January 1, 2017.

2) Expanded (*k* = 2) uncertainty

Table 8 Certified isotope amount ratio of $n(^{241}Am)/n(^{243}Am)$ and its uncertainty in IRMM-0243

IRMM-0243	Certified value [1)] [mol/mol]	$u_{char, rel}$ [%]	$U_{CRM, rel}$ [%]	U_{CRM} [2)] [mol/mol]
$n(^{241}Am)/n(^{243}Am)$	0.136138	0.020	0.040	0.000054

1) The reference date for the certified values is January 1, 2017.

2) Expanded (*k* = 2) uncertainty

The values for the amount contents of ^{241}Am and total Am, the mass fractions of ^{241}Am, ^{243}Am and total Am, the isotope amount and mass fractions (isotopic composition) and the molar mass of Am in IRMM-0243 were calculated by using the certified values of the amount content of ^{243}Am, the $n(^{241}Am)/n(^{243}Am)$ isotope amount ratio and the isotope atomic masses (Table 10). These derived certified values were calculated from the certified values from the characterisation study applying a well understood mathematical model. They are summarised in Table 9.

Table 9 Derived certified amount contents, mass fractions, isotope mass and amount fractions, molar mass and their uncertainties

IRMM-0243		Certified value [1) 3)]	Uncertainty [2)]
Amount contents [nmol/g (solution)]	^{241}Am	0.7754	0.0015
	Am	6.472	0.012
Mass fractions [μg/g (solution)]	^{241}Am	0.18692	0.00036
	^{243}Am	1.3845	0.0026
	Am	1.5716	0.0030
Am isotope amount fractions (·100) [mol/mol]	$n(^{241}\text{Am})/n(\text{Am})$	11.9810	0.0042
	$n(^{243}\text{Am})/n(\text{Am})$	88.0069	0.0042
Am isotope mass fractions (·100) [g/g]	$m(^{241}\text{Am})/m(\text{Am})$	11.8940	0.0042
	$m(^{243}\text{Am})/m(\text{Am})$	88.0940	0.0042
Molar mass of Am [g/mol]	$M(\text{Am})$	242.821094	0.000085

1) The reference date for the certified values is January 1, 2017.

2) Expanded (k = 2) uncertainty

3) The derived certified values

Table 10 Atomic masses of Am isotopes used for calculation of the derived values [28]

Isotope	Atomic mass [g/mol]	Uncertainty (k =1) [g/mol]
^{241}Am	241.0568293	0.0000019
^{242m}Am	242.0595494	0.0000019
^{243}Am	243.0613813	0.0000024

7.2 Indicative values and their uncertainties

The indicative value for the $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio and its uncertainty was assigned based on the ^{243}Am ILC organised by CEA/CETAMA using IRMM-0243 as the test sample. The assigned value is the DerSimonian-Laird weighted mean [29] of the results from nine participating laboratories (Annex G). The indicative values for the $m(^{242m}\text{Am})/m(\text{Am})$ mass and $n(^{242m}\text{Am})/n(\text{Am})$ amount fractions were calculated using the indicative value of $n(^{242m}\text{Am})/n(^{243}\text{Am})$ isotope amount ratio and the certified values. The indicative values and their uncertainties are summarised in Table 11.

Table 11 Indicative values and their uncertainties in IRMM-0243

IRMM-0243		Indicative value 1)	Uncertainty 2)
Isotope amount ratios [mol/mol]	$n(^{242m}Am)/n(^{243}Am)$	0.0001373	0.0000024
Isotope amount fractions (·100) [mol/mol]	$n(^{242m}Am)/n(Am)$ 3)	0.01208	0.00021
Isotope mass fractions (·100) [g/g]	$m(^{242m}Am)/m(Am)$ 3)	0.01205	0.00021

1) The reference date for the indicative values is January 1, 2017.

2) Expanded (k = 2) uncertainty

3) The derived indicative values

8. Metrological traceability and commutability

8.1 Metrological traceability

Identity

The measurands are structurally defined and independent of the measurement method.

Quantity value

The certified values are traceable to the SI via the values on the respective certificates of IRMM-049d and IRMM-0290b-A3 and via the half-life of ^{241}Pu [8]. The masses obtained by substitution weighing are traceable to the SI through the use of calibrated balances and reference weights.

8.2 Commutability

Many measurement procedures include one or more steps, which are selecting specific analytes (or specific groups of analytes) from the sample for the subsequent steps of the whole measurement process. Often the complete identity of these 'intermediate analytes' is not fully known or taken into account. Therefore, it is difficult to mimic all the analytically relevant properties of real samples within a CRM. The degree of equivalence in the analytical behaviour of real samples and a CRM with respect to various measurement procedures (methods) is summarised in a concept called 'commutability of a reference material'. There are various definitions expressing this concept. For instance, the CLSI Guideline C-53A [30] recommends the use of the following definition for the term *commutability*:

> "*The equivalence of the mathematical relationships among the results of different measurement procedures for an RM and for representative samples of the type intended to be measured.*"

The commutability of a CRM defines its fitness for use and, thus, is a crucial characteristic in case of the application of different measurement methods. When commutability of a CRM is not established in such cases, the results from routinely used methods cannot be legitimately compared with the certified value to determine whether a bias does not exist in calibration, nor can the CRM be used as a calibrant.

This reference material is a tailor-made ^{243}Am spike CRM to be applied for quantification of americium content in various nuclear samples by IDMS. The analytical behaviour of the IRMM-0243 will be the same as for a routine sample.

9. Instructions for use

9.1 Safety information

The IRMM-0243 contains radioactive material. The ampoules should be handled with great care and by trained and experienced personnel in a laboratory suitably equipped for the safe handling of radioactive materials.

9.2 Storage conditions

The vials should be stored at + 18 °C ± 5 °C.

Please note that the European Commission cannot be held responsible for changes that happen during storage of the material at the customer's premises, especially for opened ampoules.

9.3 Preparation and use of the material

This material is ready for use after ampoule opening. Users are cautioned that once the ampoule is opened, the amount content of americium may be affected (e.g. by evaporation)

9.4 Minimum sample intake

The IRMM-0243 material is a true solution and, therefore no minimum sample intake needs to be taken into account for analysis.

9.5 Use of the certified value

The main purpose of the material is for use as a spike isotopic reference material for determination of the americium content in an unknown sample by isotope dilution through a measurement of the isotope amount ratio $R_b = n(^{241}\text{Am})/n(^{243}\text{Am})$ in a blend.

The amount content (C_x) of americium can be calculated with the aid of the following equation, which enables an easy quantification of the uncertainty sources in the procedure:

$$C_x = C_y \cdot \frac{m_y}{m_x} \cdot \frac{R_y - R_b}{R_b - R_x} \cdot \frac{\Sigma(R_i)_x}{\Sigma(R_i)_y}$$ Equation 8

C_y	element amount content of the spike material
m_x	mass of unknown sample used in the measurement
m_y	mass of the spike solution in the measurement
R_x	amount ratio $n(^{241}\text{Am})/n(^{243}\text{Am}$ in the unknown sample
R_y	amount ratio $n(^{241}\text{Am})/n(^{243}\text{Am})$ in the spike material
R_b	amount ratio $n(^{241}\text{Am})/n(^{243}\text{Am})$ in the blend
$\Sigma(R_i)_x$	sum of all isotope amount ratios in the unknown sample
$\Sigma(R_i)_y$	sum of all isotope amount ratios in the spike material

10. Conclusions

A novel ^{243}Am spike reference material IRMM-0243 was prepared and certified for the amount content of ^{243}Am and the $n(^{241}$Am$)/n(^{243}$Am$)$ isotope amount ratio. The material was produced in compliance with international guidelines. Certified values for the amount content of ^{243}Am and the $n(^{241}$Am$)/n(^{243}$Am$)$ isotope amount ratios were established by IDMS and TIMS and confirmed by independent verification measurements. The indicative value for the $n(^{242m}$Am$)/n(^{243}$Am$)$ isotope amount ratio and its uncertainty were derived from the ^{243}Am inter-laboratory comparison (ILC) organised by CEA/CETAMA using IRMM-0243 as the test sample. The material is supplied in a glass ampule with a screw-cap containing about 3.5 mL of dilute nitric acid solution with an americium mass fraction of about 1.5 μg/g. This material is for use as a spike isotopic reference material for determination of americium content by IDMS in unknown samples.

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List of abbreviations and definitions

ANOVA	Analysis of variance
c	amount of substance concentration
CEA	Le Commissariat a l`energie atomique et aux energies alternatives, la Direction de l'énergie nucléaire (Alternative Energies and Atomic Energy Commission)
CET	Central European Time
CETAMA	Commission d'Etablissement des Methodes d'Analyse
CI	Confidence interval
CLSI	Clinical and Laboratory Standards Institute
cps	Counts per second
CRM	Certified reference material
DSA	Defined solid angle
EC	European Commission
ESARDA	European Safeguards Research and Development Association
GUM	Guide to the Expression of Uncertainty in Measurement
IAEA	International Atomic Energy Agency
ICP-MS	Inductively coupled plasma mass spectrometry
IDMS	Isotope dilution mass spectrometry
ISO	International Organization for Standardization
ITWG	The Nuclear Forensics International Technical Working Group
JRC	Joint Research Centre of the European Commission
k	Coverage factor
λ	Decay constant
m	mass
M	Molar mass
MS_{between}	Mean of squares between-unit from an ANOVA
MS_{within}	Mean of squares within-unit from an ANOVA
n	amount of substance
p.a.	pro analysis
PIPS	passivated implanted planar silicon
PVC	Polyvinyl chloride
R_b	Isotope amount ratio in the blend
R_x	Isotope amount ratio in the un-spiked sample
R_y	Isotope amount ratio in the spike
rel	Index denoting relative figures (uncertainties etc.)
RM	Reference material

s	Standard deviation
s_{bb}	Between-unit standard deviation; an additional index "rel" is added when appropriate
SI	International System of Units
s_{wb}	Within-unit standard deviation
$T_{1/2}$	Half life
TE	Total evaporation
TIMS	Thermal Ionisation Mass Spectrometry
u	Standard uncertainty
U	Expanded uncertainty
u^{*}_{bb}	Standard uncertainty related to a maximum between-unit inhomogeneity that could be hidden by method repeatability; an additional index "rel" is added as appropriate
u_{bb}	Standard uncertainty related to a possible between-unit inhomogeneity; an additional index "rel" is added as appropriate
u_{char}	Standard uncertainty of the material characterisation; an additional index "rel" is added as appropriate
u_{CRM}	Combined standard uncertainty of the certified value; an additional index "rel" is added as appropriate
U_{CRM}	Expanded uncertainty of the certified value; an additional index "rel" is added as appropriate
u_{lts}	Standard uncertainty of the long-term stability; an additional index "rel" is added as appropriate
u_{sts}	Standard uncertainty of the short-term stability; an additional index "rel" is added as appropriate
ULGS	Ultra-low-level gamma-ray spectrometry
VYNS	polyvinylchloride- polyvinyl acetate copolymer
$\bar{y}$	Arithmetic mean
$\nu_{MSwithin}$	Degrees of freedom of MS_{within}
WGDA	Working Group on Techniques and Standards for Destructive Analysis

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Annexes

Annex A Results of the impurity analysis of the americium original starting solution

Table A1 Mass concentration of elemental impurities in the americium solution after purification measured by ICP-AES (date of analysis: April 24, 2015). The mass concentrations of the major impurities before purification are shown in parentheses.

Element	Mass concentration [mg/L]	Element	Mass concentration [mg/L]
Ag	< 10.0	Na	< 10.0
Al	< 10.0 (560)	Nd	< 10.0
Ba	< 10.0	Ni	< 10.0 (995)
Be	< 10.0	P	< 10.0
Ca	< 10.0 (250)	Pb	< 10.0
Cd	< 10.0	Pr	< 10.0
Ce	< 10.0	S	< 10.0 (30)
Co	< 10.0 (1750)	Sb	< 10.0
Cr	< 10.0	Si	< 10.0
Cu	< 10.0	Sm	< 10.0
Eu	< 10.0	Sn	< 10.0
Fe	< 10.0 (3665)	Sr	< 10.0
Gd	< 10.0	Ti	< 10.0
K	< 10.0	U	< 10.0
La	< 10.0	W	< 10.0
Mg	< 10.0	Y	< 10.0
Mn	< 10.0	Zn	< 10.0
Mo	< 10.0 (61)	Zr	< 10.0

Table A2 Activity concentration of americium and curium isotopes in the americium starting solution after purification measured by alpha spectrometry (date of analysis: April 28, 2015)

Isotope	Activity concentration [Bq/L]	Relative Uncertainty [k = 2]
^{241}Am	$1.3 \cdot 10^{10}$	± 10%
^{243}Am	$5.9 \cdot 10^{9}$	± 10%
^{242}Cm	$3.1 \cdot 10^{7}$	± 20%
^{244}Cm	$7.3 \cdot 10^{6}$	± 30%

Annex B Results of the homogeneity measurements for IRMM-0243

Table B1 Results for the amount content of ^{243}Am as a function of the analytical sequence. Data are normalised to January 1, 2017.

Unit	Sequence	^{243}Am amount content [nmol/g]	Unit	Sequence	^{243}Am amount content [nmol/g]
165	1	5.6900	564	36	5.6995
465	2	5.7028	134	37	5.6999
165	3	5.6940	345	38	5.6991
465	4	5.6931	134	39	5.6995
165	5	5.6939	345	40	5.6991
465	6	5.6903	134	41	5.6959
165	7	5.6912	345	42	5.6980
465	8	5.6929	134	43	5.6978
83	9	5.6946	345	44	5.6977
83	10	5.6939	194	45	5.6953
83	11	5.6957	194	46	5.6975
83	12	5.6906	194	47	5.6953
373	13	5.6965	194	48	5.6959
517	14	5.6950	194	49	5.6973
373	15	5.6938	284	50	5.6958
517	16	5.6963	508	51	5.6934
373	17	5.6978	284	52	5.6970
517	18	5.6938	508	53	5.6945
373	19	5.6952	284	54	5.6964
517	20	5.6980	508	55	5.6943
11	21	5.6965	284	56	5.6941
309	22	5.6960	508	57	5.6955
11	23	5.6968	284	58	5.6958
309	24	5.6970	508	59	5.6950
11	25	5.6977	222	60	5.7000
309	26	5.7029	497	61	5.6978
11	27	5.6966	222	62	5.6973
309	28	5.6952	497	63	5.6995
54	29	5.6986	222	64	5.7004
564	30	5.6953	497	65	5.7002
54	31	5.6980	222	66	5.7003
564	32	5.6976	497	67	5.6970
54	33	5.6981	222	68	5.6967
564	34	5.7005	497	69	5.6921
54	35	5.6972			

Figure B2 The amount content of ^{243}Am from homogeneity study. Replicates are shown as a function of the analytical sequence.

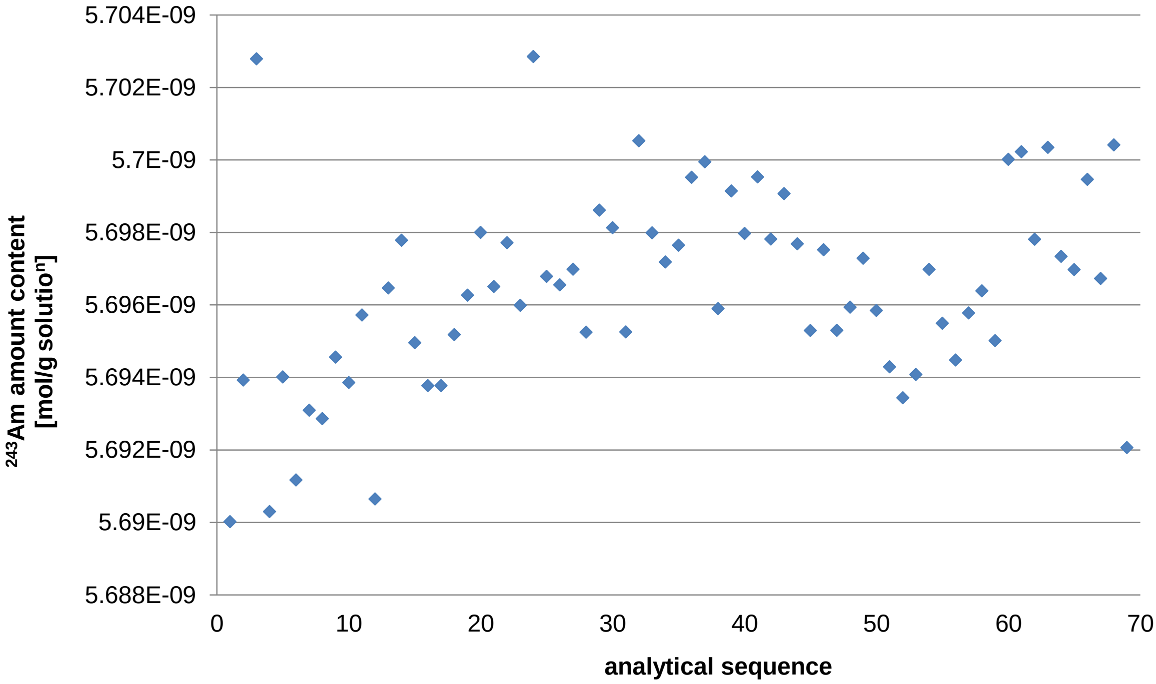


Figure B3 The amount content of ^{243}Am after trend-correction from homogeneity study. Replicates are shown as a function of the analytical sequence.

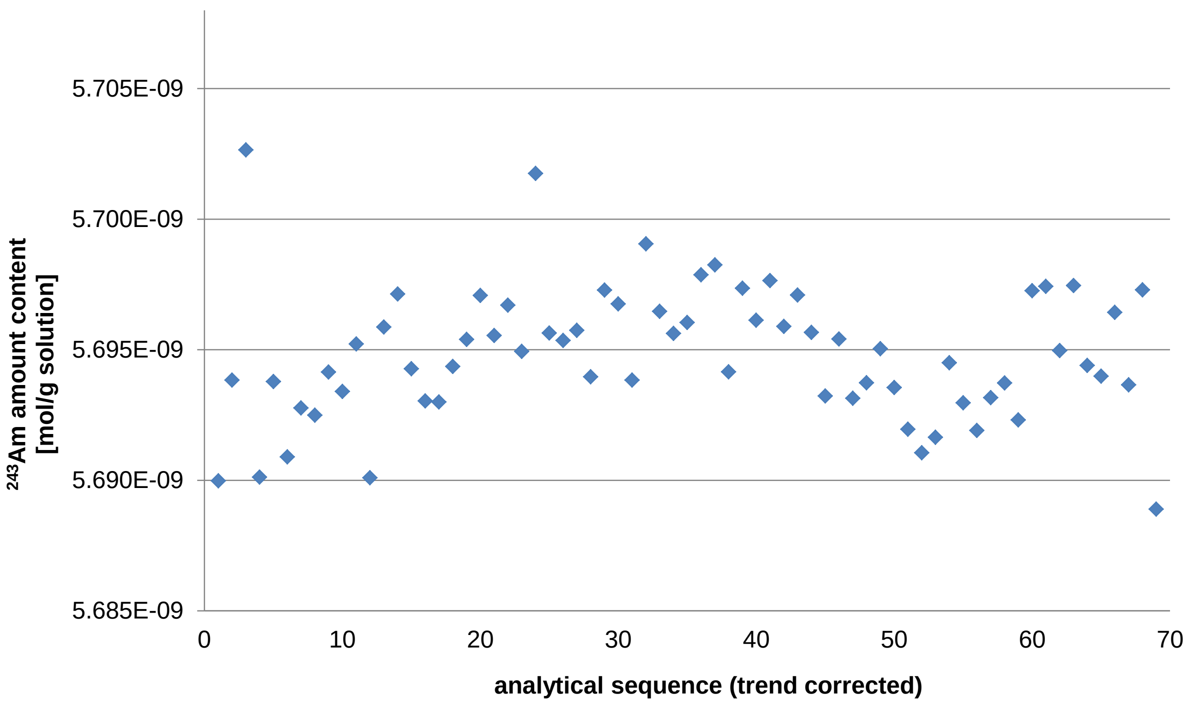
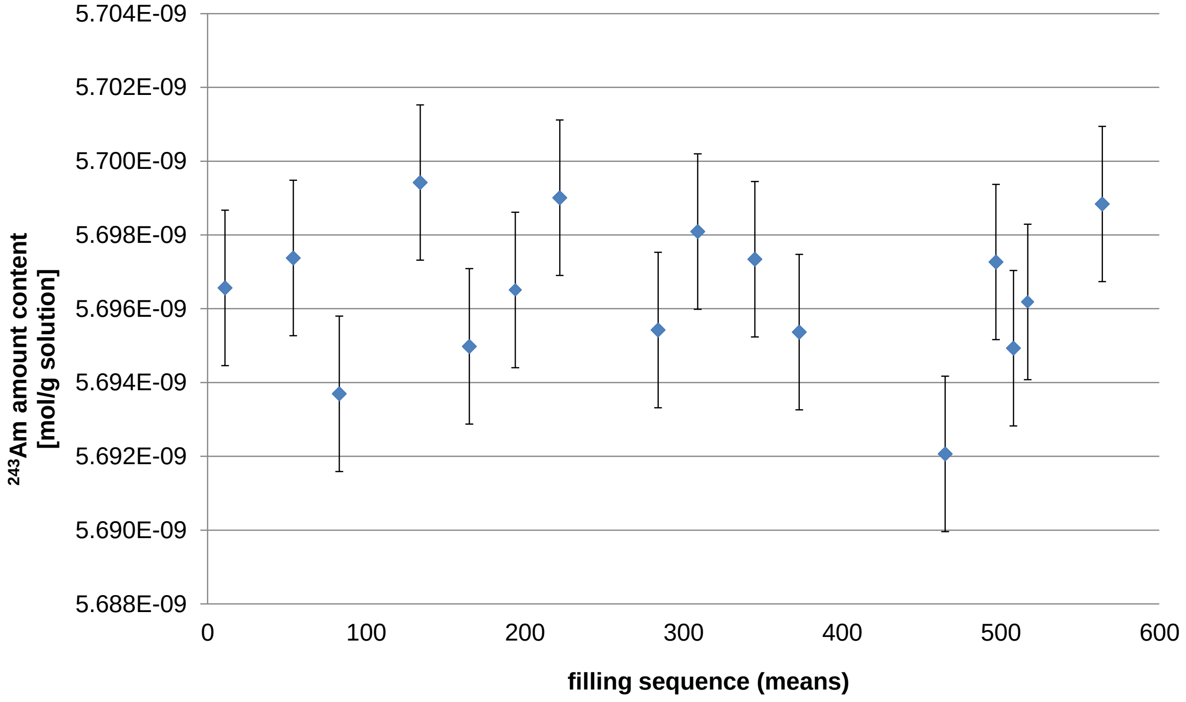
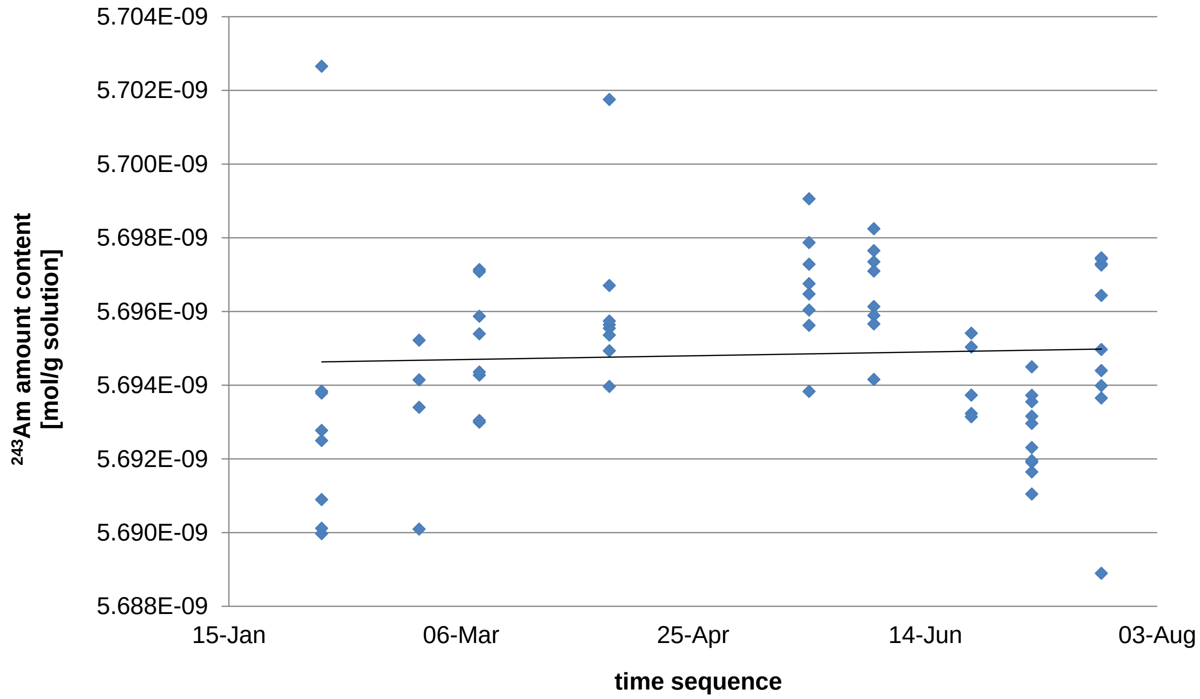


Figure B4 Mean amount contents of ^{243}Am from homogeneity study as a function of the units (filling sequence). The unit means are plotted with 95 % CI of the means.



Annex C Results of the stability measurements for the IRMM-0243

Figure C1 The amount content of ^{243}Am from stability study (trend-corrected) as a function of the time.



Annex D Uncertainty budget for the calculation of the amount content of ^{243}Am.

Am-243 amount content with Am-241 spike by IDMS

Author: Jakopic

adapted simplified equation spike ^{241}Am, sample ^{243}Am, ratio ^{243}Am/^{241}Am for IDMS equation

IDMS blends and isotopic abundance (IA) aliquots from the same selected ampoule measured on the same sample turret

^{241}Am spike amount content calculated from the ingrowth from ^{241}Pu purified solution

The completness of separation (removal) of ^{241}Am from ^{241}Pu in the spike solution was confimed by high resolution gamma-ray spectrometry. The residual amount of ^{241}Am in the ^{241}Pu spike solution after purification (June 10, 2014) was found negligable.

weighing certificate E3871 set A: ampoules IDMS/IA: 165, 465 set B: ampoules IDMS/IA: 240, 83 set C: ampoules IDMS/IA: 373, 517 set D: ampoules IDMS/IA: 11, 309 evaporation factors (due to evaporation of the ^{241}Pu purified solution): K_1, K_2, K_3 (ampoules 165, 465, 240, 83, 373, 517, 11 and 309).

weighing certificate E3873 set E: ampoules IDMS/IA: 54, 564 set F: ampoules IDMS/IA: 134, 345 set G: ampoules IDMS/IA: 194, 437 set H: ampoules IDMS/IA: 284, 508 set I: ampoules IDMS/IA: 222, 497 evaporation factors: K_1, K_2, K_3, K_4 (ampoules 54, 564, 134, 345, 194, 437). Evaporation factors: K_1, K_2, K_3, K_4, K_5 (ampoules 284, 508, 222, 497)

Reference date for certification: 1 January 2017 (individual results from the respective IDMS sets A-I are normalised to 1 January 2017)

Evaporation of the Pu-241 spike solution (under weight control) for the ingrowth of Am-241 is taken into account

Due to technical reasons ampoules 240 and 437 were discarded.

Additional uncertinaty contribution was added for ^{241}Am/^{243}Am ratio of the blend and unspiked aliquos in IDMS calculation (0.05%, k = 2 spaning 3 amu, according to ASTM standard) as there was no Am isotopic standard available to correct for mass fractionation during TIMS measurement

It was assumed that the Am behaves similar to U and Pu during the TE TIMS measurement. Therefore, an additional uncertainty of 0.02 % (k = 2) for 3 mass units was added (from U and Pu QC charts) to account for th elack of an Am isotopic standard.

The impurity analysis of the Am mother solution after purification by TRU (carried out by CEA) showed the presence of ^{242}Cm and ^{244}Cm isotopes. These two isotopes were not removed by purification on UTEVA and DGA prior to TIMS measurement. Therefore the ratio ^{242m}Am/^{243}Am measured by TIMS includes isobaric ^{242}Cm. Alpha spectrometry performed on the aliquot of IRMM-0243 solutions confirmed this. The level of ^{242}Cm impurity in the Am fraction was about 0.2 % (ICP-AES by CEA and alpha spectrometry at JRC Geel gave the same value) and was be added as an additional uncertainty component to the overall uncertinaty of the ^{242m}Am/^{243}Am ratio.

Uncertainty on the time difference is set to 12 h!

uncertainty of the time for ^{241}Am ingrowth = 0.65 days (90% *12 h + 10%*48 h (average TIME between UTEVA 1 and UTEVA 2). It is assumed 90 % of Pu and Am is separated with UTEVA 1 and 10 % with UTEVA 2. This is a conservative estimation, in fact according to the literature more than 99 % separation is achieved with UTEVA 1!

Uncertainty from the homogeneity assessement (softCRM, ANOVA) was added to the ^{243}Am amount content.

The mean values are calculated as the average of 9 ampoules: 165, 83, 373, 11, 564, 345, 194, 284, 497 (from each set A-I one unit)

Model Equation:

{---simplified IDMS equation---}

$f_{c241Am}(m_x, m_y, R_b,$

$c_{241Am},R_y,R_x)=c_{241Am}*m_y/m_x*(R_y-R_b*K_{ASTM}*K_{QC})/(R_b*K_{ASTM}*K_{QC}-R_x*K_{ASTM}*K_{QC})*(R_x*K_{ASTM}*K_{QC});$

{--set A--}

$c_{243Am165}=f_{c241Am}(m_{x1},m_{y1},R_{b1},c_{241Am1},R_{y1},R_{x1})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_A)*1/(K_1*K_2*K_3);$

$c_{243Am456}=f_{c241Am}(m_{x2},m_{y2},R_{b2},c_{241Am1},R_{y2},R_{x2})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_A)*1/(K_1*K_2*K_3);$

$c_{241Am1}=\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_A)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_A))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{ATIMS});$

{--set B--}

$c_{243Am83}=f_{c241Am}(m_{x4},m_{y4},R_{b4},c_{241Am2},R_{y4},R_{x4})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_B)*1/(K_1*K_2*K_3);$

$c_{241Am2}=\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_B)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_B))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{BTIMS});$

{--set C--}

$c_{243Am373}=f_{c241Am}(m_{x5},m_{y5},R_{b5},c_{241Am3},R_{y5},R_{x5})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_C)*1/(K_1*K_2*K_3);$

$c_{243Am517}=f_{c241Am}(m_{x6},m_{y6},R_{b6},c_{241Am3},R_{y6},R_{x6})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_C)*1/(K_1*K_2*K_3);$

$c_{241Am3}=\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_C)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_C))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{CTIMS});$

{--set D--}

$c_{243Am11}=f_{c241Am}(m_{x7},m_{y7},R_{b7},c_{241Am4},R_{y7},R_{x7})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_D)*1/(K_1*K_2*K_3);$

$c_{243Am309}=f_{c241Am}(m_{x8},m_{y8},R_{b8},c_{241Am4},R_{y8},R_{x8})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_D)*1/(K_1*K_2*K_3);$

$c_{241Am4}=\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_D)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_D))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{DTIMS});$

{--set E--}

$c_{243Am54}=f_{c241Am}(m_{x9},m_{y9},R_{b9},c_{241Am5},R_{y9},R_{x9})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_E)*1/(K_1*K_2*K_3*K_4);$

$c_{243Am564}=f_{c241Am}(m_{x10},m_{y10},R_{b10},c_{241Am5},R_{y10},R_{x10})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_E)*1/(K_1*K_2*K_3*K_4);$

$c_{241Am5}=(\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_E)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_E)))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{ETIMS});$

{--set F--}

$c_{243Am134}=f_{c241Am}(m_{x11},m_{y11},R_{b11},c_{241Am6},R_{y11},R_{x11})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_F)*1/(K_1*K_2*K_3*K_4);$

$c_{243Am345}=f_{c241Am}(m_{x12},m_{y12},R_{b12},c_{241Am6},R_{y12},R_{x12})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_F)*1/(K_1*K_2*K_3*K_4);$

$c_{241Am6}=\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_F)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_F))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{FTIMS});$

{--set G--}

$c_{243Am194}=f_{c241Am}(m_{x13},m_{y13},R_{b13},c_{241Am7},R_{y13},R_{x13})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_G)*1/(K_1*K_2*K_3*K_4);$

$c_{241Am7}=\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_G)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_G))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{GTIMS});$

{--set H--}

$c_{243Am284}=f_{c241Am}(m_{x15},m_{y15},R_{b15},c_{241Am8},R_{y15},R_{x15})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_H)*1/(K_1*K_2*K_3*K_4*K_5);$

$c_{243Am508}=f_{c241Am}(m_{x16},m_{y16},R_{b16},c_{241Am8},R_{y16},R_{x16})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_H)*1/(K_1*K_2*K_3*K_4*K_5);$

$c_{241Am8}=\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_H)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_H))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{HTIMS});$

{--set I--}

$c_{243Am222}=f_{c241Am}(m_{x17},m_{y17},R_{b17},c_{241Am9},R_{y17},R_{x17})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_I)*1/(K_1*K_2*K_3*K_4*K_5);$

$c_{243Am497}=f_{c241Am}(m_{x18},m_{y18},R_{b18},c_{241Am9},R_{y18},R_{x18})*e^\wedge(-\lambda_{243Am}\cdot\Delta T_I)*1/(K_1*K_2*K_3*K_4*K_5);$

$c_{241Am9}=\lambda_{241Pu}/(\lambda_{241Am}-\lambda_{241Pu})*c_{241Pu}*(e^\wedge(-\lambda_{241Pu}\cdot\Delta t_I)-e^\wedge(-\lambda_{241Am}\cdot\Delta t_I))*e^\wedge(-\lambda_{241Am}\cdot\Delta T_{ITIMS});$

{--average amount content calculation--}

$c_{243Amchar}=(c_{243Am165}+c_{243Am83}+c_{243Am373}+c_{243Am11}+c_{243Am564}+c_{243Am345}+c_{243Am194}+c_{243Am284}+c_{243Am497})/9;$

{--certified (assigned) amount content-------------------------------------}

$c_{243Amcert}=c_{243Amchar}+\delta c_{243Ambb} + \delta c_{243Amlts} + \delta c_{243Amsts};$

{------------------------------consistency check--}

$\varepsilon_1 = c_{243Amchar} - c_{243Am165};$

$\varepsilon_2 = c_{243Amchar} - c_{243Am456};$

$\varepsilon_4 = c_{243Amchar} - c_{243Am83};$

$\varepsilon_5 = c_{243Amchar} - c_{243Am373};$

$\varepsilon_6 = c_{243Amchar} - c_{243Am517};$

$\varepsilon_7 = c_{243Amchar} - c_{243Am11};$

$\varepsilon_8 = c_{243Amchar} - c_{243Am309};$

$\varepsilon_9 = c_{243Amchar} - c_{243Am54};$

$\varepsilon_{10} = c_{243Amchar} - c_{243Am564};$

$\varepsilon_{11} = c_{243Amchar} - c_{243Am134};$

$\varepsilon_{12} = c_{243Amchar} - c_{243Am345};$

$\varepsilon_{13} = c_{243Amchar} - c_{243Am194};$

$\varepsilon_{15} = c_{243Amchar} - c_{243Am284};$

$\varepsilon_{16} = c_{243Amchar} - c_{243Am508};$

$\varepsilon_{17} = c_{243Amchar} - c_{243Am222};$

$\varepsilon_{18} = c_{243Amchar} - c_{243Am497};$

$ln_2 = ln(2);$

$\lambda_{243Am}=ln_2/\tau_{243Am};$
$\lambda_{241Am}=ln_2/\tau_{241Am};$
$\lambda_{241Pu}=ln_2/\tau_{241Pu};$

{calculated Am, 242mAm and 241Am amount contents using the certified 243Am amount content and the isotope amount fractions}

$c_{Amcert}=c_{243Amcert}/fdnorm_{243Amcert};$

$c_{241Amcert} = c_{Amcert}*fdnorm_{241Amcert};$

$c_{242mAmILC} = c_{Amcert}*fdnorm_{242mAmILC};$

{calculated Am, 242mAm and 241Am mass fractions using certified the 243Am amount content, the isotope mass fractions and the molar masses}

$\gamma_{243Amcert}=c_{243Amcert}*M_{243Am};$

$\gamma_{241Amcert}=c_{241Amcert}*M_{241Am};$

$\gamma_{242mAmILC}=c_{242mAmILC}*M_{242mAm};$

$\gamma_{Amcert}=c_{Amcert}*Mdnorm_{Amcert};$

{calculated 243Am and 241Am mass fractions from high resolution gamma-ray and alpha counting measurements}

$\gamma_{243Amgamma1}$=M_{243Am}*$A_{243Amgamma1}$*(365.25*24*3600)/(λ_{243Am}*N_a);
$\gamma_{241Amgamma1}$=M_{241Am}*$A_{241Amgamma1}$*(365.25*24*3600)/(λ_{241Am}*N_a);

$\gamma_{243Amgamma2}$=M_{243Am}*$A_{243Amgamma2}$*(365.25*24*3600)/(λ_{243Am}*N_a);
$\gamma_{241Amgamma2}$=M_{241Am}*$A_{241Amgamma2}$*(365.25*24*3600)/(λ_{241Am}*N_a);

$\gamma_{243Amalpha}$=M_{243Am}*$A_{243Amalpha}$*(365.25*24*3600)/(λ_{243Am}*N_a);
$\gamma_{241Amalpha}$=M_{241Am}*$A_{241Amalpha}$*(365.25*24*3600)/(λ_{241Am}*N_a);

List of Quantities:

Quantity	Unit	Definition
$c_{243Amcert}$	mol/g	certified ^{243}Am amount content
$c_{241Amcert}$	mol/g	certified ^{241}Am amount content
$c_{242mAmILC}$	mol/g	indicative ^{242m}Am amount content
c_{Amcert}	mol/g	certified Am amount content
$\gamma_{243Amcert}$	g/g	certified ^{243}Am mass fraction
$\gamma_{241Amcert}$	g/g	certified ^{241}Am mass fraction
$\gamma_{242mAmILC}$	g/g	indicative ^{242m}Am mass fraction (ILC)
γ_{Amcert}	g/g	certified Am mass fraction
$Mdnorm_{Amcert}$	mol/g	certified molar mass of Am
$c_{243Amchar}$	mol/g	mean ^{243}Am amount content from characterisation (9 values)
$c_{243Am165}$	mol/g	^{243}Am amount content in the sample 165
$c_{243Am456}$	mol/g	^{243}Am amount content in the sample 465
$c_{243Am83}$	mol/g	^{243}Am amount conent in the sample 83
$c_{243Am373}$	mol/g	^{243}Am amount content in the sample 373
$c_{243Am517}$	mol/g	^{243}Am amount content in the sample 517
$c_{243Am11}$	mol/g	^{243}Am amount content in the sample 11
$c_{243Am309}$	mol/g	^{243}Am amount content in the sample 309
$c_{243Am54}$	mol/g	^{243}Am amount content in the sample 54
$c_{243Am564}$	mol/g	^{243}Am amount content in the sample 564
$c_{243Am134}$	mol/g	^{243}Am amount content in the sample 134
$c_{243Am345}$	mol/g	^{243}Am amount content in the sample 345
$c_{243Am194}$	mol/g	^{243}Am amount content in the sample 194
$c_{243Am284}$	mol/g	^{243}Am amount content in the sample 284
$c_{243Am508}$	mol/g	^{243}Am amount content in the sample 508
$c_{243Am222}$	mol/g	^{243}Am amount content in the sample 222
$c_{243Am497}$	mol/g	^{243}Am amount content in the sample 497
$\gamma_{243Amgamma1}$	g/g	^{243}Am mass fraction from high resolution gamma-ray spectrometry (above ground)
$\gamma_{241Amgamma1}$	g/g	^{241}Am mass fraction from high resolution gamma-ray spectrometry (above ground)

Quantity	Unit	Definition
$\gamma_{243Amgamma2}$	g/g	^{243}Am mass fraction from high resolution gamma -ray spectrometry (HADES laboratory)
$\gamma_{241Amgamma2}$	g/g	^{241}Am mass fraction from high resolution gamma-ray spectrometry (HADES laboratory)
$\gamma_{241Amalpha}$	g/g	^{243}Am mass fraction from alpha counting
$\gamma_{243Amalpha}$	g/g	^{243}Am mass fraction from alpha counting
m_{x1}	g	mass of sample in blend 165
m_{x2}	g	mass of sample in blend 465
m_{x4}	g	mass of sample in blend 83
m_{x5}	g	mass of sample in blend 373
m_{x6}	g	mass of sample in blend 517
m_{x7}	g	mass of sample in blend 11
m_{x8}	g	mass of sample in blend 309
m_{x9}	g	mass of sample in blend 54
m_{x10}	g	mass of sample in blend 564
m_{x11}	g	mass of sample in blend 134
m_{x12}	g	mass of sample in blend 345
m_{x13}	g	mass of sample in blend 194
m_{x15}	g	mass of sample in blend 284
m_{x16}	g	mass of sample in blend 508
m_{x17}	g	mass of sample in blend 222
m_{x18}	g	mass of sample in blend 497
m_{y1}	g	mass of spike in blend 165
m_{y2}	g	mass of spike in blend 465
m_{y4}	g	mass of spike in blend 83
m_{y5}	g	mass of spike in blend 373
m_{y6}	g	mass of spike in blend 517
m_{y7}	g	mass of spike in blend 11
m_{y8}	g	mass of spike in blend 309
m_{y9}	g	mass of spike in blend 54
m_{y10}	g	mass of spike in blend 564
m_{y11}	g	mass of spike in blend 134
m_{y12}	g	mass of spike in blend 345
m_{y13}	g	mass of spike in blend 194
m_{y15}	g	mass of spike in blend 284
m_{y16}	g	mass of spike in blend 508
m_{y17}	g	mass of spike in blend 222
m_{y18}	g	mass of spike in blend 497
R_{b1}	mol/mol	measured ratio (^{243}Am/^{241}Am) of blend 165

Quantity	Unit	Definition
R_{b2}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 465
R_{b4}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 83
R_{b5}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 373
R_{b6}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 517
R_{b7}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 11
R_{b8}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 309
R_{b9}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 54
R_{b10}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 564
R_{b11}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 134
R_{b12}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 345
R_{b13}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 194
R_{b15}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 284
R_{b16}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 508
R_{b17}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 222
R_{b18}	mol/mol	measured ratio ($^{243}Am/^{241}Am$) of blend 497
R_{y1}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set A
R_{y2}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set A
R_{y4}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set B
R_{y5}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set C
R_{y6}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set C
R_{y7}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set D
R_{y8}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set D
R_{y9}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set E
R_{y10}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set E
R_{y11}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set F
R_{y12}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set F
R_{y13}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set G
R_{y15}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set H
R_{y16}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set H
R_{y17}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set I
R_{y18}	mol/mol	$^{243}Am/^{241}Am$ amount ratio in spike for set I
R_{x1}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 165
R_{x2}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 465
R_{x4}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 83
R_{x5}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 373
R_{x6}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 517
R_{x7}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 11
R_{x8}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 309

Quantity	Unit	Definition
R_{x9}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 54
R_{x10}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 564
R_{x11}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 134
R_{x12}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 345
R_{x13}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 194
R_{x15}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 284
R_{x16}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 508
R_{x17}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 222
R_{x18}	mol/mol	measured $^{243}Am/^{241}Am$ amount ratio in sample 497
e		
Δt_A	a	time for ingrowth of ^{241}Am for set A
Δt_B	a	time for ingrowth of ^{241}Am for set B
Δt_C	a	time for ingrowth of ^{241}Am for set C
Δt_D	a	time for ingrowth of ^{241}Am for set D
Δt_E	a	time for ingrowth of ^{241}Am for set E
Δt_F	a	time for ingrowth of ^{241}Am for set F
Δt_G	a	time for ingrowth of ^{241}Am for set G
Δt_H	a	time for ingrowth of ^{241}Am for set H
Δt_I	a	time for ingrowth of ^{241}Am for set I
ε_1	mol/g	consistency check
ε_2	mol/g	consistency check
ε_4	mol/g	consistency check
ε_5	mol/g	consistency check
ε_6	mol/g	consistency check
ε_7	mol/g	consistency check
ε_8	mol/g	consistency check
ε_9	mol/g	consistency check
ε_{10}	mol/g	consistency check
ε_{11}	mol/g	consistency check
ε_{12}	mol/g	consistency check
ε_{13}	mol/g	consistency check
ε_{15}	mol/g	consistency check
ε_{16}	mol/g	consistency check
ε_{17}	mol/g	consistency check
ε_{18}	mol/g	consistency check
ln_2		
K_1		evaporation factor
K_2		evaporation factor

Quantity	Unit	Definition
K_3		evaporation factor
K_4		evaporation factor
K_5		evaporation factor
c_{241Pu}	mol/g	^{241}Pu amount content in the purified ^{241}Pu solution on June 10, 2014 (time zero)
ΔT_A	a	time difference between IDMS set A and reference date (1 Jan 2017)
ΔT_B	a	time difference between IDMS set B and reference date (1 Jan 2017)
ΔT_C	a	time difference between IDMS set C and reference date (1 Jan 2017)
ΔT_D	a	time difference between IDMS set D and reference date (1 Jan 2017)
ΔT_E	a	time difference between IDMS set E and reference date (1 Jan 2017)
ΔT_F	a	time difference between IDMS set F and reference date (1 Jan 2017)
ΔT_G	a	time difference between IDMS set G and reference date (1 Jan 2017)
ΔT_H	a	time difference between IDMS set H and reference date (1 Jan 2017)
ΔT_I	a	time difference between IDMS set I and reference date (1 Jan 2017)
c_{241Am1}	mol/g	^{241}Am spike ingrown amount content for set A
c_{241Am2}	mol/g	^{241}Am spike ingrown amount content for set B
c_{241Am3}	mol/g	^{241}Am spike ingrown amount content for set C
c_{241Am4}	mol/g	^{241}Am spike ingrown amount content for set D
c_{241Am5}	mol/g	^{241}Am spike ingrown amount content for set E
c_{241Am6}	mol/g	^{241}Am spike ingrown amount content for set F
c_{241Am7}	mol/g	^{241}Am spike ingrown amount content for set G
c_{241Am8}	mol/g	^{241}Am spike ingrown amount content for set H
c_{241Am9}	mol/g	^{241}Am spike ingrown amount content for set I
ΔT_{ATIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set A
ΔT_{BTIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set B
ΔT_{CTIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set C
ΔT_{DTIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set D
ΔT_{ETIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set E
ΔT_{FTIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set F
ΔT_{GTIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set G
ΔT_{HTIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set H
ΔT_{ITIMS}	a	time difference between ^{241}Am ingrowth and IDMS measurement for set I
τ_{241Am}	a	half life of ^{241}Am

Quantity	Unit	Definition
τ_{243Am}	a	half life of ^{243}Am
τ_{241Pu}	a	half life of ^{241}Pu
λ_{241Pu}	a^{-1}	decay constant ^{241}Pu
λ_{241Am}	a^{-1}	decay constant ^{241}Am
λ_{243Am}	a^{-1}	decay constant ^{243}Am
$fdnorm_{243Amcert}$	mol/mol	certified ^{243}Am amount fraction
$fdnorm_{241Amcert}$	mol/mol	certified ^{241}Am amount fraction
$fdnorm_{242mAmILC}$	mol/mol	indicative ^{242m}Am amount fraction (ILC)
M_{243Am}	mol/g	molar mass of ^{243}Am
M_{241Am}	mol/g	molar mass of ^{241}Am
M_{242mAm}	mol/g	molar mass of ^{242m}Am
N_a	mol^{-1}	avogadro constant
$A_{243Amgamma1}$	Bq/Bq	activity measurement ^{243}Am by gamma spectrometry (above ground)
$A_{241Amgamma1}$	Bq/Bq	activity measurement ^{241}Am by gamma spectrometry (above ground)
$A_{241Amgamma2}$	Bq/Bq	activity measurement ^{241}Am by gamma spectrometry (HADES)
$A_{243Amgamma2}$	Bq/Bq	activity measurement ^{243}Am by gamma spectrometry (HADES)
$A_{243Amalpha}$	Bq/Bq	activity measurement ^{243}Am by alpha spectrometry
$A_{241Amalpha}$	Bq/Bq	activity measurement ^{241}Am by alpha spectrometry
K_{ASTM}	mol/mol	additional uncertainty component for ^{243}Am/^{241}Am ratio measurement according to ASTM standard (no standard available for TE mass bias correction)
$\delta c_{243Amlts}$	mol/g	error term due to the long-term intsability from stability study
$\delta c_{243Amsts}$	mol/g	error term due to the short-term intsability from stability study
$\delta c_{243Ambb}$	mol/g	error term due to the between-unit variation from homogeneity assessemnt
K_{QC}	mol/mol	additional uncertainty component for ^{243}Am/^{241}Am ratio measurement from U and Pu QC charts (no standard available for TE mass bias correction)

$Mdnorm_{Amcert}$: Import
Filename: ..\Am amount ratios\Am isotope amount ratios by TIMS.smu
Symbol: $Mdnorm_{Amcert}$

m_{x1}: Type B normal distribution
Value: 2.54434 g
Expanded Uncertainty: 0.00010 g
Coverage Factor: 2

E3871 weighing certificate

m_{x2}: Type B normal distribution
Value: 2.67332 g
Expanded Uncertainty: 0.00029 g
Coverage Factor: 2

E3871 weighing certificate

m_{x4}: Type B normal distribution
Value: 2.66642 g
Expanded Uncertainty: 0.00011 g
Coverage Factor: 2

E3871 weighing certificate

m_{x5}: Type B normal distribution
Value: 2.70530 g
Expanded Uncertainty: 0.00010 g
Coverage Factor: 2

E3871 weighing certificate

m_{x6}: Type B normal distribution
Value: 2.68092 g
Expanded Uncertainty: 0.00011 g
Coverage Factor: 2

E3871 weighing certificate

m_{x7}: Type B normal distribution
Value: 2.68865 g
Expanded Uncertainty: 0.00011 g
Coverage Factor: 2

E3871 weighing certificate

m_{x8}: Type B normal distribution
Value: 2.70294 g
Expanded Uncertainty: 0.00009 g
Coverage Factor: 2

E3871 weighing certificate

m_{x9}: Type B normal distribution
Value: 2.69368 g
Expanded Uncertainty: 0.00009 g
Coverage Factor: 2

E3873 weighing certificate

m_{x10}: Type B normal distribution
Value: 2.70174 g
Expanded Uncertainty: 0.00011 g
Coverage Factor: 2

E3873 weighing certificate

m_{x11}: Type B normal distribution
Value: 2.69410 g
Expanded Uncertainty: 0.00011 g
Coverage Factor: 2

E3873 weighing certificate

m_{x12}: Type B normal distribution
Value: 2.70371 g
Expanded Uncertainty: 0.00012 g
Coverage Factor: 2

E3873 weighing certificate

m_{x13}: Type B normal distribution
Value: 2.68537 g
Expanded Uncertainty: 0.00010 g
Coverage Factor: 2

E3873 weighing certificate

m_{x15}: Type B normal distribution
Value: 2.68993 g
Expanded Uncertainty: 0.00009 g
Coverage Factor: 2

E3873 weighing certificate

m_{x16}: Type B normal distribution
Value: 2.72778 g
Expanded Uncertainty: 0.00009 g
Coverage Factor: 2

E3873 weighing certificate

m_{x17}: Type B normal distribution
Value: 2.75064 g
Expanded Uncertainty: 0.00012 g
Coverage Factor: 2

E3873 weighing certificate

m_{x18}: Type B normal distribution
Value: 2.99959 g
Expanded Uncertainty: 0.00009 g
Coverage Factor: 2

E3873 weighing certificate

m_{y1}: Type B normal distribution
Value: 0.99222 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3871 weighing certificate

m_{y2}: Type B normal distribution
Value: 1.00713 g
Expanded Uncertainty: 0.00009 g
Coverage Factor: 2

E3871 weighing certificate

m_{y4}: Type B normal distribution
Value: 0.99805 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3871 weighing certificate

m_{y5}: Type B normal distribution
Value: 0.99975 g
Expanded Uncertainty: 0.00009 g
Coverage Factor: 2

E3871 weighing certificate

m_{y6}: Type B normal distribution
Value: 1.02458 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3871 weighing certificate

m_{y7}: Type B normal distribution
Value: 1.00827 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3871 weighing certificate

m_{y8}: Type B normal distribution
Value: 1.01395 g
Expanded Uncertainty: 0.00010 g
Coverage Factor: 2

E3871 weighing certificate

m_{y9}: Type B normal distribution
Value: 1.00165 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3873 weighing certificate

m_{y10}: Type B normal distribution
Value: 1.09047 g
Expanded Uncertainty: 0.00010 g
Coverage Factor: 2

E3873 weighing certificate

m_{y11}: Type B normal distribution
Value: 1.01220 g
Expanded Uncertainty: 0.00013 g
Coverage Factor: 2

E3873 weighing certificate

m_{y12}: Type B normal distribution
Value: 1.05167 g
Expanded Uncertainty: 0.00011 g
Coverage Factor: 2

E3873 weighing certificate

m_{y13}: Type B normal distribution
Value: 1.02945 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3873 weighing certificate

m_{y15}: Type B normal distribution
Value: 1.00438 g
Expanded Uncertainty: 0.00010 g
Coverage Factor: 2

E3873 weighing certificate

m_{y16}: Type B normal distribution
Value: 1.00332 g
Expanded Uncertainty: 0.00010 g
Coverage Factor: 2

E3873 weighing certificate

m_{y17}: Type B normal distribution
Value: 1.00590 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3873 weighing certificate

m_{y18}: Type B normal distribution
Value: 0.99681 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3873 weighing certificate

R_{b1}: Type B normal distribution
Value: 1.7813 mol/mol
Expanded Uncertainty: 0.0013 mol/mol
Coverage Factor: 2

internal report 3448-1

R_{b2}: Type B normal distribution
Value: 1.82739 mol/mol
Expanded Uncertainty: 0.00039 mol/mol
Coverage Factor: 2

internal report 3448-1

R_{b4}: Type B normal distribution
Value: 1.79365 mol/mol
Expanded Uncertainty: 0.00052 mol/mol
Coverage Factor: 2

internal report 3448-2

R_{b5}: Type B normal distribution
Value: 1.78638 mol/mol
Expanded Uncertainty: 0.00030 mol/mol
Coverage Factor: 2

internal report 3448-3

R_{b6}: Type B normal distribution
Value: 1.74157 mol/mol
Expanded Uncertainty: 0.00048 mol/mol
Coverage Factor: 2

internal report 3448-3

R_{b7}: Type B normal distribution
Value: 1.71172 mol/mol
Expanded Uncertainty: 0.00010 mol/mol
Coverage Factor: 2

internal report 3448-4

R_{b8}: Type B normal distribution
Value: 1.71177 mol/mol
Expanded Uncertainty: 0.00077 mol/mol
Coverage Factor: 2

internal report 3448-4

R_{b9}: Type B normal distribution
Value: 1.64570 mol/mol
Expanded Uncertainty: 0.00033 mol/mol
Coverage Factor: 2

internal report 3553-1

R_{b10}: Type B normal distribution
Value: 1.54375 mol/mol
Expanded Uncertainty: 0.00032 mol/mol
Coverage Factor: 2

internal report 3553-1

R_{b11}: Type B normal distribution
Value: 1.610977 mol/mol
Expanded Uncertainty: 0.000089 mol/mol
Coverage Factor: 2

internal report 3553-2

R_{b12}: Type B normal distribution
Value: 1.56733 mol/mol
Expanded Uncertainty: 0.00021 mol/mol
Coverage Factor: 2

internal report 3553-2

R_{b13}: Type B normal distribution
Value: 1.54773 mol/mol
Expanded Uncertainty: 0.00021 mol/mol
Coverage Factor: 2

internal report 3553-3

R_{b15}: Type B normal distribution
Value: 1.55925 mol/mol
Expanded Uncertainty: 0.00028 mol/mol
Coverage Factor: 2

internal report 3553-4

R_{b16}: Type B normal distribution
Value: 1.57787 mol/mol
Expanded Uncertainty: 0.00014 mol/mol
Coverage Factor: 2

internal report 3553-4

R_{b17}: Type B normal distribution
Value: 1.56394 mol/mol
Expanded Uncertainty: 0.00026 mol/mol
Coverage Factor: 2

internal report 3553-5

R_{b18}: Type B normal distribution
Value: 1.68474 mol/mol
Expanded Uncertainty: 0.00069 mol/mol
Coverage Factor: 2

internal report 3553-5

R_{y1}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y2}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y4}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y5}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y6}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y7}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y8}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y9}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y10}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y11}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y12}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y13}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y15}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y16}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y17}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{y18}: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

R_{x1}: Type B normal distribution
Value: 7.3393 mol/mol
Expanded Uncertainty: 0.0018 mol/mol
Coverage Factor: 2

internal report 3448-1

R_{x2}: Type B normal distribution
Value: 7.3359 mol/mol
Expanded Uncertainty: 0.0034 mol/mol
Coverage Factor: 2

internal report 3448-1

R_{x4}: Type B normal distribution
Value: 7.3354 mol/mol
Expanded Uncertainty: 0.0025 mol/mol
Coverage Factor: 2

internal report 3448-2

R_{x5}: Type B normal distribution
Value: 7.3358 mol/mol
Expanded Uncertainty: 0.0015 mol/mol
Coverage Factor: 2

internal report 3448-3

R_{x6}: Type B normal distribution
Value: 7.3357 mol/mol
Expanded Uncertainty: 0.0018 mol/mol
Coverage Factor: 2

internal report 3448-3

R_{x7}: Type B normal distribution
Value: 7.3340 mol/mol
Expanded Uncertainty: 0.0012 mol/mol
Coverage Factor: 2

internal report 3448-4

R_{x8}: Type B normal distribution
Value: 7.3360 mol/mol
Expanded Uncertainty: 0.0015 mol/mol
Coverage Factor: 2

internal report 3448-4

R_{x9}: Type B normal distribution
Value: 7.33975 mol/mol
Expanded Uncertainty: 0.00092 mol/mol
Coverage Factor: 2

internal report 3553-1

R_{x10}: Type B normal distribution
Value: 7.34015 mol/mol
Expanded Uncertainty: 0.00057 mol/mol
Coverage Factor: 2

internal report 3553-1

R_{x11}: Type B normal distribution
Value: 7.3410 mol/mol
Expanded Uncertainty: 0.0012 mol/mol
Coverage Factor: 2

internal report 3553-2 (same as 345), vial 134 for IA was discarded

R_{x12}: Type B normal distribution
Value: 7.3410 mol/mol
Expanded Uncertainty: 0.0012 mol/mol
Coverage Factor: 2

internal report 3553-2

R_{x13}: Type B normal distribution
Value: 7.3391 mol/mol
Expanded Uncertainty: 0.0011 mol/mol
Coverage Factor: 2

internal report 3553-3

R_{x15}: Type B normal distribution
Value: 7.33848 mol/mol
Expanded Uncertainty: 0.00052 mol/mol
Coverage Factor: 2

internal report 3553-4

R_{x16}: Type B normal distribution
Value: 7.34258 mol/mol
Expanded Uncertainty: 0.00088 mol/mol
Coverage Factor: 2

internal report 3553-4

R_{x17}: Type B normal distribution
Value: 7.3370 mol/mol
Expanded Uncertainty: 0.0015 mol/mol
Coverage Factor: 2

internal report 3553-5

R_{x18}: Type B normal distribution
Value: 7.34034 mol/mol
Expanded Uncertainty: 0.00077 mol/mol
Coverage Factor: 2

internal report 3553-5

e: Constant
Value: 2.7182818284590

Δt_A: Type B rectangular distribution
Value: 1.637235 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 29 January 2016

Δt_B: Type B rectangular distribution
Value: 1.691992 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 18 February 2016

Δt_C: Type B rectangular distribution
Value: 1.724846 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 1March 2016

Δt_D: Type B rectangular distribution
Value: 1.801506 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 29 March 2016

Δt_E: Type B rectangular distribution
Value: 1.916496 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 20 May 2016

Δt_F: Type B rectangular distribution
Value: 1.952088 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 3 June 2016

Δt_G: Type B rectangular distribution
Value: 2.015058 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 24 July 2016

Δt_H: Type B rectangular distribution
Value: 2.050650 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 7 July 2016

Δt_I: Type B rectangular distribution
Value: 2.088980 a
Halfwidth of Limits: 0.001780 a

10 June 2014, 22 July 2016

K_1: Import
Filename: ..\..\Processing\Pu-241 inhouse spike characterisation\Determination of the Pu-241 amount content by IDMS using IRMM-049d spike.smu
Symbol: K_{evap1}

K_2: Import
Filename: ..\..\Processing\Pu-241 inhouse spike characterisation\Determination of the Pu-241 amount content by IDMS using IRMM-049d spike.smu
Symbol: K_{evap2}

K_3: Import
Filename: ..\..\Processing\Pu-241 inhouse spike characterisation\Determination of the Pu-241 amount content by IDMS using IRMM-049d spike.smu
Symbol: K_{evap3}

K_4: Import
Filename: ..\..\Processing\Pu-241 inhouse spike characterisation\Determination of the Pu-241 amount content by IDMS using IRMM-049d spike.smu
Symbol: K_{evap4}

K_5: Import
Filename: ..\..\Processing\Pu-241 inhouse spike characterisation\Determination of the Pu-241 amount content by IDMS using IRMM-049d spike.smu
Symbol: K_{evap5}

c_{241Pu}: Import
Filename: ..\..\Processing\Pu-241 inhouse spike characterisation\Determination of the Pu-241 amount content by IDMS using IRMM-049d spike.smu
Symbol: c_{241Pu}

ΔT_A: Type B rectangular distribution
Value: 0.908966 a
Halfwidth of Limits: 0.001369 a

4 February 2016, 1 January 2017

ΔT_B: Type B rectangular distribution
Value: 0.851472 a
Halfwidth of Limits: 0.001369 a

25 February 2016, 1 January 2017

ΔT_C: Type B rectangular distribution
Value: 0.813142 a
Halfwidth of Limits: 0.001369 a

10 March 2016, 1 January 2017

ΔT_D: Type B rectangular distribution
Value: 0.736482 a
Halfwidth of Limits: 0.001369 a

7 April 2016, 1 January 2017

ΔT_E: Type B rectangular distribution
Value: 0.618754 a
Halfwidth of Limits: 0.001369 a

20 May 2016, 1 January 2017

ΔT_F: Type B rectangular distribution
Value: 0.580424 a
Halfwidth of Limits: 0.001369 a

3 June 2016, 1 January 2017

ΔT_G: Type B rectangular distribution
Value: 0.522930 a
Halfwidth of Limits: 0.001369 a

24 June 2016, 1 January 2017

ΔT_H: Type B rectangular distribution
Value: 0.487337 a
Halfwidth of Limits: 0.001369 a

7 July 2016, 1 January 2017

ΔT_I: Type B rectangular distribution
Value: 0.446270 a
Halfwidth of Limits: 0.001369 a

22 July 2016, 1 January 2017

ΔT_{ATIMS}: Type B rectangular distribution
Value: 0.016427 a
Halfwidth of Limits: 0.001369 a

29 January, 4 February 2016 (IDMS)

ΔT_{BTIMS}: Type B rectangular distribution
Value: 0.019165 a
Halfwidth of Limits: 0.001369 a

18 February, 25 February 2016 (IDMS)

ΔT_{CTIMS}: Type B rectangular distribution
Value: 0.024641 a
Halfwidth of Limits: 0.001369 a

1 March, 10 March 2016 (IDMS)

ΔT_{DTIMS}: Type B rectangular distribution
Value: 0.024641 a
Halfwidth of Limits: 0.001369 a

29 March, 7 April 2016 (IDMS)

ΔT_{ETIMS}: Type B rectangular distribution
Value: 0.027379 a
Halfwidth of Limits: 0.001369 a

10 May, 20 May 2016 (IDMS)

ΔT_{FTIMS}: Type B rectangular distribution
Value: 0.030116 a
Halfwidth of Limits: 0.001369 a

23 May, 3 June 2016 (IDMS)

ΔT_{GTIMS}: Type B rectangular distribution
Value: 0.024641 a
Halfwidth of Limits: 0.001369 a

15 June, 24 June 2016 (IDMS)

ΔT_{HTIMS}: Type B rectangular distribution
Value: 0.024641 a
Halfwidth of Limits: 0.001369 a

28 JUne, 7 July 2016 (IDMS)

ΔT_{ITIMS}: Type B rectangular distribution
Value: 0.027379 a
Halfwidth of Limits: 0.001369 a

12 July, 22 July 2016 (IDMS)

τ_{241Am}: Type B normal distribution
Value: 432.6 a
Expanded Uncertainty: 0.6 a
Coverage Factor: 1

http://www.nucleide.org/DDEP$_{WG}$/DDEPdata.htm "last checked on March 20, 2017"

τ_{243Am}: Type B normal distribution
Value: 7367 a
Expanded Uncertainty: 23 a
Coverage Factor: 1

http://www.nucleide.org/DDEP$_{WG}$/DDEPdata.htm "last checked on March 20, 2017"

τ_{241Pu}: Type B normal distribution
Value: 14.325 a
Expanded Uncertainty: 0.024 a
Coverage Factor: 2

R. Wellum, A. Verbruggen, R. Kessel, A new evaluation of the half-life of 241Pu, J. Anal. At. Spectros., 24, 801-807, 2009

$fdnorm_{243Amcert}$: Import
Filename: ..\Am amount ratios\Am isotope amount ratios by TIMS.smu
Symbol: $fdnorm_{243Amcert}$

$fdnorm_{241Amcert}$: Import
Filename: ..\Am amount ratios\Am isotope amount ratios by TIMS.smu
Symbol: $fdnorm_{241Amcert}$

$fdnorm_{242mAmILC}$: Import
Filename: ..\Am amount ratios\Am isotope amount ratios by TIMS.smu
Symbol: $fdnorm_{242mAmILC}$

M_{243Am}: Type B normal distribution
Value: 243.0613813 mol/g
Expanded Uncertainty: 0.0000024 mol/g
Coverage Factor: 1

Wang et al. (The AME 2012 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 36, No. 12, 1603-2014, 2012).

M_{241Am}: Type B normal distribution
Value: 241.0568293 mol/g
Expanded Uncertainty: 0.0000019 mol/g
Coverage Factor: 1

Wang et al. (The AME 2012 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 36, No. 12, 1603-2014, 2012).

M_{242mAm}: Type B normal distribution
Value: 242.0595494 mol/g
Expanded Uncertainty: 0.0000019 mol/g
Coverage Factor: 1

Wang et al. (The AME 2012 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 36, No. 12, 1603-2014, 2012).

N_a: Constant
Value: $6.023 \cdot 10^{23}$ mol^{-1}

$A_{243Amgamma1}$: Type B normal distribution
Value: 10140 Bq/Bq
Expanded Uncertainty: 100 Bq/Bq
Coverage Factor: 1

gamma measurements by Timos, reference 1 Jan 2017

$A_{241Amgamma1}$: Type B normal distribution
Value: 237400 Bq/Bq
Expanded Uncertainty: 130 Bq/Bq
Coverage Factor: 1

gamma measurements by Timos, reference 1 January 2017

$A_{241Amgamma2}$: Type B normal distribution
Value: 23510 Bq/Bq
Expanded Uncertainty: 260 Bq/Bq
Coverage Factor: 1

gamma measurements by Faidra, HADES reference 1 Jan 2017

$A_{243Amgamma2}$: Type B normal distribution
Value: 10100 Bq/Bq
Expanded Uncertainty: 210 Bq/Bq
Coverage Factor: 1

gamma measurements by Faidra, HADES reference 1 Jan 2017

$A_{243Amalpha}$: Type B normal distribution
Value: 10230 Bq/Bq
Expanded Uncertainty: 70 Bq/Bq
Coverage Factor: 1

alpha measurement by Maria, 1 january 2017

$A_{241Amalpha}$: Type B normal distribution
Value: 23720 Bq/Bq
Expanded Uncertainty: 70 Bq/Bq
Coverage Factor: 1

alpha measurement by Maria, 1 january 2017

K_{ASTM}: Type B normal distribution
Value: 1 mol/mol
Expanded Uncertainty: 0.00033 mol/mol
Coverage Factor: 2

0.05 % for spanning 3 mass units (ASTM standard), for 241/243 ratio is then 0.033 % (k = 2)

$\delta c_{243Amlts}$: Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 2

$\delta c_{243Amsts}$: Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 2

$\delta c_{243Ambb}$: Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: $0.001663 \cdot 10^{-9}$ mol/g
Coverage Factor: 1

sbb, rel = 0.0292 % (k = 1, soft CRM), average value from homogeneity study c243Am = 5.696438 nmol/g, sbb = 0.001344 nmol/g

K_{QC}: Type B normal distribution
Value: 1 mol/mol
Expanded Uncertainty: 0.00013 mol/mol
Coverage Factor: 2

additional uncertainty contribution for $^{241}Am/^{243}Am$ ratio from U/Pu QC charts (no Am isotopic standard available) 0.02% for 3 mass units (0.013% for $^{241}Am/^{243}Am$ ratio)

Input Correlation:

	K_1	K_2	K_3	K_4	K_5	c_{241Pu}
K_1	1					0.0368
K_2		1				0.0383
K_3			1			0.0241
K_4				1		0.0242
K_5					1	0.0265
c_{241Pu}	0.0368	0.0383	0.0241	0.0242	0.0265	1

	$Mdnorm_{Amcert}$	$fdnorm_{243Amcert}$	$fdnorm_{241Amcert}$	$fdnorm_{242mAmILC}$
$Mdnorm_{Amcert}$	1	0.9984	-0.9984	-0.0163
$fdnorm_{243Amcert}$	0.9984	1	-0.9987	-0.0414
$fdnorm_{241Amcert}$	-0.9984	-0.9987	1	-0.0087
$fdnorm_{242mAmILC}$	-0.0163	-0.0414	-0.0087	1

Interim Results:

Quantity	Value	Standard Uncertainty
$c_{243Am456}$	$5.69148\cdot10^{-9}$ mol/g	$6.18\cdot10^{-12}$ mol/g
$c_{243Am517}$	$5.69574\cdot10^{-9}$ mol/g	$6.10\cdot10^{-12}$ mol/g
$c_{243Am309}$	$5.69806\cdot10^{-9}$ mol/g	$6.16\cdot10^{-12}$ mol/g
$c_{243Am54}$	$5.69703\cdot10^{-9}$ mol/g	$5.86\cdot10^{-12}$ mol/g
$c_{243Am134}$	$5.69927\cdot10^{-9}$ mol/g	$5.80\cdot10^{-12}$ mol/g
$c_{243Am508}$	$5.69500\cdot10^{-9}$ mol/g	$5.71\cdot10^{-12}$ mol/g
$c_{243Am222}$	$5.69911\cdot10^{-9}$ mol/g	$5.71\cdot10^{-12}$ mol/g
ε_1	$1.59\cdot10^{-12}$ mol/g	$4.03\cdot10^{-12}$ mol/g
ε_2	$4.48\cdot10^{-12}$ mol/g	$3.37\cdot10^{-12}$ mol/g
ε_4	$2.47\cdot10^{-12}$ mol/g	$3.28\cdot10^{-12}$ mol/g
ε_5	$1.04\cdot10^{-12}$ mol/g	$3.13\cdot10^{-12}$ mol/g
ε_6	$220\cdot10^{-15}$ mol/g	$3.25\cdot10^{-12}$ mol/g
ε_7	$-550\cdot10^{-15}$ mol/g	$2.96\cdot10^{-12}$ mol/g
ε_8	$-2.10\cdot10^{-12}$ mol/g	$3.41\cdot10^{-12}$ mol/g
ε_9	$-1.07\cdot10^{-12}$ mol/g	$2.90\cdot10^{-12}$ mol/g
ε_{10}	$-2.55\cdot10^{-12}$ mol/g	$2.88\cdot10^{-12}$ mol/g
ε_{11}	$-3.30\cdot10^{-12}$ mol/g	$2.78\cdot10^{-12}$ mol/g
ε_{12}	$-1.23\cdot10^{-12}$ mol/g	$2.79\cdot10^{-12}$ mol/g
ε_{13}	$140\cdot10^{-15}$ mol/g	$2.71\cdot10^{-12}$ mol/g
ε_{15}	$490\cdot10^{-15}$ mol/g	$2.70\cdot10^{-12}$ mol/g
ε_{16}	$970\cdot10^{-15}$ mol/g	$2.66\cdot10^{-12}$ mol/g
ε_{17}	$-3.14\cdot10^{-12}$ mol/g	$2.67\cdot10^{-12}$ mol/g
ε_{18}	$-1.40\cdot10^{-12}$ mol/g	$2.92\cdot10^{-12}$ mol/g
c_{241Am1}	$6.19091\cdot10^{-9}$ mol/g	$6.55\cdot10^{-12}$ mol/g
c_{241Am2}	$6.38929\cdot10^{-9}$ mol/g	$6.68\cdot10^{-12}$ mol/g
c_{241Am3}	$6.50802\cdot10^{-9}$ mol/g	$6.76\cdot10^{-12}$ mol/g
c_{241Am4}	$6.78442\cdot10^{-9}$ mol/g	$6.94\cdot10^{-12}$ mol/g
c_{241Am5}	$7.19700\cdot10^{-9}$ mol/g	$7.23\cdot10^{-12}$ mol/g
c_{241Am6}	$7.32420\cdot10^{-9}$ mol/g	$7.31\cdot10^{-12}$ mol/g
c_{241Am7}	$7.54881\cdot10^{-9}$ mol/g	$7.47\cdot10^{-12}$ mol/g
c_{241Am8}	$7.67541\cdot10^{-9}$ mol/g	$7.56\cdot10^{-12}$ mol/g
c_{241Am9}	$7.81147\cdot10^{-9}$ mol/g	$7.65\cdot10^{-12}$ mol/g
λ_{241Pu}	0.0483872 a^{-1}	$40.5\cdot10^{-6}$ a^{-1}
λ_{241Am}	$1.60228\cdot10^{-3}$ a^{-1}	$2.22\cdot10^{-6}$ a^{-1}
λ_{243Am}	$94.088\cdot10^{-6}$ a^{-1}	$294\cdot10^{-9}$ a^{-1}

Uncertainty Budgets:

$c_{243Amchar}$: **mean ^{243}Am amount content from characterisation (9 values)**

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
m_{x1}	2.5443400 g	$50.0\cdot10^{-6}$ g	normal	$-250\cdot10^{-12}$	$-12\cdot10^{-15}$ mol/g	0.0 %
m_{x4}	2.6664200 g	$55.0\cdot10^{-6}$ g	normal	$-240\cdot10^{-12}$	$-13\cdot10^{-15}$ mol/g	0.0 %
m_{x5}	2.7053000 g	$50.0\cdot10^{-6}$ g	normal	$-230\cdot10^{-12}$	$-12\cdot10^{-15}$ mol/g	0.0 %
m_{x7}	2.6886500 g	$55.0\cdot10^{-6}$ g	normal	$-240\cdot10^{-12}$	$-13\cdot10^{-15}$ mol/g	0.0 %
m_{x10}	2.7017400 g	$55.0\cdot10^{-6}$ g	normal	$-230\cdot10^{-12}$	$-13\cdot10^{-15}$ mol/g	0.0 %
m_{x12}	2.7037100 g	$60.0\cdot10^{-6}$ g	normal	$-230\cdot10^{-12}$	$-14\cdot10^{-15}$ mol/g	0.0 %
m_{x13}	2.6853700 g	$50.0\cdot10^{-6}$ g	normal	$-240\cdot10^{-12}$	$-12\cdot10^{-15}$ mol/g	0.0 %
m_{x15}	2.6899300 g	$45.0\cdot10^{-6}$ g	normal	$-240\cdot10^{-12}$	$-11\cdot10^{-15}$ mol/g	0.0 %
m_{x18}	2.9995900 g	$45.0\cdot10^{-6}$ g	normal	$-210\cdot10^{-12}$	$-9.5\cdot10^{-15}$ mol/g	0.0 %
m_{y1}	0.9922200 g	$40.0\cdot10^{-6}$ g	normal	$640\cdot10^{-12}$	$26\cdot10^{-15}$ mol/g	0.0 %
m_{y4}	0.9980500 g	$40.0\cdot10^{-6}$ g	normal	$630\cdot10^{-12}$	$25\cdot10^{-15}$ mol/g	0.0 %
m_{y5}	0.9997500 g	$45.0\cdot10^{-6}$ g	normal	$630\cdot10^{-12}$	$28\cdot10^{-15}$ mol/g	0.0 %
m_{y7}	1.0082700 g	$40.0\cdot10^{-6}$ g	normal	$630\cdot10^{-12}$	$25\cdot10^{-15}$ mol/g	0.0 %
m_{y10}	1.0904700 g	$50.0\cdot10^{-6}$ g	normal	$580\cdot10^{-12}$	$29\cdot10^{-15}$ mol/g	0.0 %
m_{y12}	1.0516700 g	$55.0\cdot10^{-6}$ g	normal	$600\cdot10^{-12}$	$33\cdot10^{-15}$ mol/g	0.0 %
m_{y13}	1.0294500 g	$40.0\cdot10^{-6}$ g	normal	$610\cdot10^{-12}$	$25\cdot10^{-15}$ mol/g	0.0 %
m_{y15}	1.0043800 g	$50.0\cdot10^{-6}$ g	normal	$630\cdot10^{-12}$	$32\cdot10^{-15}$ mol/g	0.0 %
m_{y18}	0.9968100 g	$40.0\cdot10^{-6}$ g	normal	$640\cdot10^{-12}$	$25\cdot10^{-15}$ mol/g	0.0 %
R_{b1}	1.781300 mol/mol	$650\cdot10^{-6}$ mol/mol	normal	$470\cdot10^{-12}$	$300\cdot10^{-15}$ mol/g	0.4 %
R_{b4}	1.793650 mol/mol	$260\cdot10^{-6}$ mol/mol	normal	$470\cdot10^{-12}$	$120\cdot10^{-15}$ mol/g	0.0 %
R_{b5}	1.786380 mol/mol	$150\cdot10^{-6}$ mol/mol	normal	$470\cdot10^{-12}$	$70\cdot10^{-15}$ mol/g	0.0 %
R_{b7}	1.7117200 mol/mol	$50.0\cdot10^{-6}$ mol/mol	normal	$480\cdot10^{-12}$	$24\cdot10^{-15}$ mol/g	0.0 %
R_{b10}	1.543750 mol/mol	$160\cdot10^{-6}$ mol/mol	normal	$520\cdot10^{-12}$	$83\cdot10^{-15}$ mol/g	0.0 %
R_{b12}	1.567330 mol/mol	$105\cdot10^{-6}$ mol/mol	normal	$510\cdot10^{-12}$	$54\cdot10^{-15}$ mol/g	0.0 %
R_{b13}	1.547730 mol/mol	$105\cdot10^{-6}$ mol/mol	normal	$520\cdot10^{-12}$	$54\cdot10^{-15}$ mol/g	0.0 %
R_{b15}	1.559250 mol/mol	$140\cdot10^{-6}$ mol/mol	normal	$520\cdot10^{-12}$	$72\cdot10^{-15}$ mol/g	0.0 %
R_{b18}	1.684740 mol/mol	$345\cdot10^{-6}$ mol/mol	normal	$490\cdot10^{-12}$	$170\cdot10^{-15}$ mol/g	0.1 %
R_{y1}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
R_{y4}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
R_{y5}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
R_{y7}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
R_{y10}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
R_{y12}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
R_{y13}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
R_{y15}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
R_{y18}	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
R_{x1}	7.339300 mol/mol	$900 \cdot 10^{-6}$ mol/mol	normal	$-28 \cdot 10^{-12}$	$-25 \cdot 10^{-15}$ mol/g	0.0 %
R_{x4}	7.33540 mol/mol	$1.25 \cdot 10^{-3}$ mol/mol	normal	$-28 \cdot 10^{-12}$	$-35 \cdot 10^{-15}$ mol/g	0.0 %
R_{x5}	7.335800 mol/mol	$750 \cdot 10^{-6}$ mol/mol	normal	$-28 \cdot 10^{-12}$	$-21 \cdot 10^{-15}$ mol/g	0.0 %
R_{x7}	7.334000 mol/mol	$600 \cdot 10^{-6}$ mol/mol	normal	$-26 \cdot 10^{-12}$	$-16 \cdot 10^{-15}$ mol/g	0.0 %
R_{x10}	7.340150 mol/mol	$285 \cdot 10^{-6}$ mol/mol	normal	$-23 \cdot 10^{-12}$	$-6.5 \cdot 10^{-15}$ mol/g	0.0 %
R_{x12}	7.341000 mol/mol	$600 \cdot 10^{-6}$ mol/mol	normal	$-23 \cdot 10^{-12}$	$-14 \cdot 10^{-15}$ mol/g	0.0 %
R_{x13}	7.339100 mol/mol	$550 \cdot 10^{-6}$ mol/mol	normal	$-23 \cdot 10^{-12}$	$-13 \cdot 10^{-15}$ mol/g	0.0 %
R_{x15}	7.338480 mol/mol	$260 \cdot 10^{-6}$ mol/mol	normal	$-23 \cdot 10^{-12}$	$-6.0 \cdot 10^{-15}$ mol/g	0.0 %
R_{x18}	7.340340 mol/mol	$385 \cdot 10^{-6}$ mol/mol	normal	$-26 \cdot 10^{-12}$	$-9.9 \cdot 10^{-15}$ mol/g	0.0 %
e	2.718281828459					
Δt_A	1.63724 a	$1.03 \cdot 10^{-3}$ a	rectangular	$370 \cdot 10^{-12}$	$380 \cdot 10^{-15}$ mol/g	0.5 %
Δt_B	1.69199 a	$1.03 \cdot 10^{-3}$ a	rectangular	$360 \cdot 10^{-12}$	$370 \cdot 10^{-15}$ mol/g	0.5 %
Δt_C	1.72485 a	$1.03 \cdot 10^{-3}$ a	rectangular	$350 \cdot 10^{-12}$	$360 \cdot 10^{-15}$ mol/g	0.5 %
Δt_D	1.80151 a	$1.03 \cdot 10^{-3}$ a	rectangular	$340 \cdot 10^{-12}$	$350 \cdot 10^{-15}$ mol/g	0.4 %
Δt_E	1.91650 a	$1.03 \cdot 10^{-3}$ a	rectangular	$310 \cdot 10^{-12}$	$320 \cdot 10^{-15}$ mol/g	0.4 %
Δt_F	1.95209 a	$1.03 \cdot 10^{-3}$ a	rectangular	$310 \cdot 10^{-12}$	$320 \cdot 10^{-15}$ mol/g	0.4 %
Δt_G	2.01506 a	$1.03 \cdot 10^{-3}$ a	rectangular	$300 \cdot 10^{-12}$	$310 \cdot 10^{-15}$ mol/g	0.4 %
Δt_H	2.05065 a	$1.03 \cdot 10^{-3}$ a	rectangular	$290 \cdot 10^{-12}$	$300 \cdot 10^{-15}$ mol/g	0.3 %
Δt_I	2.08898 a	$1.03 \cdot 10^{-3}$ a	rectangular	$290 \cdot 10^{-12}$	$300 \cdot 10^{-15}$ mol/g	0.3 %
K_1	0.9984064	$12.1 \cdot 10^{-6}$		$-5.7 \cdot 10^{-9}$	$-69 \cdot 10^{-15}$ mol/g	0.0 %
K_2	0.9996192	$12.6 \cdot 10^{-6}$		$-5.7 \cdot 10^{-9}$	$-72 \cdot 10^{-15}$ mol/g	0.0 %
K_3	0.9991598	$13.2 \cdot 10^{-6}$		$-5.7 \cdot 10^{-9}$	$-75 \cdot 10^{-15}$ mol/g	0.0 %
K_4	0.9992664	$13.3 \cdot 10^{-6}$		$-3.2 \cdot 10^{-9}$	$-42 \cdot 10^{-15}$ mol/g	0.0 %
K_5	0.9997767	$14.5 \cdot 10^{-6}$		$-1.3 \cdot 10^{-9}$	$-18 \cdot 10^{-15}$ mol/g	0.0 %

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
c_{241Pu}	$81.3936 \cdot 10^{-9}$ mol/g	$26.7 \cdot 10^{-12}$ mol/g		0.070	$1.9 \cdot 10^{-12}$ mol/g	13.2 %
ΔT_A	0.908966 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_B	0.851472 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_C	0.813142 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_D	0.736482 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_E	0.618754 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_F	0.580424 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_G	0.522930 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_H	0.487337 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_I	0.446270 a	$790 \cdot 10^{-6}$ a	rectangular	$-60 \cdot 10^{-15}$	$-47 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{ATIMS}	0.016427 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{BTIMS}	0.019165 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{CTIMS}	0.024641 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{DTIMS}	0.024641 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{ETIMS}	0.027379 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{FTIMS}	0.030116 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{GTIMS}	0.024641 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{HTIMS}	0.024641 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
ΔT_{ITIMS}	0.027379 a	$790 \cdot 10^{-6}$ a	rectangular	$-1.0 \cdot 10^{-12}$	$-800 \cdot 10^{-18}$ mol/g	0.0 %
τ_{241Am}	432.600 a	0.600 a	normal	$21 \cdot 10^{-15}$	$12 \cdot 10^{-15}$ mol/g	0.0 %
τ_{243Am}	7367.0 a	23.0 a	normal	$48 \cdot 10^{-18}$	$1.1 \cdot 10^{-15}$ mol/g	0.0 %
τ_{241Pu}	14.3250 a	0.0120 a	normal	$-380 \cdot 10^{-12}$	$-4.6 \cdot 10^{-12}$ mol/g	78.5 %
K_{ASTM}	1.000000 mol/mol	$165 \cdot 10^{-6}$ mol/mol	normal	$5.7 \cdot 10^{-9}$	$940 \cdot 10^{-15}$ mol/g	3.3 %
K_{QC}	1.0000000 mol/mol	$65.0 \cdot 10^{-6}$ mol/mol	normal	$5.7 \cdot 10^{-9}$	$370 \cdot 10^{-15}$ mol/g	0.5 %
$c_{243Amchar}$	$5.69597 \cdot 10^{-9}$ mol/g	$5.14 \cdot 10^{-12}$ mol/g				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
$c_{243Amcert}$	$5.696 \cdot 10^{-9}$ mol/g	$11 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{241Amcert}$	$775.4 \cdot 10^{-12}$ mol/g	$1.5 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{242mAmILC}$	$782 \cdot 10^{-15}$ mol/g	$14 \cdot 10^{-15}$ mol/g	2.00	manual
c_{Amcert}	$6.472 \cdot 10^{-9}$ mol/g	$12 \cdot 10^{-12}$ mol/g	2.00	manual
$\gamma_{243Amcert}$	$1.3845 \cdot 10^{-6}$ g/g	$2.6 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{241Amcert}$	$186.92 \cdot 10^{-9}$ g/g	$360 \cdot 10^{-12}$ g/g	2.00	manual
$\gamma_{242mAmILC}$	$189.3 \cdot 10^{-12}$ g/g	$3.3 \cdot 10^{-12}$ g/g	2.00	manual
γ_{Amcert}	$1.5716 \cdot 10^{-6}$ g/g	$3.0 \cdot 10^{-9}$ g/g	2.00	manual
$c_{243Amchar}$	$5.6960 \cdot 10^{-9}$ mol/g	$5.1 \cdot 10^{-12}$ mol/g	1.00	manual
$c_{243Am165}$	$5.694 \cdot 10^{-9}$ mol/g	$13 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{243Am83}$	$5.693 \cdot 10^{-9}$ mol/g	$12 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{243Am373}$	$5.695 \cdot 10^{-9}$ mol/g	$12 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{243Am11}$	$5.697 \cdot 10^{-9}$ mol/g	$12 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{243Am564}$	$5.699 \cdot 10^{-9}$ mol/g	$12 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{243Am345}$	$5.697 \cdot 10^{-9}$ mol/g	$12 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{243Am194}$	$5.696 \cdot 10^{-9}$ mol/g	$12 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{243Am284}$	$5.695 \cdot 10^{-9}$ mol/g	$11 \cdot 10^{-12}$ mol/g	2.00	manual
$c_{243Am497}$	$5.697 \cdot 10^{-9}$ mol/g	$12 \cdot 10^{-12}$ mol/g	2.00	manual
$\gamma_{243Amgamma1}$	$1.372 \cdot 10^{-6}$ g/g	$28 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{241Amgamma1}$	$1.8713 \cdot 10^{-6}$ g/g	$5.6 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{243Amgamma2}$	$1.367 \cdot 10^{-6}$ g/g	$57 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{241Amgamma2}$	$185.3 \cdot 10^{-9}$ g/g	$4.1 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{241Amalpha}$	$187.0 \cdot 10^{-9}$ g/g	$1.2 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{243Amalpha}$	$1.385 \cdot 10^{-6}$ g/g	$21 \cdot 10^{-9}$ g/g	2.00	manual

Annex E Results of the characterisation for IRMM-0243

Table E1 Results for the amount content of ^{243}Am, $n(^{241}\text{Am})/n(^{243}\text{Am})$ and $n(^{241}\text{Am})/n(^{243}\text{Am})$ amount ratios and their expanded uncertainties (coverage factor, k = 2). The reference date is January 1, 2017.

Unit	^{243}Am amount content [10^{-9} mol/g]	$n(^{241}\text{Am})/n(^{243}\text{Am})$ [mol/mol]	$n(^{242m}\text{Am})/n(^{243}\text{Am})$ [mol/mol]
165	5.694 ± 0.013	0.136066 ± 0.000076	0.0001531 ± 0.0000063
83	5.693 ± 0.012	0.136150 ± 0.000083	0.0001516 ± 0.0000046
373	5.695 ± 0.012	0.136152 ± 0.000074	0.0001543 ± 0.0000044
11	5.697 ± 0.012	0.136200 ± 0.000071	0.0001490 ± 0.0000047
564	5.699 ± 0.012	0.136110 ± 0.000069	0.0001487 ± 0.0000038
345	5.697 ± 0.012	0.136102 ± 0.000071	0.0001492 ± 0.0000056
194	5.696 ± 0.011	0.136150 ± 0.000071	0.0001520 ± 0.0000035
284	5.695 ± 0.011	0.136168 ± 0.000069	0.0001497 ± 0.0000038
497	5.697 ± 0.012	0.136141± 0.000069	0.0001482 ± 0.0000034
Mean (GUM)	5.696 ± 0.010	0.136138 ± 0.000051	0.0001506 ± 0.0000015
Rel. U (k = 2)	0.18 %	0.038 %	1.0 %

Figure E1 The amount content of ^{243}Am from the characterisation by IDMS on selected ampoules. 'Error bars' represent the expanded uncertainty (coverage factor, k = 2). The red data point is the mean value.

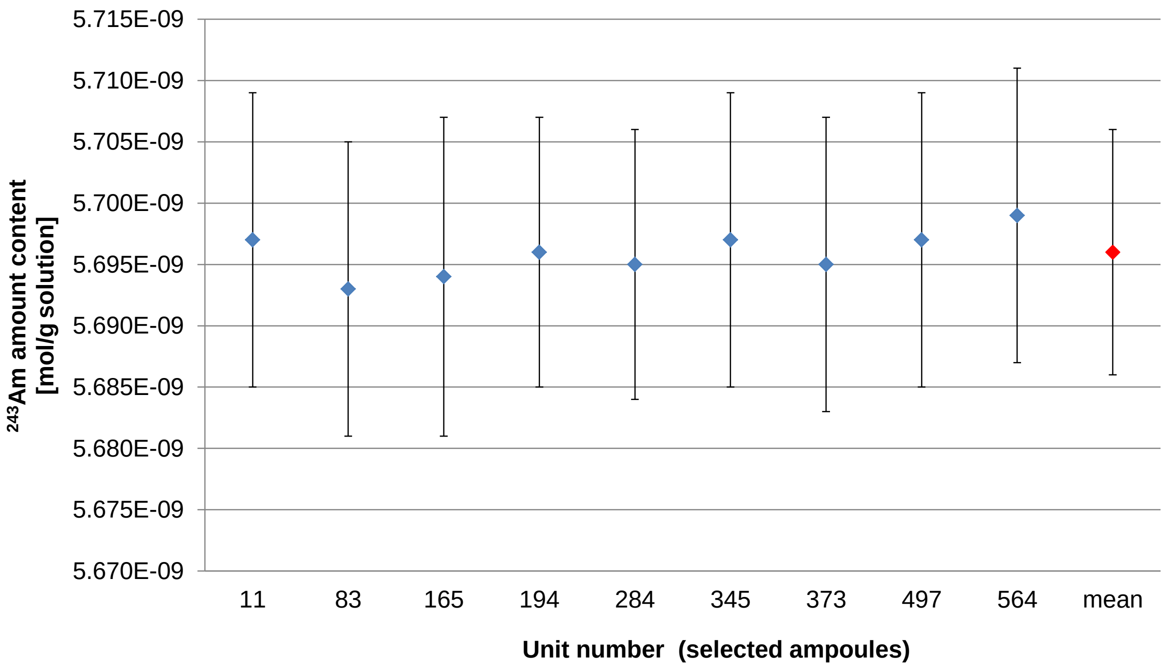


Figure E2 $n(^{241}Am)/n(^{243}Am)$ amount ratio from the characterisation by TIMS on selected ampoules. 'Error bars' represent the expanded uncertainty (coverage factor, k = 2). The red data point is the mean value.

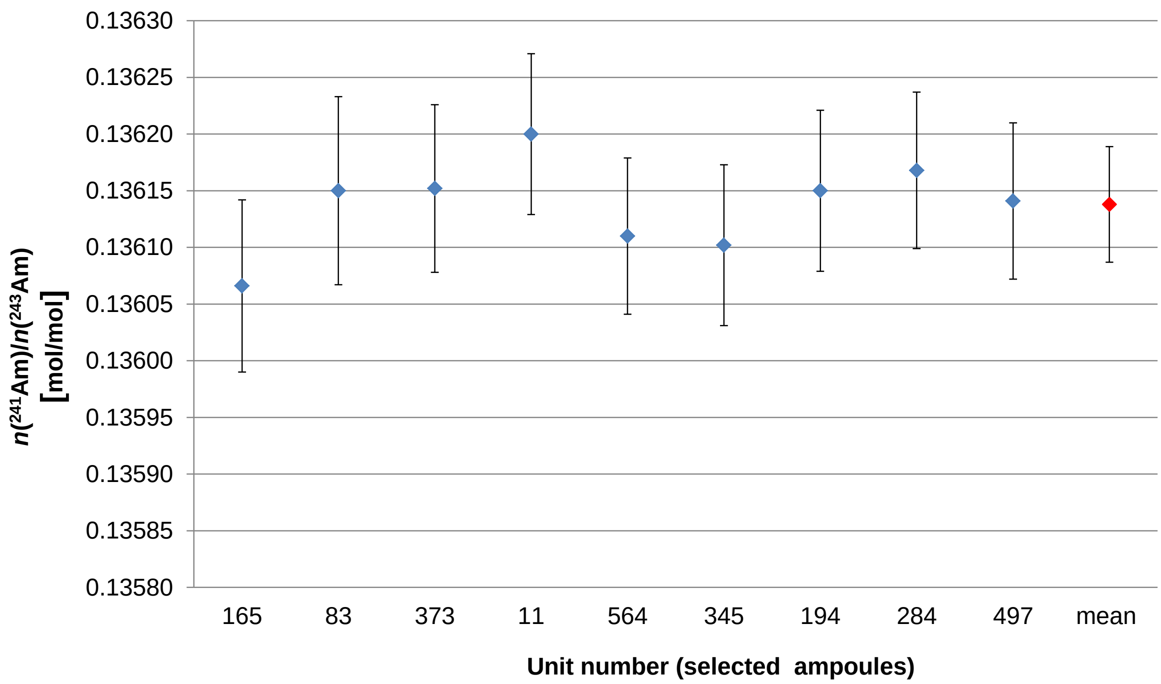
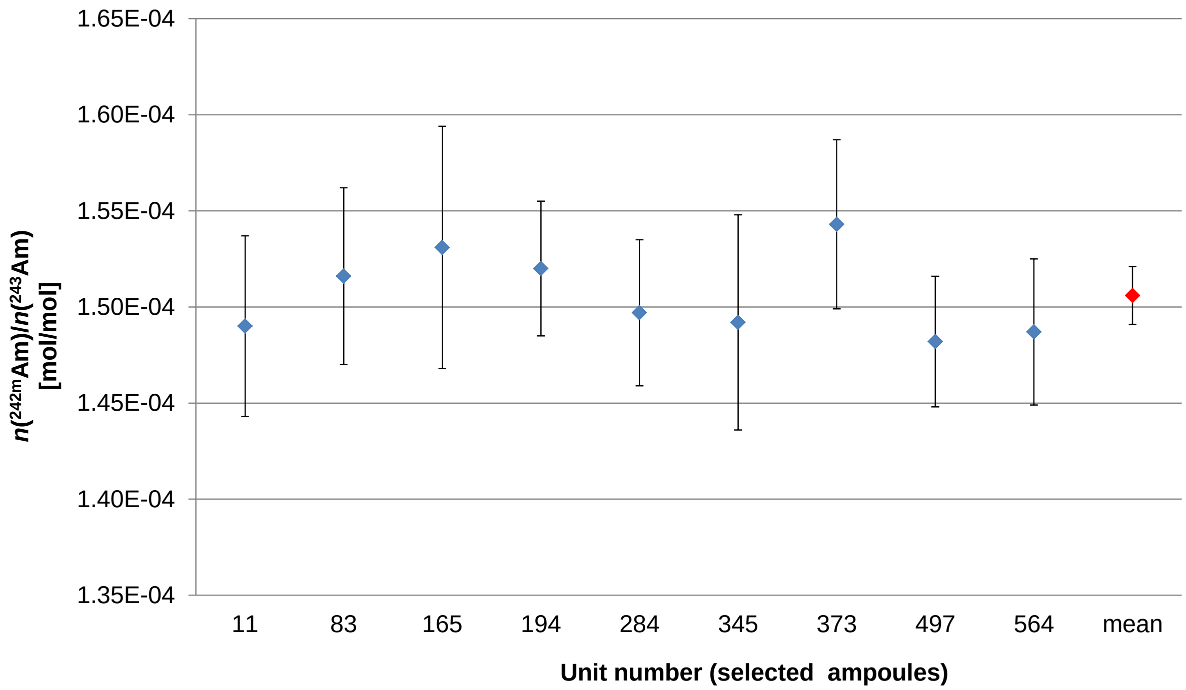
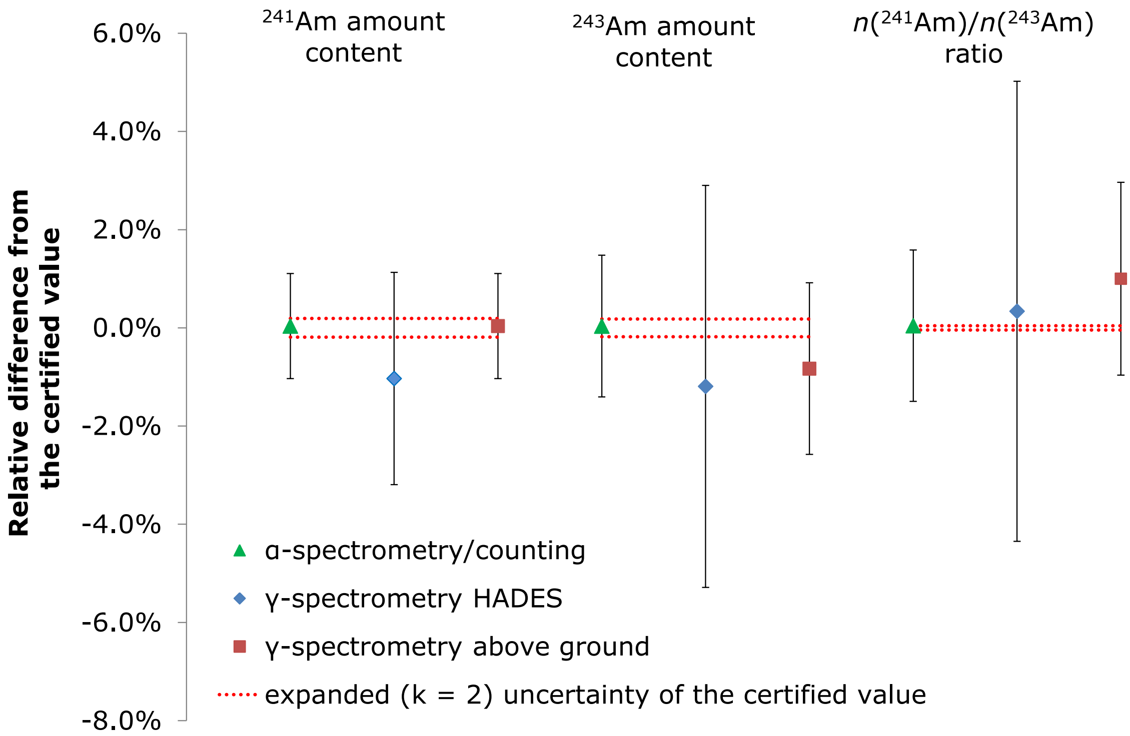


Figure E3 $n(^{242m}Am)/n(^{243}Am)$ amount ratio from the characterisation by TIMS on selected ampoules. 'Error bars' represent the expanded uncertainty (coverage factor, k = 2). The red data point is the mean value from the TIMS analysis but not the indicative value on the IRMM-0243 certificate.



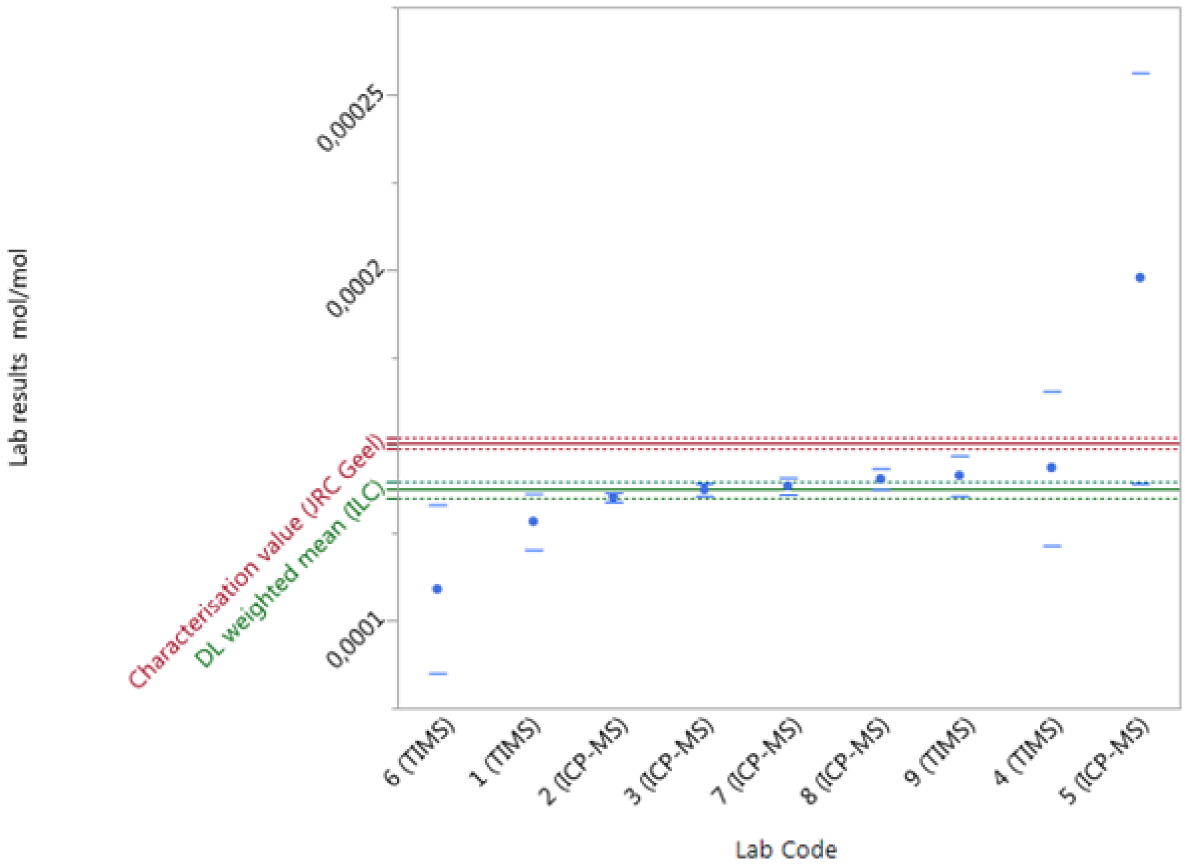
Annex F Results of the radiometric verification measurements for IRMM-0243

Figure F1 Results of the independent alpha-particle (triangles) and gamma-ray (diamonds and squares) measurements for the mass fractions of ^{241}Am and ^{243}Am and $n(^{241}\text{Am})/n(^{243}\text{Am})$ amount ratios expressed as relative differences from the certified value. 'Error bars' show the relative expanded uncertainty (k = 2). Red dotted lines show the relative expanded uncertainty (k = 2) of the respective certified values.



Annex G Results for the $n(^{242m}Am)/n(^{243}Am)$ amount ratio from the ^{243}Am ILC

Figure G1 Results for the $n(^{242m}Am)/n(^{243}Am)$ amount ratios with associated measurement uncertainty from the nine participating laboratories. The green lines show the assigned indicative value (DerSimonian-Laird weighted mean). The red lines show the characterisation value measured by JRC- Geel.



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