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JRC REFERENCE MATERIALS REPORT

CERTIFICATION REPORT

Preparation and Certification of Large-Sized Dried (LSD) Spike – IRMM-1027s

Certified reference material for the masses of ^{239}Pu, ^{235}U, ^{238}U and Pu and U isotope amount ratios

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Abstract

Large-Sized Dried (LSD) spikes are used as a fundamental part of the fissile material control of irradiated nuclear fuel and have been provided on a regular basis to safeguards authorities and industry for more than 10 years. This report describes the preparation and certification of a new batch of LSD spikes. IRMM-1027s is a dried nitrate material in cellulose acetate butyrate (CAB), certified for the mass of uranium and plutonium and the uranium and plutonium isotope amount ratios per unit. The material was produced in compliance with ISO/IEC 17034:2016 [1] and certified in accordance with ISO Guide 35:2006 [2].

The certified reference materials uranium metal EC NRM 101, enriched uranium metal NBL CRM 116-A and plutonium metal CETAMA MP2 were used as starting materials to prepare the mother solution. This solution was dispensed into individual units by means of an automated robot system and dried down. A solution of an organic substance, cellulose acetate butyrate (CAB) was dried on the spike material as a stabiliser to retain the dried material at the bottom of the vial. In total 950 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 certified values for the uranium and plutonium isotope amount ratios were obtained from the gravimetric preparation of the mother solution, taking into account the mass, purity and isotopic composition of the starting materials.

The certified values for the mass of plutonium and uranium per unit were established by isotope dilution thermal ionisation mass spectrometry (ID-TIMS) on randomly selected units. External verification measurements were performed by isotope dilution mass spectrometry (IDMS) and thermal ionisation mass spectrometry (TIMS) on randomly selected units of IRMM-1027s.

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 and to characterisation.

The main purpose of this material is for use as a spike isotopic reference material to measure the plutonium and uranium amount content of spent nuclear fuel solutions using IDMS. Each unit contains about 55 mg of uranium with a relative mass fraction $m(^{235}U)/m(U)$ of 19.0 % and 1.7 mg of plutonium with a relative mass fraction $m(^{239}Pu)/m(Pu)$ of 97.8 % as dried nitrates in CAB.

The whole amount of sample per unit has to be used for analysis.

The following values were assigned:

	Isotope amount ratios	
	Certified value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{234}U)/n(^{238}U)$	0.0027303	0.0000023
$n(^{235}U)/n(^{238}U)$	0.238155	0.000031
$n(^{235}U)/n(^{238}U)$	0.0021905	0.0000018
$n(^{240}Pu)/n(^{239}Pu)$	0.0224154	0.0000051
$n(^{241}Pu)/n(^{239}Pu)$	0.0001478	0.0000019
$n(^{242}Pu)/n(^{239}Pu)$	0.00007572	0.00000078

The certified masses and the uncertainties of ^{235}U, ^{238}U and ^{239}Pu per unit are listed in Annex 1.

[1] The certified values are traceable to the values on the respective metal certificates (Annexes 2-6). The reference date for the certified values is November 1, 2016.

[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.

The atomic masses of radionuclides were obtained from M. Wang et al. [4]

The half-lives of radionuclides were obtained from DDEP-BIPM (Table of radionuclides) [5] and R. Wellum et al. [6].

1. Introduction

1.1 Background

The International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials (ITVs) are uncertainties to be considered in judging the reliability of the measurement results of analytical techniques applied to industrial nuclear and fissile materials, which are subject to safeguards verification. ITVs should be achievable under the conditions normally encountered in typical industrial laboratories or during actual safeguards inspections. In 2010, the International Atomic Energy Agency (IAEA) together with the European Safeguards Research and Development Association (ESARDA), international standardisation organisations and regional safeguards authorities published a revised version of the ITVs [7]. The ITVs-2010 are intended to be used by nuclear plant operators and safeguards organisations as a reference of the quality of measurements necessary for nuclear material accountancy.

The series of IRMM-1027 Large-Sized Dried (LSD) spikes are prepared by the Joint Research Centre of the European Commission (EC-JRC) to meet the existing requirements for reliable isotope reference materials for the accountancy measurements of uranium and plutonium by isotope dilution mass spectrometry (IDMS) in compliance with the ITVs-2010 in spent nuclear fuel. These spikes contain relatively large amounts of uranium and plutonium (55 mg U and 1.7 mg Pu), isotopically different to the uranium and plutonium in the test sample and are in dried nitrate form. Up to 1200 units of IRMM-1027 LSD spikes are prepared annually to fulfil the demands for fissile material control from European Safeguards Authorities and industry [8].

1.2 Choice of the material

The IRMM-1027s batch of LSD spikes was prepared from natural uranium (EC NRM 101), enriched uranium (NBL CRM 116-A) and plutonium (CETAMA MP2) certified reference metals. Each unit of IRMM-1027s contains about 55 mg of uranium with a relative mass fraction $m(^{235}U)/m(U)$ of 19.0 % and 1.7 mg of plutonium with a relative mass fraction $m(^{239}Pu)/m(Pu)$ of 97.8 %. The relative mass fraction $m(^{235}U)/m(U)$ is below 20 %, so that for accountability purposes the uranium is classified as "low enriched".

Individual units are certified for the mass of plutonium and uranium and for the plutonium and uranium isotope amount ratios. The uranium and plutonium amount content in a single IRMM-1027 LSD spike is such that no dilution of a typical sample of dissolved nuclear fuel is needed prior to measurement. As the dried nitrates could flake off the vial surface over time or during transport, an organic polymer in the form of cellulose acetate butyrate (CAB) is added to retain the material at the bottom of the penicillin vial.

1.3 Design of the project

The individual units of IRMM-1027s LSD spikes were prepared by dispensing aliquots (about 2.5 g) of the mother solution into penicillin vials and dried down. The mother solution was prepared gravimetrically by dissolving uranium and plutonium certified reference metals in hydrochloric, hydrofluoric and nitric acid. Finally, the dried nitrates were treated with CAB for preservation during storage and transport. The certified values of the uranium and plutonium isotope amount ratios are based on the data given by the weighing certificates and the certificates of the starting materials. The certified masses of plutonium and uranium, along with the assessment of homogeneity and stability, were established by ID-TIMS on randomly selected vials.

2. Participants

Project management and evaluation, processing, homogeneity study, stability study and characterisation have been performed at the European Commission, Joint Research Centre, Directorate G – Nuclear Safety and Security, G.2 - Standards for Nuclear Safety, Security and Safeguards in Geel, Belgium.

3. Material processing and process control

3.1 Origin and purity of the starting material

CRMs of high purity uranium (EC NRM 101, Geel, Belgium and NBL CRM 116-A, Argonne, USA) and plutonium (CETAMA MP2, Marcoule, France) metals were used as starting materials for the preparation of the IRMM-1027s LSD spikes. The isotopic composition and the purity of the metals are given in Annexes 2 - 6.

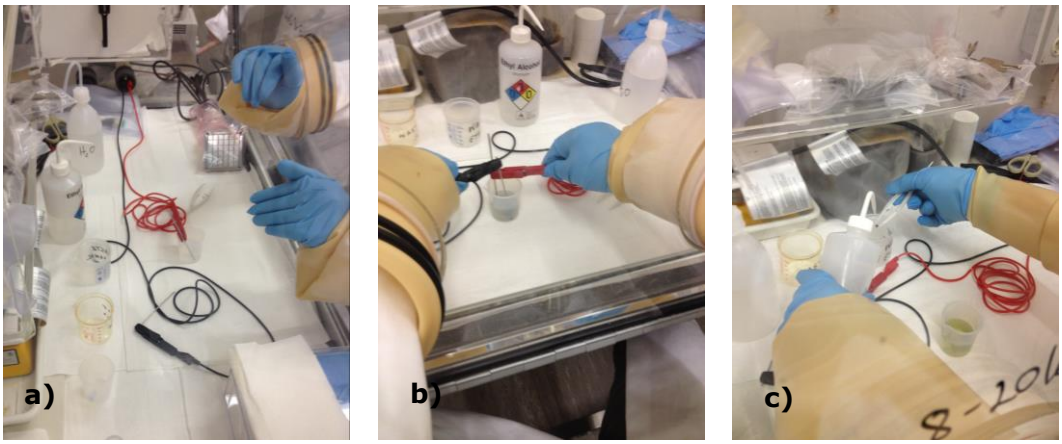
3.2 Processing

Cleaning and dissolution of the Pu metal

The certificate of the plutonium MP2 metal provided by CETAMA (Annex 4) does not recommend any pre-treatment of the metal prior to dissolution. Nevertheless, pre-cleaning of the plutonium by electro-polishing as described below was performed to remove any surface oxidation products. This additional step has shown to improve the dissolution procedure of the Pu MP2 metal applied at the JRC-Geel. Consequently, the masses and associated uncertainties of the respective units of MP2 provided on the certificate were not used. Instead, the cleaned Pu metal pieces were weighed (by substitution method) prior to dissolution.

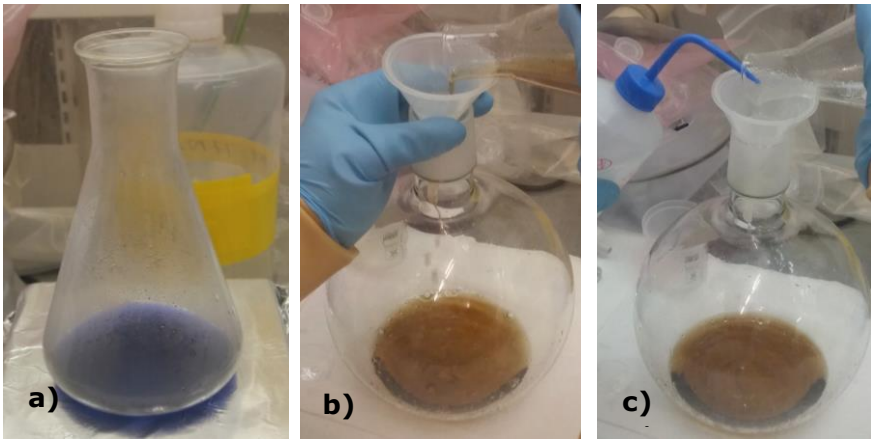
The cleaning was carried out in a dedicated glove box equipped with an electrolytic cell. The cell consisted of two Pt rods, the power supply (set to 4.5 V) and a Teflon beaker. Potassium carbonate solution (20 g K_2CO_3/100 g H_2O) was used as a conducting media. The metal piece (one at a time) was put inside a Teflon beaker and covered with potassium carbonate solution. Cleaning was performed by touching the sides of the metal piece with a Pt electrode attached to the positive terminal for about 20-30 s, while the other Pt electrode was in contact with the solution. The reaction proceeded with evolution of hydrogen gas and formation of a soluble green plutonium carbonate complex. The cleaning procedure was repeated until the metal was thoroughly cleaned and the colour of the metal changed from black to grey. The cleaned metal pieces (three pieces in total) were rinsed with deionised water, ethanol (p.a., Merck, Darmstadt, Germany) and dried down. The cleaning of Pu MP2 metal is shown in Figure 1.

Figure 1 Cleaning of Pu MP2 metal by electro-polishing: a) an electrolytic cell with Pt rods, b) cleaning of the Pu metal piece and c) rinsing of the cleaned Pu metal piece with deionised water and ethanol



The cleaned Pu metal pieces were weighed (by substitution method) and transferred into an Erlenmeyer flask with 20 mL hydrochloric acid (c = 6 mol L^{-1}, *p.a.*, Merck, Darmstadt, Germany). The dissolution of the plutonium metal in hydrochloric acid was completed within 5 minutes and resulted in a clear blue solution. The Erlenmeyer flask was washed with about 50 mL nitric acid solution (*c* = 8 mol L^{-1}, *p.a.*, Merck, Darmstadt, Germany). 4 mL of hydrofluoric acid (*c* = 1 mol L^{-1}, *p.a.*, Merck, Darmstadt, Germany) were added to dissolve any remaining pieces of the Pu metal. The solution with the dissolved plutonium was transferred into a pre-cleaned 3L borosilicate flask for the preparation of IRMM-1027s mother solution using a funnel. Both the Erlenmeyer flask and the funnel were thoroughly rinsed with nitric acid solution (*c* = 8 mol L^{-1}, *p.a.*, Merck, Darmstadt, Germany) and the rinsed solution collected in the flask with the dissolved plutonium. About 200 mL of nitric acid solution (*c* = 8 mol L^{-1}) was used to rinse the Erlenmeyer flask and the funnel to make sure that all of the plutonium solution was quantitatively transferred into the flask. No precipitate or residue was observed. The dissolution of Pu MP2 metal is shown in Figure 2.

Figure 2 Dissolution of Pu metal: a) dissolution of Pu MP2 metal in hydrochloric acid, b) transferring of the dissolved Pu into the borosilicate flask c) rinsing of the Erlenmeyer flask with nitric acid solution

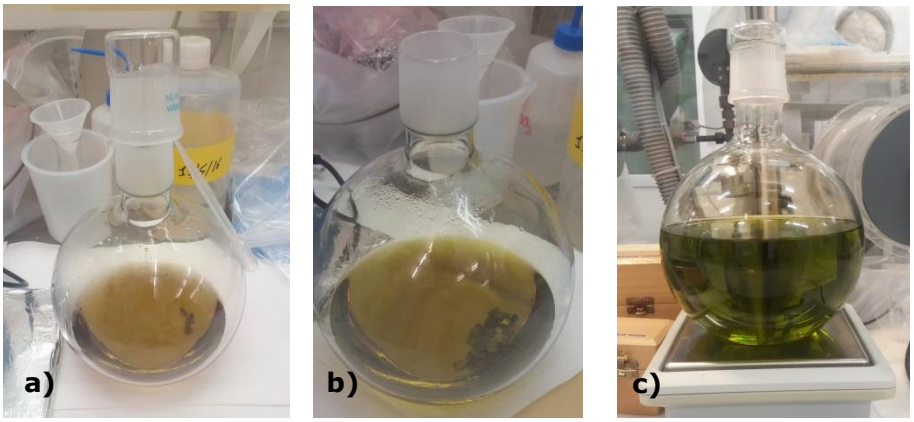


Dissolution of the U metals

The respective units of enriched uranium metal (NBL CRM 116-A) and of natural uranium metal (EC NRM 101) were weighed (by substitution method) and added into the prepared plutonium solution. Prior to weighing, the units of NBL CRM 116-A metal were etched with nitric acid (*c* = 8 mol L^{-1}) to remove surface oxidation products as described in the certificate, and subsequently rinsed with deionised water and acetone (*p.a.*, Merck, Darmstadt, Germany) and dried down. The units of the EC NRM 101 uranium metal were weighed as provided without any cleaning, as the material was stored in an inert atmosphere. The final amounts of concentrated nitric acid and deionised water were added to adjust the concentration of the nitric acid solution (*c* = 6 mol L^{-1}). The solution was left to homogenise for a few days with occasional stirring by hand, and weighed to determine the final mass of the mother solution, taking into account the necessary corrections for air buoyancy effects. The dissolution of the uranium metals is shown in Figure 3.

Prior to dispensing the mother solution into individual penicillin vials five aliquots were analysed by isotope dilution thermal ionisation mass spectrometry (ID-TIMS) to verify the gravimetrically determined amount contents of plutonium and uranium and five aliquots by thermal ionisation mass spectrometry (TIMS) to verify the uranium and plutonium isotope amount ratios (see Process Control, Section 3.3)

Figure 3 Dissolution of U metals: a) addition of the NBL 116-A enriched U metal into the Pu solution, b) addition of the EC NRM 101 natural U metals into the Pu solution c) the mother solution of IRMM-1027s



Dispensing, drying and application of CAB

Dispensing and weighing of the mother solution into individual penicillin vials were performed by a validated automated system, which was installed at the JRC Geel in collaboration with Nucomat (Lokeren, Belgium) [9]. The major components of the system are a robot, two balances and a dispenser. The robot is software driven and designed to control all movements inside the glove box, such as identifying the vial with a barcode reader, dispensing and weighing of an aliquot of the solution (2.5 g) into the penicillin vials. The weighing component is equipped with an analytical balance (Sartorius TE124S, Göttingen, Germany) and a 5 kg balance (Sartorius TE6101, Göttingen, Germany) to monitor the mass of the mother solution during dispensing. The whole solution (about 3 kg) was dispensed into 950 units over four consecutive working days.

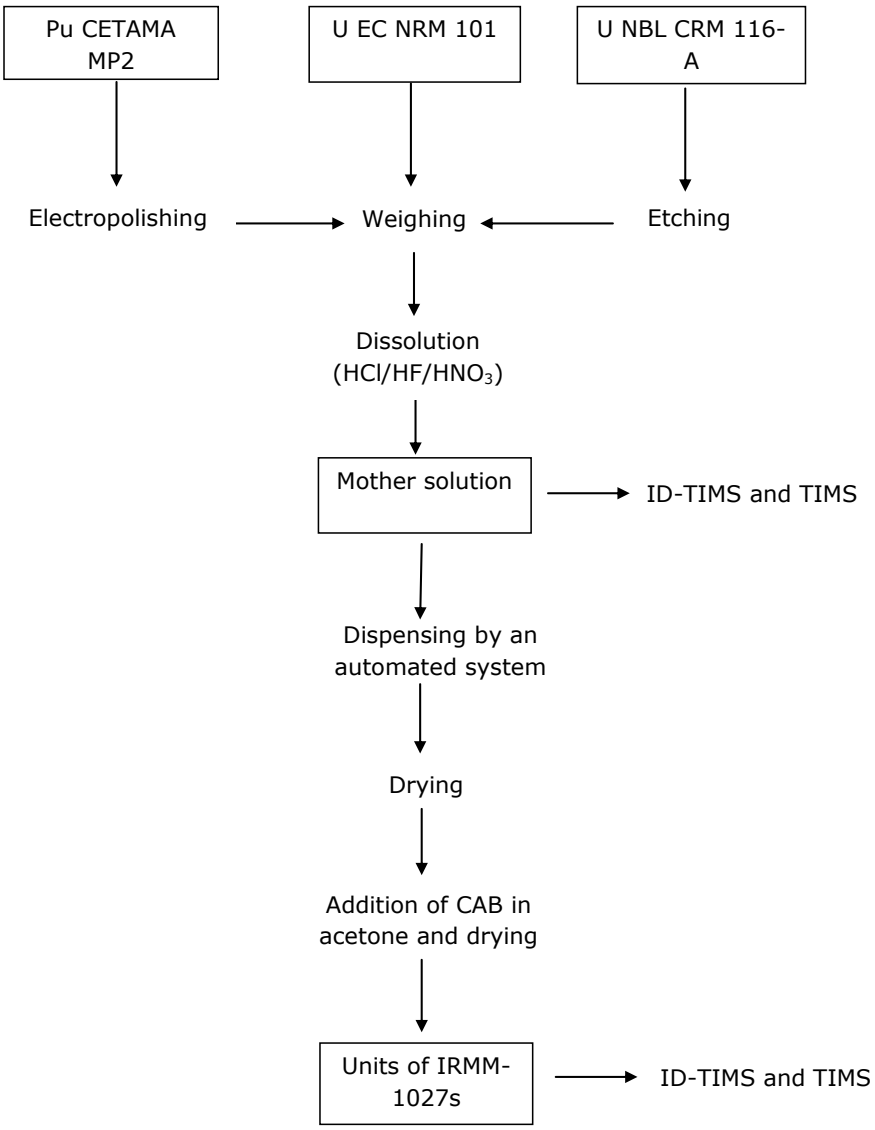
The drying of the dispensed solution contained in the units was carried out on a hot plate. This temperature was increased to a maximum of 60 °C and the units were kept at this temperature for several days (typically 4-5 days continuous heating) to evaporate the solution completely. After the solution had dried, about 0.7 mL of CAB solution in acetone (10 g CAB/100g acetone, 35-39 g/100 g butyryl content, Acros, New Jersey, USA) was added. This solution was evaporated at room temperature and then heated to about 45 °C to dry completely. Two separate glove boxes were used for drying and CAB application, allowing the preparation of up to 48 units per week. The vials were closed with a stopper and an aluminium cap, sealed in PVC package and labelled.

CAB was added to retain the dried material at the bottom of the penicillin vial so that it can resist physical shocks that might be encountered during transport and to avoid flaking of the material during long-term storage. This cellulose matrix dissolves readily in warm nitric acid solution and has no significant effect on the subsequent IDMS analysis. This has been demonstrated by measurements performed both on the vials (containing CAB) and on the mother solution (without CAB). The units of IRMM-1027s LSD spikes can be seen in Figure 4.

Figure 4 Units of IRMM-1027 s LSD spike

The processing steps are shown in Figure 5.

Figure 5 Preparation of IRMM-1027s LSD spikes



3.3 Process control

This section describes the measurements performed on the mother solution of IRMM-1027s prior to dispensing into vials to verify the amount contents of uranium and plutonium in the solution from gravimetric preparation (see Annex 13).

Five aliquots of the mother solution (about 1.0 g each) were individually spiked with a mixed $^{233}U/^{242}Pu$ spike CRM (three aliquots with ca 2.85g IRMM-046b and two with ca. 5.0 g IRMM-046c) for ID-TIMS analysis. The certificate of IRMM-046b and IRMM-046c can be found in Annex 7 and Annex 8.

Five un-spiked aliquots of the IRMM-1027s mother solution were analysed to verify the uranium and plutonium isotope amount ratios by thermal ionisation mass spectrometry (TIMS).

The U/Pu separation of the spiked and un-spiked samples was performed using anion-exchange columns (Bio-Rad AG1-X4, 100-200 mesh, Bio-Rad, Hercules, USA) as described in detail in [10].

The results of the process control measurements for ^{238}U, ^{235}U and ^{239}Pu amount contents as well as the uranium and plutonium isotope amount ratios in the mother solution of IRMM-1027s agreed within the uncertainties with the values from the gravimetric preparation (Annex 14 and Annex 15), except for the $n(^{238}Pu)/n(^{239}Pu)$ amount ratio. A higher value for the $n(^{238}Pu)/n(^{239}Pu)$ ratio was measured by TIMS compared to the value from the gravimetric preparation of the mother solution. This is due to an isobaric interference with ^{238}U coming from the incomplete removal of uranium in the plutonium fraction. This isotope amount ratio will not be certified and will be given in the certificate as additional material information. The results of the confirmation measurements for the mother solution of IRMM-1027s are shown in Annex 9 and Annex 10.

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/IEC 17034:2016 [1] requires reference material (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

The between-unit homogeneity was evaluated to ensure that the certified values of the CRM are valid for all 950 units of the material, within the stated uncertainty.

Ten units were selected (unit No.: 53, 134, 208, 341, 418, 496, 617, 730, 794 and 888) to assess the homogeneity for the amount content of ^{235}U, ^{238}U and ^{239}Pu using a random stratified sampling scheme covering the whole batch for the between-unit homogeneity test. The number of selected units corresponds to approximately the cubic root of the total number of the produced units (950). The batch was divided into ten groups (with a similar number of units) and one unit was selected randomly from each group.

For this project, the homogeneity and characterisation studies were performed on the same units (see Section 6). The data obtained from the homogeneity study were also used for the material characterisation.

The whole amount of sample per unit (equals minimum sample intake) was taken for analysis. Selected units of IRMM-1027s were spiked with a mixed $^{233}U/^{242}Pu$ spike CRM (IRMM-046c) and the solution in the vials evaporated to dryness. The U/Pu separation was carried out prior to isotope ratio measurements on each unit in the same way as for the process control measurements (see Section 3.3) [10].

Each sample was measured in three replicates together with isotopic standards (IRMM-074/10 for U and IRMM-290/A3 for Pu) to correct for instrumental mass fractionation. This enabled five independent samples to be measured on the same TIMS turret on the same day. Therefore, the measurements for all ten units of IRMM-1027s were performed under intermediate precision conditions rather than repeatability conditions within short intervals of time.

The respective fractions of the samples were measured in a randomised manner to be able to separate a potential analytical drift from a trend in the filling sequence. The results of the homogeneity study are shown in Annex 11.

Regression analyses were performed to evaluate potential trends in the analytical sequence as well as trends in the filling sequence. No trends in the filling sequence or the analytical sequence were visible at a confidence level of 95 %. The data were tested for consistency using Grubbs outlier test at a confidence level of 99 % on the individual results and on the unit means. One outlying individual result (No. 14) was found for the amount content of ^{239}Pu. Since no technical reason was found to exclude this data point, it was retained for statistical evaluation.

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-unit standard deviations. The results of all statistical evaluations are given in Table 1.

Table 1 Results of the statistical evaluation of the homogeneity studies of the amount content of ^{235}U, ^{238}U and ^{239}Pu in IRMM-1027s

	Trends [1]		Outliers [2]		Distribution	
	Analytical sequence	Filling sequence	Individual results	Unit means	Individual results	Unit means
^{235}U amount content	no	no	none	none	unimodal	unimodal
^{238}U amount content	no	no	none	none	unimodal	unimodal
^{239}Pu amount content	no	no	one	none	unimodal	unimodal

[1] at 95 % confidence level

[2] at 99 % confidence level

One has to bear in mind 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, u^*_{bb}, the maximum inhomogeneity that could be hidden by method repeatability, was calculated as described by Linsinger et al. [11]. 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:

$$s_{wb,rel} = \frac{\sqrt{MS_{within}}}{\bar{y}} \qquad \text{Equation 1}$$

$$s_{bb,rel} = \frac{\sqrt{\frac{MS_{between} - MS_{within}}{N}}}{\bar{y}} \qquad \text{Equation 2}$$

$$u^*_{bb,rel} = \frac{\sqrt{\frac{MS_{within}}{N}}\sqrt[4]{\frac{2}{v_{MSwithin}}}}{\bar{y}} \qquad \text{Equation 3}$$

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

$v_{MSwithin}$ degrees of freedom of MS_{within}

The uncertainty contribution for homogeneity was determined under intermediate precision conditions as described earlier in this section. Consequently, day-to-day effects can occur that could mask the between-unit variation. Therefore, the data were first checked using one way-ANOVA for any significant difference in between-day means. A significant day-to-day difference was observed for the amount content of ^{239}Pu. For that reason, the data for the amount content of ^{239}Pu were first normalised by the respective day mean and the resulting data evaluated using one way-ANOVA. The results of the evaluation of the between-unit variation are summarised in Table 2.

Table 2 Results of the homogeneity studies of the amount content in IRMM-1027s

	$s_{wb,rel}$ [%]	$s_{bb,rel}$ [%]	$u^*_{bb,rel}$ [%]
^{235}U amount content	0.014	0.021	0.0045
^{238}U amount content	0.034	0.010	0.011
^{239}Pu amount content	0.033	0.020	0.011

The homogeneity study showed no outlying unit means at a 99 % confidence level and no trends in the filling sequence at a 95 % confidence level. Therefore, the between-unit standard deviation 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} or u^*_{bb} is adopted as uncertainty contribution to account for potential inhomogeneity.

4.2 Homogeneity of the U and Pu isotope ratios

The homogeneity assessment of the uranium and plutonium isotope amount ratios was deemed unnecessary. The IRMM-1027s LSD spikes were prepared by dissolution of the plutonium and uranium metals, dispensing of the solution into individual units and drying. Any differences in the isotope amount ratios could only stem from a contamination with plutonium and uranium of a different isotopic composition, from the isotope fractionation during the evaporation of the nitrate solution in the vial and from an incomplete mixing of the uranium metals. Dedicated glove boxes were used for the preparation of the spikes with no other sources of uranium and plutonium, so the contamination can be excluded. The drying temperature was less than 60 °C, where the fractionation effects are negligible. Moreover, the results of the process control measurements (see Section 3.3) for the uranium and plutonium isotope amount ratios agreed with the values from the gravimetric preparation, confirming the isotope mixing of the metals. For these reasons, no heterogeneity of the plutonium and uranium isotope amount ratios is to be expected in the vials of IRMM-1027s.

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.

The whole amount of sample per unit has to be used for analysis and thus equals the minimum sample intake. Quantification of within-unit inhomogeneity to determine the minimum sample intake for IRMM-1027s is therefore not necessary.

5. Stability

Stability testing is necessary to establish conditions for storage (long-term stability) as well as conditions for dispatch to the customers (short-term stability). The IRMM-1027s is a mixed U/Pu reference material, consisting of U and Pu radionuclides. 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 [5, 6].

5.1 Short-term stability

In the scope of the preparation and certification of the IRMM-1027q, a thorough short-term stability study of the CAB was carried out [12]. The same CAB and chemical treatment were applied for the preparation of IRMM-1027s LSD spikes; therefore, the re-assessment of the short-term stability was not necessary.

IRMM-1027s LSD spikes are packed and shipped to customers following the legal requirements related to radioprotection measures for transport of radioactive materials [13]. IRMM-1027s LSD spikes are 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 ($u_{sts,\ rel} = 0$) was applied.

5.2 Long-term stability

The long-term stability of IRMM-1027 LSD spikes has been demonstrated via the results of the stability monitoring of previous batches of LSD spikes for the period of three years [14] and the verification results of IRMM-1027m over a period of four years after the certification in the context of the inter-calibration of JRC-IRMM spike CRMs [15, 16, 17]. Furthermore, the JRC-Geel (Belgium), the JRC-Karlsruhe (Germany) and the IAEA are engaged in mutual verification measurements of mixed uranium/plutonium spike

reference materials via EC support task to the IAEA [18]. In the frame of this support task, verification measurements of randomly selected IRMM-1027 LSD spikes from different batches are performed up to two years after the issuance of the certificate. This is not only an external verification of the certified values but also a demonstration of the long-term stability of the IRMM-1027 series of LSD spikes. Taking all these considerations into account, no additional uncertainty component ($u_{lts,\ rel}$ = 0) was applied.

After the certification campaign, IRMM-1027s material will be subjected to the stability monitoring programme to control its stability. Two units of IRMM-1027s 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 for the uranium and plutonium isotope amount ratios was based on gravimetric preparation of the mother solution (see Section 6.2) and by ID-TIMS for the mass of uranium and plutonium (see Section 6.3), verified by independent analysis. The IRMM-1027s series of LSD spikes was prepared by dispensing an aliquot (about 2.5 g) of the mother solution into individual units by an automated system and subsequent drying. The masses of dispensed aliquots per unit before drying are given in Annex 12. The mother solution was prepared by gravimetric mixing of uranium and plutonium metals (see Section 3.2).

Each unit of IRMM-1027s LSD spike is certified for the mass of ^{239}Pu, ^{235}U and ^{238}U and the $n(^{234}U)/n(^{238}U)$, $n(^{235}U)/n(^{238}U)$, $n(^{236}U)/n(^{238}U)$, $n(^{240}Pu)/n(^{239}Pu)$, $n(^{241}Pu)/n(^{239}Pu)$, and $n(^{242}Pu)/n(^{239}Pu)$ amount ratios.

6.1 Purity of the starting materials

The purity of the starting materials (metals) was taken from the corresponding certificates (Annexes 2 - 4). The purity of the Pu MP2 metal was calculated for November 1, 2016 from the original purity of the CETAMA certificate (Annex 4).

6.2 U and Pu isotope amount ratios and their uncertainties

The U and Pu isotope amount ratios in each individual unit of IRMM-1027s are calculated from the gravimetric preparation of the mother solution, taking into account the mass of the metals, their purity and isotopic composition (e.g. isotope amount ratios) see Annex 14 and Annex 15. In Table 3 the data supporting the calculation of the Pu and U amount ratios of IRMM-1027s are summarised.

Table 3 Gravimetric mixing to prepare the mother solution of IRMM-1027s

	MP2	EC NRM 101	NBL CRM116-A	Mother solution
Mass [1] [g]	1.65903	41.65132	10.24309	2460.69
Purity [2] [g/g]	0.9990	0.99985	0.99945	
Isotope amount ratios [3] [mol/mol]	$n(^{238}Pu)/n(^{239}Pu)$ 0.00003083 $n(^{240}Pu)/n(^{239}Pu)$ 0.0224324 $n(^{241}Pu)/n(^{239}Pu)$	$n(^{234}U)/n(^{238}U)$ 0.00005548 $n(^{235}U)/n(^{238}U)$ 0.0072593 $n(^{236}U)/n(^{238}U)$	$n(^{233}U)/n(^{235}U)$ 0.0000003863 $n(^{234}U)/n(^{235}U)$ 0.0115836 $n(^{236}U)/n(^{235}U)$	

	0.0002378 $n(^{242}Pu)/n(^{239}Pu)$ 0.00007570	0.000000151	0.0094713 $n(^{238}U)/n(^{235}U)$ 0.051277	

[1)] The masses of the metals are obtained from the weighing certificate, see Annex 13.

[2)] The purity of the metals is obtained from the metal certificates, see Annexes 2 – 4, 15.

[3)] The isotope amount ratios are obtained from the metal certificates; see Annexes 3, 5 – 6.

The plutonium and uranium isotope amount ratios obtained from the gravimetric preparation were confirmed by TIMS measurements on selected aliquots of the mother solution for all the U and Pu isotope amount ratios, except for the $n(^{238}Pu)/n(^{239}Pu)$ ratio. As explained in section 3.3, this is due to an isobaric interference with ^{238}U during the isotope ratio measurement, most likely coming from the incomplete removal of the uranium in the plutonium fraction. This isotope amount ratio will only be provided on the certificate as additional material information (see Section 3.3 and Annex 10).

The results of the process control measurement on the mother solution confirmed the complete mixing of the uranium and plutonium metals, and therefore enable the characterisation of the isotope amount ratios in IRMM-1027s based on the gravimetric preparation. In addition, the gravimetric values for the uranium and plutonium isotope amount ratios were also verified by external measurements performed on the selected units of IRMM-1027s by the NML-IAEA and JRC-Karlsruhe (Tables 9 and 10, Section 6.5).

The uncertainties of the certified U and Pu isotope amount ratios are composed of several contributions i.e. the uncertainty on the mass determination of the metals, the uncertainty on the purity of the metals, and the uncertainty on the isotope amount ratios. The complete and detailed calculations of the uranium and plutonium isotope amount ratios and their uncertainty budgets are given in Annex 14 and Annex 15. The results of the characterisation assessment for the uranium and plutonium isotope amount ratios in IRMM-1027s are summarised in Table 4.

Table 4 The U and Pu isotope amount ratios and their standard uncertainties from the characterisation assessment of IRMM-1027s

	Value [1)] [mol/mol]	u_{char} [mol/mol]	$u_{char, rel}$ [%]
$n(^{234}U)/n(^{238}U)$	0.0027303	$1.14 \cdot 10^{-6}$	0.042
$n(^{235}U)/n(^{238}U)$	0.238155	$16.2 \cdot 10^{-6}$	0.0068
$n(^{236}U)/n(^{238}U)$	0.0021905	$8.95 \cdot 10^{-7}$	0.041
$n(^{240}Pu)/n(^{239}Pu)$	0.0224154	$2.55 \cdot 10^{-6}$	0.011
$n(^{241}Pu)/n(^{239}Pu)$	0.0001478	$9.65 \cdot 10^{-7}$	0.65
$n(^{242}Pu)/n(^{239}Pu)$	0.00007572	$3.90 \cdot 10^{-7}$	0.52

[1)] The reference date for the isotope amount ratios is November 1, 2016.

6.3 Masses of ^{235}U, ^{238}U, ^{239}Pu and their uncertainties

The results of the homogeneity assessment for the amount content of ^{235}U, ^{238}U, ^{239}Pu on the ten selected units of IRMM-1027s showed somewhat lower values compared to the values from the gravimetric preparation. The results are shown in Figures 6-8.

Figure 6 The amount content of ^{235}U in the selected vials of IRMM-1027s measured by ID-TIMS (blue diamonds) expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainty (coverage factor $k = 2$). Red dotted lines show the relative expanded uncertainty ($k = 2$) of the gravimetric value

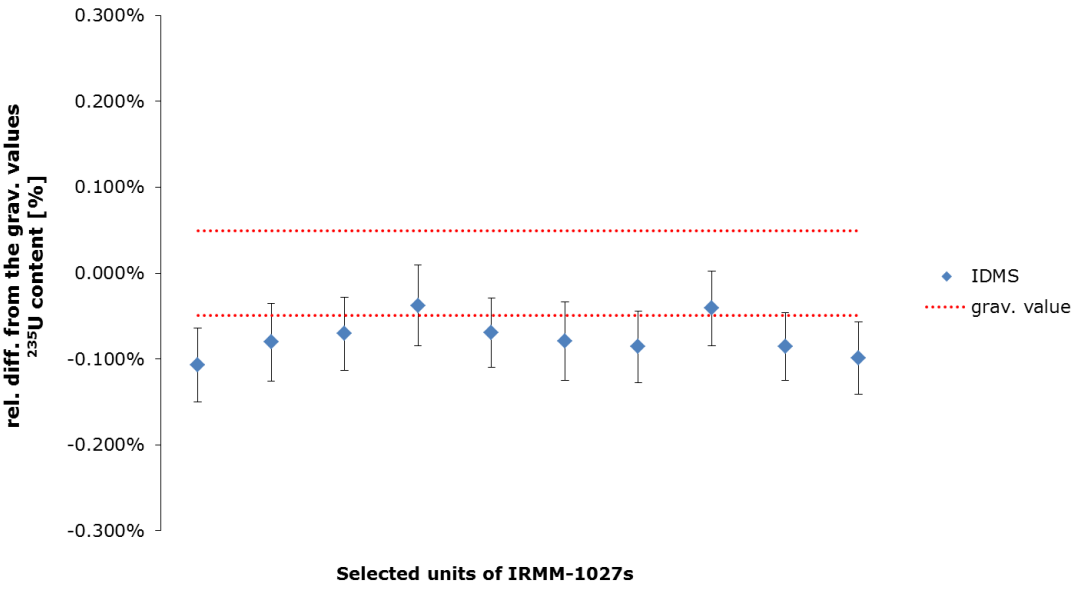


Figure 7 The amount content of ^{238}U in the selected vials of IRMM-1027s measured by ID-TIMS (blue diamonds) expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainty (coverage factor k = 2). Red dotted lines show the relative expanded uncertainty (k = 2) of the gravimetric value

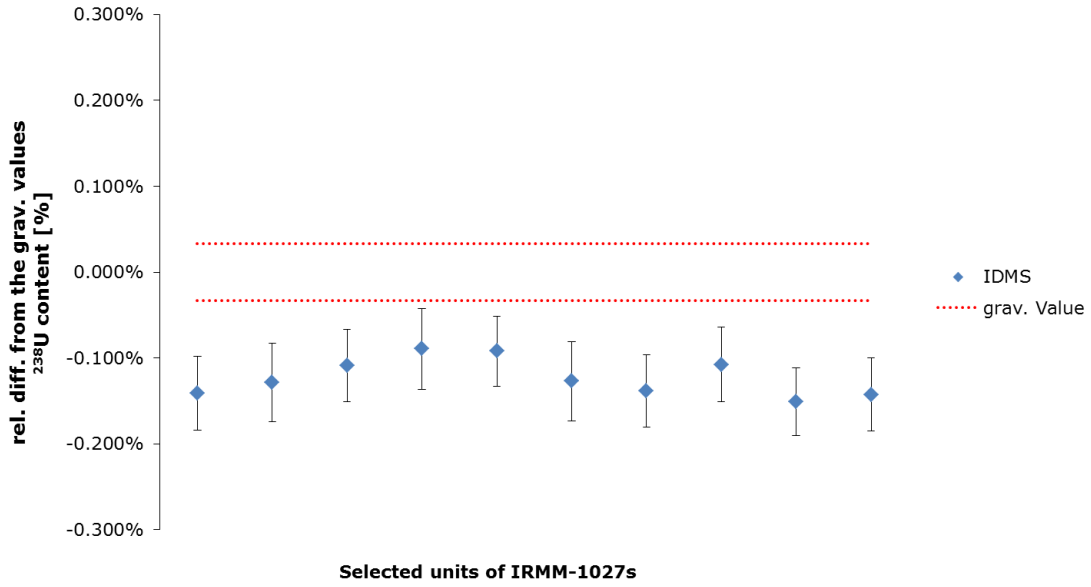
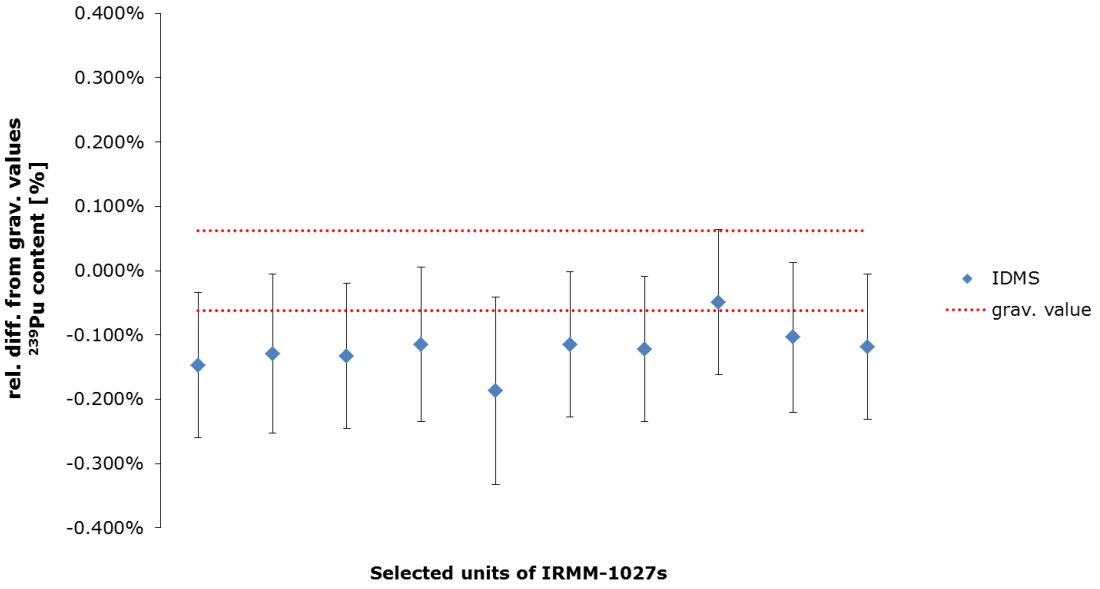


Figure 8 The amount content of ^{239}Pu in the selected vials of IRMM-1027s measured by ID-TIMS (blue diamonds) expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainty (coverage factor k = 2). Red dotted lines show the relative expanded uncertainty (k = 2) of the gravimetric value



On average, this relative difference was about -0.08 % for the ^{235}U amount content and about -0.12 % for the ^{239}Pu and ^{238}U amount contents. Consequently, the IDMS results did not agree with the gravimetric values within measurement uncertainties at a 95% confidence level. On the other hand, the process control measurements performed on the mother solution prior to dispensing and drying (see 3.3 and Annex 9) did confirm the values for the amount contents of ^{235}U, ^{238}U and ^{239}Pu from the gravimetric preparation. Therefore, some uncontrolled effects influencing the whole batch uniformly might have occurred during the processing of the mother solution after the dissolution (e.g. dispensing, drying, CAB application, etc.). The reason for the discrepancy in the selected units of IRMM-1027s was not found, despite a thorough review of the measurement results, and the balances and reference weights used for weighing. For this reason, the characterisation of the amount contents of ^{235}U, ^{238}U and ^{239}Pu was based on the IDMS results from the homogeneity assessment and not from the gravimetric preparation of the mother solution. These IDMS results on the individual units of IRMM-1027s were also supported by the external verification measurements performed by the IAEA and JRC-Karlsruhe (see Section 6.5).

The masses of ^{235}U, ^{238}U and ^{239}Pu in each individual unit of IRMM-1027s are calculated from the mass fractions of the plutonium and uranium established by ID-TIMS analysis using IRMM-046c as a spike CRM on the ten randomly selected units (as given in Section 4.1), taking into account the mass of the aliquot taken from the mother solution in each vial (Annex 12), the mass of the spike in each blend (Annex 16), the amount content and the isotope amount ratios of the spike (Annex 8) and the isotope amount ratios of the blend (Annex 17). A general IDMS equation is shown below:

$$C_x = C_y \frac{m_y}{m_x} \frac{R_y - R_b}{R_b - R_x} \frac{\Sigma(R_i)_x}{\Sigma(R_i)_y} \qquad \text{Equation 4}$$

where C_y is the element amount content of the spike (IRMM-046c), m_x and m_y are the masses of sample and spike, respectively, R_x, R_y and R_b are the isotope amount ratios of the sample, the spike and the blend, respectively, $\Sigma(R_i)_x$ and $\Sigma(R_i)_y$ are the sums of all isotope amount ratios in sample and in spike, respectively.

The results of the characterisation of ^{235}U, ^{238}U and ^{239}Pu amount contents are summarised in Table 5.

Table 5 Results for the amount contents of ^{235}U, ^{238}U and ^{239}Pu and their expanded uncertainties (coverage factor, k = 2) from the characterisation assessment. The reference date for the amount content of ^{235}U, ^{238}U and ^{239}Pu is November 1, 2016

Unit	^{235}U amount content [µmol/g]	^{238}U amount content [µmol/g]	^{239}Pu amount content [µmol/g]
134	16.9934 ± 0.0073	71.330 ± 0.052	2.7490 ± 0.0031
341	17.0052 ± 0.0080	71.367 ± 0.055	2.7499 ± 0.0033
496	16.9979 ± 0.0077	71.339 ± 0.060	2.7495 ± 0.0034
730	16.9998 ± 0.0069	71.365 ± 0.049	2.7479 ± 0.0040
888	16.9996 ± 0.0072	71.353 ± 0.053	2.7494 ± 0.0031
53	16.9981 ± 0.0078	71.340 ± 0.060	2.7499 ± 0.0031
208	17.0046 ± 0.0074	71.354 ± 0.046	2.7517 ± 0.0031
418	16.9948 ± 0.0072	71.329 ± 0.053	2.7498 ± 0.0031
617	16.9970 ± 0.0071	71.332 ± 0.050	2.7497 ± 0.0031
794	16.9971 ± 0.0067	71.323 ± 0.043	2.7502 ± 0.0032
Mean	16.9987 ± 0.0040	71.343 ± 0.031	2.7497 ± 0.0025

The uncertainties on the mass (u_{char}) of ^{235}U, ^{238}U and ^{239}Pu in the vials are composed of several contributions, i.e. the uncertainties on the mass determination of the sample and the spike, the uncertainties on the amount content and isotope amount ratio of the spike (IRMM-046c), the uncertainty on the isotope amount ratio measurements of the blend and the uncertainty on the isotope amount ratio of the sample.

Detailed calculations of the mass fractions, amount contents and their uncertainty budgets (e.g. propagation of various uncertainty contributions) of IRMM-1027s are given in Annex 18-20.

The uncertainty for the mass of ^{235}U, ^{238}U and ^{239}Pu in vial No.53 as an example are summarised in Table 6.

Table 6 The ^{235}U, ^{238}U and ^{239}Pu masses and their standard uncertainties in vial No.53 of IRMM-1027s as an example. The reference date for the masses of ^{235}U, ^{238}U and ^{239}Pu is November 1, 2016

Vial No. 53	Value [mg]	u_{char} [mg]	$u_{char, rel}$ [%]
^{235}U mass	10.038	0.0017	0.017
^{238}U mass	42.666	0.011	0.025
^{239}Pu mass	1.65135	0.00068	0.041

6.4 Weighing and associated uncertainties

Masses of dispensed aliquots of the mother solution per unit used for the calculation of the certified values can be found in Annex 12. The dispensed masses were corrected for air buoyancy, taking into account the density of the air and the sample, the ambient humidity, temperature and pressure inside the glove box, and for the evaporation losses. Traceability to the SI is ensured by weighing a reference weight before and after

dispensing a series of 96 units. The uncertainties on the dispensed mass (± 0.0006 g, coverage factor k = 2) are composed of several contributions, i.e. the uncertainty on the mass determination by an automated system, the uncertainty on the buoyancy correction, the uncertainty due to evaporation correction, and the uncertainty associated with the variability of the balance [6].

For the determination of the mass of the starting materials (metals) and the mother solution, substitution weighing was used. In the 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 of the metals are the uncertainties associated with the calibrated reference weights (certificate), air buoyancy correction and the variability of the balance used in "SUUS" method.

6.5 Verification measurements

Verification measurements were performed by the Nuclear Material Laboratory of the International Atomic Energy Agency (NML-IAEA) and by the Analytical Services of the JRC-Karlsruhe in the frame of the EC support task to the IAEA [18]. Several units of IRMM-1027s were randomly selected from the whole batch and analysed by ID-TIMS to verify the uranium and plutonium amount contents and by TIMS to verify the plutonium and uranium isotope amount ratios from the gravimetric preparation of the mother solution. Details about the verification measurements are summarised in Table 7.

Table 7 Spikes and procedures for the analysis of the IRMM-1027s by the IAEA and JRC-Karlsruhe

	NML-IAEA	JRC-Karlsruhe
Number of samples (IRMM-1027s)	8 for IDMS (amount content) and 2 for TIMS (isotope amount ratios)	4 for IDMS (amount content) and 2 for TIMS (isotope amount ratios)
U spike for IDMS	^{233}U (NBL CRM 111-A)	^{238}U (EC NRM-110)
Pu spike for IDMS	^{242}Pu (KRI-RM1-662-2004)	^{240}Pu in-house spike SM4, calibrated with MP2
U/Pu separation	UTEVA (valence adjustment with H_2O_2)	UTEVA (valence adjustment with H_2O_2)
Mass spectrometer	Triton TIMS	Triton TIMS
Quality Control	IAEA LSD-28 for U and Pu amount content NBL CRM 137 and NBL CRM 138 for Pu and IRMM-185 and IRMM-186 for U isotope amount ratios	In-house prepared for U and Pu amount content IRMM-290F for Pu and IRMM-185 for U isotope amount ratios

The results of the verification measurements for the uranium and plutonium amount contents in the selected units of IRMM-1027s by the NML-IAEA and JRC-Karlsruhe are shown in Figures 9-11, together with the characterisation results from the JRC-Geel. All results are shown as the relative difference from the gravimetric value of the mother solution.

Figure 9 The amount content of ^{239}Pu in the selected vials of IRMM-1027s measured by ID-TIMS expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainty (coverage factor k = 2). Red dotted line shows the relative expanded uncertainty (k = 2) of the gravimetric value and the black dotted line shows the relative expanded uncertainty (k = 2.3) of the IDMS value

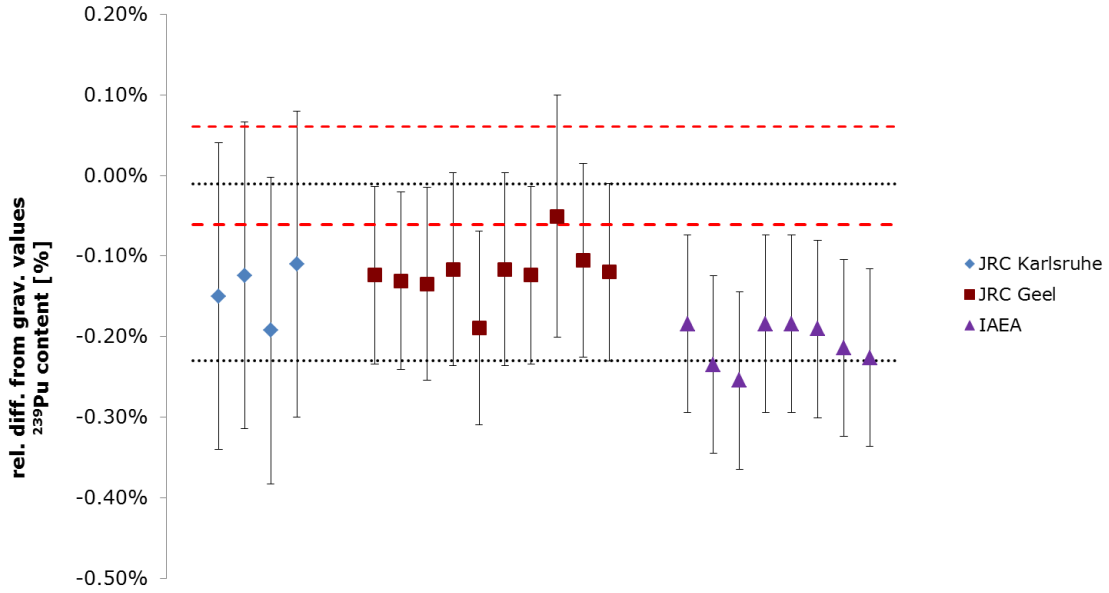


Figure 10 The amount content of ^{235}U in the selected vials of IRMM-1027s measured by ID-TIMS expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainty (coverage factor k = 2). Red dotted line shows the relative expanded uncertainty (k = 2) of the gravimetric value and the black dotted line shows the relative expanded uncertainty (k = 2.3) of the IDMS value

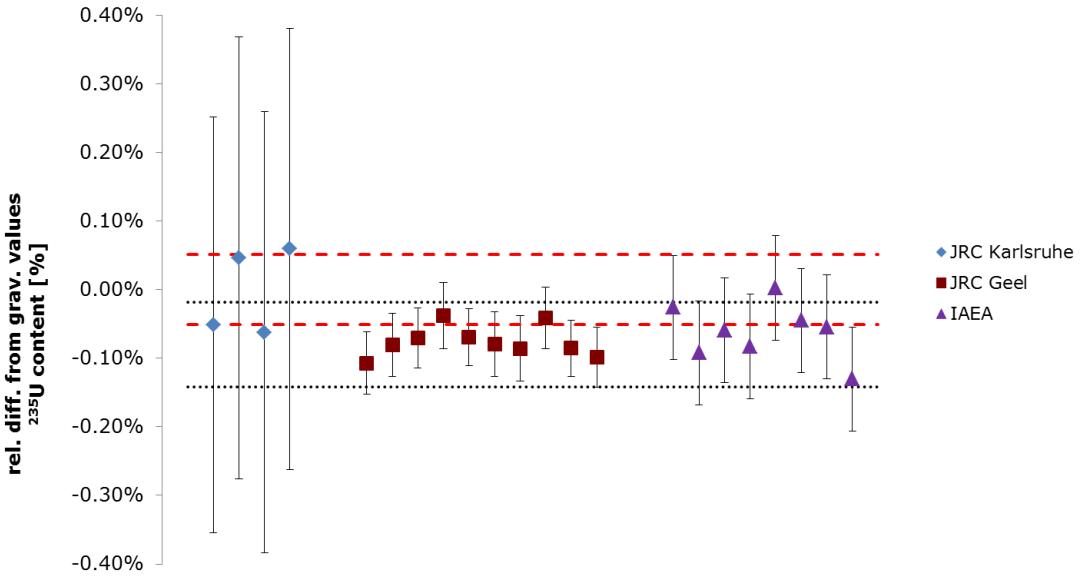
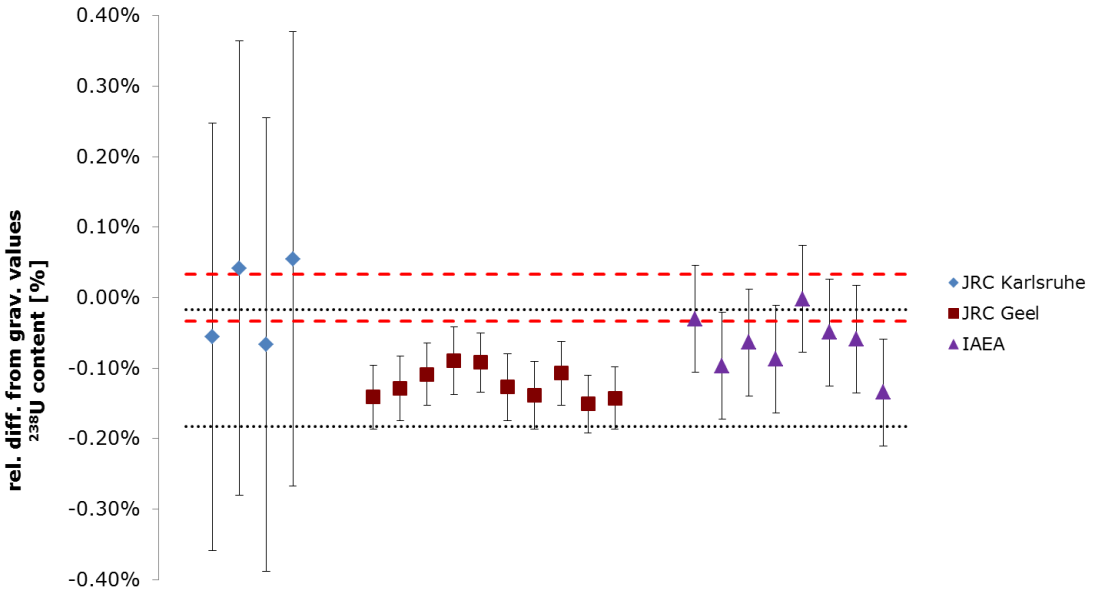


Figure 11 The amount content of ^{238}U in the selected vials of IRMM-1027s measured by ID-TIMS expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainty (coverage factor k = 2). Red dotted line shows the relative expanded uncertainty (k = 2) of the gravimetric value and the black dotted line shows the relative expanded uncertainty (k = 2.3) of the IDMS value



The results of the verification measurements for the ^{235}U, ^{238}U and ^{239}Pu amount contents from the NML-IAEA and JRC-Karlsruhe agreed with the IDMS results (red squares) from the characterisation assessment (as given in Section 6.3) within measurement uncertainties. Quality control samples (see Table 7) were successfully measured by the IAEA and JRC-Karlsruhe together with the samples of IRMM-1027s on the same turret to exclude any biases in their analytical procedures.

Furthermore, the compatibility check was performed for the results of the verification measurements performed by the NML-IAEA and JRC-Karlsruhe using the compatibility equation [19] below:

$$\boldsymbol{compatibility} = \frac{|X_{lab} - X_{IDMS}|}{\sqrt{u_{lab}^2 + u_{IDMS}^2}} \qquad \text{Equation 5}$$

X_{lab} individual result of the external laboratory

X_{IDMA} IDMS mean value established by the JRC-Geel

U_{lab} standard uncertainty reported by the external laboratory

u_{IDMS} standard uncertainty of the IDMS value

The results of the compatibility evaluations are summarised in Table 8.

Table 8 Results of the compatibility evaluation for the ^{235}U, ^{238}U and ^{239}Pu amount content

Vial No.	Laboratory	^{235}U amount content	^{238}U amount content	^{239}Pu amount content
252	NML-IAEA	1.02	1.88	0.78
375	NML-IAEA	0.34	0.53	1.43
474	NML-IAEA	0.34	1.20	1.68
653	NML-IAEA	0.14	0.72	0.78

719	NML-IAEA	1.60	2.45	0.78
761	NML-IAEA	0.63	1.49	0.86
54	NML-IAEA	0.44	1.30	1.16
163	NML-IAEA	1.11	0.24	1.32
477	JRC-Karlsruhe	0.16	0.43	0.24
605	JRC-Karlsruhe	0.75	1.00	0.01
710	JRC-Karlsruhe	0.08	0.34	0.63
915	JRC-Karlsruhe	0.82	1.08	0.12

From Table 8 it can be seen that the compatibility is found to be ≤ 2 at a 95 % CI for the ^{235}U, ^{238}U and ^{239}Pu amount contents. It can be concluded that there is no significant difference between the results of the external verification measurements from the NML-IAEA and JRC-Karlsruhe and the IDMS values established by the JRC-Geel for characterisation of the IRMM-1027s batch.

The results of the verification measurements for the uranium and plutonium isotope amount ratios in the selected units of IRMM-1027s by the NML-IAEA and JRC-Karlsruhe are summarised in Table 9.

Table 9 The results of the verification measurements for the U and Pu isotope amount ratios

Isotope ratio [1)]	Vial No. 539 [mol/mol]	Vial No. 898 [mol/mol]	Vial No. 119 [mol/mol]	Vial No. 322 [mol/mol]	Gravimetric value [mol/mol]
$n(^{234}U)/n(^{238}U)$	0.0027306 ± 0.0000028	0.0027303 ± 0.0000026	0.002734 ± 0.000054	0.002733 ± 0.000054	0.0027303 ± 0.0000023
$n(^{235}U)/n(^{238}U)$	0.23818 ± 0.00012	0.23815 ± 0.00012	0.23815 ± 0.00021	0.23817 ± 0.00024	0.238155 ± 0.000031
$n(^{236}U)/n(^{238}U)$	0.0021913 ± 0.0000030	0.0021915 ± 0.0000037	0.002195 ± 0.000043	0.002196 ± 0.000043	0.0021905 ± 0.0000018
$n(^{240}Pu)/n(^{239}Pu)$	0.022419 ± 0.000027	0.022419 ± 0.000028	0.022418 ± 0.000012	0.022419± 0.000012	0.0224154 ± 0.0000051
$n(^{241}Pu)/n(^{239}Pu)$	0.0001487 ± 0.0000046	0.0001493 ± 0.0000046	0.0001493 ± 0.0000090	0.000147 ± 0.000017	0.0001478 ± 0.0000019
$n(^{242}Pu)/n(^{239}Pu)$	0.0000762 ± 0.0000045	0.0000760 ± 0.0000044	0.000077 ± 0.000012	0.0000781 ± 0.0000064	0.00007572 ± 0.00000078

[1)] The reference date for the isotope amount ratios is November 1, 2016.

The results of the verification measurements by the NML-IAEA and JRC-Karlsruhe for the uranium and plutonium isotope amount ratios agreed with the characterisation values from the gravimetric preparation of the mother solution and with the results from the process control measurements of the mother solution by TIMS (see Section 3.3 and Annex 10). A compatibility check was also performed for the uranium and plutonium isotope amount ratios. The results are summarised in Table 10.

Table 10 Results of the compatibility evaluation for the U and Pu isotope amount ratios

Isotope ratio	Vial No. 539 NML-IAEA	Vial No. 898 NML-IAEA	Vial No. 119 JRC-Karlsruhe	Vial No. 322 JRC-Karlsruhe
$n(^{234}U)/n(^{238}U)$	0.17	0.00	0.14	0.10
$n(^{235}U)/n(^{238}U)$	0.40	0.08	0.05	0.12
$n(^{236}U)/n(^{238}U)$	0.46	0.49	0.21	0.26
$n(^{240}Pu)/n(^{239}Pu)$	0.26	0.25	0.40	0.55
$n(^{241}Pu)/n(^{239}Pu)$	0.36	0.60	0.33	0.09
$n(^{242}Pu)/n(^{239}Pu)$	0.21	0.13	0.21	0.74

This demonstrated that there was no significant difference (compatibility ≤ 2 at a 95 % CI) observed between the measured isotope ratios in the mother solution and in the dried spikes [12, 20].

7. Value Assignment

Certified values are values that fulfil the highest standards of accuracy. Certified values for IRMM-1027s were assigned on the basis of the gravimetric preparation for the uranium and plutonium isotope amount ratios and by IDMS on ten randomly selected IRMM-1027s units for the masses of ^{235}U, ^{238}U and ^{239}Pu from the homogeneity assessment. Full uncertainty budgets in accordance with the 'Guide to the Expression of Uncertainty in Measurement' [4] were established.

7.1 Certified values and their uncertainties

The assigned uncertainty consists of uncertainties related to characterisation, u_{char} (Section 6), potential between-unit inhomogeneity, u_{bb} (Section 3) and potential degradation during transport (u_{sts}) and long-term storage, u_{lts} (Section 5). As described in Section 5 the uncertainty related to degradation during transport and long-term storage was found to be negligible. These different contributions were combined to estimate the expanded uncertainty of the certified value (U_{CRM}) with a coverage factor k as:

$$U_{CRM} = k \cdot \sqrt{u_{char}^2 + u_{bb}^2} \qquad \text{Equation 6}$$

- u_{char} was estimated as described in Section 6
- u_{bb} was estimated as described in Section 3.

Because of sufficient degrees of freedom of the different uncertainty contributions**,** a coverage factor k of 2 was applied to obtain the expanded uncertainties for the U and Pu isotope amount ratios. A coverage factor of 2.3 (degrees of freedom was applied for the masses of ^{235}U, ^{238}U and ^{239}Pu. The certified masses and their uncertainties for unit No. 53 are summarised in Table 11. The certified values of all 950 units are given in Annex 1.

Table 11 Certified masses and their uncertainties in vial No.53 of IRMM-1027s (as an example)

Mass	Certified value [mg]	$u_{char, rel}$ [%]	$s_{bb, rel}$ or $u^*_{bb,rel}$ [%]	$U_{CRM, rel}$ [1)] [%]	U_{CRM} [1)] [mg]
^{235}U mass	10.038	0.017	0.021	0.062	0.0062
^{238}U mass	42.666	0.025	0.011	0.063	0.027
^{239}Pu mass	1.6513	0.041	0.020	0.11	0.0017

[1)] Expanded (k = 2.3) uncertainty

The certified isotope amount ratios of uranium and plutonium are summarised in Table 12.

Table 12 Certified isotope amount ratios in IRMM-1027s and their uncertainties

Isotope amount ratios	Certified value [1)] [mol/mol]	$u_{char, rel}$ [%]	$U_{CRM, rel}$ [2)] [%]	U_{CRM} [2)] [mol/mol]
$n(^{234}U)/n(^{238}U)$	0.0027303	0.041	0.083	0.0000023
$n(^{235}U)/n(^{238}U)$	0.238155	0.0066	0.013	0.000031
$n(^{236}U)/n(^{238}U)$	0.0021905	0.041	0.082	0.0000018
$n(^{240}Pu)/n(^{239}Pu)$	0.0224154	0.011	0.023	0.0000051
$n(^{241}Pu)/n(^{239}Pu)$	0.0001478	0.65	1.30	0.0000019
$n(^{242}Pu)/n(^{239}Pu)$	0.00007572	0.52	1.03	0.00000078

[1)] The reference date for the plutonium and uranium isotope amount ratios is November 1, 2016.

[2)] Expanded (k = 2) uncertainty.

7.2 Additional material information

As additional information, the values for the plutonium and uranium amount contents, mass fractions and isotopic composition of the mother solution (see Annexes 18-20) are summarised in Table 13.

Table 13 Uranium and plutonium isotopic mass fraction, amount content, mass fraction and isotope amount ratios for the nitrate solution of IRMM-1027s

	Isotope mass fraction (·100)	
	Value [1)] [g/g]	Uncertainty [2)] [g/g]
$m(^{234}U)/m(U)$ [3)]	0.21648	0.00018
$m(^{235}U)/m(U)$ [3)]	18.9634	0.0021
$m(^{236}U)/m(U)$ [3)]	0.17516	0.00014
$m(^{238}U)/m(U)$ [3)]	80.6450	0.0021
$m(^{238}Pu)/m(Pu)$ [3)]	0.002778	0.000026

$m(^{239}Pu)/m(Pu)$ [3]	97.77432	0.00053
$m(^{240}Pu)/m(Pu)$ [3]	2.20084	0.00049
$m(^{241}Pu)/m(Pu)$ [3]	0.01457	0.00019
$m(^{242}Pu)/m(Pu)$ [3]	0.007497	0.000077
	Amount content	
	Value [1] [µmol/g solution]	Uncertainty [2] [4] [µmol/g solution]
^{235}U	16.9987	0.0046
^{238}U	71.343	0.035
U	88.727	0.027
^{239}Pu	2.7497	0.0025
Pu	2.8120	0.0026
	Mass fraction	
	Value [1] [mg/g solution]	Uncertainty [2] [4] [mg/g solution]
^{235}U	3.9955	0.0011
^{238}U	16.9833	0.0084
U	21.0693	0.0063
^{239}Pu	0.65732	0.00060
Pu	0.67228	0.00061
	Isotope amount ratios	
	Value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{238}Pu)/n(^{239}Pu)$	0.00002853	0.00000027

[1] The reference date for the plutonium and uranium isotope mass fraction, amount content, mass fractions and isotope amount ratios of the mother solution of IRMM-1027s is November 1, 2016.

[2] Expanded uncertainty with a coverage factor $k = 2$ for the isotope mass fractions and the $n(^{238}Pu)/n(^{239}Pu)$ ratio and a coverage factor $k = 2.3$ for the amount content and mass fractions of ^{235}U, ^{238}U, ^{239}Pu, U and Pu.

[3] Isotope mass fraction is expressed as $^{xxx}U/^{tot}U$ and $^{xxx}Pu/^{tot}Pu$.

[4] Dispensed nitrate solution before drying and application of CAB

The atomic masses of radionuclides were obtained from M. Wang et al. [4]

The half-lives of radionuclides were obtained from DDEP-BIPM (Table of radionuclides) [5] and R. Wellum et al. [6]

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 masses of the ^{235}U, ^{238}U and ^{239}Pu are traceable to the SI via the IRMM-046c spike CRM. The certified values for the U and Pu isotope amount ratios are traceable to the values on the respective metal certificates (EC NRM 101, CETAMA MP2 and NBL CRM 116-A).

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 [21] 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.

The IRMM-1027s is a dried nitrate in CAB certified for uranium and plutonium isotope amount ratios and masses of ^{235}U, ^{238}U and ^{239}Pu per unit. This CRM is tailor-made by the JRC for its intended use and serves as a spike for determination of uranium and plutonium content by IDMS measurements of samples from input solutions at reprocessing plants and is not intended to be used for other measurement methods.

9. Instructions for use

9.1 Safety information

The IRMM-1027s series contains radioactive material. The vials should be handled with great care and by 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 in an upright position.

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 vials.

9.3 Preparation and use of the material

The spike CRM has to be dissolved in the appropriate amount of acid (e.g. nitric acid with an amount of substance concentration c = 5 mol L^{-1}) or sample solution to ensure the isotopic equilibrium between the spike and the sample. Heating on a hotplate (avoid boiling) may be applied to facilitate the dissolution process.

9.4 Minimum sample intake

The whole amount of sample per unit has to be used for analysis.

9.5 Use of the certified value

This spike CRM is for use as a spike isotopic reference material to measure the plutonium and uranium amount content in an unknown sample of dissolved nuclear fuel solution using IDMS. The amount content (C_x) of plutonium or uranium can be calculated using the Equation 4 (see 6.3).

10. Conclusions

A new batch of IRMM-1027s LSD spikes was prepared and certified in compliance with international guidelines. The material is certified for the U and Pu isotope amount ratios and for the mass of ^{235}U, ^{238}U and ^{239}Pu per vial. This tailor-made CRM is applied for the determination of the U and Pu amount content of dissolved spent nuclear fuel by nuclear safeguards authorities and industry worldwide. Certified values for the masses of ^{235}U, ^{238}U and ^{239}Pu and for the U and Pu isotope amount ratios were established by ID-TIMS and by gravimetric preparation, respectively. The uncertainties of the certified values were estimated in compliance with the Guide to the Expression of Uncertainty in Measurement (GUM). They are fit for purpose and enable laboratories to meet the The International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials (ITVs) ITV2010. A unit of IRMM-1027s contains about 55 mg of uranium with a relative mass fraction $m(^{235}U)/m(U)$ of 19.0 % and 1.7 mg of plutonium with a relative mass fraction $m(^{239}Pu)/m(Pu)$ of 97.8 % as dried nitrates in CAB.

Reference

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List of abbreviations and definitions

ANOVA	Analysis of variance
BIPM	Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
c	amount of substance concentration
CAB	Cellulose acetate butyrate
CETAMA	Commission d'Etablissement des Methodes d'Analyse
CI	Confidence interval
CLSI	Clinical and Laboratory Standards Institute
CRM	Certified reference material
EC	European Commission
ESARDA	European Safeguards Research and Development Association
GUM	Guide to the Expression of Uncertainty in Measurement
IAEA	International Atomic Energy Agency
IDMS	Isotope dilution mass spectrometry
ID-TIMS	Isotope dilution thermal ionisation mass spectrometry
ISO	International Organization for Standardization
ITVs	International Target Values
JRC	Joint Research Centre of the European Commission
k	Coverage factor
LSD	Large-Sized dried
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
NBL	New Brunswick laboratory
NML	Nuclear Material Laboratory
p.a.	pro analysis
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
$\bar{y}$	Arithmetic mean
$\nu_{MSwithin}$	Degrees of freedom of MS_{within}

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Annexes

Annex 1 The certified masses of ^{235}U, ^{238}U and ^{239}Pu per unit (Vial No. 001 - 950) of IRMM-1027s

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
001	42.656	0.016	10.0352	0.0062	1.6510	0.0017
002	42.641	0.016	10.0316	0.0062	1.6504	0.0017
003	42.632	0.016	10.0296	0.0062	1.6500	0.0017
004	42.663	0.016	10.0368	0.0062	1.6512	0.0017
005	42.668	0.016	10.0380	0.0062	1.6514	0.0017
006	42.639	0.016	10.0312	0.0062	1.6503	0.0017
007	42.666	0.016	10.0376	0.0062	1.6513	0.0017
008	42.622	0.016	10.0272	0.0062	1.6496	0.0017
009	42.654	0.016	10.0348	0.0062	1.6509	0.0017
010	42.659	0.016	10.0360	0.0062	1.6511	0.0017
011	42.666	0.016	10.0376	0.0062	1.6513	0.0017
012	42.619	0.016	10.0264	0.0062	1.6495	0.0017
013	42.673	0.016	10.0392	0.0062	1.6516	0.0017
014	42.644	0.016	10.0324	0.0062	1.6505	0.0017
015	42.659	0.016	10.0360	0.0062	1.6511	0.0017
016	42.627	0.016	10.0284	0.0062	1.6498	0.0017
017	42.659	0.016	10.0360	0.0062	1.6511	0.0017
018	42.653	0.016	10.0344	0.0062	1.6508	0.0017
019	42.668	0.016	10.0380	0.0062	1.6514	0.0017
020	42.593	0.016	10.0204	0.0062	1.6485	0.0017
021	42.697	0.016	10.0447	0.0062	1.6525	0.0017
022	42.600	0.016	10.0220	0.0062	1.6488	0.0017
023	42.673	0.016	10.0392	0.0062	1.6516	0.0017
024	42.700	0.016	10.0455	0.0062	1.6527	0.0017
025	42.648	0.016	10.0332	0.0062	1.6506	0.0017
026	42.641	0.016	10.0316	0.0062	1.6504	0.0017
027	42.620	0.016	10.0268	0.0062	1.6496	0.0017
028	42.636	0.016	10.0304	0.0062	1.6502	0.0017
029	42.683	0.016	10.0416	0.0062	1.6520	0.0017
030	42.649	0.016	10.0336	0.0062	1.6507	0.0017
031	42.680	0.016	10.0408	0.0062	1.6519	0.0017
032	42.600	0.016	10.0220	0.0062	1.6488	0.0017
033	42.654	0.016	10.0348	0.0062	1.6509	0.0017
034	42.671	0.016	10.0388	0.0062	1.6515	0.0017
035	42.636	0.016	10.0304	0.0062	1.6502	0.0017
036	42.671	0.016	10.0388	0.0062	1.6515	0.0017
037	42.648	0.016	10.0332	0.0062	1.6506	0.0017
038	42.639	0.016	10.0312	0.0062	1.6503	0.0017
039	42.625	0.016	10.0280	0.0062	1.6498	0.0017
040	42.688	0.016	10.0427	0.0062	1.6522	0.0017
041	42.617	0.016	10.0260	0.0062	1.6494	0.0017
042	42.649	0.016	10.0336	0.0062	1.6507	0.0017
043	42.615	0.016	10.0256	0.0062	1.6494	0.0017
044	42.619	0.016	10.0264	0.0062	1.6495	0.0017
045	42.663	0.016	10.0368	0.0062	1.6512	0.0017
046	42.629	0.016	10.0288	0.0062	1.6499	0.0017
047	42.641	0.016	10.0316	0.0062	1.6504	0.0017
048	42.586	0.016	10.0188	0.0062	1.6483	0.0017
049	42.632	0.016	10.0296	0.0062	1.6500	0.0017
050	42.608	0.016	10.0240	0.0062	1.6491	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
051	42.614	0.016	10.0252	0.0062	1.6493	0.0017
052	42.612	0.016	10.0248	0.0062	1.6492	0.0017
053	42.666	0.016	10.0376	0.0062	1.6513	0.0017
054	42.564	0.016	10.0136	0.0062	1.6474	0.0017
055	42.597	0.016	10.0212	0.0062	1.6487	0.0017
056	42.634	0.016	10.0300	0.0062	1.6501	0.0017
057	42.566	0.016	10.0140	0.0062	1.6475	0.0017
058	42.591	0.016	10.0200	0.0062	1.6485	0.0017
059	42.600	0.016	10.0220	0.0062	1.6488	0.0017
060	42.581	0.016	10.0176	0.0062	1.6481	0.0017
061	42.597	0.016	10.0212	0.0062	1.6487	0.0017
062	42.581	0.016	10.0176	0.0062	1.6481	0.0017
063	42.608	0.016	10.0240	0.0062	1.6491	0.0017
064	42.597	0.016	10.0212	0.0062	1.6487	0.0017
065	42.542	0.016	10.0084	0.0062	1.6465	0.0017
066	42.636	0.016	10.0304	0.0062	1.6502	0.0017
067	42.540	0.016	10.0080	0.0062	1.6465	0.0017
068	42.590	0.016	10.0196	0.0062	1.6484	0.0017
069	42.571	0.016	10.0152	0.0062	1.6477	0.0017
070	42.540	0.016	10.0080	0.0062	1.6465	0.0017
071	42.612	0.016	10.0248	0.0062	1.6492	0.0017
072	42.513	0.016	10.0016	0.0062	1.6454	0.0017
073	42.615	0.016	10.0256	0.0062	1.6494	0.0017
074	42.496	0.016	9.9976	0.0062	1.6448	0.0017
075	42.554	0.016	10.0112	0.0062	1.6470	0.0017
076	42.614	0.016	10.0252	0.0062	1.6493	0.0017
077	42.563	0.016	10.0132	0.0062	1.6473	0.0017
078	42.544	0.016	10.0088	0.0062	1.6466	0.0017
079	42.574	0.016	10.0160	0.0062	1.6478	0.0017
080	42.546	0.016	10.0092	0.0062	1.6467	0.0017
081	42.573	0.016	10.0156	0.0062	1.6477	0.0017
082	42.542	0.016	10.0084	0.0062	1.6465	0.0017
083	42.527	0.016	10.0048	0.0062	1.6460	0.0017
084	42.551	0.016	10.0104	0.0062	1.6469	0.0017
085	42.571	0.016	10.0152	0.0062	1.6477	0.0017
086	42.512	0.016	10.0012	0.0062	1.6454	0.0017
087	42.534	0.016	10.0064	0.0062	1.6462	0.0017
088	42.561	0.016	10.0128	0.0062	1.6473	0.0017
089	42.571	0.016	10.0152	0.0062	1.6477	0.0017
090	42.525	0.016	10.0044	0.0062	1.6459	0.0017
091	42.564	0.016	10.0136	0.0062	1.6474	0.0017
092	42.571	0.016	10.0152	0.0062	1.6477	0.0017
093	42.515	0.016	10.0020	0.0062	1.6455	0.0017
094	42.542	0.016	10.0084	0.0062	1.6465	0.0017
095	42.529	0.016	10.0052	0.0062	1.6460	0.0017
096	42.578	0.016	10.0168	0.0062	1.6479	0.0017
097	42.525	0.016	10.0044	0.0062	1.6459	0.0017
098	42.488	0.016	9.9956	0.0062	1.6444	0.0017
099	42.513	0.016	10.0016	0.0062	1.6454	0.0017
100	42.558	0.016	10.0120	0.0062	1.6471	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
101	42.532	0.016	10.0060	0.0062	1.6462	0.0017
102	42.556	0.016	10.0116	0.0062	1.6471	0.0017
103	42.508	0.016	10.0004	0.0062	1.6452	0.0017
104	42.558	0.016	10.0120	0.0062	1.6471	0.0017
105	42.488	0.016	9.9956	0.0062	1.6444	0.0017
106	42.527	0.016	10.0048	0.0062	1.6460	0.0017
107	42.576	0.016	10.0164	0.0062	1.6479	0.0017
108	42.525	0.016	10.0044	0.0062	1.6459	0.0017
109	42.573	0.016	10.0156	0.0062	1.6477	0.0017
110	42.518	0.016	10.0028	0.0062	1.6456	0.0017
111	42.532	0.016	10.0060	0.0062	1.6462	0.0017
112	42.503	0.016	9.9992	0.0062	1.6450	0.0017
113	42.510	0.016	10.0008	0.0062	1.6453	0.0017
114	42.524	0.016	10.0040	0.0062	1.6458	0.0017
115	42.580	0.016	10.0172	0.0062	1.6480	0.0017
116	42.515	0.016	10.0020	0.0062	1.6455	0.0017
117	42.501	0.016	9.9988	0.0062	1.6450	0.0017
118	42.527	0.016	10.0048	0.0062	1.6460	0.0017
119	42.573	0.016	10.0156	0.0062	1.6477	0.0017
120	42.522	0.016	10.0036	0.0062	1.6458	0.0017
121	42.508	0.016	10.0004	0.0062	1.6452	0.0017
122	42.520	0.016	10.0032	0.0062	1.6457	0.0017
123	42.566	0.016	10.0140	0.0062	1.6475	0.0017
124	42.493	0.016	9.9968	0.0062	1.6446	0.0017
125	42.573	0.016	10.0156	0.0062	1.6477	0.0017
126	42.510	0.016	10.0008	0.0062	1.6453	0.0017
127	42.474	0.016	9.9924	0.0062	1.6439	0.0017
128	42.532	0.016	10.0060	0.0062	1.6462	0.0017
129	42.595	0.016	10.0208	0.0062	1.6486	0.0017
130	42.469	0.016	9.9912	0.0062	1.6437	0.0017
131	42.515	0.016	10.0020	0.0062	1.6455	0.0017
132	42.507	0.016	10.0000	0.0062	1.6452	0.0017
133	42.563	0.016	10.0132	0.0062	1.6473	0.0017
134	42.518	0.016	10.0028	0.0062	1.6456	0.0017
135	42.498	0.016	9.9980	0.0062	1.6448	0.0017
136	42.573	0.016	10.0156	0.0062	1.6477	0.0017
137	42.493	0.016	9.9968	0.0062	1.6446	0.0017
138	42.522	0.016	10.0036	0.0062	1.6458	0.0017
139	42.503	0.016	9.9992	0.0062	1.6450	0.0017
140	42.491	0.016	9.9964	0.0062	1.6446	0.0017
141	42.539	0.016	10.0076	0.0062	1.6464	0.0017
142	42.552	0.016	10.0108	0.0062	1.6469	0.0017
143	42.484	0.016	9.9948	0.0062	1.6443	0.0017
144	42.512	0.016	10.0012	0.0062	1.6454	0.0017
145	42.495	0.016	9.9972	0.0062	1.6447	0.0017
146	42.505	0.016	9.9996	0.0062	1.6451	0.0017
147	42.529	0.016	10.0052	0.0062	1.6460	0.0017
148	42.512	0.016	10.0012	0.0062	1.6454	0.0017
149	42.512	0.016	10.0012	0.0062	1.6454	0.0017
150	42.541	0.016	10.0080	0.0062	1.6465	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
151	42.508	0.016	10.0004	0.0062	1.6452	0.0017
152	42.522	0.016	10.0036	0.0062	1.6458	0.0017
153	42.473	0.016	9.9920	0.0062	1.6439	0.0017
154	42.586	0.016	10.0188	0.0062	1.6483	0.0017
155	42.490	0.016	9.9960	0.0062	1.6445	0.0017
156	42.467	0.016	9.9908	0.0062	1.6437	0.0017
157	42.527	0.016	10.0048	0.0062	1.6460	0.0017
158	42.532	0.016	10.0060	0.0062	1.6462	0.0017
159	42.571	0.016	10.0152	0.0062	1.6477	0.0017
160	42.503	0.016	9.9992	0.0062	1.6450	0.0017
161	42.484	0.016	9.9948	0.0062	1.6443	0.0017
162	42.534	0.016	10.0064	0.0062	1.6462	0.0017
163	42.512	0.016	10.0012	0.0062	1.6454	0.0017
164	42.505	0.016	9.9996	0.0062	1.6451	0.0017
165	42.541	0.016	10.0080	0.0062	1.6465	0.0017
166	42.559	0.016	10.0124	0.0062	1.6472	0.0017
167	42.483	0.016	9.9944	0.0062	1.6442	0.0017
168	42.501	0.016	9.9988	0.0062	1.6450	0.0017
169	42.498	0.016	9.9980	0.0062	1.6448	0.0017
170	42.518	0.016	10.0028	0.0062	1.6456	0.0017
171	42.561	0.016	10.0128	0.0062	1.6473	0.0017
172	42.488	0.016	9.9956	0.0062	1.6444	0.0017
173	42.510	0.016	10.0008	0.0062	1.6453	0.0017
174	42.564	0.016	10.0136	0.0062	1.6474	0.0017
175	42.541	0.016	10.0080	0.0062	1.6465	0.0017
176	42.449	0.016	9.9864	0.0062	1.6429	0.0017
177	42.530	0.016	10.0056	0.0062	1.6461	0.0017
178	42.529	0.016	10.0052	0.0062	1.6460	0.0017
179	42.493	0.016	9.9968	0.0062	1.6446	0.0017
180	42.558	0.016	10.0120	0.0062	1.6471	0.0017
181	42.454	0.016	9.9876	0.0062	1.6431	0.0017
182	42.539	0.016	10.0076	0.0062	1.6464	0.0017
183	42.564	0.016	10.0136	0.0062	1.6474	0.0017
184	42.512	0.016	10.0012	0.0062	1.6454	0.0017
185	42.518	0.016	10.0028	0.0062	1.6456	0.0017
186	42.454	0.016	9.9876	0.0062	1.6431	0.0017
187	42.552	0.016	10.0108	0.0062	1.6469	0.0017
188	42.498	0.016	9.9980	0.0062	1.6448	0.0017
189	42.585	0.016	10.0184	0.0062	1.6482	0.0017
190	42.488	0.016	9.9956	0.0062	1.6444	0.0017
191	42.505	0.016	9.9996	0.0062	1.6451	0.0017
192	42.559	0.016	10.0124	0.0062	1.6472	0.0017
193	42.465	0.016	9.9903	0.0062	1.6436	0.0017
194	42.481	0.016	9.9939	0.0062	1.6442	0.0017
195	42.567	0.016	10.0143	0.0062	1.6475	0.0017
196	42.477	0.016	9.9931	0.0062	1.6440	0.0017
197	42.520	0.016	10.0031	0.0062	1.6457	0.0017
198	42.482	0.016	9.9943	0.0062	1.6442	0.0017
199	42.542	0.016	10.0083	0.0062	1.6465	0.0017
200	42.537	0.016	10.0071	0.0062	1.6463	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
201	42.554	0.016	10.0111	0.0062	1.6470	0.0017
202	42.474	0.016	9.9923	0.0062	1.6439	0.0017
203	42.511	0.016	10.0011	0.0062	1.6454	0.0017
204	42.581	0.016	10.0175	0.0062	1.6481	0.0017
205	42.465	0.016	9.9903	0.0062	1.6436	0.0017
206	42.544	0.016	10.0087	0.0062	1.6466	0.0017
207	42.503	0.016	9.9991	0.0062	1.6450	0.0017
208	42.537	0.016	10.0071	0.0062	1.6463	0.0017
209	42.479	0.016	9.9935	0.0062	1.6441	0.0017
210	42.516	0.016	10.0023	0.0062	1.6456	0.0017
211	42.556	0.016	10.0115	0.0062	1.6471	0.0017
212	42.499	0.016	9.9983	0.0062	1.6449	0.0017
213	42.493	0.016	9.9967	0.0062	1.6446	0.0017
214	42.530	0.016	10.0055	0.0062	1.6461	0.0017
215	42.501	0.016	9.9987	0.0062	1.6450	0.0017
216	42.510	0.016	10.0007	0.0062	1.6453	0.0017
217	42.540	0.016	10.0079	0.0062	1.6465	0.0017
218	42.498	0.016	9.9979	0.0062	1.6448	0.0017
219	42.540	0.016	10.0079	0.0062	1.6465	0.0017
220	42.516	0.016	10.0023	0.0062	1.6456	0.0017
221	42.499	0.016	9.9983	0.0062	1.6449	0.0017
222	42.537	0.016	10.0071	0.0062	1.6463	0.0017
223	42.508	0.016	10.0003	0.0062	1.6452	0.0017
224	42.533	0.016	10.0063	0.0062	1.6462	0.0017
225	42.494	0.016	9.9971	0.0062	1.6447	0.0017
226	42.578	0.016	10.0167	0.0062	1.6479	0.0017
227	42.530	0.016	10.0055	0.0062	1.6461	0.0017
228	42.491	0.016	9.9963	0.0062	1.6446	0.0017
229	42.501	0.016	9.9987	0.0062	1.6450	0.0017
230	42.583	0.016	10.0179	0.0062	1.6481	0.0017
231	42.568	0.016	10.0144	0.0062	1.6475	0.0017
232	42.490	0.016	9.9960	0.0062	1.6445	0.0017
233	42.491	0.016	9.9964	0.0062	1.6446	0.0017
234	42.507	0.016	10.0000	0.0062	1.6452	0.0017
235	42.590	0.016	10.0196	0.0062	1.6484	0.0017
236	42.478	0.016	9.9932	0.0062	1.6441	0.0017
237	42.500	0.016	9.9984	0.0062	1.6449	0.0017
238	42.539	0.016	10.0076	0.0062	1.6464	0.0017
239	42.512	0.016	10.0012	0.0062	1.6454	0.0017
240	42.524	0.016	10.0040	0.0062	1.6458	0.0017
241	42.485	0.016	9.9948	0.0062	1.6443	0.0017
242	42.517	0.016	10.0024	0.0062	1.6456	0.0017
243	42.452	0.016	9.9872	0.0062	1.6431	0.0017
244	42.485	0.016	9.9948	0.0062	1.6443	0.0017
245	42.585	0.016	10.0184	0.0062	1.6482	0.0017
246	42.571	0.016	10.0152	0.0062	1.6477	0.0017
247	42.474	0.016	9.9924	0.0062	1.6439	0.0017
248	42.551	0.016	10.0104	0.0062	1.6469	0.0017
249	42.415	0.016	9.9784	0.0062	1.6416	0.0017
250	42.519	0.016	10.0028	0.0062	1.6456	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
251	42.510	0.016	10.0008	0.0062	1.6453	0.0017
252	42.505	0.016	9.9996	0.0062	1.6451	0.0017
253	42.532	0.016	10.0060	0.0062	1.6462	0.0017
254	42.548	0.016	10.0096	0.0062	1.6468	0.0017
255	42.529	0.016	10.0052	0.0062	1.6460	0.0017
256	42.503	0.016	9.9992	0.0062	1.6450	0.0017
257	42.463	0.016	9.9896	0.0062	1.6435	0.0017
258	42.515	0.016	10.0020	0.0062	1.6455	0.0017
259	42.527	0.016	10.0048	0.0062	1.6460	0.0017
260	42.498	0.016	9.9980	0.0062	1.6448	0.0017
261	42.508	0.016	10.0004	0.0062	1.6452	0.0017
262	42.474	0.016	9.9924	0.0062	1.6439	0.0017
263	42.527	0.016	10.0048	0.0062	1.6460	0.0017
264	42.519	0.016	10.0028	0.0062	1.6456	0.0017
265	42.541	0.016	10.0080	0.0062	1.6465	0.0017
266	42.520	0.016	10.0032	0.0062	1.6457	0.0017
267	42.461	0.016	9.9892	0.0062	1.6434	0.0017
268	42.498	0.016	9.9980	0.0062	1.6448	0.0017
269	42.440	0.016	9.9844	0.0062	1.6426	0.0017
270	42.531	0.016	10.0056	0.0062	1.6461	0.0017
271	42.561	0.016	10.0128	0.0062	1.6473	0.0017
272	42.539	0.016	10.0076	0.0062	1.6464	0.0017
273	42.485	0.016	9.9948	0.0062	1.6443	0.0017
274	42.541	0.016	10.0080	0.0062	1.6465	0.0017
275	42.478	0.016	9.9932	0.0062	1.6441	0.0017
276	42.503	0.016	9.9992	0.0062	1.6450	0.0017
277	42.485	0.016	9.9948	0.0062	1.6443	0.0017
278	42.515	0.016	10.0020	0.0062	1.6455	0.0017
279	42.531	0.016	10.0056	0.0062	1.6461	0.0017
280	42.469	0.016	9.9912	0.0062	1.6437	0.0017
281	42.580	0.016	10.0172	0.0062	1.6480	0.0017
282	42.442	0.016	9.9848	0.0062	1.6427	0.0017
283	42.500	0.016	9.9984	0.0062	1.6449	0.0017
284	42.529	0.016	10.0052	0.0062	1.6460	0.0017
285	42.502	0.016	9.9988	0.0062	1.6450	0.0017
286	42.480	0.016	9.9936	0.0062	1.6441	0.0017
287	42.480	0.016	9.9936	0.0062	1.6441	0.0017
288	42.459	0.016	9.9889	0.0062	1.6433	0.0017
289	42.560	0.016	10.0124	0.0062	1.6472	0.0017
290	42.578	0.016	10.0168	0.0062	1.6479	0.0017
291	42.459	0.016	9.9889	0.0062	1.6433	0.0017
292	42.442	0.016	9.9849	0.0062	1.6427	0.0017
293	42.524	0.016	10.0040	0.0062	1.6458	0.0017
294	42.558	0.016	10.0120	0.0062	1.6472	0.0017
295	42.517	0.016	10.0025	0.0062	1.6456	0.0017
296	42.473	0.016	9.9921	0.0062	1.6439	0.0017
297	42.483	0.016	9.9945	0.0062	1.6443	0.0017
298	42.441	0.016	9.9845	0.0062	1.6426	0.0017
299	42.578	0.016	10.0168	0.0062	1.6479	0.0017
300	42.492	0.016	9.9965	0.0062	1.6446	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
301	42.507	0.016	10.0001	0.0062	1.6452	0.0017
302	42.500	0.016	9.9985	0.0062	1.6449	0.0017
303	42.488	0.016	9.9957	0.0062	1.6445	0.0017
304	42.509	0.016	10.0005	0.0062	1.6452	0.0017
305	42.429	0.016	9.9817	0.0062	1.6422	0.0017
306	42.668	0.016	10.0380	0.0062	1.6514	0.0017
307	42.407	0.016	9.9765	0.0061	1.6413	0.0017
308	42.571	0.016	10.0152	0.0062	1.6477	0.0017
309	42.459	0.016	9.9889	0.0062	1.6433	0.0017
310	42.476	0.016	9.9929	0.0062	1.6440	0.0017
311	42.505	0.016	9.9997	0.0062	1.6451	0.0017
312	42.602	0.016	10.0224	0.0062	1.6489	0.0017
313	42.478	0.016	9.9933	0.0062	1.6441	0.0017
314	42.551	0.016	10.0104	0.0062	1.6469	0.0017
315	42.396	0.016	9.9741	0.0061	1.6409	0.0017
316	42.541	0.016	10.0080	0.0062	1.6465	0.0017
317	42.507	0.016	10.0001	0.0062	1.6452	0.0017
318	42.514	0.016	10.0017	0.0062	1.6454	0.0017
319	42.478	0.016	9.9933	0.0062	1.6441	0.0017
320	42.534	0.016	10.0064	0.0062	1.6462	0.0017
321	42.493	0.016	9.9969	0.0062	1.6447	0.0017
322	42.585	0.016	10.0184	0.0062	1.6482	0.0017
323	42.430	0.016	9.9821	0.0062	1.6422	0.0017
324	42.553	0.016	10.0108	0.0062	1.6470	0.0017
325	42.485	0.016	9.9949	0.0062	1.6443	0.0017
326	42.539	0.016	10.0076	0.0062	1.6464	0.0017
327	42.478	0.016	9.9933	0.0062	1.6441	0.0017
328	42.549	0.016	10.0100	0.0062	1.6468	0.0017
329	42.492	0.016	9.9965	0.0062	1.6446	0.0017
330	42.524	0.016	10.0040	0.0062	1.6458	0.0017
331	42.469	0.016	9.9913	0.0062	1.6437	0.0017
332	42.571	0.016	10.0152	0.0062	1.6477	0.0017
333	42.554	0.016	10.0112	0.0062	1.6470	0.0017
334	42.439	0.016	9.9841	0.0062	1.6425	0.0017
335	42.531	0.016	10.0056	0.0062	1.6461	0.0017
336	42.517	0.016	10.0025	0.0062	1.6456	0.0017
337	42.485	0.016	9.9949	0.0062	1.6443	0.0017
338	42.464	0.016	9.9901	0.0062	1.6435	0.0017
339	42.636	0.016	10.0304	0.0062	1.6502	0.0017
340	42.439	0.016	9.9841	0.0062	1.6425	0.0017
341	42.575	0.016	10.0160	0.0062	1.6478	0.0017
342	42.505	0.016	9.9997	0.0062	1.6451	0.0017
343	42.531	0.016	10.0056	0.0062	1.6461	0.0017
344	42.458	0.016	9.9885	0.0062	1.6433	0.0017
345	42.568	0.016	10.0144	0.0062	1.6475	0.0017
346	42.400	0.016	9.9749	0.0061	1.6410	0.0017
347	42.597	0.016	10.0212	0.0062	1.6487	0.0017
348	42.488	0.016	9.9957	0.0062	1.6445	0.0017
349	42.575	0.016	10.0160	0.0062	1.6478	0.0017
350	42.517	0.016	10.0025	0.0062	1.6456	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
351	42.461	0.016	9.9893	0.0062	1.6434	0.0017
352	42.621	0.016	10.0268	0.0062	1.6496	0.0017
353	42.434	0.016	9.9829	0.0062	1.6424	0.0017
354	42.531	0.016	10.0056	0.0062	1.6461	0.0017
355	42.515	0.016	10.0021	0.0062	1.6455	0.0017
356	42.561	0.016	10.0128	0.0062	1.6473	0.0017
357	42.447	0.016	9.9861	0.0062	1.6429	0.0017
358	42.629	0.016	10.0288	0.0062	1.6499	0.0017
359	42.442	0.016	9.9849	0.0062	1.6427	0.0017
360	42.510	0.016	10.0009	0.0062	1.6453	0.0017
361	42.583	0.016	10.0180	0.0062	1.6481	0.0017
362	42.546	0.016	10.0092	0.0062	1.6467	0.0017
363	42.493	0.016	9.9969	0.0062	1.6447	0.0017
364	42.441	0.016	9.9845	0.0062	1.6426	0.0017
365	42.548	0.016	10.0096	0.0062	1.6468	0.0017
366	42.468	0.016	9.9909	0.0062	1.6437	0.0017
367	42.656	0.016	10.0352	0.0062	1.6510	0.0017
368	42.512	0.016	10.0013	0.0062	1.6454	0.0017
369	42.502	0.016	9.9989	0.0062	1.6450	0.0017
370	42.427	0.016	9.9813	0.0062	1.6421	0.0017
371	42.565	0.016	10.0136	0.0062	1.6474	0.0017
372	42.497	0.016	9.9977	0.0062	1.6448	0.0017
373	42.556	0.016	10.0116	0.0062	1.6471	0.0017
374	42.502	0.016	9.9989	0.0062	1.6450	0.0017
375	42.490	0.016	9.9961	0.0062	1.6445	0.0017
376	42.551	0.016	10.0104	0.0062	1.6469	0.0017
377	42.422	0.016	9.9801	0.0062	1.6419	0.0017
378	42.611	0.016	10.0244	0.0062	1.6492	0.0017
379	42.588	0.016	10.0192	0.0062	1.6483	0.0017
380	42.480	0.016	9.9937	0.0062	1.6441	0.0017
381	42.556	0.016	10.0116	0.0062	1.6471	0.0017
382	42.369	0.016	9.9677	0.0061	1.6399	0.0017
383	42.643	0.016	10.0320	0.0062	1.6504	0.0017
384	42.429	0.016	9.9817	0.0062	1.6422	0.0017
385	42.621	0.016	10.0269	0.0062	1.6496	0.0017
386	42.480	0.016	9.9937	0.0062	1.6441	0.0017
387	42.548	0.016	10.0097	0.0062	1.6468	0.0017
388	42.439	0.016	9.9841	0.0062	1.6426	0.0017
389	42.587	0.016	10.0189	0.0062	1.6483	0.0017
390	42.475	0.016	9.9925	0.0062	1.6439	0.0017
391	42.481	0.016	9.9941	0.0062	1.6442	0.0017
392	42.677	0.016	10.0401	0.0062	1.6518	0.0017
393	42.522	0.016	10.0037	0.0062	1.6458	0.0017
394	42.507	0.016	10.0001	0.0062	1.6452	0.0017
395	42.458	0.016	9.9885	0.0062	1.6433	0.0017
396	42.512	0.016	10.0013	0.0062	1.6454	0.0017
397	42.529	0.016	10.0053	0.0062	1.6460	0.0017
398	42.536	0.016	10.0069	0.0062	1.6463	0.0017
399	42.485	0.016	9.9949	0.0062	1.6443	0.0017
400	42.538	0.016	10.0073	0.0062	1.6464	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
401	42.560	0.016	10.0125	0.0062	1.6472	0.0017
402	42.532	0.016	10.0061	0.0062	1.6462	0.0017
403	42.498	0.016	9.9981	0.0062	1.6449	0.0017
404	42.510	0.016	10.0009	0.0062	1.6453	0.0017
405	42.585	0.016	10.0185	0.0062	1.6482	0.0017
406	42.512	0.016	10.0013	0.0062	1.6454	0.0017
407	42.532	0.016	10.0061	0.0062	1.6462	0.0017
408	42.497	0.016	9.9977	0.0062	1.6448	0.0017
409	42.517	0.016	10.0025	0.0062	1.6456	0.0017
410	42.555	0.016	10.0113	0.0062	1.6470	0.0017
411	42.529	0.016	10.0053	0.0062	1.6460	0.0017
412	42.454	0.016	9.9877	0.0062	1.6431	0.0017
413	42.519	0.016	10.0029	0.0062	1.6456	0.0017
414	42.612	0.016	10.0249	0.0062	1.6493	0.0017
415	42.461	0.016	9.9893	0.0062	1.6434	0.0017
416	42.556	0.016	10.0117	0.0062	1.6471	0.0017
417	42.524	0.016	10.0041	0.0062	1.6458	0.0017
418	42.538	0.016	10.0073	0.0062	1.6464	0.0017
419	42.461	0.016	9.9893	0.0062	1.6434	0.0017
420	42.534	0.016	10.0065	0.0062	1.6462	0.0017
421	42.568	0.016	10.0145	0.0062	1.6476	0.0017
422	42.510	0.016	10.0009	0.0062	1.6453	0.0017
423	42.521	0.016	10.0033	0.0062	1.6457	0.0017
424	42.551	0.016	10.0105	0.0062	1.6469	0.0017
425	42.437	0.016	9.9837	0.0062	1.6425	0.0017
426	42.575	0.016	10.0161	0.0062	1.6478	0.0017
427	42.536	0.016	10.0069	0.0062	1.6463	0.0017
428	42.565	0.016	10.0137	0.0062	1.6474	0.0017
429	42.473	0.016	9.9921	0.0062	1.6439	0.0017
430	42.553	0.016	10.0109	0.0062	1.6470	0.0017
431	42.492	0.016	9.9965	0.0062	1.6446	0.0017
432	42.539	0.016	10.0077	0.0062	1.6464	0.0017
433	42.430	0.016	9.9821	0.0062	1.6422	0.0017
434	42.655	0.016	10.0349	0.0062	1.6509	0.0017
435	42.515	0.016	10.0021	0.0062	1.6455	0.0017
436	42.553	0.016	10.0109	0.0062	1.6470	0.0017
437	42.481	0.016	9.9941	0.0062	1.6442	0.0017
438	42.497	0.016	9.9977	0.0062	1.6448	0.0017
439	42.577	0.016	10.0165	0.0062	1.6479	0.0017
440	42.532	0.016	10.0061	0.0062	1.6462	0.0017
441	42.456	0.016	9.9881	0.0062	1.6432	0.0017
442	42.617	0.016	10.0261	0.0062	1.6495	0.0017
443	42.500	0.016	9.9985	0.0062	1.6449	0.0017
444	42.504	0.016	9.9993	0.0062	1.6451	0.0017
445	42.502	0.016	9.9989	0.0062	1.6450	0.0017
446	42.543	0.016	10.0085	0.0062	1.6466	0.0017
447	42.570	0.016	10.0149	0.0062	1.6476	0.0017
448	42.464	0.016	9.9901	0.0062	1.6435	0.0017
449	42.553	0.016	10.0109	0.0062	1.6470	0.0017
450	42.498	0.016	9.9981	0.0062	1.6449	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
451	42.532	0.016	10.0061	0.0062	1.6462	0.0017
452	42.475	0.016	9.9925	0.0062	1.6439	0.0017
453	42.583	0.016	10.0181	0.0062	1.6481	0.0017
454	42.590	0.016	10.0197	0.0062	1.6484	0.0017
455	42.424	0.016	9.9805	0.0062	1.6420	0.0017
456	42.563	0.016	10.0133	0.0062	1.6474	0.0017
457	42.534	0.016	10.0065	0.0062	1.6462	0.0017
458	42.466	0.016	9.9905	0.0062	1.6436	0.0017
459	42.595	0.016	10.0209	0.0062	1.6486	0.0017
460	42.468	0.016	9.9909	0.0062	1.6437	0.0017
461	42.481	0.016	9.9941	0.0062	1.6442	0.0017
462	42.556	0.016	10.0117	0.0062	1.6471	0.0017
463	42.570	0.016	10.0149	0.0062	1.6476	0.0017
464	42.476	0.016	9.9929	0.0062	1.6440	0.0017
465	42.478	0.016	9.9933	0.0062	1.6441	0.0017
466	42.543	0.016	10.0085	0.0062	1.6466	0.0017
467	42.623	0.016	10.0273	0.0062	1.6497	0.0017
468	42.524	0.016	10.0041	0.0062	1.6458	0.0017
469	42.515	0.016	10.0021	0.0062	1.6455	0.0017
470	42.488	0.016	9.9957	0.0062	1.6445	0.0017
471	42.531	0.016	10.0057	0.0062	1.6461	0.0017
472	42.492	0.016	9.9965	0.0062	1.6446	0.0017
473	42.582	0.016	10.0177	0.0062	1.6481	0.0017
474	42.463	0.016	9.9897	0.0062	1.6435	0.0017
475	42.527	0.016	10.0049	0.0062	1.6460	0.0017
476	42.548	0.016	10.0097	0.0062	1.6468	0.0017
477	42.519	0.016	10.0029	0.0062	1.6456	0.0017
478	42.541	0.016	10.0081	0.0062	1.6465	0.0017
479	42.514	0.016	10.0017	0.0062	1.6454	0.0017
480	42.470	0.016	9.9913	0.0062	1.6437	0.0017
481	42.568	0.016	10.0145	0.0062	1.6476	0.0017
482	42.422	0.016	9.9801	0.0062	1.6419	0.0017
483	42.490	0.016	9.9961	0.0062	1.6445	0.0017
484	42.548	0.016	10.0097	0.0062	1.6468	0.0017
485	42.507	0.016	10.0001	0.0062	1.6452	0.0017
486	42.422	0.016	9.9801	0.0062	1.6419	0.0017
487	42.524	0.016	10.0041	0.0062	1.6458	0.0017
488	42.563	0.016	10.0133	0.0062	1.6474	0.0017
489	42.521	0.016	10.0033	0.0062	1.6457	0.0017
490	42.562	0.016	10.0129	0.0062	1.6473	0.0017
491	42.499	0.016	9.9981	0.0062	1.6449	0.0017
492	42.460	0.016	9.9889	0.0062	1.6433	0.0017
493	42.439	0.016	9.9841	0.0062	1.6426	0.0017
494	42.548	0.016	10.0097	0.0062	1.6468	0.0017
495	42.522	0.016	10.0037	0.0062	1.6458	0.0017
496	42.546	0.016	10.0093	0.0062	1.6467	0.0017
497	42.512	0.016	10.0013	0.0062	1.6454	0.0017
498	42.494	0.016	9.9969	0.0062	1.6447	0.0017
499	42.597	0.016	10.0213	0.0062	1.6487	0.0017
500	42.465	0.016	9.9901	0.0062	1.6435	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
501	42.607	0.016	10.0237	0.0062	1.6491	0.0017
502	42.432	0.016	9.9825	0.0062	1.6423	0.0017
503	42.543	0.016	10.0085	0.0062	1.6466	0.0017
504	42.507	0.016	10.0001	0.0062	1.6452	0.0017
505	42.495	0.016	9.9973	0.0062	1.6447	0.0017
506	42.534	0.016	10.0065	0.0062	1.6462	0.0017
507	42.550	0.016	10.0101	0.0062	1.6468	0.0017
508	42.507	0.016	10.0001	0.0062	1.6452	0.0017
509	42.548	0.016	10.0097	0.0062	1.6468	0.0017
510	42.497	0.016	9.9977	0.0062	1.6448	0.0017
511	42.528	0.016	10.0049	0.0062	1.6460	0.0017
512	42.514	0.016	10.0017	0.0062	1.6455	0.0017
513	42.490	0.016	9.9961	0.0062	1.6445	0.0017
514	42.560	0.016	10.0125	0.0062	1.6472	0.0017
515	42.517	0.016	10.0025	0.0062	1.6456	0.0017
516	42.480	0.016	9.9937	0.0062	1.6441	0.0017
517	42.483	0.016	9.9945	0.0062	1.6443	0.0017
518	42.567	0.016	10.0141	0.0062	1.6475	0.0017
519	42.521	0.016	10.0033	0.0062	1.6457	0.0017
520	42.536	0.016	10.0069	0.0062	1.6463	0.0017
521	42.570	0.016	10.0149	0.0062	1.6476	0.0017
522	42.471	0.016	9.9917	0.0062	1.6438	0.0017
523	42.629	0.016	10.0289	0.0062	1.6499	0.0017
524	42.458	0.016	9.9885	0.0062	1.6433	0.0017
525	42.545	0.016	10.0089	0.0062	1.6466	0.0017
526	42.460	0.016	9.9889	0.0062	1.6433	0.0017
527	42.567	0.016	10.0141	0.0062	1.6475	0.0017
528	42.436	0.016	9.9833	0.0062	1.6424	0.0017
529	42.650	0.016	10.0337	0.0062	1.6507	0.0017
530	42.480	0.016	9.9937	0.0062	1.6441	0.0017
531	42.534	0.016	10.0065	0.0062	1.6462	0.0017
532	42.471	0.016	9.9917	0.0062	1.6438	0.0017
533	42.584	0.016	10.0181	0.0062	1.6482	0.0017
534	42.550	0.016	10.0101	0.0062	1.6468	0.0017
535	42.514	0.016	10.0017	0.0062	1.6455	0.0017
536	42.482	0.016	9.9941	0.0062	1.6442	0.0017
537	42.546	0.016	10.0093	0.0062	1.6467	0.0017
538	42.548	0.016	10.0097	0.0062	1.6468	0.0017
539	42.505	0.016	9.9997	0.0062	1.6451	0.0017
540	42.539	0.016	10.0077	0.0062	1.6464	0.0017
541	42.612	0.016	10.0249	0.0062	1.6493	0.0017
542	42.454	0.016	9.9877	0.0062	1.6432	0.0017
543	42.456	0.016	9.9881	0.0062	1.6432	0.0017
544	42.582	0.016	10.0177	0.0062	1.6481	0.0017
545	42.528	0.016	10.0049	0.0062	1.6460	0.0017
546	42.512	0.016	10.0013	0.0062	1.6454	0.0017
547	42.485	0.016	9.9949	0.0062	1.6443	0.0017
548	42.556	0.016	10.0117	0.0062	1.6471	0.0017
549	42.499	0.016	9.9981	0.0062	1.6449	0.0017
550	42.551	0.016	10.0105	0.0062	1.6469	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
551	42.485	0.016	9.9949	0.0062	1.6443	0.0017
552	42.514	0.016	10.0017	0.0062	1.6455	0.0017
553	42.643	0.016	10.0321	0.0062	1.6505	0.0017
554	42.490	0.016	9.9961	0.0062	1.6445	0.0017
555	42.471	0.016	9.9917	0.0062	1.6438	0.0017
556	42.528	0.016	10.0049	0.0062	1.6460	0.0017
557	42.531	0.016	10.0057	0.0062	1.6461	0.0017
558	42.526	0.016	10.0045	0.0062	1.6459	0.0017
559	42.509	0.016	10.0005	0.0062	1.6453	0.0017
560	42.567	0.016	10.0141	0.0062	1.6475	0.0017
561	42.471	0.016	9.9917	0.0062	1.6438	0.0017
562	42.538	0.016	10.0073	0.0062	1.6464	0.0017
563	42.589	0.016	10.0193	0.0062	1.6483	0.0017
564	42.436	0.016	9.9833	0.0062	1.6424	0.0017
565	42.497	0.016	9.9977	0.0062	1.6448	0.0017
566	42.577	0.016	10.0165	0.0062	1.6479	0.0017
567	42.461	0.016	9.9893	0.0062	1.6434	0.0017
568	42.579	0.016	10.0169	0.0062	1.6480	0.0017
569	42.456	0.016	9.9881	0.0062	1.6432	0.0017
570	42.558	0.016	10.0121	0.0062	1.6472	0.0017
571	42.563	0.016	10.0133	0.0062	1.6474	0.0017
572	42.546	0.016	10.0093	0.0062	1.6467	0.0017
573	42.545	0.016	10.0089	0.0062	1.6466	0.0017
574	42.417	0.016	9.9789	0.0062	1.6417	0.0017
575	42.658	0.016	10.0357	0.0062	1.6510	0.0017
576	42.490	0.016	9.9961	0.0062	1.6445	0.0017
577	42.504	0.016	9.9993	0.0062	1.6451	0.0017
578	42.521	0.016	10.0033	0.0062	1.6457	0.0017
579	42.516	0.016	10.0021	0.0062	1.6455	0.0017
580	42.546	0.016	10.0093	0.0062	1.6467	0.0017
581	42.543	0.016	10.0085	0.0062	1.6466	0.0017
582	42.526	0.016	10.0045	0.0062	1.6459	0.0017
583	42.434	0.016	9.9829	0.0062	1.6424	0.0017
584	42.529	0.016	10.0053	0.0062	1.6460	0.0017
585	42.541	0.016	10.0081	0.0062	1.6465	0.0017
586	42.476	0.016	9.9929	0.0062	1.6440	0.0017
587	42.606	0.016	10.0233	0.0062	1.6490	0.0017
588	42.458	0.016	9.9885	0.0062	1.6433	0.0017
589	42.590	0.016	10.0197	0.0062	1.6484	0.0017
590	42.567	0.016	10.0141	0.0062	1.6475	0.0017
591	42.468	0.016	9.9909	0.0062	1.6437	0.0017
592	42.548	0.016	10.0097	0.0062	1.6468	0.0017
593	42.592	0.016	10.0201	0.0062	1.6485	0.0017
594	42.436	0.016	9.9833	0.0062	1.6424	0.0017
595	42.527	0.016	10.0049	0.0062	1.6460	0.0017
596	42.553	0.016	10.0109	0.0062	1.6470	0.0017
597	42.422	0.016	9.9801	0.0062	1.6419	0.0017
598	42.568	0.016	10.0145	0.0062	1.6476	0.0017
599	42.517	0.016	10.0025	0.0062	1.6456	0.0017
600	42.492	0.016	9.9965	0.0062	1.6446	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
601	42.476	0.016	9.9929	0.0062	1.6440	0.0017
602	42.636	0.016	10.0305	0.0062	1.6502	0.0017
603	42.521	0.016	10.0033	0.0062	1.6457	0.0017
604	42.527	0.016	10.0049	0.0062	1.6460	0.0017
605	42.526	0.016	10.0045	0.0062	1.6459	0.0017
606	42.538	0.016	10.0073	0.0062	1.6464	0.0017
607	42.492	0.016	9.9965	0.0062	1.6446	0.0017
608	42.500	0.016	9.9985	0.0062	1.6449	0.0017
609	42.570	0.016	10.0149	0.0062	1.6476	0.0017
610	42.483	0.016	9.9945	0.0062	1.6443	0.0017
611	42.590	0.016	10.0197	0.0062	1.6484	0.0017
612	42.543	0.016	10.0085	0.0062	1.6466	0.0017
613	42.420	0.016	9.9797	0.0062	1.6418	0.0017
614	42.626	0.016	10.0281	0.0062	1.6498	0.0017
615	42.437	0.016	9.9837	0.0062	1.6425	0.0017
616	42.572	0.016	10.0153	0.0062	1.6477	0.0017
617	42.524	0.016	10.0041	0.0062	1.6458	0.0017
618	42.510	0.016	10.0009	0.0062	1.6453	0.0017
619	42.485	0.016	9.9949	0.0062	1.6443	0.0017
620	42.529	0.016	10.0053	0.0062	1.6460	0.0017
621	42.609	0.016	10.0241	0.0062	1.6491	0.0017
622	42.471	0.016	9.9917	0.0062	1.6438	0.0017
623	42.492	0.016	9.9965	0.0062	1.6446	0.0017
624	42.602	0.016	10.0225	0.0062	1.6489	0.0017
625	42.502	0.016	9.9989	0.0062	1.6450	0.0017
626	42.516	0.016	10.0021	0.0062	1.6455	0.0017
627	42.548	0.016	10.0097	0.0062	1.6468	0.0017
628	42.471	0.016	9.9917	0.0062	1.6438	0.0017
629	42.517	0.016	10.0025	0.0062	1.6456	0.0017
630	42.563	0.016	10.0133	0.0062	1.6474	0.0017
631	42.502	0.016	9.9989	0.0062	1.6450	0.0017
632	42.558	0.016	10.0121	0.0062	1.6472	0.0017
633	42.470	0.016	9.9913	0.0062	1.6437	0.0017
634	42.565	0.016	10.0137	0.0062	1.6474	0.0017
635	42.517	0.016	10.0025	0.0062	1.6456	0.0017
636	42.522	0.016	10.0037	0.0062	1.6458	0.0017
637	42.509	0.016	10.0005	0.0062	1.6453	0.0017
638	42.510	0.016	10.0009	0.0062	1.6453	0.0017
639	42.521	0.016	10.0033	0.0062	1.6457	0.0017
640	42.533	0.016	10.0061	0.0062	1.6462	0.0017
641	42.526	0.016	10.0045	0.0062	1.6459	0.0017
642	42.538	0.016	10.0073	0.0062	1.6464	0.0017
643	42.521	0.016	10.0033	0.0062	1.6457	0.0017
644	42.492	0.016	9.9965	0.0062	1.6446	0.0017
645	42.565	0.016	10.0137	0.0062	1.6474	0.0017
646	42.534	0.016	10.0065	0.0062	1.6462	0.0017
647	42.499	0.016	9.9981	0.0062	1.6449	0.0017
648	42.507	0.016	10.0001	0.0062	1.6452	0.0017
649	42.616	0.016	10.0257	0.0062	1.6494	0.0017
650	42.558	0.016	10.0121	0.0062	1.6472	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
651	42.412	0.016	9.9777	0.0062	1.6415	0.0017
652	42.558	0.016	10.0121	0.0062	1.6472	0.0017
653	42.499	0.016	9.9981	0.0062	1.6449	0.0017
654	42.485	0.016	9.9949	0.0062	1.6443	0.0017
655	42.519	0.016	10.0029	0.0062	1.6456	0.0017
656	42.565	0.016	10.0137	0.0062	1.6474	0.0017
657	42.582	0.016	10.0177	0.0062	1.6481	0.0017
658	42.487	0.016	9.9953	0.0062	1.6444	0.0017
659	42.563	0.016	10.0133	0.0062	1.6474	0.0017
660	42.492	0.016	9.9965	0.0062	1.6446	0.0017
661	42.551	0.016	10.0105	0.0062	1.6469	0.0017
662	42.539	0.016	10.0077	0.0062	1.6464	0.0017
663	42.480	0.016	9.9937	0.0062	1.6441	0.0017
664	42.536	0.016	10.0069	0.0062	1.6463	0.0017
665	42.507	0.016	10.0001	0.0062	1.6452	0.0017
666	42.527	0.016	10.0049	0.0062	1.6460	0.0017
667	42.536	0.016	10.0069	0.0062	1.6463	0.0017
668	42.594	0.016	10.0205	0.0062	1.6485	0.0017
669	42.431	0.016	9.9821	0.0062	1.6422	0.0017
670	42.529	0.016	10.0053	0.0062	1.6460	0.0017
671	42.624	0.016	10.0277	0.0062	1.6497	0.0017
672	42.434	0.016	9.9829	0.0062	1.6424	0.0017
673	42.553	0.016	10.0109	0.0062	1.6470	0.0017
674	42.492	0.016	9.9965	0.0062	1.6446	0.0017
675	42.492	0.016	9.9965	0.0062	1.6446	0.0017
676	42.527	0.016	10.0049	0.0062	1.6460	0.0017
677	42.499	0.016	9.9981	0.0062	1.6449	0.0017
678	42.534	0.016	10.0065	0.0062	1.6462	0.0017
679	42.541	0.016	10.0081	0.0062	1.6465	0.0017
680	42.504	0.016	9.9993	0.0062	1.6451	0.0017
681	42.516	0.016	10.0021	0.0062	1.6455	0.0017
682	42.641	0.016	10.0317	0.0062	1.6504	0.0017
683	42.448	0.016	9.9861	0.0062	1.6429	0.0017
684	42.507	0.016	10.0001	0.0062	1.6452	0.0017
685	42.521	0.016	10.0033	0.0062	1.6457	0.0017
686	42.521	0.016	10.0033	0.0062	1.6457	0.0017
687	42.536	0.016	10.0069	0.0062	1.6463	0.0017
688	42.502	0.016	9.9989	0.0062	1.6450	0.0017
689	42.490	0.016	9.9961	0.0062	1.6445	0.0017
690	42.539	0.016	10.0077	0.0062	1.6464	0.0017
691	42.573	0.016	10.0157	0.0062	1.6478	0.0017
692	42.521	0.016	10.0033	0.0062	1.6457	0.0017
693	42.522	0.016	10.0037	0.0062	1.6458	0.0017
694	42.516	0.016	10.0021	0.0062	1.6455	0.0017
695	42.539	0.016	10.0077	0.0062	1.6464	0.0017
696	42.497	0.016	9.9977	0.0062	1.6448	0.0017
697	42.510	0.016	10.0009	0.0062	1.6453	0.0017
698	42.575	0.016	10.0161	0.0062	1.6478	0.0017
699	42.544	0.016	10.0089	0.0062	1.6466	0.0017
700	42.412	0.016	9.9777	0.0062	1.6415	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
701	42.509	0.016	10.0005	0.0062	1.6453	0.0017
702	42.509	0.016	10.0005	0.0062	1.6453	0.0017
703	42.558	0.016	10.0121	0.0062	1.6472	0.0017
704	42.551	0.016	10.0105	0.0062	1.6469	0.0017
705	42.468	0.016	9.9909	0.0062	1.6437	0.0017
706	42.510	0.016	10.0009	0.0062	1.6453	0.0017
707	42.521	0.016	10.0033	0.0062	1.6457	0.0017
708	42.595	0.016	10.0209	0.0062	1.6486	0.0017
709	42.490	0.016	9.9961	0.0062	1.6445	0.0017
710	42.538	0.016	10.0073	0.0062	1.6464	0.0017
711	42.580	0.016	10.0173	0.0062	1.6480	0.0017
712	42.441	0.016	9.9845	0.0062	1.6426	0.0017
713	42.601	0.016	10.0221	0.0062	1.6488	0.0017
714	42.451	0.016	9.9869	0.0062	1.6430	0.0017
715	42.584	0.016	10.0181	0.0062	1.6481	0.0017
716	42.539	0.016	10.0077	0.0062	1.6464	0.0017
717	42.522	0.016	10.0037	0.0062	1.6458	0.0017
718	42.352	0.016	9.9637	0.0061	1.6392	0.0017
719	42.534	0.016	10.0065	0.0062	1.6462	0.0017
720	42.471	0.016	9.9917	0.0062	1.6438	0.0017
721	42.480	0.016	9.9937	0.0062	1.6441	0.0017
722	42.516	0.016	10.0021	0.0062	1.6455	0.0017
723	42.580	0.016	10.0173	0.0062	1.6480	0.0017
724	42.550	0.016	10.0101	0.0062	1.6468	0.0017
725	42.432	0.016	9.9825	0.0062	1.6423	0.0017
726	42.475	0.016	9.9925	0.0062	1.6439	0.0017
727	42.567	0.016	10.0141	0.0062	1.6475	0.0017
728	42.451	0.016	9.9869	0.0062	1.6430	0.0017
729	42.555	0.016	10.0113	0.0062	1.6470	0.0017
730	42.570	0.016	10.0149	0.0062	1.6476	0.0017
731	42.519	0.016	10.0029	0.0062	1.6456	0.0017
732	42.536	0.016	10.0069	0.0062	1.6463	0.0017
733	42.485	0.016	9.9949	0.0062	1.6443	0.0017
734	42.504	0.016	9.9993	0.0062	1.6451	0.0017
735	42.465	0.016	9.9901	0.0062	1.6435	0.0017
736	42.504	0.016	9.9993	0.0062	1.6451	0.0017
737	42.567	0.016	10.0141	0.0062	1.6475	0.0017
738	42.570	0.016	10.0149	0.0062	1.6476	0.0017
739	42.468	0.016	9.9909	0.0062	1.6437	0.0017
740	42.495	0.016	9.9973	0.0062	1.6447	0.0017
741	42.538	0.016	10.0073	0.0062	1.6464	0.0017
742	42.597	0.016	10.0213	0.0062	1.6487	0.0017
743	42.391	0.016	9.9729	0.0061	1.6407	0.0017
744	42.582	0.016	10.0177	0.0062	1.6481	0.0017
745	42.444	0.016	9.9853	0.0062	1.6428	0.0017
746	42.531	0.016	10.0057	0.0062	1.6461	0.0017
747	42.527	0.016	10.0049	0.0062	1.6460	0.0017
748	42.539	0.016	10.0077	0.0062	1.6464	0.0017
749	42.538	0.016	10.0073	0.0062	1.6464	0.0017
750	42.422	0.016	9.9801	0.0062	1.6419	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
751	42.587	0.016	10.0189	0.0062	1.6483	0.0017
752	42.516	0.016	10.0021	0.0062	1.6455	0.0017
753	42.517	0.016	10.0025	0.0062	1.6456	0.0017
754	42.580	0.016	10.0173	0.0062	1.6480	0.0017
755	42.499	0.016	9.9981	0.0062	1.6449	0.0017
756	42.578	0.016	10.0169	0.0062	1.6480	0.0017
757	42.517	0.016	10.0025	0.0062	1.6456	0.0017
758	42.573	0.016	10.0157	0.0062	1.6478	0.0017
759	42.408	0.016	9.9769	0.0062	1.6414	0.0017
760	42.568	0.016	10.0145	0.0062	1.6476	0.0017
761	42.526	0.016	10.0045	0.0062	1.6459	0.0017
762	42.553	0.016	10.0109	0.0062	1.6470	0.0017
763	42.504	0.016	9.9993	0.0062	1.6451	0.0017
764	42.470	0.016	9.9913	0.0062	1.6437	0.0017
765	42.548	0.016	10.0097	0.0062	1.6468	0.0017
766	42.558	0.016	10.0121	0.0062	1.6472	0.0017
767	42.497	0.016	9.9977	0.0062	1.6448	0.0017
768	42.548	0.016	10.0097	0.0062	1.6468	0.0017
769	42.557	0.016	10.0117	0.0062	1.6471	0.0017
770	42.485	0.016	9.9950	0.0062	1.6443	0.0017
771	42.565	0.016	10.0137	0.0062	1.6474	0.0017
772	42.477	0.016	9.9930	0.0062	1.6440	0.0017
773	42.468	0.016	9.9910	0.0062	1.6437	0.0017
774	42.681	0.016	10.0409	0.0062	1.6519	0.0017
775	42.536	0.016	10.0069	0.0062	1.6463	0.0017
776	42.538	0.016	10.0073	0.0062	1.6464	0.0017
777	42.390	0.016	9.9726	0.0061	1.6407	0.0017
778	42.568	0.016	10.0145	0.0062	1.6476	0.0017
779	42.553	0.016	10.0109	0.0062	1.6470	0.0017
780	42.517	0.016	10.0025	0.0062	1.6456	0.0017
781	42.545	0.016	10.0089	0.0062	1.6466	0.0017
782	42.512	0.016	10.0013	0.0062	1.6454	0.0017
783	42.585	0.016	10.0185	0.0062	1.6482	0.0017
784	42.551	0.016	10.0105	0.0062	1.6469	0.0017
785	42.500	0.016	9.9985	0.0062	1.6449	0.0017
786	42.502	0.016	9.9989	0.0062	1.6450	0.0017
787	42.449	0.016	9.9866	0.0062	1.6430	0.0017
788	42.625	0.016	10.0277	0.0062	1.6497	0.0017
789	42.448	0.016	9.9862	0.0062	1.6429	0.0017
790	42.563	0.016	10.0133	0.0062	1.6474	0.0017
791	42.551	0.016	10.0105	0.0062	1.6469	0.0017
792	42.570	0.016	10.0149	0.0062	1.6476	0.0017
793	42.489	0.016	9.9958	0.0062	1.6445	0.0017
794	42.507	0.016	10.0001	0.0062	1.6452	0.0017
795	42.553	0.016	10.0109	0.0062	1.6470	0.0017
796	42.524	0.016	10.0041	0.0062	1.6459	0.0017
797	42.546	0.016	10.0093	0.0062	1.6467	0.0017
798	42.609	0.016	10.0241	0.0062	1.6491	0.0017
799	42.473	0.016	9.9922	0.0062	1.6439	0.0017
800	42.499	0.016	9.9981	0.0062	1.6449	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
801	42.582	0.016	10.0177	0.0062	1.6481	0.0017
802	42.497	0.016	9.9978	0.0062	1.6448	0.0017
803	42.506	0.016	9.9997	0.0062	1.6451	0.0017
804	42.575	0.016	10.0161	0.0062	1.6478	0.0017
805	42.478	0.016	9.9934	0.0062	1.6441	0.0017
806	42.545	0.016	10.0089	0.0062	1.6466	0.0017
807	42.614	0.016	10.0253	0.0062	1.6493	0.0017
808	42.487	0.016	9.9954	0.0062	1.6444	0.0017
809	42.543	0.016	10.0085	0.0062	1.6466	0.0017
810	42.558	0.016	10.0121	0.0062	1.6472	0.0017
811	42.448	0.016	9.9862	0.0062	1.6429	0.0017
812	42.575	0.016	10.0161	0.0062	1.6478	0.0017
813	42.497	0.016	9.9978	0.0062	1.6448	0.0017
814	42.563	0.016	10.0133	0.0062	1.6474	0.0017
815	42.546	0.016	10.0093	0.0062	1.6467	0.0017
816	42.528	0.016	10.0049	0.0062	1.6460	0.0017
817	42.477	0.016	9.9930	0.0062	1.6440	0.0017
818	42.543	0.016	10.0085	0.0062	1.6466	0.0017
819	42.558	0.016	10.0121	0.0062	1.6472	0.0017
820	42.526	0.016	10.0045	0.0062	1.6459	0.0017
821	42.523	0.016	10.0037	0.0062	1.6458	0.0017
822	42.557	0.016	10.0117	0.0062	1.6471	0.0017
823	42.560	0.016	10.0125	0.0062	1.6472	0.0017
824	42.480	0.016	9.9938	0.0062	1.6441	0.0017
825	42.631	0.016	10.0293	0.0062	1.6500	0.0017
826	42.489	0.016	9.9958	0.0062	1.6445	0.0017
827	42.475	0.016	9.9926	0.0062	1.6439	0.0017
828	42.545	0.016	10.0089	0.0062	1.6466	0.0017
829	42.580	0.016	10.0173	0.0062	1.6480	0.0017
830	42.540	0.016	10.0077	0.0062	1.6464	0.0017
831	42.519	0.016	10.0029	0.0062	1.6457	0.0017
832	42.599	0.016	10.0217	0.0062	1.6487	0.0017
833	42.448	0.016	9.9862	0.0062	1.6429	0.0017
834	42.540	0.016	10.0077	0.0062	1.6464	0.0017
835	42.584	0.016	10.0181	0.0062	1.6482	0.0017
836	42.436	0.016	9.9834	0.0062	1.6424	0.0017
837	42.558	0.016	10.0121	0.0062	1.6472	0.0017
838	42.528	0.016	10.0049	0.0062	1.6460	0.0017
839	42.500	0.016	9.9985	0.0062	1.6449	0.0017
840	42.551	0.016	10.0105	0.0062	1.6469	0.0017
841	42.506	0.016	9.9997	0.0062	1.6451	0.0017
842	42.623	0.016	10.0273	0.0062	1.6497	0.0017
843	42.465	0.016	9.9902	0.0062	1.6436	0.0017
844	42.574	0.016	10.0157	0.0062	1.6478	0.0017
845	42.470	0.016	9.9914	0.0062	1.6437	0.0017
846	42.562	0.016	10.0129	0.0062	1.6473	0.0017
847	42.545	0.016	10.0089	0.0062	1.6466	0.0017
848	42.495	0.016	9.9974	0.0062	1.6447	0.0017
849	42.616	0.016	10.0257	0.0062	1.6494	0.0017
850	42.543	0.016	10.0085	0.0062	1.6466	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
851	42.507	0.016	10.0001	0.0062	1.6452	0.0017
852	42.495	0.016	9.9974	0.0062	1.6447	0.0017
853	42.506	0.016	9.9997	0.0062	1.6451	0.0017
854	42.648	0.016	10.0333	0.0062	1.6507	0.0017
855	42.468	0.016	9.9910	0.0062	1.6437	0.0017
856	42.536	0.016	10.0069	0.0062	1.6463	0.0017
857	42.550	0.016	10.0101	0.0062	1.6468	0.0017
858	42.579	0.016	10.0169	0.0062	1.6480	0.0017
859	42.455	0.016	9.9878	0.0062	1.6432	0.0017
860	42.574	0.016	10.0157	0.0062	1.6478	0.0017
861	42.477	0.016	9.9930	0.0062	1.6440	0.0017
862	42.572	0.016	10.0153	0.0062	1.6477	0.0017
863	42.531	0.016	10.0057	0.0062	1.6461	0.0017
864	42.489	0.016	9.9957	0.0062	1.6445	0.0017
865	42.613	0.016	10.0249	0.0062	1.6493	0.0017
866	42.495	0.016	9.9973	0.0062	1.6447	0.0017
867	42.534	0.016	10.0065	0.0062	1.6462	0.0017
868	42.492	0.016	9.9965	0.0062	1.6446	0.0017
869	42.533	0.016	10.0061	0.0062	1.6462	0.0017
870	42.596	0.016	10.0209	0.0062	1.6486	0.0017
871	42.519	0.016	10.0029	0.0062	1.6457	0.0017
872	42.475	0.016	9.9925	0.0062	1.6439	0.0017
873	42.461	0.016	9.9893	0.0062	1.6434	0.0017
874	42.567	0.016	10.0141	0.0062	1.6475	0.0017
875	42.609	0.016	10.0241	0.0062	1.6491	0.0017
876	42.455	0.016	9.9877	0.0062	1.6432	0.0017
877	42.556	0.016	10.0117	0.0062	1.6471	0.0017
878	42.531	0.016	10.0057	0.0062	1.6461	0.0017
879	42.562	0.016	10.0129	0.0062	1.6473	0.0017
880	42.485	0.016	9.9949	0.0062	1.6443	0.0017
881	42.541	0.016	10.0081	0.0062	1.6465	0.0017
882	42.533	0.016	10.0061	0.0062	1.6462	0.0017
883	42.531	0.016	10.0057	0.0062	1.6461	0.0017
884	42.584	0.016	10.0181	0.0062	1.6482	0.0017
885	42.517	0.016	10.0025	0.0062	1.6456	0.0017
886	42.533	0.016	10.0061	0.0062	1.6462	0.0017
887	42.546	0.016	10.0093	0.0062	1.6467	0.0017
888	42.490	0.016	9.9961	0.0062	1.6445	0.0017
889	42.619	0.016	10.0265	0.0062	1.6495	0.0017
890	42.460	0.016	9.9889	0.0062	1.6434	0.0017
891	42.538	0.016	10.0073	0.0062	1.6464	0.0017
892	42.584	0.016	10.0181	0.0062	1.6482	0.0017
893	42.472	0.016	9.9917	0.0062	1.6438	0.0017
894	42.529	0.016	10.0053	0.0062	1.6460	0.0017
895	42.545	0.016	10.0089	0.0062	1.6466	0.0017
896	42.555	0.016	10.0113	0.0062	1.6470	0.0017
897	42.545	0.016	10.0089	0.0062	1.6466	0.0017
898	42.533	0.016	10.0061	0.0062	1.6462	0.0017
899	42.494	0.016	9.9969	0.0062	1.6447	0.0017
900	42.536	0.016	10.0069	0.0062	1.6463	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
901	42.519	0.016	10.0029	0.0062	1.6457	0.0017
902	42.553	0.016	10.0109	0.0062	1.6470	0.0017
903	42.517	0.016	10.0025	0.0062	1.6456	0.0017
904	42.504	0.016	9.9993	0.0062	1.6451	0.0017
905	42.548	0.016	10.0097	0.0062	1.6468	0.0017
906	42.601	0.016	10.0221	0.0062	1.6488	0.0017
907	42.490	0.016	9.9961	0.0062	1.6445	0.0017
908	42.511	0.016	10.0009	0.0062	1.6453	0.0017
909	42.505	0.016	9.9997	0.0062	1.6451	0.0017
910	42.585	0.016	10.0185	0.0062	1.6482	0.0017
911	42.538	0.016	10.0073	0.0062	1.6464	0.0017
912	42.480	0.016	9.9937	0.0062	1.6441	0.0017
913	42.541	0.016	10.0081	0.0062	1.6465	0.0017
914	42.490	0.016	9.9961	0.0062	1.6445	0.0017
915	42.512	0.016	10.0013	0.0062	1.6454	0.0017
916	42.556	0.016	10.0117	0.0062	1.6471	0.0017
917	42.562	0.016	10.0129	0.0062	1.6473	0.0017
918	42.590	0.016	10.0197	0.0062	1.6484	0.0017
919	42.456	0.016	9.9881	0.0062	1.6432	0.0017
920	42.582	0.016	10.0177	0.0062	1.6481	0.0017
921	42.528	0.016	10.0049	0.0062	1.6460	0.0017
922	42.516	0.016	10.0021	0.0062	1.6455	0.0017
923	42.492	0.016	9.9965	0.0062	1.6446	0.0017
924	42.456	0.016	9.9881	0.0062	1.6432	0.0017
925	42.623	0.016	10.0273	0.0062	1.6497	0.0017
926	42.597	0.016	10.0213	0.0062	1.6487	0.0017
927	42.499	0.016	9.9981	0.0062	1.6449	0.0017
928	42.504	0.016	9.9993	0.0062	1.6451	0.0017
929	42.524	0.016	10.0041	0.0062	1.6459	0.0017
930	42.582	0.016	10.0177	0.0062	1.6481	0.0017
931	42.560	0.016	10.0125	0.0062	1.6472	0.0017
932	42.465	0.016	9.9901	0.0062	1.6435	0.0017
933	42.573	0.016	10.0157	0.0062	1.6478	0.0017
934	42.546	0.016	10.0093	0.0062	1.6467	0.0017
935	42.463	0.016	9.9897	0.0062	1.6435	0.0017
936	42.596	0.016	10.0209	0.0062	1.6486	0.0017
937	42.483	0.016	9.9945	0.0062	1.6443	0.0017
938	42.514	0.016	10.0017	0.0062	1.6455	0.0017
939	42.538	0.016	10.0073	0.0062	1.6464	0.0017
940	42.497	0.016	9.9977	0.0062	1.6448	0.0017
941	42.534	0.016	10.0065	0.0062	1.6462	0.0017
942	42.611	0.016	10.0245	0.0062	1.6492	0.0017
943	42.470	0.016	9.9913	0.0062	1.6437	0.0017
944	42.526	0.016	10.0045	0.0062	1.6459	0.0017
945	42.553	0.016	10.0109	0.0062	1.6470	0.0017
946	42.517	0.016	10.0025	0.0062	1.6456	0.0017
947	42.534	0.016	10.0065	0.0062	1.6462	0.0017
948	42.534	0.016	10.0065	0.0062	1.6462	0.0017
949	42.514	0.016	10.0017	0.0062	1.6455	0.0017
950	42.607	0.016	10.0237	0.0062	1.6491	0.0017

Annex 1 The certified masses of ^{238}U, ^{235}U and ^{239}Pu per unit of IRMM-1027s

Vial No.	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]

[1] The certified values are traceable to the SI via the IRMM-046c spike CRM. The reference date for the mass of ^{238}U, ^{235}U and ^{239}Pu per vial is November 1, 2016.
[2] The uncertainty is the expanded uncertainty with a coverage factor k = 2.3 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.
The atomic masses of radionuclides were obtained from M. Wang et al. (The AME 2012 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 36, No. 12, 1603-2014, 2012).
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).

European Commission – Joint Research Centre
Directorate G – Nuclear Safety and Security
G.2 – Standards for Nuclear Safety, Security and Safeguards Unit
Retieseweg 111, B - 2440 Geel (Belgium)

Annex 2 The certificate of EC NRM 101 uranium metal

Certified Nuclear Reference Material

Certificate of Analysis

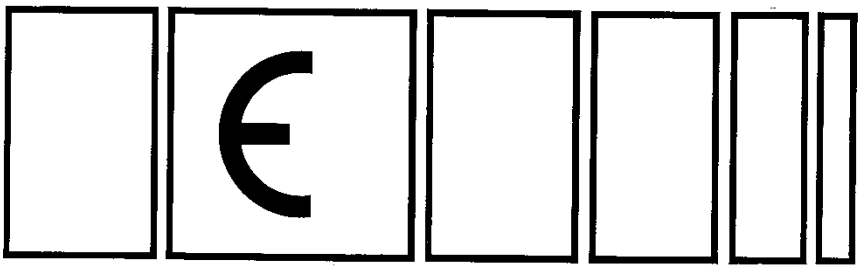
EC NUCLEAR REFERENCE MATERIAL NO. 101

MATERIAL : URANIUM METAL

URANIUM MASS FRACTION : (999.85 ± 0.05) g·kg-1

The uncertainty has been calculated by multiplying the estimated overall standard deviation by a factor of two. This corresponds to a confidence level of about 95 percent.

Commission of the European Communities
Joint Research Centre
Geel Establishment (CBNM)



Annex 3 The certificate of NBL CRM 116-A uranium metal

New Brunswick Laboratory
U.S. Department of Energy

Certificate of Analysis
CRM 116-A
Uranium (enriched) Metal Assay and Isotopic Standard

Certified Property Values

Amount Content	Value	Expanded[1] Uncertainty	Isotope-Amount Ratio	Value	Expanded[1] Uncertainty
g U•g^{-1} metal	0.99945	0.00014	$n(^{233}U)/n(^{235}U)$	0.0000003863	0.0000000086
			$n(^{234}U)/n(^{235}U)$	0.0115836	0.0000097
Molar Mass	Value	Expanded[1] Uncertainty	$n(^{236}U)/n(^{235}U)$	0.0094713	0.0000077
g•mol^{-1}	235.18572	0.00011	$n(^{238}U)/n(^{235}U)$	0.051277	0.000041
Isotope-Amount Fraction (•100)	Value	Expanded[1] Uncertainty	Isotope Mass Fraction (•100)	Value	Expanded[1] Uncertainty
$n(^{233}U)/n(U)$	0.00003603	0.00000080	$m(^{233}U)/m(U)$	0.00003570	0.00000079
$n(^{234}U)/n(U)$	1.08023	0.00089	$m(^{234}U)/m(U)$	1.07497	0.00088
$n(^{235}U)/n(U)$	93.2547	0.0038	$m(^{235}U)/m(U)$	93.1985	0.0038
$n(^{236}U)/n(U)$	0.88324	0.00071	$m(^{236}U)/m(U)$	0.88647	0.00071
$n(^{238}U)/n(U)$	4.7818	0.0036	$m(^{238}U)/m(U)$	4.8401	0.0037

[1] Expanded uncertainties for certified property values have a coverage factor of approximately 2.0 with the exception of the amount content value which has a coverage factor of 2.4 and the ^{233}U values which have a coverage factor of 3.3 for isotope amount ratio, isotope-amount fraction, and isotope mass fraction.

Notes:

Certified Reference Material 116-A (CRM 116-A) is a uranium amount content and isotope-amount ratio standard intended for use in calibration of and/or quality control for uranium analysis methods. Each unit of CRM 116-A consists of a metal piece with a mass of approximately 1.1 grams. This CRM is not characterized for total quantity of material which may be somewhat greater or less than the nominal mass (between 1.0 g and 1.2 g).

CRM 116-A is a radioactive material and should be handled and stored under proper radiologically-controlled conditions at all times.

October 31, 2013
Steven Bakhtiar
Laboratory Director

New Brunswick Laboratory
Argonne, Illinois
www.science.energy.gov/nbl

CRM 116-A units do not have an expiration date. To maintain the integrity of an unused unit, it should remain in the original packaging and should be stored in a dry, temperature controlled location.

Measurements for uranium amount content and isotope-amount ratios were performed on metal samples with a mass of 1.1 gram or greater. The homogeneity of uranium amount content or isotopic composition has not been assessed for metal pieces smaller than 1.1 gram. Prior to use, surface oxide must be removed to ensure accurate uranium amount content values. A suggested procedure is provided below.

Suggested Preparation Procedure for Achieving Accurate Mass and Amount Content Values

1. Cover the uranium metal sample in 8 $mol \cdot L^{-1}$ nitric acid for 10-20 minutes to remove all visible surface oxides.
2. To minimize oxidation of the sample and ensure an accurate determination of uranium metal mass, the following steps should be performed immediately following Step 1.
   2.1 Thoroughly rinse the metal piece with distilled, deionized water.
   2.2 Remove excess water by thoroughly rinsing the metal piece with pure acetone.
   2.3 Allow the acetone to evaporate (30 – 60 seconds is typically sufficient).
   2.4 Perform a weighing of sufficient accuracy and precision for user's need.

Description:

The CRM 116-A metal pieces are machined metal cylinders. The stock material for the CRM was obtained from a single casting of a HEU right-annular cylinder of metal. Several wedges of material were cut from the annular cylinder and machined into rods which were stamped into narrow-diameter rods. The rods were then machined to shape and cut into the individual 1.1-gram metal cylinders that comprise each CRM 116-A unit.

Uranium amount content for CRM 116-A was determined by the NBL High Precision Titrimetric method using CRM 99 Potassium Dichromate Oxidimetric Standard as the titrant. The CRM 112-A Uranium Metal Assay and Isotopic Standard was used as a control to verify performance of the measurement system. Traceability of the measurements is primarily established by direct determination of uranium amount content based on the titration of uranium using CRM 99 Potassium Dichromate Oxidimetric Standard. CRM 99 was calibrated against CRM 112-A which, in turn, was originally provided by the National Bureau of Standards (now known as the National Institute of Standards and Technology) as SRM 960.

A detailed thermal ionization mass spectrometry measurement campaign was performed on CRM 116-A to determine uranium isotope-amount ratios and uncertainties. Mass discrimination calibrations were performed on a sample turret basis using multiple measurements of NBL Uranium Isotopic Standards U900 and U930-D. Analyses of CRM U970 Uranium Isotopic Standard were performed to verify that mass spectrometric measurements were in control. Traceability of the isotope-amount ratio measurements for CRM 116-A was established by calibration of the mass spectrometers using combined measurements of CRMs U900 and U930-D Uranium Isotopic Standards. CRM 900 was originally provided by the National Bureau of Standards (now known as the National Institute of Standards and Technology) as SRM U900. U930-D is directly traceable to National Bureau of Standards SRM U930 Uranium Isotopic Standard.

Measurement Uncertainty:

Reported numerical uncertainties for values are expressed as expanded uncertainties ($U = k \cdot u_c$) at the 95% level of confidence, where the expanded uncertainty (U) is the product of the combined standard uncertainty (u_c) and a coverage factor (k). The last figure in reported values and uncertainties is provided for information purposes and is not intended to convey a significant degree of reliability. The isotope-amount and weight fraction values and uncertainties are provided primarily for information purposes. To assure proper uncertainty propagation, it is recommended that isotope-amount ratios and associated uncertainties be used for calculations incorporating CRM 116-A values.

Uncertainties were determined according to the protocols outlined in JCGM 100:2008 *Guide to the Expression of Uncertainty in Measurement*. The combined standard uncertainties for attribute values consist of Type A and Type B components. The Type A uncertainty components for amount content is derived from the standard deviation of high precision titrations performed on 1.1 g U metal samples and the standard uncertainty for the primary analytical amount content measurements, which utilized 3-g U metal samples. The Type B component is the combined standard uncertainty of the CRM 99 oxidimetric standard. The Type A components for isotope-amount ratios are derived from standard deviations associated with isotopic ratio measurements of the samples and the $n(^{238}U)/n(^{235}U)$ ratio of NBL CRMs U900 and U930-D. Type B components are based on the combined standard uncertainties for the $n(^{238}U)/n(^{235}U)$ ratios of CRMs U900 and U930-D and components to account for additional sources of uncertainty associated with background corrections and analytical biases. Isotope mass fractions incorporate an additional Type B component associated with the uncertainty of the atomic mass for the U isotopes. The coverage factor (k) for each expanded uncertainty is based on the effective degrees of freedom for that quantity and is the Student's t-factor necessary to provide a 95% level of confidence ($k \approx 2.0$ for the values cited in this certificate except for the amount content value with $k = 2.4$ and the ^{233}U isotope amount ratio, amount fraction, and mass fraction which have coverage factors of $k = 3.3$). A more detailed explanation of measurement uncertainty can be obtained upon request from NBL.

References:

Bureau International des Poids et Measures (BIPM), Evaluation of Measurement Data - Guide to the Expression of Uncertainty in Measurement, JCGM 100: 2008.

Annex 4 The certificate of CETAMA MP2 plutonium metal

CETAMA

COMMISSARIAT A L'ENERGIE ATOMIQUE

COMMISSION D'ETABLISSEMENT DES METHODES D'ANALYSE

cea

REFERENCE MATERIAL CERTIFICATE

PLUTONIUM METAL
"MP2"

Sample n° Xxxx Mass : 0.xxxxxx ± 0.000012 g

(For X and x values see list page 4)

The reference material to which this certificate relates is intended for the calibration of chemical composition measurement. The overall chemical content of plutonium is certified. The confidence interval associated with the certified value for a single sample, takes into account uncertainties associated to with analysis and heteregenity of metal. This content, expressed as a percentage of mass, was the following on 12 march 2001 for a single sample with a probability level of 0.95.

99.90 ± 0.04 %

THE TRUE MASS OF THE SAMPLE A ± **12 µg**, RELATED TO A VACUUM, IS THAT INDICATED IN THIS CERTIFICATE AND ON THE AMPOULE.

The possibility of surface oxidation makes it impossible to envisage weighing at the time of use

Isotopique composition is certified on 12 march 2001 : see certificate IRMM page3

The preparation, analysis and certification of the plutonium to which this certificate relates was carried out by different units of the CEA group under the supervision of the Committee for Establishing Analysis Methods (CETAMA).

CETAMA CRM manager

CETAMA
CEA VALRHO Marcoule
30207 BAGNOLS SUR CEZE CEDEX
Téléphone 04.66.79.69.88 - Télécopie 04.66.79.69.89

ISO 9001 BUREAU VERITAS Certification

Version : 10.2007

On 12/03/2001, the metal contained around:

- by weight, 489 $mg.kg^{-1}$ of uranium,
- by weight, 438 $mg.kg^{-1}$ of américium..

UTILISATION

The sample, which consists of a piece of metal, is supplied in a double glass ampoule filled with pure nitrogen at a pressure of around 0.1 Pascal.

The ampoule must be opened with care inside a glove box. All the sample must be transferred to the dissolver.

Cover with 0.1 $mol.l^{-1}$ hydrochloric acid. The ampoule must be thoroughly washed with the same acid to recover any particles of metal which may have become separated. In 2 ml fractions, add the necessary quantity of 12 $mol.l^{-1}$ hydrochloric acid of guaranteed purity to obtain a 4 $mol.l^{-1}$ hydrochloric acid solution. Allow dissolving to proceed without heating for 10 to 15 minutes, then heat to boiling point. If there are still particles of plutonium at the bottom of the dissolver after heating for two hours, add 2 ml of 12 $mol.l^{-1}$ hydrochloric acid and 2 drops of 1 $mol.l^{-1}$ hydrofluoric acid and continue heating for another two hours. Repeat the operation if necessary until the material is totally dissolved.
If plutonium fluoride precipitates out, add a few drops of aluminium nitrate (approximately one $mol.l^{-1}$)..
Allow to cool and adjust to the required volume.

ADDITIONAL INFORMATION

The certified plutonium content has been deduced from analysis of impurities carried out by five laboratories and checked by chemical assay of the plutonium in two different laboratories using three different methods of analysis.
Spark Source Mass Spectrometry has given a full analysis of the impurities and, where concentration levels allowed, inductively-coupled plasma atomic emission spectrometry has been used to establish the concentrations of some of them.
The uranium was determined by laser spectrofluorimetry and the americium by gamma spectrometry.Carbon was determined by coulometry, after transformation into gaseous form by combustion in oxygen.
The gases were analysed by chromatography in the aqueous phase:
- for nitrogen and oxygen after extraction by high temperature stream under an inert gas,
- for hydrogen after diffusion in a vacuum.

CETAMA
CEA VALRHO Marcoule
30207 BAGNOLS SUR CEZE CEDEX
Téléphone 04.66.79.69.88 - Télécopie 04.66.79.69.89

IRMM

Institute for Reference Materials and Measurements

CERTIFICATE OF ISOTOPIC COMPOSITION

Geel, 30 May 2001

1. Applicant: Mr G. Lamarque
   Président de la Cetama

2. Sample Identification: MP2 (Pu metal)

3. Isotopic composition:

isotope amount ratio(s)	
$n(^{238}Pu)/\,n(^{239}Pu)$	0.000 033 15(41)
$n(^{240}Pu)/\,n(^{239}Pu)$	0.022 437 4(99)
$n(^{241}Pu)/\,n(^{239}Pu)$	0.000 298 0(17)
$n(^{242}Pu)/\,n(^{239}Pu)$	0.000 070 87(71)

amount fraction (·100)		mass fraction (·100)	
$n(^{238}Pu)/n(Pu)$	0.003 241(40)	$m(^{238}Pu)/m(Pu)$	0.003 227(40)
$n(^{239}Pu)/n(Pu)$	97.767 05(98)	$m(^{239}Pu)/m(Pu)$	97.757 76(98)
$n(^{240}Pu)/n(Pu)$	2.193 64(94)	$m(^{240}Pu)/m(Pu)$	2.202 62(95)
$n(^{241}Pu)/n(Pu)$	0.029 14(17)	$m(^{241}Pu)/m(Pu)$	0.029 38(17)
$n(^{242}Pu)/n(Pu)$	0.006 929(69)	$m(^{242}Pu)/m(Pu)$	0.007 015(70)

molar mass: 239.074 888(11) g·mol^{-1}

4. Reference number: IMN 10031

5. Remarks:

The above values are valid for 12 March 2001. All uncertainties indicated are expanded uncertainties $U = k \cdot u_c$ where u_c is the combined standard uncertainty calculated according to the ISO/BIPM guide. The uncertainties are given in parentheses and include a coverage factor k=2. They apply to the last two digits of the value. The values certified are traceable to the SI.
The primary certified values are the isotope amount ratios; other values are derived from them. Reproducing the derived values may result in differences due to rounding errors.
Mass spectrometric measurements were performed by A Verbruggen and F Kehoe by TIMS on samples chemically prepared by F Kehoe. A Verbruggen was responsible for the preparation and issuance of the certificate.

A Verbruggen
Isotope Measurements Unit

Copy: R Wellum
F Kehoe

B-2440 GEEL (Belgium)
Tel. +32-14-571 608 - Fax +32-14-571 863

European Commission - JRC

30207 BAGNOLS SUR CEZE CEDEX
Téléphone 04.66.79.69.88 - Télécopie 04.66.79.69.89

Packaging list for IRMM

The numbers of the ingots and the associated masses are as follows:

Ingot number	Mass (g)
A934	0.587859
A949	0.430987
A952	0.567216
A968	0.434526
A975	0.510770
C321	0.640299
C569	0.592943
C581	0.632827
A123	0.414082
A174	0.602206
A307	0.434852
A314	0.561821
A345	0.514834
A451	0.436194
A518	0.624022
A662	0.469822
A035	0.479086
A453	0.598728
A455	0.563210

CETAMA CRM manager

CETAMA
CEA VALRHO Marcoule
30207 BAGNOLS SUR CEZE CEDEX
Téléphone 04.66.79.69.88 - Télécopie 04.66.79.69.89

Annex 5 The certificate of isotopic abundances of CETAMA MP2

EUROPEAN COMMISSION
DIRECTORATE GENERAL JRC
JOINT RESEARCH CENTRE
IRMM
Institute for Reference Materials and Measurements

CERTIFICATE of a reference measurement

IM/MeaC/07/116

11 April 2007

SUBJECT : Recertification of CEA CETAMA MP2

1. Applicant: A. Verbruggen

2. Sample Identification:
   - CEA/CETAMA/MP2
   - Chemical form: Pu metal provided by CEA/CETAMA

3. Measurands:
   - Isotopic composition

isotope amount ratio(s)	
$n(^{238}Pu)/\ n(^{239}Pu)$	0.000 030 83(29)
$n(^{240}Pu)/\ n(^{239}Pu)$	0.022 432 4(51)
$n(^{241}Pu)/\ n(^{239}Pu)$	0.000 237 8(31)
$n(^{242}Pu)/\ n(^{238}Pu)$	0.000 075 70(78)

amount fraction (·100)		mass fraction (·100)	
$n(^{238}Pu)/n(Pu)$	0.003 015(29)	$m(^{238}Pu)/m(Pu)$	0.003 002(28)
$n(^{239}Pu)/n(Pu)$	97.773 05(58)	$m(^{239}Pu)/m(Pu)$	97.763 80(59)
$n(^{240}Pu)/n(Pu)$	2.193 28(49)	$m(^{240}Pu)/m(Pu)$	2.202 27(49)
$n(^{241}Pu)/n(Pu)$	0.023 25(30)	$m(^{241}Pu)/m(Pu)$	0.023 44(31)
$n(^{242}Pu)/n(Pu)$	0.007 402(76)	$m(^{242}Pu)/m(Pu)$	0.007 494(77)

molar mass: 239.074 790 8(91) $g \cdot mol^{-1}$

4. Date of sample receipt : n.a.
   Date of completion of measurement : 7 November 2006

5. All uncertainties indicated are expanded uncertainties $U = k \cdot u_c$ where u_c is the combined standard uncertainty estimated following the ISO/BIPM guide[1]. They are given in parentheses and include a coverage factor k=2. They apply to the last two digits of the value. The values certified are traceable to the SI. The primary certified values are the isotope amount ratio ; other values are derived from them. Reproducing the derived values may result in difference due to rounding errors.

[1] International Organisation for Standardisation, Guide to the expression of Uncertainty in Measurement, ©ISO, ISBN 92-67-10188-9, Geneva, Switserland, 1993

Uncertainty budget :

Quantity	Value	Standard Uncertainty	Index
Atomic mass ^{239}Pu	239.05215760 g/mol	$5.1 \cdot 10^{-6}$ g/mol	59.6 %
Measurement ratio 240/239	0.02243535 mol/mol	$3.81 \cdot 10^{-6}$ mol/mol	14.9 %
Measurement ratio 241/239	$240 \cdot 10^{-6}$ mol/mol	$450 \cdot 10^{-9}$ mol/mol	0.9 %
Measurement ratio 242/239	$75 \cdot 10^{-6}$ mol/mol	$175 \cdot 10^{-9}$ mol/mol	0.4 %
$variability_{241/239}$	0.0 mol/mol	$2.65 \cdot 10^{-6}$ mol/mol	21.0 %
$variability_{242/239}$	0.0 mol/mol	$650 \cdot 10^{-9}$ mol/mol	3.0 %
M_{Pu}	239.07478500 g/mol	$6.46 \cdot 10^{-6}$ g/mol	

6. The traceability to SI is established through standards from IRMM-290.

7. Analytical measurement procedure
   - Mass spectrometric measurments were performed by H Kühn an F Kehoe for the $[n(^{238}Pu)/n(^{239}Pu)]$, $[n(^{240}Pu)/n(^{239}Pu)]$, $[n(^{241}Pu)/n(^{239}Pu)]$ and $[n(^{242}Pu)/n(^{239}Pu)]$ using the MAT262 TIMS, sample solutions were prepared for TIMS analysis by F Kehoe. A. Verbruggen was responsible for preparation and issuance of the certificate.
   - The atomic masses, used in the calculation are from G. Audi and A.H. Wapstra.[2]
   - Reference numbers of the measurement data: measurements number T26629, T26A03, T26B07, logged in S:\D04-IM\Secure Data\Project Data\MP2 (based on 081a and LSD1027i)\MP2 IA Summary MAT262 measurements.
   - Full details of the preparation and the certification procedure can be found in certification report EUR*****.

8. These samples will be stored for a minimum period of six months from the date of this certificate

André Verbruggen
Group leader Nuclear Chemistry

Stephan Richter
Group leader Nuclear Mass Spectrometry

Copies
P Taylor, IM unit head
Y Aregbe, Action leader Nuclear Safeguards
F Kehoe
H Kühn

[2] G. Audi and A.H. Wapstra, The 2003 atomic mass evaluation, Nucl Phys A729 (2003) 337-676

Annex 6 The certificate of isotopic composition of EC NRM 101

European Commission
JOINT
RESEARCH
CENTRE

Institute for Reference Materials and Measurements
Steenweg op Retie,2440 Geel,Belgium
Tel.(014)571.211-Telex 33589 EURAT B
Telefax 014/58.42.73

CERTIFICATE OF ISOTOPIC COMPOSITION
****

1. Applicant : Dr.K.Mayer
Stable Isotope Measurements
IRMM

2. Sample identification : EC 101

3. Results :

	Amount Ratio(s)	Mass Ratio(s)	Uncertainty (computed on a 2s basis for each element)
n(234U)/n(238U)	0.00005548		+/- 0.00000022
n(235U)/n(238U)	0.0072593		+/- 0.0000036
n(236U)/n(238U)	0.000000151		+/- 0.000000040

4. Reference number : SMS 7315

5. Remarks : This sample will be stored for a minimum period of six months from the date of this certificate.

Request received at laboratory : 1995.06.23
Sample received at laboratory : 1995.06.23
Measurement achieved : 1995.06.23
Telephone or telex communication :

Mass spectrometric measurements were performed by W.De Bolle (n(235U)/n(238U) ratio by UF6) and A.Alonso (THMS) on samples chemically prepared by A.Alonso.

The values certified are traceable to the SI system and its unit for amount of substance: the mole.

c. P.De Bievre / A.Alonso

W.DE BOLLE
Stable Isotope Measurements

Annex 7 The certificate of IRMM-046b

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Institute for Reference Materials and Measurements (Geel)

CERTIFIED REFERENCE MATERIAL
IRMM – 046b

CERTIFICATE OF ANALYSIS

Uranium and Plutonium in nitric acid solution		
	Isotope amount content	
	Certified value [1] [µmol/g]	Uncertainty [2] [µmol/g]
^{242}Pu	0.46504	0.00018
^{233}U	4.1154	0.0009
	Isotope amount ratio	
	Certified value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{234}U)/n(^{233}U)$	0.009396	0.000012
$n(^{235}U)/n(^{233}U)$	0.002252	0.000006
$n(^{236}U)/n(^{233}U)$	0.000280	0.000004
$n(^{238}U)/n(^{233}U)$	0.008186	0.000011
$n(^{238}Pu)/n(^{242}Pu)$	0.005332	0.000020
$n(^{239}Pu)/n(^{242}Pu)$	0.002212	0.000016
$n(^{240}Pu)/n(^{242}Pu)$	0.04607	0.00007
$n(^{241}Pu)/n(^{242}Pu)$	0.003000	0.000009
$n(^{244}Pu)/n(^{242}Pu)$	0.00024	0.00004

[1] The certified values are traceable to the International System of units (SI) via IRMM-1027m. The reference date for the certified values is June 1, 2010.
[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.

The certificate is valid for 3 years; the validity may be extended after further tests on the stability of the material are carried out.

Geel, June 2010,

Last revision February 2016

Signed: 16/02/2016

Prof. Dr. Hendrik Emons
European Commission
Joint Research Centre
Institute for Reference Materials and Measurements
Retieseweg 111
B-2440 Geel, Belgium

Additional Material Information

	Isotopic mass fraction	
	Value [1] [g/g]	Uncertainty [2] [g/g]
$m(^{233}U)/m(U)$ [3]	0.980053	0.000017
$m(^{234}U)/m(U)$ [3]	0.009248	0.000012
$m(^{235}U)/m(U)$ [3]	0.002226	0.000006
$m(^{236}U)/m(U)$ [3]	0.000278	0.000004
$m(^{238}U)/m(U)$ [3]	0.008195	0.000011
$m(^{238}Pu)/m(Pu)$ [3]	0.004964	0.000018
$m(^{239}Pu)/m(Pu)$ [3]	0.002068	0.000015
$m(^{240}Pu)/m(Pu)$ [3]	0.04325	0.00006
$m(^{241}Pu)/m(Pu)$ [3]	0.002828	0.000009
$m(^{242}Pu)/m(Pu)$ [3]	0.94667	0.00007
$m(^{244}Pu)/m(Pu)$ [3]	0.000226	0.000030
	Amount content	
	Value [1] [µmol/g]	Uncertainty [2] [µmol/g]
Pu	0.49147	0.00019
U	4.1982	0.0009
	Mass fraction	
	Value [1] [mg/g]	Uncertainty [2] [mg/g]
Pu	0.11891	0.00005
U	0.97857	0.00020
	Molar mass	
	Value [1] [g/mol]	Uncertainty [2] [g/mol]
Pu	241.94244	0.00015
U	233.09432	0.00006

[1] The information values are derived from the certified values. The reference date for the derived values is June 1, 2010.
[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] Isotopic mass fraction is expressed as $^{xxx}U/^{tot}U$ and $^{xxx}Pu/^{tot}Pu$.

DESCRIPTION OF THE MATERIAL

The IRMM-046b is a mixed uranium-plutonium spike Certified Reference Material (CRM) supplied with an isotope amount content of ^{233}U and ^{242}Pu and isotope amount ratios as certified above. A unit of IRMM-046b consists of a flame-sealed glass ampoule containing about 10 mg uranium and 1 mg plutonium in 10 mL of nitric acid solution. The concentration of nitric acid is about 5 mol·L^{-1}.

ANALYTICAL METHODS USED FOR CERTIFICATION

The certified values were established by isotope dilution mass spectrometry (IDMS) on randomly selected units of IRMM-046b. The isotope ratio measurements were performed on a Triton TIMS (Thermo Fisher Scientific) using the total evaporation method. Pu standard IRMM-290/A3 and U standard IRMM-074/10 were used to correct for the mass fractionation effects during isotopic measurement.

SAFETY INFORMATION

The IRMM-046b contains radioactive material. The ampoules should be handled with great care and by experienced personnel in a laboratory suitably equipped for the safe handling of radioactive materials.

INSTRUCTIONS FOR USE AND INTENDED USE

This spike Certified Reference Material (CRM) is used as a calibrant to determine the plutonium and uranium amount content by isotope dilution mass spectrometry (IDMS).

STORAGE

The vials should be stored at + 18 °C ± 5 °C in an upright position.
However, the European Commission cannot be held responsible for changes that happen during storage of the material at the customer's premises, especially of opened samples.

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Annex 8 The certificate of IRMM-046c

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Directorate G – Nuclear Safety and Security
G.2 – Standards for Nuclear Safety, Security and Safeguards Unit

CERTIFIED REFERENCE MATERIAL
IRMM – 046c

CERTIFICATE OF ANALYSIS

NITRIC ACID SOLUTION		
	Isotope amount content	
	Certified value [1] [µmol/g]	Uncertainty [2] [µmol/g]
^{242}Pu	0.35498	0.00014
^{233}U	4.4636	0.0010
	Isotope amount ratio	
	Certified value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{234}U)/n(^{233}U)$	0.0001939	0.0000012
$n(^{235}U)/n(^{233}U)$	0.0000735	0.0000023
$n(^{236}U)/n(^{233}U)$	0.0000038	0.0000018
$n(^{238}U)/n(^{233}U)$	0.0021043	0.0000039
$n(^{238}Pu)/n(^{242}Pu)$	0.0053359	0.0000049
$n(^{239}Pu)/n(^{242}Pu)$	0.0022699	0.0000014
$n(^{240}Pu)/n(^{242}Pu)$	0.046084	0.000037
$n(^{241}Pu)/n(^{242}Pu)$	0.0029924	0.0000032
$n(^{244}Pu)/n(^{242}Pu)$	0.00025739	0.00000049

[1] The certified values are traceable to the International System of units (SI) via IRMM-1027m. The reference date for the certified values is July 1, 2010.
[2] The certified 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.

The certificate is valid for 3 years; the validity may be extended after further tests on the stability of the material are carried out.

Geel, January 2014

Last revision January 2017

Signed: 10/02/2017

Dr. Willy Mondelaers
European Commission
Joint Research Centre
Directorate G – Nuclear Safety and Security
G.2 – Standard for Nuclear safety, Security and Safeguards
Retieseweg 111
B-2440 Geel, Belgium

Derived Values

	Isotopic mass fraction	
	Value [1] [%]	Uncertainty [2] [%]
$m(^{233}U)/m(U)\times100$	99.75836	0.00051
$m(^{234}U)/m(U)\times100$	0.01942	0.00012
$m(^{235}U)/m(U)\times100$	0.00740	0.00023
$m(^{236}U)/m(U)\times100$	0.00038	0.00019
$m(^{238}U)/m(U)\times100$	0.21443	0.00040
$m(^{238}Pu)/m(Pu)\times100$	0.49672	0.00044
$m(^{239}Pu)/m(Pu)\times100$	0.21220	0.00012
$m(^{240}Pu)/m(Pu)\times100$	4.3261	0.0033
$m(^{241}Pu)/m(Pu)\times100$	0.28208	0.00030
$m(^{242}Pu)/m(Pu)\times100$	94.6583	0.0038
$m(^{244}Pu)/m(Pu)\times100$	0.024364	0.000046
	Amount content	
	Value [1] [µmol/g]	Uncertainty [2] [µmol/g]
Pu	0.37519	0.00015
U	4.4742	0.0010
	Mass fraction	
	Value [1] [mg/g]	Uncertainty [2] [mg/g]
Pu	0.090775	0.000037
U	1.04271	0.00024

[1] The derived values are obtained from the certified values. The reference date for the derived values is July 1, 2010.
[2] The certified 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.

DESCRIPTION OF THE MATERIAL

The IRMM-046c is a mixed uranium-plutonium spike Isotopic Reference Material suplied with an isotope amount content of ^{233}U and ^{242}Pu and isotope amount ratios as certified above. A unit of IRMM-046c consists of a glass ampoule with a screw cap containing about 10 mg uranium and 1 mg plutonium in a 10 mL of nitric acid solution. The molarity is about 5 $mol \cdot L^{-1}$.

ANALYTICAL METHODS USED FOR CERTIFICATION

The certified values were established by isotope dilution mass spectrometry (IDMS) on a randomly selected units of IRMM-046c. The isotope ratio measurements were performed on a Triton TIMS (Thermo Fisher Scientific) using total evaporation method. Pu standard IRMM-290/A3 and U standard IRMM-074/10 were used to correct for the mass fractionation effects during isotopic measurement.

SAFETY INFORMATION

The IRMM-046c contains radioactive material. The ampoules should be handled with great care and by experienced personnel in a laboratory suitably equipped for the safe handling of radioactive materials.

INSTRUCTIONS FOR USE AND INTENDED USE

This spike Isotopic Reference Material (IRM) is used as a calibrant to determine the plutonium and uranium amount content by isotope dilution mass spectrometry (IDMS).

STORAGE

The vials should be stored at + 18 °C ± 5 °C in an upright position.
However, the European Commission cannot be held responsible for changes that happen during storage of the material at the customer's premises, especially of opened samples.

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LEGAL NOTICE

A technical report on the preparation of IRMM-046c can be obtained from JRC Directorate G – Nuclear Safety and Security, G.2 – Standards for Nuclear Safety, Security and Safeguards unit in Geel, Belgium on request.

European Commission – Joint Research Centre
Directorate G – Nuclear Safety and Security
G.2 – Standards for Nuclear safety, Security and Safeguards Unit
Retieseweg 111, B - 2440 Geel (Belgium)

Annex 9 Results of the process control measurements (5 blends, 3 replicates) for ^{235}U, ^{238}U and ^{239}Pu amount content in the mother solution of IRMM-1027s

Figure 12 The amount content of ^{235}U in the mother solution of IRMM-1027s measured by ID-TIMS using IRMM-046b (blue diamonds) and IRMM-046c (black triangles) spike CRM expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainties (coverage factor k = 2). Red dotted lines show the relative expanded uncertainty (k = 2) of the gravimetric value

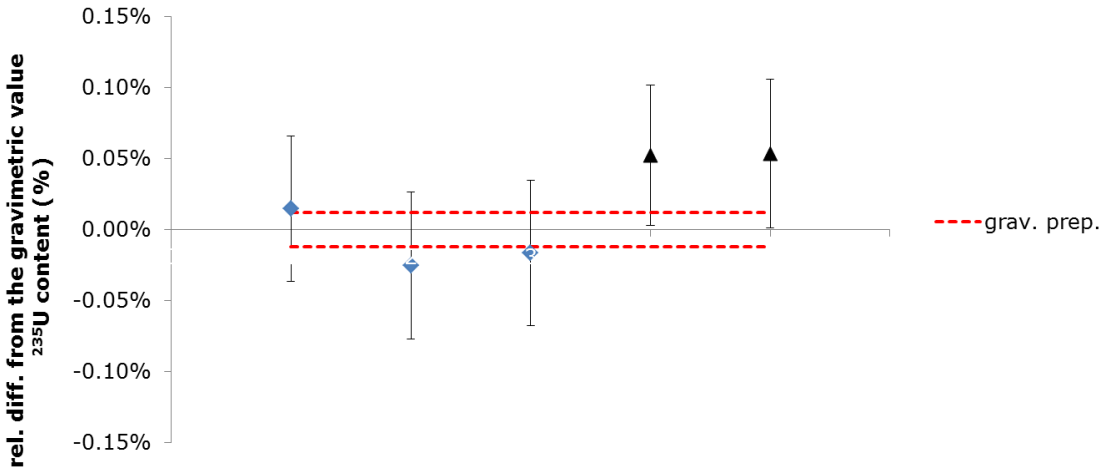


Figure 13 The amount content of ^{238}U in the mother solution of IRMM-1027s measured by ID-TIMS using IRMM-046b (blue diamonds) and IRMM-046c (black triangles) spike CRM expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainties (coverage factor k = 2). Red dotted lines show the relative expanded uncertainty (k = 2) of the gravimetric value

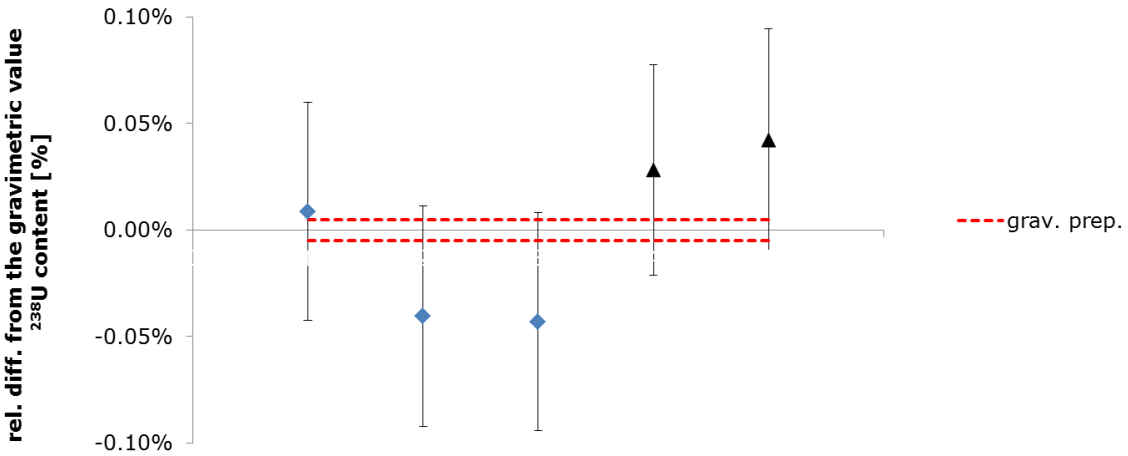
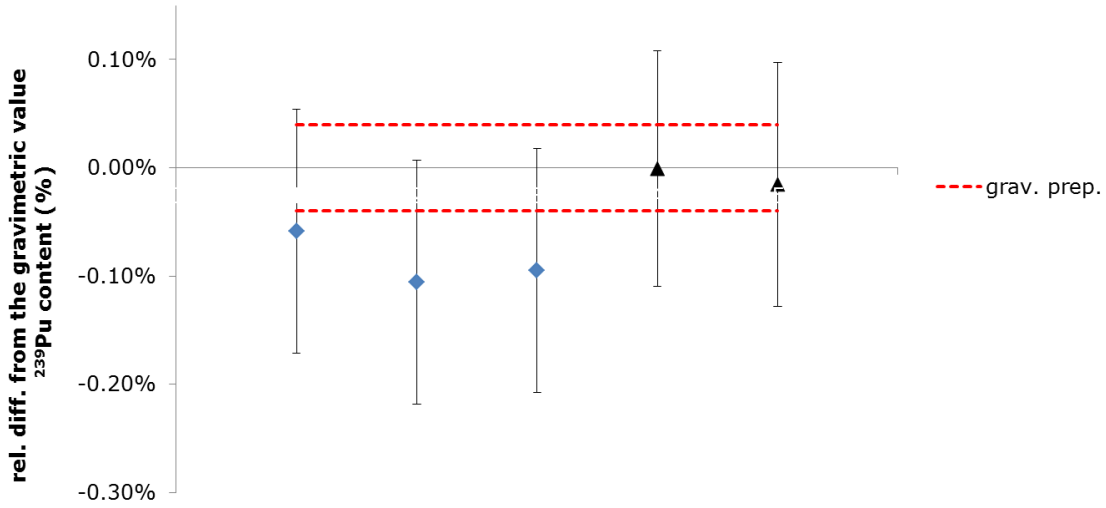


Figure 14 The amount content of ^{239}Pu in the mother solution of IRMM-1027s measured by ID-TIMS using IRMM-046b (blue diamonds) and IRMM-046c (black triangles) spike CRM expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainties (coverage factor k = 2). Red dotted lines show the relative expanded uncertainty (k = 2) of the gravimetric value



Annex 10 Results of the process control measurements (5 aliquots, 3 replicates) for the uranium and plutonium isotope amount ratios in the mother solution of IRMM-1027s

Figure 15 The $n(^{234}U)/n(^{238}U)$ amount ratio in the solution of IRMM-1027s prepared by gravimetric mixing compared with the measured values by TIMS (individual aliquots with blue diamonds and the average value with a green diamond). Error bars show the expanded uncertainties (coverage factor k = 2)

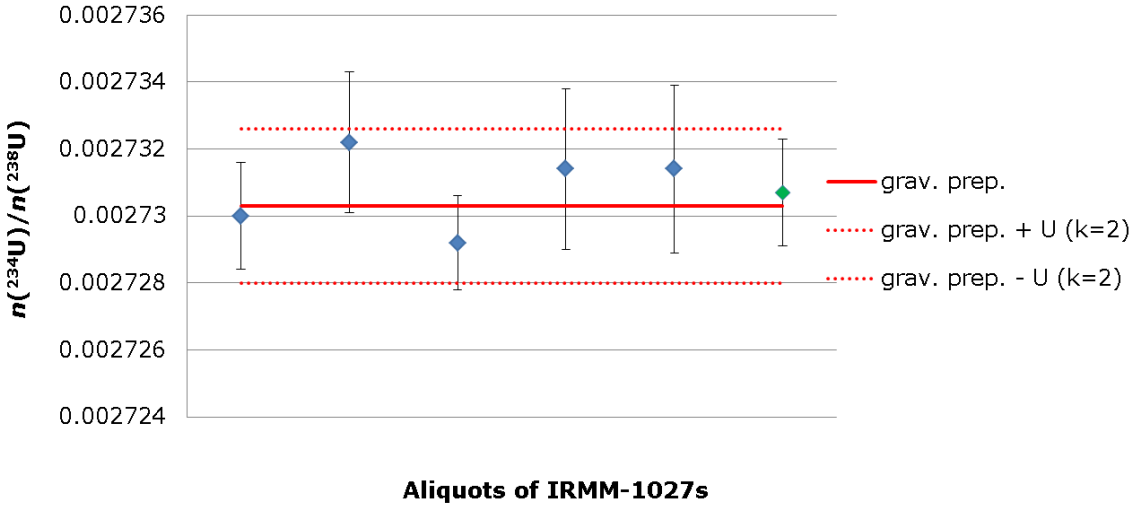


Figure 16 The $n(^{235}U)/n(^{238}U)$ amount ratio in the solution of IRMM-1027s prepared by gravimetric mixing compared with the measured values by TIMS (individual aliquots with blue diamonds and the average value with a green diamond). Error bars show the expanded uncertainties (coverage factor k = 2)

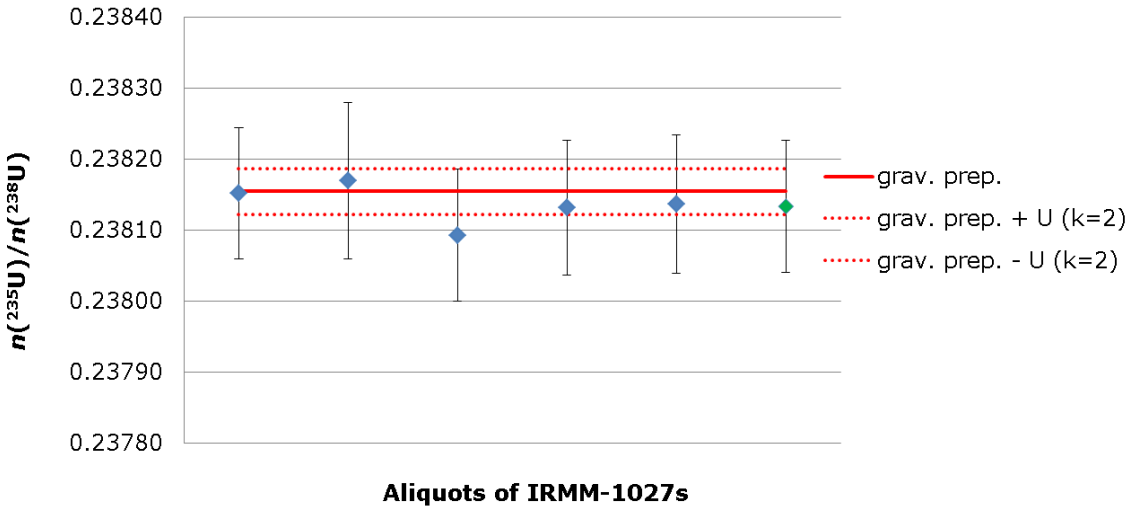


Figure 17 The $n(^{236}U)/n(^{238}U)$ amount ratio in the solution of IRMM-1027s prepared by gravimetric mixing compared with the measured values by TIMS (individual aliquots with blue diamonds and the average value with a green diamond). Error bars show the expanded uncertainties (coverage factor k = 2)

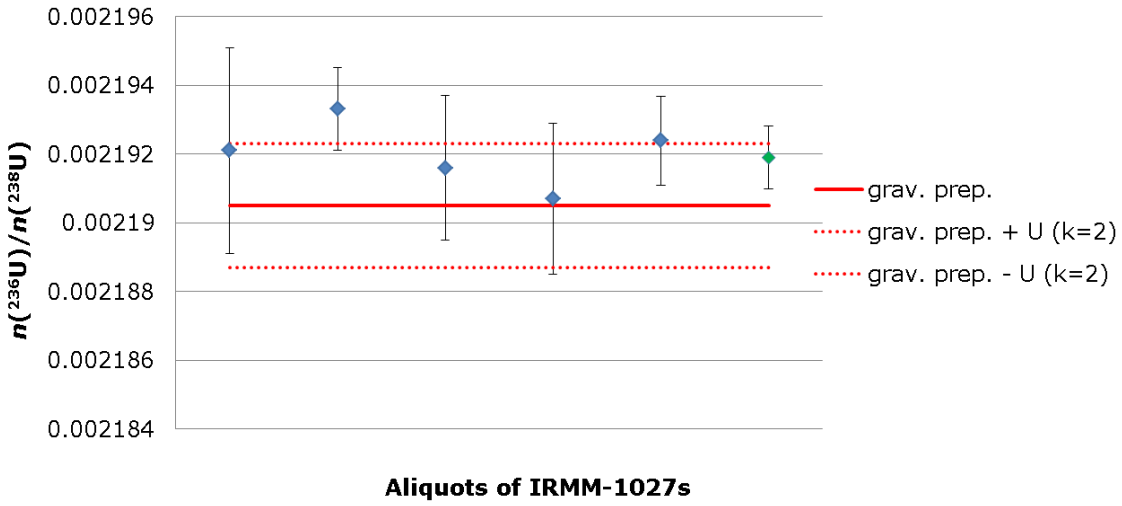


Figure 18 The $n(^{238}Pu)/n(^{239}Pu)$ amount ratio in the solution of IRMM-1027s prepared by gravimetric mixing compared with the measured values by TIMS (individual aliquots with blue diamonds and the average value with a green diamond). Error bars show the expanded uncertainties (coverage factor k = 2)

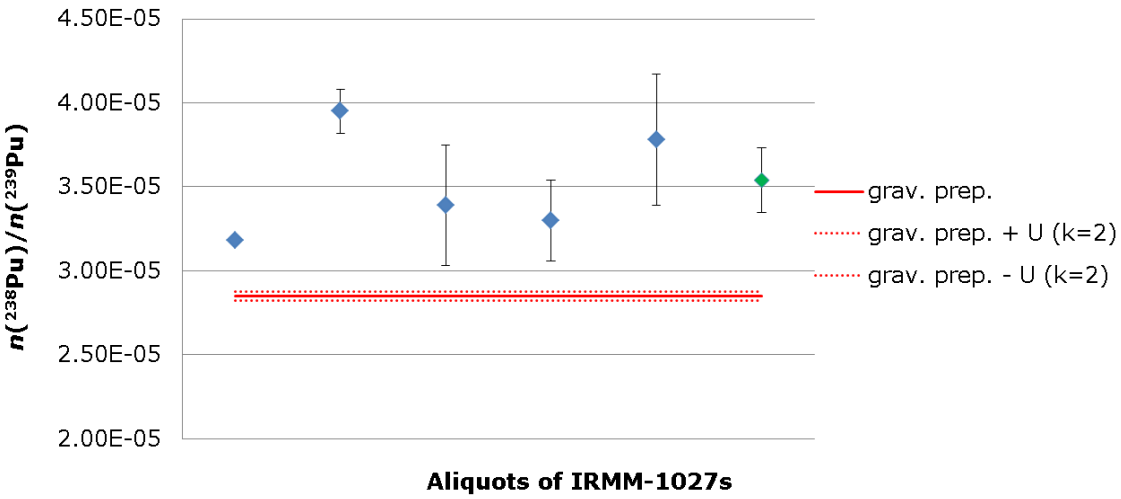


Figure 19 The $n(^{240}Pu)/n(^{239}Pu)$ amount ratio in the solution of IRMM-1027s prepared by gravimetric mixing compared with the measured values by TIMS (individual aliquots with blue diamonds and the average value with a green diamond). Error bars show the expanded uncertainties (coverage factor k = 2)

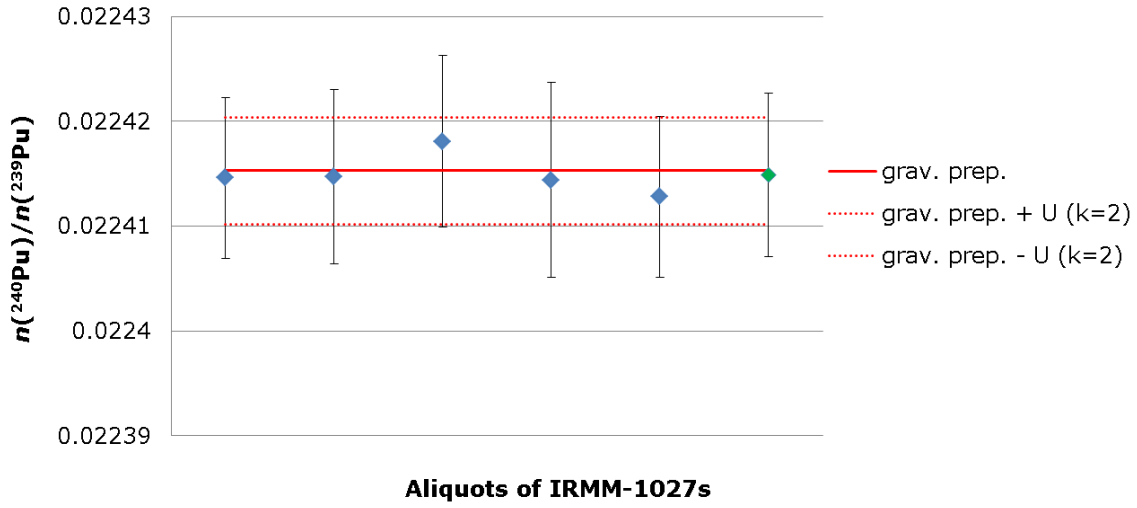


Figure 20 The $n(^{241}Pu)/n(^{239}Pu)$ amount ratio in the solution of IRMM-1027s prepared by gravimetric mixing compared with the measured values by TIMS (individual aliquots with blue diamonds and the average value with a green diamond). Error bars show the expanded uncertainties (coverage factor k = 2)

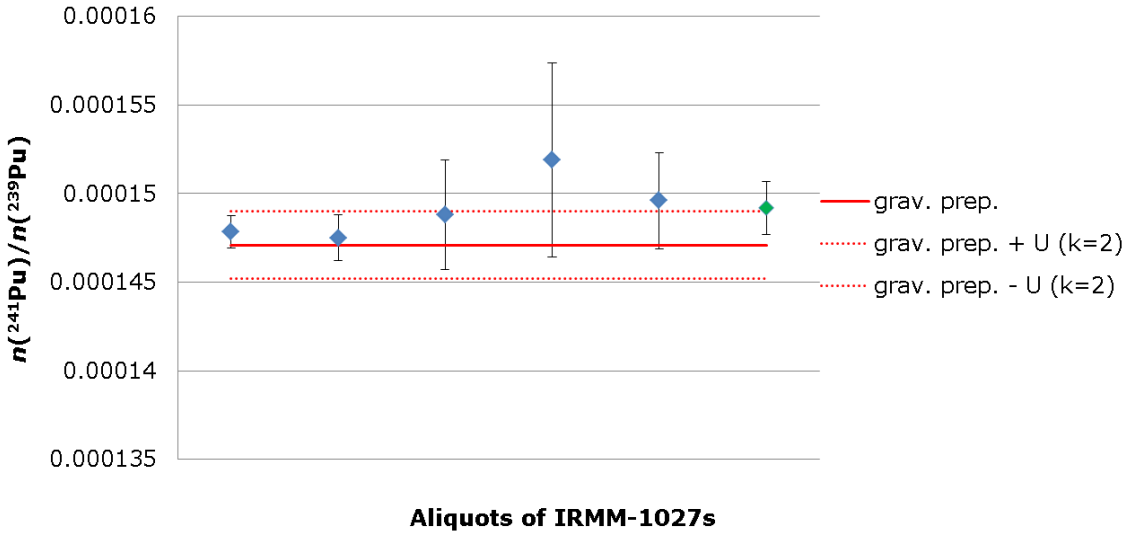
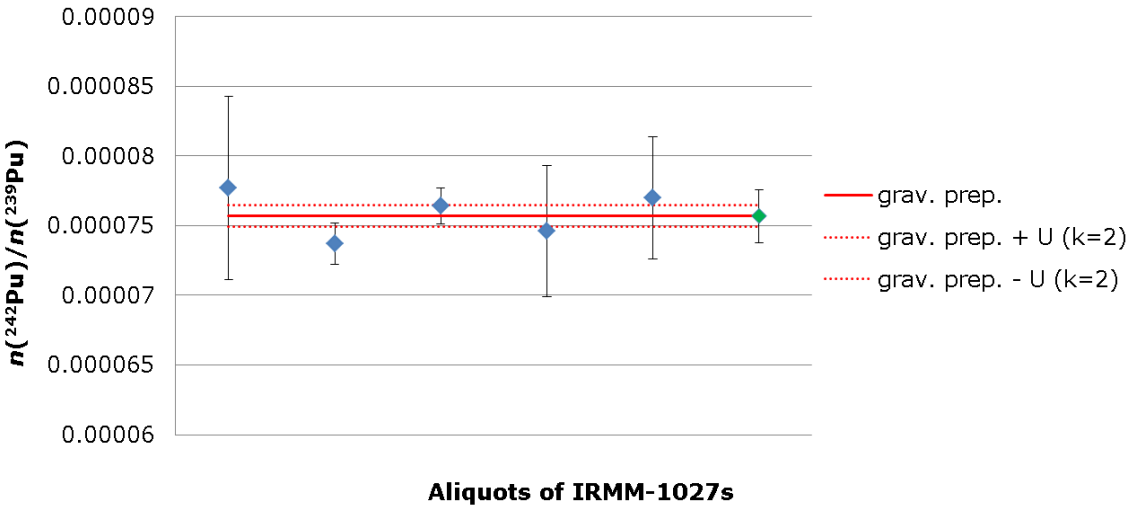


Figure 21 The $n(^{242}Pu)/n(^{239}Pu)$ amount ratio in the solution of IRMM-1027s prepared by gravimetric mixing compared with the measured values by TIMS (individual aliquots with blue diamonds and the average value with a green diamond). Error bars show the expanded uncertainties (coverage factor k = 2)



Annex 11 Results of the homogeneity assessment for IRMM-1027s

Figure 22 The amount content of ^{235}U from homogeneity study for the 30 replicate measurements (10 selected units, 3 replicates each) are shown as a function of the analytical sequence

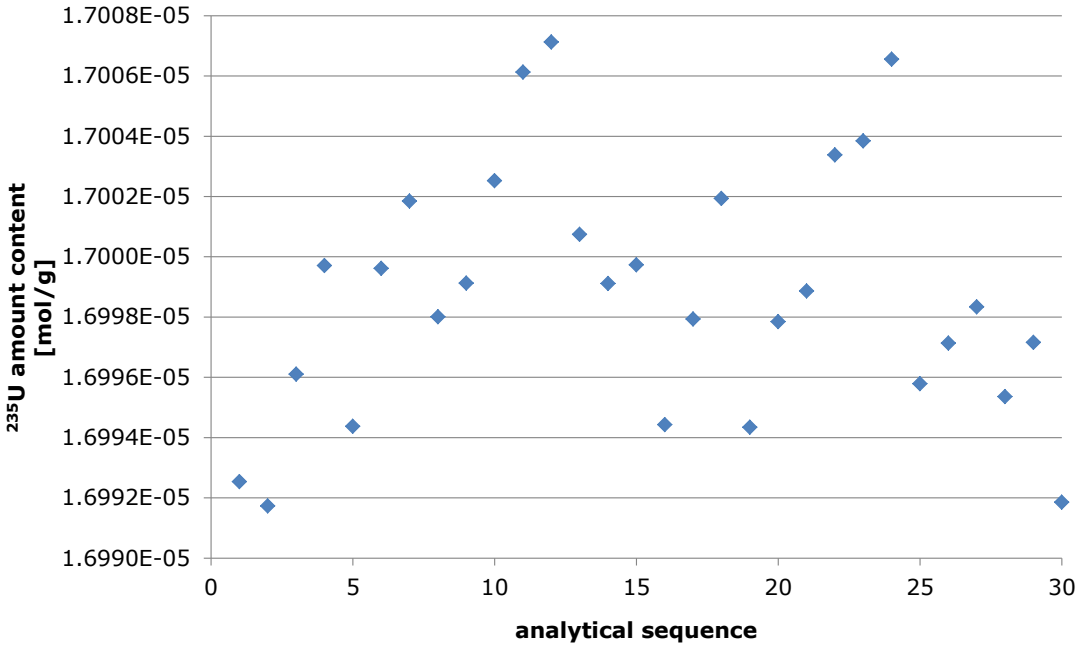


Figure 23 Mean amount contents of ^{235}U from homogeneity study as a function of the units (filling sequence). The unit means are plotted with 95 % CI of the means

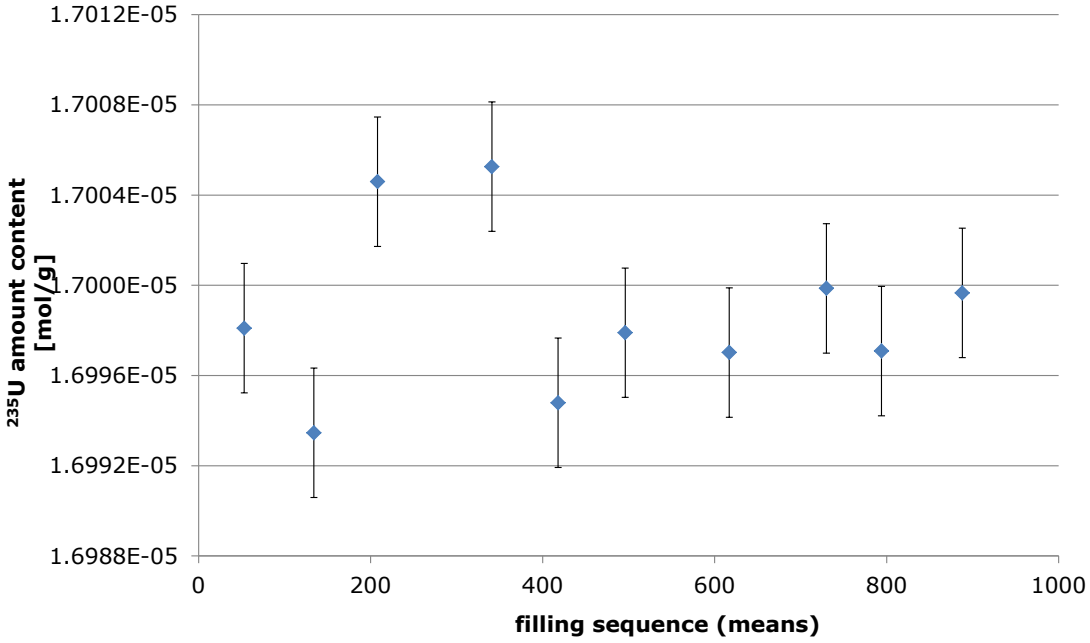


Figure 24 The amount content of ^{238}U from homogeneity study. Replicates are shown as a function of the analytical sequence

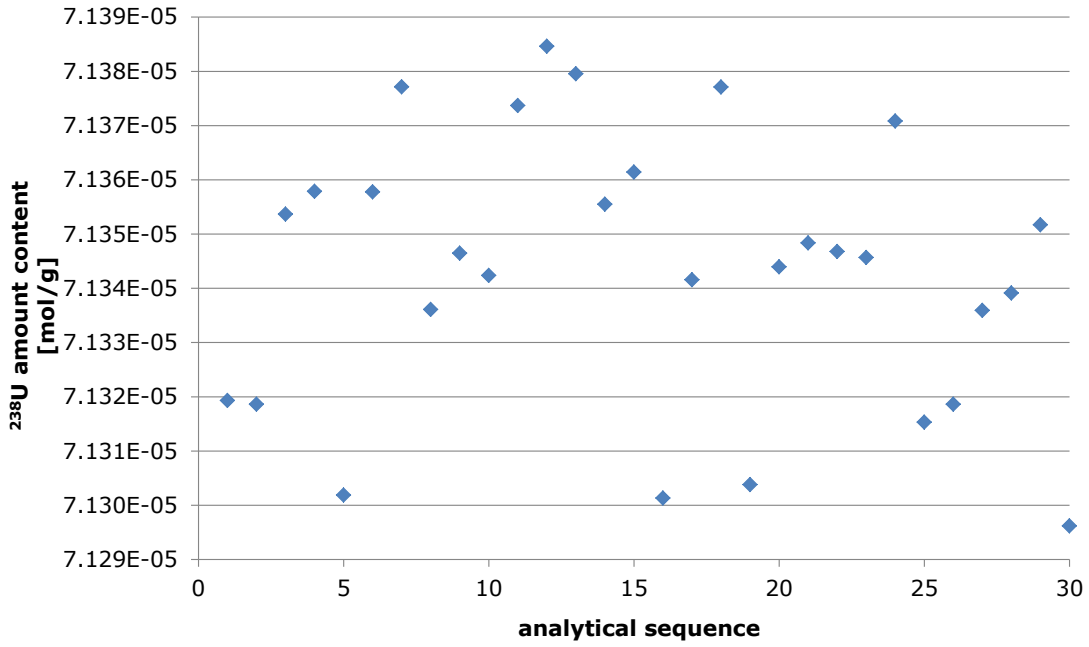


Figure 25 Mean amount contents of ^{238}U from homogeneity study as a function of the units (filling sequence). The unit means are plotted with 95 % CI of the means.

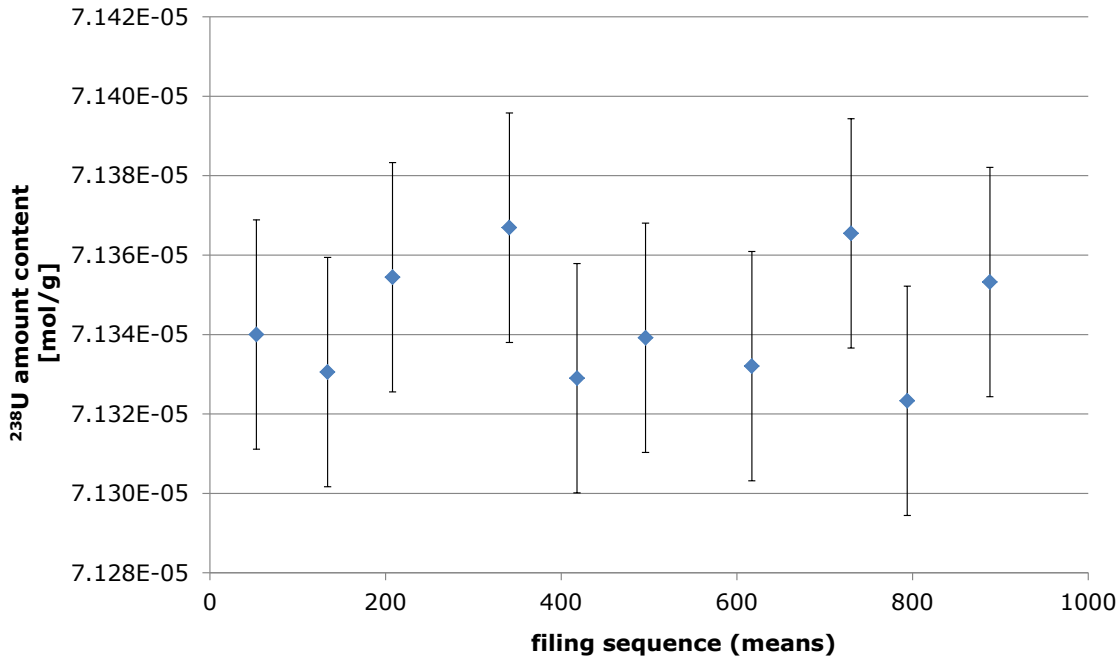


Figure 26 The amount content (normalised) of ^{239}Pu from homogeneity study. Replicates are shown as a function of the analytical sequence

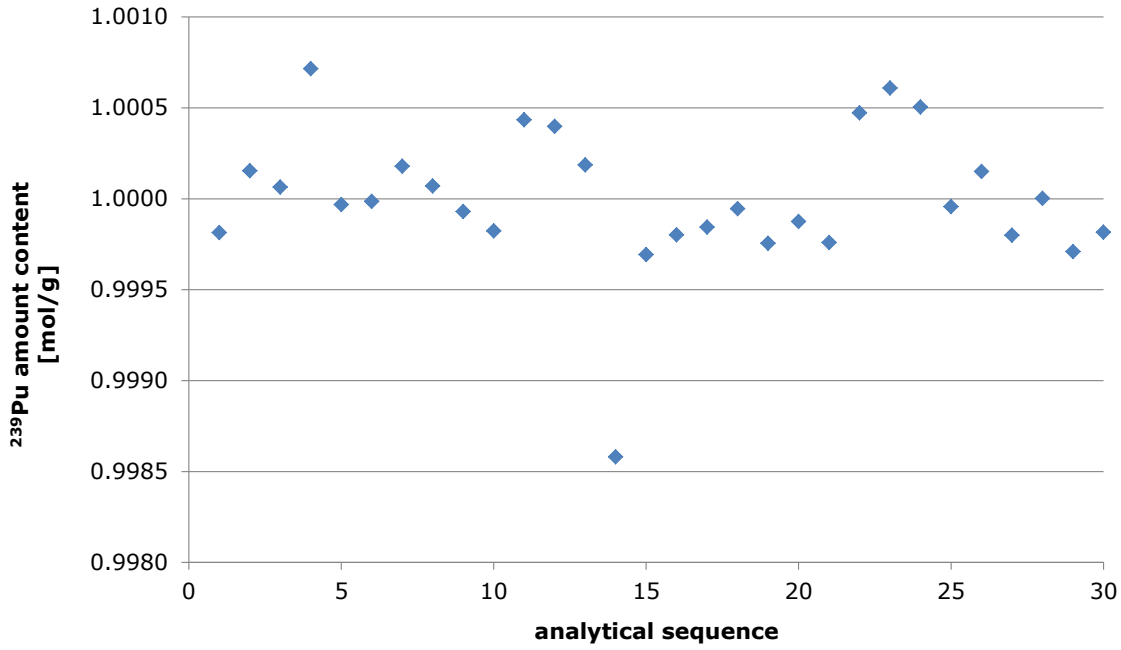
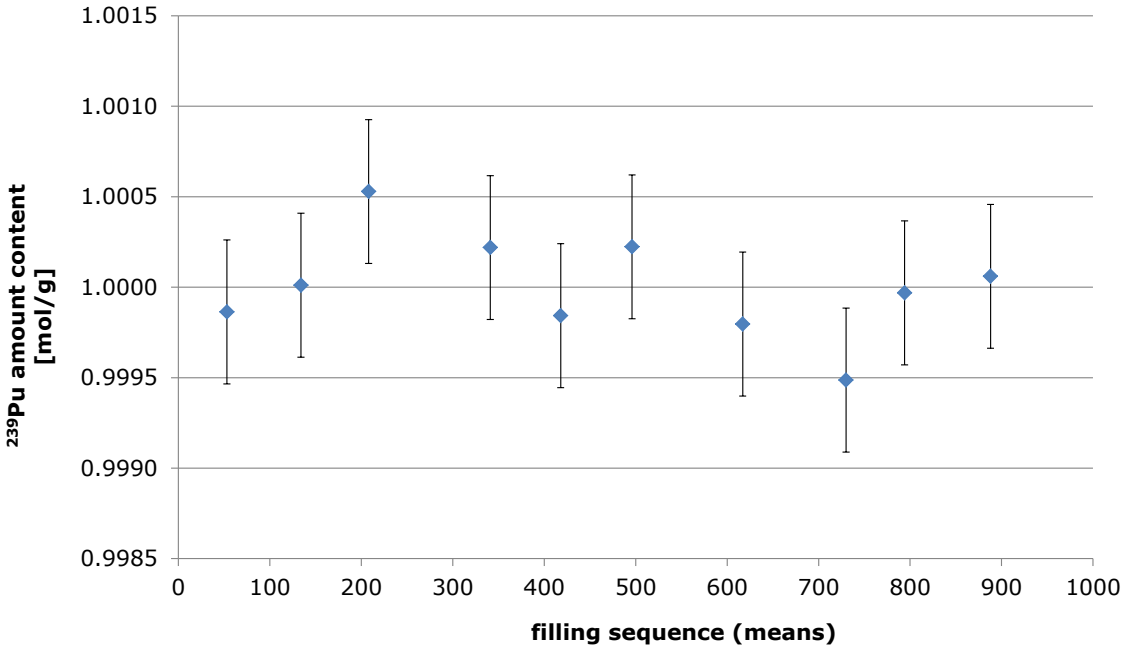


Figure 27 Mean amount contents (normalised) of ^{239}Pu from homogeneity study as a function of the units (filling sequence). The unit means are plotted with 95 % CI of the means



Annex 12 The weighing certificate of the aliquots of dispensed solution of IRMM-1027s per unit before drying

Joint Research Centre

Directorate G – Nuclear Safety and Security
G.2 - Standards for Nuclear Safety, Security and Safeguards Unit

Certificate of weighing

E.3891 **Issued date**: 30/01/2017 **Page 1 of 6**

Applicant:	R. Jakopič	**Unit**: SN3S
Project:	Preparation and certification of IRMM-1027s LSD spikes	
Description:	Dispensing of IRMM-1027s U/Pu nitrate solution into individual vials	
Weighing date:	21-24 November 2016	

The reported results apply only to the objects/samples described in this certificate and are shown in Annex.

Observations:
The dispensing and weighing were performed according to working instruction WI-D-00786/2 Preparation of Large-sized dried (LSD) spikes" on balance Sartorius TE124 installed in the dispensing robot box with inventory No. 2006 00290 17.

Traceability:
The certified masses are traceable to the International Kilogram Prototype via regular calibrations of the principal kilogram at JRC Geel. The mass standard identified as H208 (cylinder + vial certificate E3162) was used to verify the balance performance in the mass determinations.

Uncertainty:
The uncertainty on the mass determinations has a value of ± 0.0006 g. The reported uncertainties is expanded uncertainties $U = k \cdot u_c$ where u_c is the combined standard uncertainty calculated according to the ISO/IEC Guide to the Expression of Uncertainty in Measurement. The coverage factor $k = 2$ corresponds to a coverage probability of about 95%.

Nuclear Chemistry Laboratory Responsible

R. Jakopič

Analyst

J. Bauwens

Retieseweg, B-2440 Geel, Belgium; Tel.: +32-(0)14-571 617

Annex: Mass of the nitrate solution in the vials of IRMM-1027s before drying.

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
001	2.5116	051	2.5091	101	2.5043	151	2.5029
002	2.5107	052	2.5090	102	2.5057	152	2.5037
003	2.5102	053	2.5122	103	2.5029	153	2.5008
004	2.5120	054	2.5062	104	2.5058	154	2.5075
005	2.5123	055	2.5081	105	2.5017	155	2.5018
006	2.5106	056	2.5103	106	2.5040	156	2.5005
007	2.5122	057	2.5063	107	2.5069	157	2.5040
008	2.5096	058	2.5078	108	2.5039	158	2.5043
009	2.5115	059	2.5083	109	2.5067	159	2.5066
010	2.5118	060	2.5072	110	2.5035	160	2.5026
011	2.5122	061	2.5081	111	2.5043	161	2.5015
012	2.5094	062	2.5072	112	2.5026	162	2.5044
013	2.5126	063	2.5088	113	2.5030	163	2.5031
014	2.5109	064	2.5081	114	2.5038	164	2.5027
015	2.5118	065	2.5049	115	2.5071	165	2.5048
016	2.5099	066	2.5104	116	2.5033	166	2.5059
017	2.5118	067	2.5048	117	2.5025	167	2.5014
018	2.5114	068	2.5077	118	2.5040	168	2.5025
019	2.5123	069	2.5066	119	2.5067	169	2.5023
020	2.5079	070	2.5048	120	2.5037	170	2.5035
021	2.5140	071	2.5090	121	2.5029	171	2.5060
022	2.5083	072	2.5032	122	2.5036	172	2.5017
023	2.5126	073	2.5092	123	2.5063	173	2.5030
024	2.5142	074	2.5022	124	2.5020	174	2.5062
025	2.5111	075	2.5056	125	2.5067	175	2.5048
026	2.5107	076	2.5091	126	2.5030	176	2.4994
027	2.5095	077	2.5061	127	2.5009	177	2.5042
028	2.5104	078	2.5050	128	2.5043	178	2.5041
029	2.5132	079	2.5068	129	2.5080	179	2.5020
030	2.5112	080	2.5051	130	2.5006	180	2.5058
031	2.5130	081	2.5067	131	2.5033	181	2.4997
032	2.5083	082	2.5049	132	2.5028	182	2.5047
033	2.5115	083	2.5040	133	2.5061	183	2.5062
034	2.5125	084	2.5054	134	2.5035	184	2.5031
035	2.5104	085	2.5066	135	2.5023	185	2.5035
036	2.5125	086	2.5031	136	2.5067	186	2.4997
037	2.5111	087	2.5044	137	2.5020	187	2.5055
038	2.5106	088	2.5060	138	2.5037	188	2.5023
039	2.5098	089	2.5066	139	2.5026	189	2.5074
040	2.5135	090	2.5039	140	2.5019	190	2.5017
041	2.5093	091	2.5062	141	2.5047	191	2.5027
042	2.5112	092	2.5066	142	2.5055	192	2.5059
043	2.5092	093	2.5033	143	2.5015	193	2.5004
044	2.5094	094	2.5049	144	2.5031	194	2.5013
045	2.5120	095	2.5041	145	2.5021	195	2.5064
046	2.5100	096	2.5070	146	2.5027	196	2.5011
047	2.5107	097	2.5039	147	2.5041	197	2.5036
048	2.5075	098	2.5017	148	2.5031	198	2.5014
049	2.5102	099	2.5032	149	2.5031	199	2.5049
050	2.5088	100	2.5058	150	2.5048	200	2.5046

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Annex: Mass of the nitrate solution in the vials of IRMM-1027s before drying.

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
201	2.5056	251	2.5031	301	2.5029	351	2.5002
202	2.5009	252	2.5028	302	2.5025	352	2.5096
203	2.5031	253	2.5044	303	2.5018	353	2.4986
204	2.5072	254	2.5053	304	2.5030	354	2.5043
205	2.5004	255	2.5042	305	2.4983	355	2.5034
206	2.5050	256	2.5027	306	2.5124	356	2.5061
207	2.5026	257	2.5003	307	2.4970	357	2.4994
208	2.5046	258	2.5034	308	2.5067	358	2.5101
209	2.5012	259	2.5041	309	2.5001	359	2.4991
210	2.5034	260	2.5024	310	2.5011	360	2.5031
211	2.5057	261	2.5030	311	2.5028	361	2.5074
212	2.5024	262	2.5010	312	2.5085	362	2.5052
213	2.5020	263	2.5041	313	2.5012	363	2.5021
214	2.5042	264	2.5036	314	2.5055	364	2.4990
215	2.5025	265	2.5049	315	2.4964	365	2.5053
216	2.5030	266	2.5037	316	2.5049	366	2.5006
217	2.5048	267	2.5002	317	2.5029	367	2.5117
218	2.5023	268	2.5024	318	2.5033	368	2.5032
219	2.5048	269	2.4989	319	2.5012	369	2.5026
220	2.5034	270	2.5043	320	2.5045	370	2.4982
221	2.5024	271	2.5061	321	2.5021	371	2.5063
222	2.5046	272	2.5048	322	2.5075	372	2.5023
223	2.5029	273	2.5016	323	2.4984	373	2.5058
224	2.5044	274	2.5049	324	2.5056	374	2.5026
225	2.5021	275	2.5012	325	2.5016	375	2.5019
226	2.5070	276	2.5027	326	2.5048	376	2.5055
227	2.5042	277	2.5016	327	2.5012	377	2.4979
228	2.5019	278	2.5034	328	2.5054	378	2.5090
229	2.5025	279	2.5043	329	2.5020	379	2.5077
230	2.5073	280	2.5007	330	2.5039	380	2.5013
231	2.5065	281	2.5072	331	2.5007	381	2.5058
232	2.5019	282	2.4990	332	2.5067	382	2.4948
233	2.5020	283	2.5025	333	2.5057	383	2.5109
234	2.5029	284	2.5042	334	2.4989	384	2.4983
235	2.5078	285	2.5026	335	2.5043	385	2.5096
236	2.5012	286	2.5013	336	2.5035	386	2.5013
237	2.5025	287	2.5013	337	2.5016	387	2.5053
238	2.5048	288	2.5001	338	2.5004	388	2.4989
239	2.5032	289	2.5060	339	2.5105	389	2.5076
240	2.5039	290	2.5071	340	2.4989	390	2.5010
241	2.5016	291	2.5001	341	2.5069	391	2.5014
242	2.5035	292	2.4991	342	2.5028	392	2.5129
243	2.4997	293	2.5039	343	2.5043	393	2.5038
244	2.5016	294	2.5059	344	2.5000	394	2.5029
245	2.5075	295	2.5035	345	2.5065	395	2.5000
246	2.5067	296	2.5009	346	2.4966	396	2.5032
247	2.5010	297	2.5015	347	2.5082	397	2.5042
248	2.5055	298	2.4990	348	2.5018	398	2.5046
249	2.4974	299	2.5071	349	2.5069	399	2.5016
250	2.5036	300	2.5020	350	2.5035	400	2.5047

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Annex: Mass of the nitrate solution in the vials of IRMM-1027s before drying.

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
401	2.5060	451	2.5044	501	2.5088	551	2.5016
402	2.5044	452	2.5010	502	2.4985	552	2.5033
403	2.5024	453	2.5074	503	2.5050	553	2.5109
404	2.5031	454	2.5078	504	2.5029	554	2.5019
405	2.5075	455	2.4980	505	2.5022	555	2.5008
406	2.5032	456	2.5062	506	2.5045	556	2.5041
407	2.5044	457	2.5045	507	2.5054	557	2.5043
408	2.5023	458	2.5005	508	2.5029	558	2.5040
409	2.5035	459	2.5081	509	2.5053	559	2.5030
410	2.5057	460	2.5006	510	2.5023	560	2.5064
411	2.5042	461	2.5014	511	2.5041	561	2.5008
412	2.4998	462	2.5058	512	2.5033	562	2.5047
413	2.5036	463	2.5066	513	2.5019	563	2.5077
414	2.5091	464	2.5011	514	2.5060	564	2.4987
415	2.5002	465	2.5012	515	2.5035	565	2.5023
416	2.5058	466	2.5050	516	2.5013	566	2.5070
417	2.5039	467	2.5097	517	2.5015	567	2.5002
418	2.5047	468	2.5039	518	2.5064	568	2.5071
419	2.5002	469	2.5034	519	2.5037	569	2.4999
420	2.5045	470	2.5018	520	2.5046	570	2.5059
421	2.5065	471	2.5043	521	2.5066	571	2.5062
422	2.5031	472	2.5020	522	2.5008	572	2.5052
423	2.5037	473	2.5073	523	2.5101	573	2.5051
424	2.5055	474	2.5003	524	2.5000	574	2.4976
425	2.4988	475	2.5041	525	2.5051	575	2.5118
426	2.5069	476	2.5053	526	2.5001	576	2.5019
427	2.5046	477	2.5036	527	2.5064	577	2.5027
428	2.5063	478	2.5049	528	2.4987	578	2.5037
429	2.5009	479	2.5033	529	2.5113	579	2.5034
430	2.5056	480	2.5007	530	2.5013	580	2.5052
431	2.5020	481	2.5065	531	2.5045	581	2.5050
432	2.5048	482	2.4979	532	2.5008	582	2.5040
433	2.4984	483	2.5019	533	2.5074	583	2.4986
434	2.5116	484	2.5053	534	2.5054	584	2.5042
435	2.5034	485	2.5029	535	2.5033	585	2.5049
436	2.5056	486	2.4979	536	2.5014	586	2.5011
437	2.5014	487	2.5039	537	2.5052	587	2.5087
438	2.5023	488	2.5062	538	2.5053	588	2.5000
439	2.5070	489	2.5037	539	2.5028	589	2.5078
440	2.5044	490	2.5061	540	2.5048	590	2.5064
441	2.4999	491	2.5024	541	2.5091	591	2.5006
442	2.5094	492	2.5001	542	2.4998	592	2.5053
443	2.5025	493	2.4989	543	2.4999	593	2.5079
444	2.5027	494	2.5053	544	2.5073	594	2.4987
445	2.5026	495	2.5038	545	2.5041	595	2.5041
446	2.5050	496	2.5052	546	2.5032	596	2.5056
447	2.5066	497	2.5032	547	2.5016	597	2.4979
448	2.5004	498	2.5021	548	2.5058	598	2.5065
449	2.5056	499	2.5082	549	2.5024	599	2.5035
450	2.5024	500	2.5004	550	2.5055	600	2.5020

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Annex: Mass of the nitrate solution in the vials of IRMM-1027s before drying.

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
601	2.5011	651	2.4973	701	2.5030	751	2.5076
602	2.5105	652	2.5059	702	2.5059	752	2.5034
603	2.5037	653	2.5024	703	2.5055	753	2.5035
604	2.5041	654	2.5016	704	2.5006	754	2.5072
605	2.5040	655	2.5036	705	2.5031	755	2.5024
606	2.5047	656	2.5063	706	2.5037	756	2.5071
607	2.5020	657	2.5073	707	2.5081	757	2.5035
608	2.5025	658	2.5017	708	2.5019	758	2.5068
609	2.5066	659	2.5062	709	2.5047	759	2.4971
610	2.5015	660	2.5020	710	2.5072	760	2.5065
611	2.5078	661	2.5055	711	2.4990	761	2.5040
612	2.5050	662	2.5048	712	2.5084	762	2.5056
613	2.4978	663	2.5013	713	2.4996	763	2.5027
614	2.5099	664	2.5046	714	2.5074	764	2.5007
615	2.4988	665	2.5029	715	2.5048	765	2.5053
616	2.5067	666	2.5041	716	2.5038	766	2.5059
617	2.5039	667	2.5046	717	2.4938	767	2.5023
618	2.5031	668	2.5080	718	2.5045	768	2.5053
619	2.5016	669	2.4984	719	2.5008	769	2.5058
620	2.5042	670	2.5042	720	2.5013	770	2.5016
621	2.5089	671	2.5098	721	2.5034	771	2.5063
622	2.5008	672	2.4986	722	2.5072	772	2.5011
623	2.5020	673	2.5056	723	2.5054	773	2.5006
624	2.5085	674	2.5020	724	2.4985	774	2.5131
625	2.5026	675	2.5020	725	2.5010	775	2.5046
626	2.5034	676	2.5041	726	2.5064	776	2.5047
627	2.5053	677	2.5024	727	2.4996	777	2.4960
628	2.5008	678	2.5045	728	2.5057	778	2.5065
629	2.5035	679	2.5049	729	2.5066	779	2.5056
630	2.5062	680	2.5027	730	2.5036	780	2.5035
631	2.5026	681	2.5034	731	2.5046	781	2.5051
632	2.5059	682	2.5108	732	2.5016	782	2.5032
633	2.5007	683	2.4994	733	2.5027	783	2.5075
634	2.5063	684	2.5029	734	2.5004	784	2.5055
635	2.5035	685	2.5037	735	2.5027	785	2.5025
636	2.5038	686	2.5037	736	2.5064	786	2.5026
637	2.5030	687	2.5046	737	2.5066	787	2.4995
638	2.5031	688	2.5026	738	2.5006	788	2.5098
639	2.5037	689	2.5019	739	2.5022	789	2.4994
640	2.5044	690	2.5048	740	2.5047	790	2.5062
641	2.5040	691	2.5068	741	2.5082	791	2.5055
642	2.5047	692	2.5037	742	2.4961	792	2.5066
643	2.5037	693	2.5038	743	2.5073	793	2.5018
644	2.5020	694	2.5034	744	2.4992	794	2.5029
645	2.5063	695	2.5048	745	2.5043	795	2.5056
646	2.5045	696	2.5023	746	2.5041	796	2.5039
647	2.5024	697	2.5031	747	2.5048	797	2.5052
648	2.5029	698	2.5069	748	2.5047	798	2.5089
649	2.5093	699	2.5051	749	2.4979	799	2.5009
650	2.5059	700	2.5030	750	2.5028	800	2.5024

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Annex: Mass of the nitrate solution in the vials of IRMM-1027s before drying.

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
801	2.5073	851	2.5029	901	2.5036		
802	2.5023	852	2.5022	902	2.5056		
803	2.5028	853	2.5028	903	2.5035		
804	2.5069	854	2.5112	904	2.5027		
805	2.5012	855	2.5006	905	2.5053		
806	2.5051	856	2.5046	906	2.5084		
807	2.5092	857	2.5054	907	2.5019		
808	2.5017	858	2.5071	908	2.5031		
809	2.5050	859	2.4998	909	2.5028		
810	2.5059	860	2.5068	910	2.5075		
811	2.4994	861	2.5011	911	2.5047		
812	2.5069	862	2.5067	912	2.5013		
813	2.5023	863	2.5043	913	2.5049		
814	2.5062	864	2.5018	914	2.5019		
815	2.5052	865	2.5091	915	2.5032		
816	2.5041	866	2.5022	916	2.5058		
817	2.5011	867	2.5045	917	2.5061		
818	2.5050	868	2.5020	918	2.5078		
819	2.5059	869	2.5044	919	2.4999		
820	2.5040	870	2.5081	920	2.5073		
821	2.5038	871	2.5036	921	2.5041		
822	2.5058	872	2.5010	922	2.5034		
823	2.5060	873	2.5002	923	2.5020		
824	2.5013	874	2.5064	924	2.4999		
825	2.5102	875	2.5089	925	2.5097		
826	2.5018	876	2.4998	926	2.5082		
827	2.5010	877	2.5058	927	2.5024		
828	2.5051	878	2.5043	928	2.5027		
829	2.5072	879	2.5061	929	2.5039		
830	2.5048	880	2.5016	930	2.5073		
831	2.5036	881	2.5049	931	2.5060		
832	2.5083	882	2.5044	932	2.5004		
833	2.4994	883	2.5043	933	2.5068		
834	2.5048	884	2.5074	934	2.5052		
835	2.5074	885	2.5035	935	2.5003		
836	2.4987	886	2.5044	936	2.5081		
837	2.5059	887	2.5052	937	2.5015		
838	2.5041	888	2.5019	938	2.5033		
839	2.5025	889	2.5095	939	2.5047		
840	2.5055	890	2.5001	940	2.5023		
841	2.5028	891	2.5047	941	2.5045		
842	2.5097	892	2.5074	942	2.5090		
843	2.5004	893	2.5008	943	2.5007		
844	2.5068	894	2.5042	944	2.5040		
845	2.5007	895	2.5051	945	2.5056		
846	2.5061	896	2.5057	946	2.5035		
847	2.5051	897	2.5051	947	2.5045		
848	2.5022	898	2.5044	948	2.5045		
849	2.5093	899	2.5021	949	2.5033		
850	2.5050	900	2.5046	950	2.5088		

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Annex 13 The weighing certificate for the preparation of the mother solution of IRMM-1027s

Joint Research Centre

Directorate G – Nuclear Safety and Security
G.2 - Standards for Nuclear Safety, Security and Safeguards Unit

Certificate of weighing

Reg. No. E.3882 **Issued date**: 10 November 2016 **Page** 1 **of** 1

Applicant:	R. Jakopič	**Unit**: SN3S	
Project:	Preparation and certification of IRMM-1027s LSD spikes		
Description:	Preparation of U/Pu nitrate solution for IRMM-1027s		
Date of request:	N/A	**Weighing date**:	October/November 2016

The reported results apply only to the objects / samples described in this certificate.

	Mass [g]	Uncertainty [g]
Mass of Pu metal (MP2)	1.65903	0.00009
Mass of enriched U metal (CRM 116-A)	10.24309	0.00007
Mass of natural U metal (EC 101)	41.65132	0.00008
Mass of IRMM-1027s U/Pu nitrate solution	2460.69	0.03

Observations:
Masses were determined by substitution weighing on balances AT 261 and AT 201 with inventory No. 1999003727 and 19960054773 and balance PR 5002 with inventory No. 9800298.

Traceability:
The certified mass values are traceable to the International Kilogram Prototype via regular calibrations of the principal kilogram at JRC Geel. The sets of working mass standards M3 and M10 were used as reference in the mass determination.

Uncertainty:
All reported uncertainties are expanded uncertainties $U = k \cdot u_c$ where u_c is the combined standard uncertainty calculated according to the ISO/IEC Guide to the expression of Uncertainty in Measurement. The coverage factor $k = 2$ corresponds to a coverage probability of about 95 %.

Rožle Jakopič
Nuclear Chemistry Laboratory Responsible

Jeroen Bauwens,
Analyst

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Annex 14 The uranium isotope amount ratios and their associated uncertainties for the uranium gravimetric mixture of IRMM-1027s

Uranium gravimetric mixture for IRMM-1027s

Author: Jakopic

Author: Rozle Jakopic

A uranium gravimetric mixture was prepared by dissolving natural uranium (EC NRM 101) and enriched uranium (NBL CRM 116-A) metals in hydrochloric/nitric acid solution.

Input parameters: a) masses of the metals and the nitrate solution (E3882) b) purity of the metals (metal certificates) c) uranium isotope amount ratios of the metals (certificate) d) the atomic masses according Wang et al. (The AME 2012 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 36, No. 12, 1603-2014, 2012).

U ingrowth from Pu MP2 metal is calculated from the measurement data (2006, IRMM) plus the ingrowth from 2006 until 1 November 2016 (reference date for the certificate)

Model Equation:

{Molar mass of uranium in gravimetric mixture, IRMM-1027s}

$M_U = M_{233U} \cdot f_{233U} + M_{234U} \cdot f_{234U} + M_{235U} \cdot f_{235U} + M_{236U} \cdot f_{236U} + M_{238U} \cdot f_{238U}$;

{Isotope amount fraction in gravimetric mixture, IRMM-1027s}

$f_{233U} = R_{233U/238U}/\Sigma R_U$;

$f_{234U} = R_{234U/238U}/\Sigma R_U$;

$f_{235U} = R_{235U/238U}/\Sigma R_U$;

$f_{236U} = R_{236U/238U}/\Sigma R_U$;

$f_{238U} = 1/\Sigma R_U$;

$\Sigma R_U = R_{233U/238U} + R_{234U/238U} + R_{235U/238U} + R_{236U/238U} + 1$;

{Isotope mass fraction in gravimetric mixture, IRMM-1027s}

$w_{233U} = f_{233U} \cdot M_{233U}/M_U$;

$w_{234U} = f_{234U} \cdot M_{234U}/M_U$;

$w_{235U} = f_{235U} \cdot M_{235U}/M_U$;

$w_{236U} = f_{236U} \cdot M_{236U}/M_U$;

$w_{238U} = f_{238U} \cdot M_{238U}/M_U$;

{Isotope amount ratios in gravimetric mixture, IRMM-1027s}

$R_{233U/238U} = n_{233U}/n_{238U}$;

$R_{234U/238U} = n_{234U}/n_{238U}$;

$R_{235U/238U} = n_{235U}/n_{238U}$;

$R_{236U/238U} = n_{236U}/n_{238U}$;

{Amount of uranium isotopes in gravimetric mixture, IRMM-1027s}

$n_{233U} = (n_{233.a} + n_{233.b} + n_{233.c})$;

$n_{234U} = (n_{234.a} + n_{234.b} + n_{234.c})$;

$n_{235U} = (n_{235.a} + n_{235.b} + n_{235.c})$;

$n_{236U} = (n_{236.a} + n_{236.b} + n_{236.c})$;

$n_{238U} = (n_{238.a} + n_{238.b} + n_{238.c})$;

{uranium mass fraction in gravimetric mixture, IRMM-1027s}

$\gamma_{Umixture}=(m_{UCRM116A}*\eta_{purityCRM116A}+m_{UEC101}*\eta_{purityEC101}+m_{UMP2})/m_{solution1027s}$;

$\gamma_{235Umixture}=\gamma_{Umixture}*w_{235U}$;

$\gamma_{238Umixture}=\gamma_{Umixture}*w_{238U}$;

{uranium amount content in gravimetric mixture, IRMM-1027s}

$c_{Umixture}=\gamma_{Umixture}/M_U$;

$c_{235Umixture}=c_{Umixture}*f_{235U}$;

$c_{238Umixture}=c_{Umixture}*f_{238U}$;

{Amount of uranium isotopes in EC NRM 101}

$n_{233.a} = m_{UEC101} * \eta_{purityEC101} * f_{233Ua} / M_{Ua}$;

$n_{234.a} = m_{UEC101} * \eta_{purityEC101} * f_{234Ua} / M_{Ua}$;

$n_{235.a} = m_{UEC101} * \eta_{purityEC101} * f_{235Ua} / M_{Ua}$;

$n_{236.a} = m_{UEC101} * \eta_{purityEC101} * f_{236Ua} / M_{Ua}$;

$n_{238.a} = m_{UEC101} * \eta_{purityEC101} * f_{238Ua} / M_{Ua}$;

{Amount of uranium isotopes in NBL CRM116-A}

$n_{233.b} = m_{UCRM116A} * \eta_{purityCRM116A} * f_{233Ub} / M_{Ub}$;

$n_{234.b} = m_{UCRM116A} * \eta_{purityCRM116A} * f_{234Ub} / M_{Ub}$;

$n_{235.b} = m_{UCRM116A} * \eta_{purityCRM116A} * f_{235Ub} / M_{Ub}$;

$n_{236.b} = m_{UCRM116A} * \eta_{purityCRM116A} * f_{236Ub} / M_{Ub}$;

$n_{238.b} = m_{UCRM116A} * \eta_{purityCRM116A} * f_{238Ub} / M_{Ub}$;

{Isotope amount fraction of uranium in EC NRM 101}

$f_{233Ua} = R_{233U/238Ua}/\Sigma R_{Ua}$;

$f_{234Ua} = R_{234U/238Ua}/\Sigma R_{Ua}$;

$f_{235Ua} = R_{235U/238Ua}/\Sigma R_{Ua}$;

$f_{236Ua} = R_{236U/238Ua}/\Sigma R_{Ua}$;

$f_{238Ua} = 1/\Sigma R_{Ua}$;

$\Sigma R_{Ua} = R_{233U/238Ua} + R_{234U/238Ua} + R_{235U/238Ua} + R_{236U/238Ua} + 1$;

{Molar mass of uranium in EC NRM 101}

$M_{Ua} = M_{233U}\cdot f_{233Ua} + M_{234U}\cdot f_{234Ua} + M_{235U}\cdot f_{235Ua} + M_{236U}\cdot f_{236Ua} + M_{238U}\cdot f_{238Ua}$;

$w_{233Ua}=f_{233Ua}*M_{233U}/M_{Ua}$;

$w_{234Ua}=f_{234Ua}*M_{234U}/M_{Ua}$;

$w_{235Ua}=f_{235Ua}*M_{235U}/M_{Ua}$;

$w_{236Ua}=f_{236Ua}*M_{236U}/M_{Ua}$;

$w_{238Ua}=f_{238Ua}*M_{238U}/M_{Ua}$;

{Isotope amount fraction of uranium in NBL CRM 116-A}

$f_{233Ub} = R_{233U/235Ub}/\Sigma R_{Ub}$;

$f_{234Ub} = R_{234U/235Ub}/\Sigma R_{Ub}$;

$f_{238Ub} = R_{238U/235Ub}/\Sigma R_{Ub}$;

$f_{236Ub} = R_{236U/235Ub}/\Sigma R_{Ub}$;

$f_{235Ub} = 1/\Sigma R_{Ub}$;

$\Sigma R_{Ub} = R_{233U/235Ub} + R_{234U/235Ub} + R_{238U/235Ub} + R_{236U/235Ub} + 1$;

{Molar mass of uranium in NBL CRM 116-A}

$M_{Ub} = M_{233U} \cdot f_{233Ub} + M_{234U} \cdot f_{234Ub} + M_{235U} \cdot f_{235Ub} + M_{236U} \cdot f_{236Ub} + M_{238U} \cdot f_{238Ub}$;

$w_{233Ub} = f_{233Ub} * M_{233U}/M_{Ub}$;

$w_{234Ub} = f_{234Ub} * M_{234U}/M_{Ub}$;

$w_{235Ub} = f_{235Ub} * M_{235U}/M_{Ub}$;

$w_{236Ub} = f_{236Ub} * M_{236U}/M_{Ub}$;

$w_{238Ub} = f_{238Ub} * M_{238U}/M_{Ub}$;

List of Quantities:

Quantity	Unit	Definition
$\gamma_{Umixture}$	g/g	U mass fraction in IRMM-1027s
$\gamma_{235Umixture}$	g/g	^{235}U mass fraction in IRMM-1027s
$\gamma_{238Umixture}$	g/g	^{238}U mass fraction in IRMM-1027s
$c_{Umixture}$	mol/g	U amount content in IRMM-1027s
$c_{235Umixture}$	mol/g	^{235}U amount content in IRMM-1027s
$c_{238Umixture}$	mol/g	^{238}U amount content in IRMM-1027s
M_U	g/mol	Molar mass of U in IRMM-1027s
$R_{233U/238U}$	mol/mol	^{233}U/^{238}U amount ratio in IRMM-1027s
$R_{234U/238U}$	mol/mol	^{234}U/^{238}U amount ratio in IRMM-1027s
$R_{235U/238U}$	mol/mol	^{235}U/^{238}U amount ratio in IRMM-1027s
$R_{236U/238U}$	mol/mol	^{236}U/^{238}U amount ratio in IRMM-1027s
f_{233U}	mol/mol	^{233}U amount fraction in IRMM-1027s
f_{234U}	mol/mol	^{234}U amount fraction in IRMM-1027s
f_{235U}	mol/mol	^{235}U amount fraction in IRMM-1027s
f_{236U}	mol/mol	^{236}U amount fraction in IRMM-1027s
f_{238U}	mol/mol	^{238}U amount fraction in IRMM-1027s
w_{233U}	g/g	^{233}U mass fraction in IRMM-1027s
w_{234U}	g/g	^{234}U mass fraction in IRMM-1027s
w_{235U}	g/g	^{235}U mass fraction in IRMM-1027s
w_{236U}	g/g	^{236}U mass fraction in IRMM-1027s
w_{238U}	g/g	^{238}U mass fraction in IRMM-1027s
n_{233U}	mol	Amount of U-233 in the mixture
n_{234U}	mol	Amount of U-234 in the mixture
n_{235U}	mol	Amount of U-235 in the mixture
n_{236U}	mol	Amount of U-236 in the mixture
n_{238U}	mol	Amount of U-238 in the mixture

Quantity	Unit	Definition
M_{233U}	g/mol	Atomic mass of ^{233}U
M_{234U}	g/mol	Atomic mass of ^{234}U
M_{235U}	g/mol	Atomic mass of ^{235}U
M_{236U}	g/mol	Atomic mass of ^{236}U
M_{238U}	g/mol	Atomic mass of ^{238}U
$m_{solution1027s}$	g	Mass of gravimetric mixture, IRMM-1027s
m_{UEC101}	g	Mass of natural uranium metal, EC-NRM 101
$\eta_{purityEC101}$	g/g	Purity of natural uranium metal, EC NRM 101
$m_{UCRM116A}$	g	Mass of enriched uranium metal, NBL CRM 116-A
$\eta_{purityCRM116A}$	g/g	Purity of enriched uranium metal, NBL CRM 116-A
M_{Ua}	g/mol	Molar mass of U in EC NRM 101
f_{233Ua}	mol/mol	^{233}U amount fraction in EC NRM 101
f_{234Ua}	mol/mol	^{234}U amount fraction in EC NRM 101
f_{235Ua}	mol/mol	^{235}U amount fraction in EC NRM 101
f_{236Ua}	mol/mol	^{236}U amount fraction in EC NRM 101
f_{238Ua}	mol/mol	^{238}U amount fraction in EC NRM 101
M_{Ub}	g/mol	Molar mass of U in NBL CRM 116-A
f_{233Ub}	mol/mol	^{233}U amount fraction in NBL CRM 116-A
f_{234Ub}	mol/mol	^{234}U amount fraction in NBL CRM 116-A
f_{235Ub}	mol/mol	^{235}U amount fraction in NBL CRM 116-A
f_{236Ub}	mol/mol	^{236}U amount fraction in NBL CRM 116-A
f_{238Ub}	mol/mol	^{238}U amount fraction in NBL CRM 116-A
$n_{233,a}$	mol	^{233} U amount in EC NRM 101
$n_{234,a}$	mol	^{234} U amount in EC NRM 101
$n_{235,a}$	mol	^{235} U amount in EC NRM 101
$n_{236,a}$	mol	^{236} U amount in EC NRM 101
$n_{238,a}$	mol	^{238} U amount in EC NRM 101
$n_{233,b}$	mol	^{233} U amount in NBL CRM 116-A
$n_{234,b}$	mol	^{234} U amount in NBL CRM 116-A
$n_{235,b}$	mol	^{235} U amount in NBL CRM 116-A
$n_{236,b}$	mol	^{236} U amount in NBL CRM 116-A
$n_{238,b}$	mol	^{238} U amount in NBL CRM 116-A
$R_{233U/238Ua}$	mol/mol	$^{233}U/^{238}U$ amount ratio in EC NRM 101
$R_{234U/238Ua}$	mol/mol	$^{234}U/^{238}U$ amount ratio in EC NRM 101
$R_{235U/238Ua}$	mol/mol	$^{235}U/^{238}U$ amount ratio in EC NRM 101
$R_{236U/238Ua}$	mol/mol	$^{236}U/^{238}U$ amount ratio in EC NRM 101
$R_{233U/235Ub}$	mol/mol	$^{233}U/^{235}U$ amount ratio in NBL CRM 116-A
$R_{234U/235Ub}$	mol/mol	$^{234}U/^{235}U$ amount ratio in NBL CRM 116-A

Quantity	Unit	Definition
$R_{238U/235Ub}$	mol/mol	$^{238}U/^{235}U$ amount ratio in NBL CRM 116-A
$R_{236U/235Ub}$	mol/mol	$^{236}U/^{235}U$ amount ratio in NBL CRM 116-A
ΣR_U	mol/mol	Sum of amount ratios in gravimteric mixture, IRMM-1027s
ΣR_{Ua}	mol/mol	Sum of amount ratios in EC- NRM 101
ΣR_{Ub}	mol/mol	Sum of amount ratios in NBL CRM 116-A
w_{233Ua}	g/g	^{233}U mass fraction in EC 101
w_{234Ua}	g/g	^{234}U mass fraction in EC 101
w_{235Ua}	g/g	^{235}U mass fraction in EC 101
w_{236Ua}	g/g	^{236}U mass fraction in EC 101
w_{238Ua}	g/g	^{238}U mass fraction in EC 101
w_{233Ub}	g/g	^{233}U mass fraction in CRM 116-A
w_{234Ub}	g/g	^{234}U mass fraction in CRM 116-A
w_{235Ub}	g/g	^{235}U mass fraction in CRM 116-A
w_{236Ub}	g/g	^{236}U mass fraction in CRM 116-A
w_{238Ub}	g/g	^{238}U mass fraction in CRM 116-A
$n_{234,c}$	mol	^{234}U amount ingrowth from Pu MP2
$n_{235,c}$	mol	^{235}U amount ingrowth from Pu MP2
$n_{236,c}$	mol	^{236}U amount ingrowth from Pu MP2
$n_{233,c}$	mol	^{233}U amount ingrowth from Pu MP2
$n_{238,c}$	mol	^{238}U amount ingrowth from Pu MP2
m_{UMP2}	g	mass of total ingrown U from Pu MP2

M_{233U}: Type B normal distribution
Value: 233.0396355 g/mol
Expanded Uncertainty: 0.0000029 g/mol
Coverage Factor: 1

the atomic masses according 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_{234U}: Type B normal distribution
Value: 234.0409523 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

the atomic masses according 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_{235U}: Type B normal distribution
Value: 235.0439301 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

the atomic masses according 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_{236U}: Type B normal distribution
Value: 236.0455682 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

the atomic masses according 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_{238U}: Type B normal distribution
Value: 238.0507884 g/mol
Expanded Uncertainty: 0.0000020 g/mol
Coverage Factor: 1

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

$m_{solution1027s}$: Type B normal distribution
Value: 2460.69 g
Expanded Uncertainty: 0.03 g
Coverage Factor: 2

E3882 certificate

m_{UEC101}: Type B normal distribution
Value: 41.65132 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3882 certificate

$\eta_{purityEC101}$: Type B normal distribution
Value: 0.99985 g/g
Expanded Uncertainty: 0.00005 g/g
Coverage Factor: 2

EC NRM 101 certificate

$m_{UCRM116A}$: Type B normal distribution
Value: 10.24309 g
Expanded Uncertainty: 0.00007 g
Coverage Factor: 2

E3882 certificate

$\eta_{purityCRM116A}$: Type B normal distribution
Value: 0.99945 g/g
Expanded Uncertainty: 0.00014 g/g
Coverage Factor: 2.4

NBL CRM 116-A certificate (coverage factor 2.4)

$R_{233U/238Ub}$: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

Certificate of isotopic coposition (IRMM, W. De Bolle)

$R_{234U/238Ua}$: Type B normal distribution
Value: 0.00005548 mol/mol
Expanded Uncertainty: 0.00000022 mol/mol
Coverage Factor: 1

Certificate of isotopic coposition (IRMM, W. De Bolle)

$R_{235U/238Ua}$: Type B normal distribution
Value: 0.0072593 mol/mol
Expanded Uncertainty: 0.0000036 mol/mol
Coverage Factor: 1

Certificate of isotopic coposition (IRMM, W. De Bolle)

$R_{236U/238Ua}$: Type B normal distribution
Value: 0.000000151 mol/mol
Expanded Uncertainty: 0.000000040 mol/mol
Coverage Factor: 1

Certificate of isotopic coposition (IRMM, W. De Bolle)

$R_{233U/235Ub}$: Type B normal distribution
Value: 0.0000003863 mol/mol
Expanded Uncertainty: 0.0000000086 mol/mol
Coverage Factor: 3.3

CRM 116-A certificate (coverage factor k= 3.3)

$R_{234U/235Ub}$: Type B normal distribution
Value: 0.0115836 mol/mol
Expanded Uncertainty: 0.0000097 mol/mol
Coverage Factor: 2

CRM 116-A certificate

$R_{238U/235Ub}$: Type B normal distribution
Value: 0.051277 mol/mol
Expanded Uncertainty: 0.000041 mol/mol
Coverage Factor: 2

CRM 116-A certificate

$R_{236U/235Ub}$: Type B normal distribution
Value: 0.0094713 mol/mol
Expanded Uncertainty: 0.0000077 mol/mol
Coverage Factor: 2

CRM 116-A certificate

$n_{234.c}$: Import
Filename: U ingrowth from Pu MP2.smu
Symbol: n_{234U}Total

$n_{235.c}$: Import
Filename: U ingrowth from Pu MP2.smu
Symbol: n_{235U}Total

$n_{236.c}$: Import
Filename: U ingrowth from Pu MP2.smu
Symbol: n_{236U}Total

$n_{233.c}$:
Type B normal distribution
Value: 0 mol
Expanded Uncertainty: 0 mol
Coverage Factor: 2

$n_{238.c}$:
Import
Filename: U ingrowth from Pu MP2.smu
Symbol: n_{238U}Total

m_{UMP2}:
Import
Filename: U ingrowth from Pu MP2.smu
Symbol: m_UTotal

Input Correlation:

	$n_{234.c}$	$n_{235.c}$	$n_{236.c}$	$n_{238.c}$	m_{UMP2}
$n_{234.c}$	1	0.2332	0.1691	0.0028	0.2644
$n_{235.c}$	0.2332	1	0.6773	0.0114	0.9965
$n_{236.c}$	0.1691	0.6773	1	0.0083	0.7321
$n_{238.c}$	0.0028	0.0114	0.0083	1	0.0115
m_{UMP2}	0.2644	0.9965	0.7321	0.0115	1

Interim Results:

Quantity	Value	Standard Uncertainty
f_{233U}	$71.769 \cdot 10^{-9}$ mol/mol	$484 \cdot 10^{-12}$ mol/mol
w_{233U}	$70.432 \cdot 10^{-9}$ g/g	$475 \cdot 10^{-12}$ g/g
n_{233U}	$15.681 \cdot 10^{-9}$ mol	$106 \cdot 10^{-12}$ mol
n_{234U}	$479.905 \cdot 10^{-6}$ mol	$201 \cdot 10^{-9}$ mol
n_{235U}	0.04186024 mol	$2.59 \cdot 10^{-6}$ mol
n_{236U}	$385.018 \cdot 10^{-6}$ mol	$157 \cdot 10^{-9}$ mol
n_{238U}	0.17576903 mol	$4.46 \cdot 10^{-6}$ mol
M_{Ua}	238.0288981 g/mol	$10.9 \cdot 10^{-6}$ g/mol
f_{234Ua}	$55.077 \cdot 10^{-6}$ mol/mol	$218 \cdot 10^{-9}$ mol/mol
f_{235Ua}	$7.20658 \cdot 10^{-3}$ mol/mol	$3.55 \cdot 10^{-6}$ mol/mol
f_{236Ua}	$149.9 \cdot 10^{-9}$ mol/mol	$39.7 \cdot 10^{-9}$ mol/mol
f_{238Ua}	0.99273819 mol/mol	$3.55 \cdot 10^{-6}$ mol/mol
M_{Ub}	235.1857244 g/mol	$55.1 \cdot 10^{-6}$ g/mol
f_{233Ub}	$360.24 \cdot 10^{-9}$ mol/mol	$2.43 \cdot 10^{-9}$ mol/mol
f_{234Ub}	0.01080225 mol/mol	$4.48 \cdot 10^{-6}$ mol/mol
f_{235Ub}	0.9325468 mol/mol	$18.6 \cdot 10^{-6}$ mol/mol
f_{236Ub}	$8.83243 \cdot 10^{-3}$ mol/mol	$3.56 \cdot 10^{-6}$ mol/mol
f_{238Ub}	0.0478182 mol/mol	$18.2 \cdot 10^{-6}$ mol/mol
$n_{234,a}$	$9.6362 \cdot 10^{-6}$ mol	$38.2 \cdot 10^{-9}$ mol
$n_{235,a}$	$1.260850 \cdot 10^{-3}$ mol	$622 \cdot 10^{-9}$ mol
$n_{236,a}$	$26.23 \cdot 10^{-9}$ mol	$6.95 \cdot 10^{-9}$ mol
$n_{238,a}$	0.17368754 mol	$4.39 \cdot 10^{-6}$ mol
$n_{233,b}$	$15.681 \cdot 10^{-9}$ mol	$106 \cdot 10^{-12}$ mol
$n_{234,b}$	$470.214 \cdot 10^{-6}$ mol	$197 \cdot 10^{-9}$ mol
$n_{235,b}$	0.04059305 mol	$2.51 \cdot 10^{-6}$ mol
$n_{236,b}$	$384.469 \cdot 10^{-6}$ mol	$157 \cdot 10^{-9}$ mol
$n_{238,b}$	$2.081490 \cdot 10^{-3}$ mol	$801 \cdot 10^{-9}$ mol
ΣR_U	1.2430757 mol/mol	$16.5 \cdot 10^{-6}$ mol/mol
ΣR_{Ua}	1.00731493 mol/mol	$3.61 \cdot 10^{-6}$ mol/mol
ΣR_{Ub}	1.0723323 mol/mol	$21.4 \cdot 10^{-6}$ mol/mol
w_{234Ua}	$54.154 \cdot 10^{-6}$ g/g	$215 \cdot 10^{-9}$ g/g
w_{235Ua}	$7.11621 \cdot 10^{-3}$ g/g	$3.50 \cdot 10^{-6}$ g/g
w_{236Ua}	$148.7 \cdot 10^{-9}$ g/g	$39.4 \cdot 10^{-9}$ g/g
w_{238Ua}	0.99282949 g/g	$3.51 \cdot 10^{-6}$ g/g
w_{233Ub}	$356.96 \cdot 10^{-9}$ g/g	$2.41 \cdot 10^{-9}$ g/g
w_{234Ub}	0.01074967 g/g	$4.46 \cdot 10^{-6}$ g/g

Quantity	Value	Standard Uncertainty
w_{235Ub}	0.9319845 g/g	$18.8 \cdot 10^{-6}$ g/g
w_{236Ub}	$8.86472 \cdot 10^{-3}$ g/g	$3.58 \cdot 10^{-6}$ g/g
w_{238Ub}	0.0484007 g/g	$18.4 \cdot 10^{-6}$ g/g

Uncertainty Budgets:

$R_{234U/238U}$: $^{234}U/^{238}U$ amount ratio in IRMM-1027s

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
M_{233U}	233.03963550 g/mol	$2.90 \cdot 10^{-6}$ g/mol	normal	$-4.0 \cdot 10^{-12}$	$-12 \cdot 10^{-18}$ mol/mol	0.0 %
M_{234U}	234.04095230 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-120 \cdot 10^{-9}$	$-230 \cdot 10^{-15}$ mol/mol	0.0 %
M_{235U}	235.04393010 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-10 \cdot 10^{-6}$	$-20 \cdot 10^{-12}$ mol/mol	0.0 %
M_{236U}	236.04556820 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-99 \cdot 10^{-9}$	$-190 \cdot 10^{-15}$ mol/mol	0.0 %
M_{238U}	238.05078840 g/mol	$2.00 \cdot 10^{-6}$ g/mol	normal	$10 \cdot 10^{-6}$	$21 \cdot 10^{-12}$ mol/mol	0.0 %
m_{UEC101}	41.6513200 g	$40.0 \cdot 10^{-6}$ g	normal	$-63 \cdot 10^{-6}$	$-2.5 \cdot 10^{-9}$ mol/mol	0.0 %
$\eta_{purityEC101}$	0.9998500 g/g	$25.0 \cdot 10^{-6}$ g/g	normal	$-2.6 \cdot 10^{-3}$	$-66 \cdot 10^{-9}$ mol/mol	0.3 %
$m_{UCRM116A}$	10.2430900 g	$35.0 \cdot 10^{-6}$ g	normal	$260 \cdot 10^{-6}$	$9.0 \cdot 10^{-9}$ mol/mol	0.0 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3 \cdot 10^{-6}$ g/g	normal	$2.6 \cdot 10^{-3}$	$150 \cdot 10^{-9}$ mol/mol	1.8 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/mol	0.0 %
$R_{234U/238Ua}$	$55.480 \cdot 10^{-6}$ mol/mol	$220 \cdot 10^{-9}$ mol/mol	normal	0.99	$220 \cdot 10^{-9}$ mol/mol	3.6 %
$R_{235U/238Ua}$	$7.25930 \cdot 10^{-3}$ mol/mol	$3.60 \cdot 10^{-6}$ mol/mol	normal	$2.6 \cdot 10^{-3}$	$9.3 \cdot 10^{-9}$ mol/mol	0.0 %
$R_{236U/238Ua}$	$151.0 \cdot 10^{-9}$ mol/mol	$40.0 \cdot 10^{-9}$ mol/mol	normal	$2.6 \cdot 10^{-3}$	$100 \cdot 10^{-12}$ mol/mol	0.0 %
$R_{233U/235Ub}$	$386.30 \cdot 10^{-9}$ mol/mol	$2.61 \cdot 10^{-9}$ mol/mol	normal	$-2.4 \cdot 10^{-3}$	$-6.4 \cdot 10^{-12}$ mol/mol	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85 \cdot 10^{-6}$ mol/mol	normal	0.23	$1.1 \cdot 10^{-6}$ mol/mol	93.9 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	$-3.1 \cdot 10^{-3}$	$-64 \cdot 10^{-9}$ mol/mol	0.3 %
$R_{236U/235Ub}$	$9.47130 \cdot 10^{-3}$ mol/mol	$3.85 \cdot 10^{-6}$ mol/mol	normal	$-2.5 \cdot 10^{-3}$	$-9.5 \cdot 10^{-9}$ mol/mol	0.0 %
$n_{234,c}$	$55.1874 \cdot 10^{-9}$ mol	$84.5 \cdot 10^{-12}$ mol		5.7	$480 \cdot 10^{-12}$ mol/mol	0.0 %
$n_{238,c}$	$10.1978 \cdot 10^{-12}$ mol	$97.3 \cdot 10^{-15}$ mol		-0.016	$-1.5 \cdot 10^{-15}$ mol/mol	0.0 %
$R_{234U/238U}$	$2.73032 \cdot 10^{-3}$ mol/mol	$1.14 \cdot 10^{-6}$ mol/mol				

$R_{235U/238U}$: $^{235}U/^{238}U$ amount ratio in IRMM-1027s

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
M_{233U}	233.03963550 g/mol	$2.90 \cdot 10^{-6}$ g/mol	normal	$-350 \cdot 10^{-12}$	$-1.0 \cdot 10^{-15}$ mol/mol	0.0 %
M_{234U}	234.04095230 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-10 \cdot 10^{-6}$	$-20 \cdot 10^{-12}$ mol/mol	0.0 %
M_{235U}	235.04393010 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-900 \cdot 10^{-6}$	$-1.7 \cdot 10^{-9}$ mol/mol	0.0 %
M_{236U}	236.04556820 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-8.6 \cdot 10^{-6}$	$-16 \cdot 10^{-12}$ mol/mol	0.0 %
M_{238U}	238.05078840 g/mol	$2.00 \cdot 10^{-6}$ g/mol	normal	$910 \cdot 10^{-6}$	$1.8 \cdot 10^{-9}$ mol/mol	0.0 %
m_{UEC101}	41.6513200 g	$40.0 \cdot 10^{-6}$ g	normal	$-5.5 \cdot 10^{-3}$	$-220 \cdot 10^{-9}$ mol/mol	0.0 %
$\eta_{purityEC101}$	0.9998500 g/g	$25.0 \cdot 10^{-6}$ g/g	normal	-0.23	$-5.7 \cdot 10^{-6}$ mol/mol	12.4 %
$m_{UCRM116A}$	10.2430900 g	$35.0 \cdot 10^{-6}$ g	normal	0.022	$780 \cdot 10^{-9}$ mol/mol	0.2 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3 \cdot 10^{-6}$ g/g	normal	0.23	$13 \cdot 10^{-6}$ mol/mol	67.7 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/mol	0.0 %
$R_{234U/238Ua}$	$55.480 \cdot 10^{-6}$ mol/mol	$220 \cdot 10^{-9}$ mol/mol	normal	0.22	$49 \cdot 10^{-9}$ mol/mol	0.0 %
$R_{235U/238Ua}$	$7.25930 \cdot 10^{-3}$ mol/mol	$3.60 \cdot 10^{-6}$ mol/mol	normal	1.2	$4.4 \cdot 10^{-6}$ mol/mol	7.3 %
$R_{236U/238Ua}$	$151.0 \cdot 10^{-9}$ mol/mol	$40.0 \cdot 10^{-9}$ mol/mol	normal	0.22	$9.0 \cdot 10^{-9}$ mol/mol	0.0 %
$R_{233U/235Ub}$	$386.30 \cdot 10^{-9}$ mol/mol	$2.61 \cdot 10^{-9}$ mol/mol	normal	-0.21	$-550 \cdot 10^{-12}$ mol/mol	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85 \cdot 10^{-6}$ mol/mol	normal	-0.21	$-1.0 \cdot 10^{-6}$ mol/mol	0.4 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	-0.27	$-5.5 \cdot 10^{-6}$ mol/mol	11.7 %
$R_{236U/235Ub}$	$9.47130 \cdot 10^{-3}$ mol/mol	$3.85 \cdot 10^{-6}$ mol/mol	normal	-0.21	$-820 \cdot 10^{-9}$ mol/mol	0.3 %
$n_{235,c}$	$6.33280 \cdot 10^{-6}$ mol	$2.37 \cdot 10^{-9}$ mol		5.7	$13 \cdot 10^{-9}$ mol/mol	0.0 %
$n_{238,c}$	$10.1978 \cdot 10^{-12}$ mol	$97.3 \cdot 10^{-15}$ mol		-1.4	$-130 \cdot 10^{-15}$ mol/mol	0.0 %
$R_{235U/238U}$	0.2381548 mol/mol	$16.2 \cdot 10^{-6}$ mol/mol				

$R_{236U/238U}$: $^{236}U/^{238}U$ amount ratio in IRMM-1027s

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
M_{233U}	233.03963550 g/mol	$2.90 \cdot 10^{-6}$ g/mol	normal	$-3.3 \cdot 10^{-12}$	$-9.6 \cdot 10^{-18}$ mol/mol	0.0 %
M_{234U}	234.04095230 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-99 \cdot 10^{-9}$	$-190 \cdot 10^{-15}$ mol/mol	0.0 %
M_{235U}	235.04393010 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-8.5 \cdot 10^{-6}$	$-16 \cdot 10^{-12}$ mol/mol	0.0 %
M_{236U}	236.04556820 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$-81 \cdot 10^{-9}$	$-150 \cdot 10^{-15}$ mol/mol	0.0 %
M_{238U}	238.05078840 g/mol	$2.00 \cdot 10^{-6}$ g/mol	normal	$8.6 \cdot 10^{-6}$	$17 \cdot 10^{-12}$ mol/mol	0.0 %
m_{UEC101}	41.6513200 g	$40.0 \cdot 10^{-6}$ g	normal	$-52 \cdot 10^{-6}$	$-2.1 \cdot 10^{-9}$ mol/mol	0.0 %
$\eta_{purityEC101}$	0.9998500 g/g	$25.0 \cdot 10^{-6}$ g/g	normal	$-2.2 \cdot 10^{-3}$	$-54 \cdot 10^{-9}$ mol/mol	0.4 %
$m_{UCRM116A}$	10.2430900 g	$35.0 \cdot 10^{-6}$ g	normal	$210 \cdot 10^{-6}$	$7.4 \cdot 10^{-9}$ mol/mol	0.0 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3 \cdot 10^{-6}$ g/g	normal	$2.2 \cdot 10^{-3}$	$130 \cdot 10^{-9}$ mol/mol	2.0 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/mol	0.0 %
$R_{234U/238Ua}$	$55.480 \cdot 10^{-6}$ mol/mol	$220 \cdot 10^{-9}$ mol/mol	normal	$2.1 \cdot 10^{-3}$	$460 \cdot 10^{-12}$ mol/mol	0.0 %
$R_{235U/238Ua}$	$7.25930 \cdot 10^{-3}$ mol/mol	$3.60 \cdot 10^{-6}$ mol/mol	normal	$2.1 \cdot 10^{-3}$	$7.6 \cdot 10^{-9}$ mol/mol	0.0 %
$R_{236U/238Ua}$	$151.0 \cdot 10^{-9}$ mol/mol	$40.0 \cdot 10^{-9}$ mol/mol	normal	0.99	$40 \cdot 10^{-9}$ mol/mol	0.2 %
$R_{233U/235Ub}$	$386.30 \cdot 10^{-9}$ mol/mol	$2.61 \cdot 10^{-9}$ mol/mol	normal	$-2.0 \cdot 10^{-3}$	$-5.2 \cdot 10^{-12}$ mol/mol	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85 \cdot 10^{-6}$ mol/mol	normal	$-2.0 \cdot 10^{-3}$	$-9.7 \cdot 10^{-9}$ mol/mol	0.0 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	$-2.5 \cdot 10^{-3}$	$-52 \cdot 10^{-9}$ mol/mol	0.3 %
$R_{236U/235Ub}$	$9.47130 \cdot 10^{-3}$ mol/mol	$3.85 \cdot 10^{-6}$ mol/mol	normal	0.23	$880 \cdot 10^{-9}$ mol/mol	97.1 %
$n_{236,c}$	$522.477 \cdot 10^{-9}$ mol	$270 \cdot 10^{-12}$ mol		5.7	$1.5 \cdot 10^{-9}$ mol/mol	0.0 %
$n_{238,c}$	$10.1978 \cdot 10^{-12}$ mol	$97.3 \cdot 10^{-15}$ mol		-0.012	$-1.2 \cdot 10^{-15}$ mol/mol	0.0 %
$R_{236U/238U}$	$2.190475 \cdot 10^{-3}$ mol/mol	$895 \cdot 10^{-9}$ mol/mol				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
$\gamma_{Umixture}$	0.0210852 g/g	$1.0 \cdot 10^{-6}$ g/g	2.00	manual
$\gamma_{235Umixture}$	$3.99847 \cdot 10^{-3}$ g/g	$500 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{238Umixture}$	0.01700416 g/g	$890 \cdot 10^{-9}$ g/g	2.00	manual
$c_{Umixture}$	$88.7939 \cdot 10^{-6}$ mol/g	$4.3 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235Umixture}$	$17.0116 \cdot 10^{-6}$ mol/g	$2.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238Umixture}$	$71.4308 \cdot 10^{-6}$ mol/g	$3.7 \cdot 10^{-9}$ mol/g	2.00	manual
M_U	237.462378 g/mol	$64 \cdot 10^{-5}$ g/mol	2.00	manual
$R_{233U/238U}$	$89.2 \cdot 10^{-9}$ mol/mol	$1.2 \cdot 10^{-9}$ mol/mol	2.00	manual
$R_{234U/238U}$	$2.7303 \cdot 10^{-3}$ mol/mol	$2.3 \cdot 10^{-6}$ mol/mol	2.00	manual
$R_{235U/238U}$	0.238155 mol/mol	$32 \cdot 10^{-6}$ mol/mol	2.00	manual
$R_{236U/238U}$	$2.1905 \cdot 10^{-3}$ mol/mol	$1.8 \cdot 10^{-6}$ mol/mol	2.00	manual
f_{234U}	$2.1964 \cdot 10^{-3}$ mol/mol	$1.8 \cdot 10^{-6}$ mol/mol	2.00	manual
f_{235U}	0.191585 mol/mol	$21 \cdot 10^{-6}$ mol/mol	2.00	manual
f_{236U}	$1.7621 \cdot 10^{-3}$ mol/mol	$1.4 \cdot 10^{-6}$ mol/mol	2.00	manual
f_{238U}	0.804456 mol/mol	$21 \cdot 10^{-6}$ mol/mol	2.00	manual
w_{234U}	$2.1648 \cdot 10^{-3}$ g/g	$1.8 \cdot 10^{-6}$ g/g	2.00	manual
w_{235U}	0.189634 g/g	$21 \cdot 10^{-6}$ g/g	2.00	manual
w_{236U}	$1.7516 \cdot 10^{-3}$ g/g	$1.4 \cdot 10^{-6}$ g/g	2.00	manual
w_{238U}	0.806450 g/g	$21 \cdot 10^{-6}$ g/g	2.00	manual

Annex 15 The plutonium isotope amount ratios and their associated uncertainties for the plutonium gravimetric mixture of IRMM-1027s

Plutonium gravimetric mixture for IRMM-1027s

Author: Jakopic

Author: Rozle Jakopic

A plutonium gravimetric mixture was prepared by dissolving plutonium MP2 metal (CEA/CETAMA) in hydrochloric/nitric acid.

Input parameters:

a) Mass of plutonium metal and the nitrate solution (E3882) b) Purity of plutonium metal (metal certificate) c) Plutonium isotope amount ratios (IRMM certificate, issued 11 April 2007) d) the atomic masses according Wang et al. (The AME 2012 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 36, No. 12, 1603-2014, 2012). Purity of MP2 metal on 1 Nov 2016 was calculated from the the purity on 1 Jan 2007 (99.875 +/-0.040), which was derived from the original CETAMA certificate (99.90 +/- 0.04).

The values are normalised to 1 Nov 2016 (reference date for IRMM-1027s certificate)

Model Equation:

{Molar mass of plutonium in MP2, 1 Jan 2007}

$M_{Pu} = M_{238Pu} \cdot f_{238Pu} + M_{239Pu} \cdot f_{239Pu} + M_{240Pu} \cdot f_{240Pu} + M_{241Pu} \cdot f_{241Pu} + M_{242Pu} \cdot f_{242Pu}$;

{Isotope amount fraction in MP2, 1 Jan 2007}

$f_{238Pu} = R_{238Pu/239Pu}/\Sigma R_{Pu}$;

$f_{239Pu} = 1/\Sigma R_{Pu}$;

$f_{240Pu} = R_{240Pu/239Pu}/\Sigma R_{Pu}$;

$f_{241Pu} = R_{241Pu/239Pu}/\Sigma R_{Pu}$;

$f_{242Pu} = R_{242Pu/239Pu}/\Sigma R_{Pu}$;

$\Sigma R_{Pu} = R_{238Pu/239Pu} + 1 + R_{240Pu/239Pu} + R_{241Pu/239Pu} + R_{242Pu/239Pu}$;

{Isotope mass fractios in MP2, 1 Jan 2007}

$w_{238Pu} = f_{238Pu} \cdot M_{238Pu}/M_{Pu}$;

$w_{239Pu} = f_{239Pu} \cdot M_{239Pu}/M_{Pu}$;

$w_{240Pu} = f_{240Pu} \cdot M_{240Pu}/M_{Pu}$;

$w_{241Pu} = f_{241Pu} \cdot M_{241Pu}/M_{Pu}$;

$w_{242Pu} = f_{242Pu} \cdot M_{242Pu}/M_{Pu}$;

{Decayed isotope amount ratios in gravimetric mixture, IRMM-1027s, 1 Nov 2016}

$Rd_{238Pu/239Pu} = R_{238Pu/239Pu} \cdot (e^{\wedge}(-\lambda_{238} \cdot \Delta t)/e^{\wedge}(-\lambda_{239} \cdot \Delta t))$;

$Rd_{240Pu/239Pu} = R_{240Pu/239Pu} \cdot (e^{\wedge}(-\lambda_{240} \cdot \Delta t)/e^{\wedge}(-\lambda_{239} \cdot \Delta t))$;

$Rd_{241Pu/239Pu} = R_{241Pu/239Pu} \cdot (e^{\wedge}(-\lambda_{241} \cdot \Delta t)/e^{\wedge}(-\lambda_{239} \cdot \Delta t))$;

$Rd_{242Pu/239Pu} = R_{242Pu/239Pu} \cdot (e^{\wedge}(-\lambda_{242} \cdot \Delta t)/e^{\wedge}(-\lambda_{239} \cdot \Delta t))$;

$\Sigma Rd_{Pu} = Rd_{238Pu/239Pu} + 1 + Rd_{240Pu/239Pu} + Rd_{241Pu/239Pu} + Rd_{242Pu/239Pu}$;

{Decayed and normalised isotope amount fractios in gravimetric mixture, IRMM-1027s, 1 Nov 2016}

$fdnorm_{238Pu} = Rd_{238Pu/239Pu}/\Sigma Rd_{Pu}$;

$fdnorm_{239Pu} = 1/\Sigma Rd_{Pu}$;

$fdnorm_{240Pu} = Rd_{240Pu/239Pu}/\Sigma Rd_{Pu}$;

$fdnorm_{241Pu} = Rd_{241Pu/239Pu}/\Sigma Rd_{Pu}$;

$fdnorm_{242Pu} = Rd_{242Pu/239Pu}/\Sigma Rd_{Pu}$;

{Decayed molar mass of plutonium in gravimetric mixtures, IRMM-1027s, 1 Nov 2016}

$Md_{Pu} = M_{238Pu}\cdot fdnorm_{238Pu} + M_{239Pu}\cdot fdnorm_{239Pu} + M_{240Pu}\cdot fdnorm_{240Pu} + M_{241Pu}\cdot fdnorm_{241Pu} + M_{242Pu}\cdot fdnorm_{242Pu}$;

{Decayed and normalised isotope mass fractios in gravimetric mixture, IRMM-1027s, 1 Nov 2016}

$wdnorm_{238Pu} = fdnorm_{238Pu}\cdot M_{238Pu}/Md_{Pu}$;

$wdnorm_{239Pu} = fdnorm_{239Pu}\cdot M_{239Pu}/Md_{Pu}$;

$wdnorm_{240Pu} = fdnorm_{240Pu}\cdot M_{240Pu}/Md_{Pu}$;

$wdnorm_{241Pu} = fdnorm_{241Pu}\cdot M_{241Pu}/Md_{Pu}$;

$wdnorm_{242Pu} = fdnorm_{242Pu}\cdot M_{242Pu}/Md_{Pu}$;

{Decayed amount ratios for purity calculation, 1 Nov 2015}

$fd_{238Pu}=f_{238Pu}*e^{(-\lambda_{238}*\Delta t)}$;

$fd_{239Pu}=f_{239Pu}*e^{(-\lambda_{239}*\Delta t)}$;

$fd_{240Pu}=f_{240Pu}*e^{(-\lambda_{240}*\Delta t)}$;

$fd_{241Pu}=f_{241Pu}*e^{(-\lambda_{241}*\Delta t)}$;

$fd_{242Pu}=f_{242Pu}*e^{(-\lambda_{242}*\Delta t)}$;

{Decayed isotope masses for purity calculation, 1 Nov 2016}

$md_{238Pu}=fd_{238Pu}*M_{238Pu}*m_{Pu}/M_{Pu}$;

$md_{239Pu}=fd_{239Pu}*M_{239Pu}*m_{Pu}/M_{Pu}$;

$md_{240Pu}=fd_{240Pu}*M_{240Pu}*m_{Pu}/M_{Pu}$;

$md_{241Pu}=fd_{241Pu}*M_{241Pu}*m_{Pu}/M_{Pu}$;

$md_{242Pu}=fd_{242Pu}*M_{242Pu}*m_{Pu}/M_{Pu}$;

$\Sigma md_{Pu}= md_{238Pu}+md_{239Pu}+md_{240Pu}+md_{241Pu}+md_{242Pu}$;

$\eta_{PuMP2Nov2016}=\eta_{PuMP2Jan2007}*\Sigma md_{Pu}/m_{Pu}$;

{Decay constants}

$ln_2 = ln(2)$;

$\lambda_{238} = ln_2 / \tau_{238}$;

$\lambda_{239} = ln_2 / \tau_{239}$;

$\lambda_{240} = ln_2 / \tau_{240}$;

$\lambda_{241} = ln_2 / \tau_{241}$;

$\lambda_{242} = ln_2 / \tau_{242}$;

{Plutonium mass fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016}

$\gamma_{Pumixture}=(m_{PuMP2}*\eta_{PuMP2Nov2016})/m_{solution1027s}$;

$\gamma_{Pumixture239}=\gamma_{Pumixture}*wdnorm_{239Pu}$;

{Plutonium amount content in gravimetric mixture, IRMM-1027s, 1 Nov 2016}

$c_{Pumixture}=\gamma_{Pumixture}/Md_{Pu}$;

$c_{Pumixture239} = c_{Pumixture}*fdnorm_{239Pu}$;

List of Quantities:

Quantity	Unit	Definition
$w_{PuMixture}$	g/g	Pu mass fraction in IRMM-1027s
$w_{PuMixture239}$	g/g	^{239}Pu mass fraction in IRMM-1027s
$c_{PuMixture239}$	mol/g	^{239}Pu amount content in IRMM-1027s
$c_{PuMixture}$	mol/g	Pu amount content in IRMM-1027s
$Rd_{238Pu/239Pu}$	mol/mol	decayed ^{238}Pu/^{239}Pu amount ratio in IRMM-1027s, 1 Nov 2016
$Rd_{240Pu/239Pu}$	mol/mol	decayed ^{240}Pu/^{239}Pu amount ratio in IRMM-1027s, 1 Nov 2016
$Rd_{241Pu/239Pu}$	mol/mol	decayed ^{241}Pu/^{239}Pu amount ratio in IRMM-1027s, 1 Nov 2016
$Rd_{242Pu/239Pu}$	mol/mol	decayed ^{242}Pu/^{239}Pu amount ratio in IRMM-1027s, 1 Nov 2016
$R_{238Pu/239Pu}$	mol/mol	^{238}Pu/^{239}Pu amount ratio in MP2, 1 Jan 2007
Δt	a	time difference between certification date MP2 (1 Jan 2007) and reference date (1 Nov 2016)
$R_{240Pu/239Pu}$	mol/mol	^{240}Pu/^{239}Pu amount ratio in MP2, 1 Jan 2007
$R_{241Pu/239Pu}$	mol/mol	^{241}Pu/^{239}Pu amount ratio in MP2, 1 Jan 2007
$R_{242Pu/239Pu}$	mol/mol	^{242}Pu/^{239}Pu amount ratio in MP2, 1 Jan 2007
M_{Pu}	g/mol	molar mass of Pu in MP2, 1 Jan 2007
f_{238Pu}	mol/mol	^{238}Pu amount fraction in MP2, 1 Jan 2007
f_{239Pu}	mol/mol	^{239}Pu amount fraction in MP2, 1 Jan 2007
f_{240Pu}	mol/mol	^{240}Pu amount fraction in MP2, 1 Jan 2007
f_{241Pu}	mol/mol	^{241}Pu amount fraction in MP2, 1 Jan 2007
f_{242Pu}	mol/mol	^{242}Pu amount fraction in MP2, 1 Jan 2007
e		
ΣR_{Pu}	mol/mol	Sum of amount ratios in MP2, 1 Jan 2007
λ_{238}	a^{-1}	Decay constant ^{238}Pu
λ_{239}	a^{-1}	Decay constant ^{239}Pu
λ_{240}	a^{-1}	Decay constant ^{240}Pu
λ_{241}	a^{-1}	Decay constant ^{241}Pu
λ_{242}	a^{-1}	Decay constant ^{242}Pu
M_{238Pu}	g/mol	Atomic mass of ^{238}Pu
M_{239Pu}	g/mol	Atomic mass of ^{239}Pu
M_{240Pu}	g/mol	Atomic mass of ^{240}Pu
M_{241Pu}	g/mol	Atomic mass of ^{241}Pu
M_{242Pu}	g/mol	Atomic mass of ^{242}Pu
ΣRd_{Pu}	mol/mol	Sum of decayed amount ratios in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$fdnorm_{238Pu}$	mol/mol	Decayed and normalised ^{238}Pu amount fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$fdnorm_{239Pu}$	mol/mol	Decayed and normalised ^{239}Pu amount fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016

Quantity	Unit	Definition
$fdnorm_{240Pu}$	mol/mol	Decayed and normalised ^{240}Pu amount fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$fdnorm_{241Pu}$	mol/mol	Decayed and normalised ^{241}Pu amount fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$fdnorm_{242Pu}$	mol/mol	Decayed and normalised ^{242}Pu amount fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
Md_{Pu}	g/mol	Decayed molar mass of Pu in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$wdnorm_{238Pu}$	g/g	Decayed and normalised ^{238}Pu mass fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$wdnorm_{239Pu}$	g/g	Decayed and normalised ^{239}Pu mass fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$wdnorm_{240Pu}$	g/g	Decayed and normalised ^{240}Pu mass fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$wdnorm_{241Pu}$	g/g	Decayed and normalised ^{241}Pu mass fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$wdnorm_{242Pu}$	g/g	Decayed and normalised ^{242}Pu mass fraction in gravimetric mixture, IRMM-1027s, 1 Nov 2016
$\eta_{PuMP2Nov2016}$	g/g	Purity of MP2 metal, 1 Nov 2016
ln_2		
τ_{238}	a	Half-life ^{238}Pu
τ_{239}	a	Half-life ^{239}Pu
τ_{240}	a	Half-life ^{240}Pu
τ_{241}	a	Half-life ^{241}Pu
τ_{242}	a	Half-life ^{242}Pu
m_{PuMP2}	g	Mass of plutonium MP2 metal
$m_{solution1027s}$	g	Mass of gravimetric mixture, IRMM-1027s
m_{Pu}	g	
md_{238Pu}	g	Decayed mass of ^{238}Pu, from 1 Jan 2007 to 1 Nov 2016
md_{239Pu}	g	Decayed mass of ^{239}Pu, from 1 Jan 2007 to 1 Nov 2016
md_{240Pu}	g	Decayed mass of ^{240}Pu, from 1 Jan 2007 to 1 Nov 2016
md_{241Pu}	g	Decayed mass of ^{241}Pu, from 1 Jan 2007 to 1 Nov 2016
md_{242Pu}	g	Decayed mass of ^{242}Pu, from 1 Jan 2007 to 1 Nov 2016
Σmd_{Pu}	g	Sum of decayed Pu masses
$\eta_{PuMP2Jan2007}$	g/g	Purity of MP2 metal, 1 Jan 2007
w_{238Pu}	g/g	^{238}Pu mass fraction in MP2, 1 Jan 2007
w_{239Pu}	g/g	^{239}Pu mass fraction in MP2, 1 Jan 2007
w_{240Pu}	g/g	^{240}Pu mass fraction in MP2, 1 Jan 2007
w_{241Pu}	g/g	^{241}Pu mass fraction in MP2, 1 Jan 2007
w_{242Pu}	g/g	^{242}Pu mass fraction in MP2, 1 Jan 2007
fd_{238Pu}	mol/mol	Decayed ^{238}Pu amount fraction in MP2, from 1 Jan 2007 to 1 Nov 2016

Quantity	Unit	Definition
fd_{239Pu}	mol/mol	Decayed ^{239}Pu amount fraction in MP2, from 1 Jan 2007 to 1 Nov 2016
fd_{240Pu}	mol/mol	Decayed ^{240}Pu amount fraction in MP2, from 1 Jan 2007 to 1 Nov 2016
fd_{241Pu}	mol/mol	Decayed ^{241}Pu amount fraction in MP2, from 1 Jan 2007 to 1 Nov 2016
fd_{242Pu}	mol/mol	Decayed ^{242}Pu amount fraction in MP2, from 1 Jan 2007 to 1 Nov 2016

$R_{238Pu/239Pu}$: Type B normal distribution
Value: 0.00003083 mol/mol
Expanded Uncertainty: 0.00000029 mol/mol
Coverage Factor: 2

IRMM MP2 certificate 2007

Δt: Constant
Value: 9.83436 a

01/01/2007, 01/11/2016, delta t= 3592 days / 365.25 = 9.83436 a

$R_{240Pu/239Pu}$: Type B normal distribution
Value: 0.0224324 mol/mol
Expanded Uncertainty: 0.0000051 mol/mol
Coverage Factor: 2

IRMM MP2 certificate 2007

$R_{241Pu/239Pu}$: Type B normal distribution
Value: 0.0002378 mol/mol
Expanded Uncertainty: 0.0000031 mol/mol
Coverage Factor: 2

IRMM MP2 certificate 2007

$R_{242Pu/239Pu}$: Type B normal distribution
Value: 0.00007570 mol/mol
Expanded Uncertainty: 0.00000078 mol/mol
Coverage Factor: 2

IRMM MP2 certificate 2007

e: Constant
Value: 2.71828182845904523536

M_{238Pu}: Type B normal distribution
Value: 238.0495601 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

The atomic masses according 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_{239Pu}: Type B normal distribution
Value: 239.0521636 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

the atomic masses according 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_{240Pu}: Type B normal distribution
Value: 240.0538138 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

the atomic masses according 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_{241Pu}: Type B normal distribution
Value: 241.0568517 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

the atomic masses according 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_{242Pu}: Type B normal distribution
Value: 242.0587428 g/mol
Expanded Uncertainty: 0.0000020 g/mol
Coverage Factor: 1

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

τ_{238}: Type B normal distribution
Value: 87.74 a
Expanded Uncertainty: 0.03 a
Coverage Factor: 1

Laboratorie National Henri Becquerel, http://www.nucleide.org/$DDEP_{WG}$/DDEPdata.htm

τ_{239}: Type B normal distribution
Value: 24100 a
Expanded Uncertainty: 11 a
Coverage Factor: 1

Laboratorie National Henri Becquerel, http://www.nucleide.org/$DDEP_{WG}$/DDEPdata.htm

τ_{240}: Type B normal distribution
Value: 6561 a
Expanded Uncertainty: 7 a
Coverage Factor: 1

Laboratorie National Henri Becquerel, http://www.nucleide.org/$DDEP_{WG}$/DDEPdata.htm

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

Wellum et al., J. Anal. At. Spectrom., 2009, 24, 801-807

τ_{242}: Type B normal distribution
Value: 373000 a
Expanded Uncertainty: 3000 a
Coverage Factor: 1

Laboratorie National Henri Becquerel, http://www.nucleide.org/$DDEP_{WG}$/DDEPdata.htm

m_{PuMP2}:
Type B normal distribution
Value: 1.65903 g
Expanded Uncertainty: 0.00009 g
Coverage Factor: 2

E3882 certificate

$m_{solution1027s}$:
Type B normal distribution
Value: 2460.69 g
Expanded Uncertainty: 0.03 g
Coverage Factor: 2

E3882 certificate

m_{Pu}:
Type B normal distribution
Value: 1.00 g
Expanded Uncertainty: 0 g
Coverage Factor: 1

$\eta_{PuMP2Jan2007}$:
Import
Filename: Decay MP2 from 12-03-2001 to 01-01-2007.smu
Symbol: $\eta_{PuMP2Jan2007}$

Input Correlation:

The abundance set for Pu is assumed as uncorrelated.

Interim Results:

Quantity	Value	Standard Uncertainty
M_{Pu}	239.07479104 g/mol	$4.44 \cdot 10^{-5}$ g/mol
f_{238Pu}	$30.143 \cdot 10^{-6}$ mol/mol	$142 \cdot 10^{-9}$ mol/mol
f_{239Pu}	0.97773050 mol/mol	$2.88 \cdot 10^{-6}$ mol/mol
f_{240Pu}	0.02193284 mol/mol	$2.44 \cdot 10^{-6}$ mol/mol
f_{241Pu}	$232.50 \cdot 10^{-6}$ mol/mol	$1.52 \cdot 10^{-6}$ mol/mol
f_{242Pu}	$74.014 \cdot 10^{-6}$ mol/mol	$381 \cdot 10^{-9}$ mol/mol
ΣR_{Pu}	1.02277673 mol/mol	$3.01 \cdot 10^{-6}$ mol/mol
λ_{238}	$7.90001 \cdot 10^{-3}$ a^{-1}	$2.70 \cdot 10^{-6}$ a^{-1}
λ_{239}	$28.7613 \cdot 10^{-6}$ a^{-1}	$13.1 \cdot 10^{-9}$ a^{-1}
λ_{240}	$105.647 \cdot 10^{-6}$ a^{-1}	$113 \cdot 10^{-9}$ a^{-1}
λ_{241}	0.0483872 a^{-1}	$40.5 \cdot 10^{-6}$ a^{-1}
λ_{242}	$1.8583 \cdot 10^{-6}$ a^{-1}	$14.9 \cdot 10^{-9}$ a^{-1}
ΣRd_{Pu}	1.02266750 mol/mol	$2.76 \cdot 10^{-6}$ mol/mol
$\eta_{PuMP2Nov2016}$	0.998356 g/g	$200 \cdot 10^{-6}$ g/g
md_{238Pu}	$27.771 \cdot 10^{-6}$ g	$131 \cdot 10^{-9}$ g
md_{239Pu}	0.97736147 g	$2.90 \cdot 10^{-6}$ g
md_{240Pu}	0.02199979 g	$2.45 \cdot 10^{-6}$ g
md_{241Pu}	$145.665 \cdot 10^{-6}$ g	$951 \cdot 10^{-9}$ g
md_{242Pu}	$74.937 \cdot 10^{-6}$ g	$386 \cdot 10^{-9}$ g
Σmd_{Pu}	0.999609634 g	$595 \cdot 10^{-9}$ g
w_{238Pu}	$30.014 \cdot 10^{-6}$ g/g	$141 \cdot 10^{-9}$ g/g
w_{239Pu}	0.97763796 g/g	$2.90 \cdot 10^{-6}$ g/g
w_{240Pu}	0.02202266 g/g	$2.45 \cdot 10^{-6}$ g/g
w_{241Pu}	$234.43 \cdot 10^{-6}$ g/g	$1.53 \cdot 10^{-6}$ g/g
w_{242Pu}	$74.938 \cdot 10^{-6}$ g/g	$386 \cdot 10^{-9}$ g/g
fd_{238Pu}	$27.890 \cdot 10^{-6}$ mol/mol	$131 \cdot 10^{-9}$ mol/mol
fd_{239Pu}	0.97745399 mol/mol	$2.88 \cdot 10^{-6}$ mol/mol
fd_{240Pu}	0.02191007 mol/mol	$2.44 \cdot 10^{-6}$ mol/mol
fd_{241Pu}	$144.467 \cdot 10^{-6}$ mol/mol	$943 \cdot 10^{-9}$ mol/mol
fd_{242Pu}	$74.013 \cdot 10^{-6}$ mol/mol	$381 \cdot 10^{-9}$ mol/mol

Uncertainty Budgets:

$Rd_{240Pu/239Pu}$: decayed $^{240}Pu/^{239}Pu$ amount ratio in IRMM-1027s, 1 Nov 2016

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
Δt	9.83436 a					
$R_{240Pu/239Pu}$	0.02243240 mol/mol	$2.55 \cdot 10^{-6}$ mol/mol	normal	1.0	$2.5 \cdot 10^{-6}$ mol/mol	100.0 %
e	2.718281828459					
τ_{239}	24100.0 a	11.0 a	normal	$-260 \cdot 10^{-12}$	$-2.9 \cdot 10^{-9}$ mol/mol	0.0 %
τ_{240}	6561.00 a	7.00 a	normal	$3.5 \cdot 10^{-9}$	$25 \cdot 10^{-9}$ mol/mol	0.0 %
$Rd_{240Pu/239Pu}$	0.02241544 mol/mol	$2.55 \cdot 10^{-6}$ mol/mol				

$Rd_{241Pu/239Pu}$: decayed $^{241}Pu/^{239}Pu$ amount ratio in IRMM-1027s, 1 Nov 2016

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
Δt	9.83436 a					
$R_{241Pu/239Pu}$	$237.80 \cdot 10^{-6}$ mol/mol	$1.55 \cdot 10^{-6}$ mol/mol	normal	0.62	$960 \cdot 10^{-9}$ mol/mol	99.6 %
e	2.718281828459					
τ_{239}	24100.0 a	11.0 a	normal	$-1.7 \cdot 10^{-12}$	$-19 \cdot 10^{-12}$ mol/mol	0.0 %
τ_{241}	14.3250 a	0.0120 a	normal	$4.9 \cdot 10^{-6}$	$59 \cdot 10^{-9}$ mol/mol	0.4 %
$Rd_{241Pu/239Pu}$	$147.799 \cdot 10^{-6}$ mol/mol	$965 \cdot 10^{-9}$ mol/mol				

$Rd_{242Pu/239Pu}$: decayed $^{242}Pu/^{239}Pu$ amount ratio in IRMM-1027s, 1 Nov 2016

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
Δt	9.83436 a					
$R_{242Pu/239Pu}$	$75.700 \cdot 10^{-6}$ mol/mol	$390 \cdot 10^{-9}$ mol/mol	normal	1.0	$390 \cdot 10^{-9}$ mol/mol	100.0 %
e	2.718281828459					
τ_{239}	24100.0 a	11.0 a	normal	$-890 \cdot 10^{-15}$	$-9.8 \cdot 10^{-12}$ mol/mol	0.0 %
τ_{242}	$373.00 \cdot 10^{3}$ a	3000 a	normal	$3.7 \cdot 10^{-15}$	$11 \cdot 10^{-12}$ mol/mol	0.0 %
$Rd_{242Pu/239Pu}$	$75.720 \cdot 10^{-6}$ mol/mol	$390 \cdot 10^{-9}$ mol/mol				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
$\gamma_{Pumixture}$	$673.11 \cdot 10^{-6}$ g/g	$270 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{Pumixture239}$	$658.12 \cdot 10^{-6}$ g/g	$270 \cdot 10^{-9}$ g/g	2.00	manual
$c_{Pumixture239}$	$2.7531 \cdot 10^{-5}$ mol/g	$1.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{Pumixture}$	$2.8155 \cdot 10^{-5}$ mol/g	$1.1 \cdot 10^{-9}$ mol/g	2.00	manual
$Rd_{238Pu/239Pu}$	$28.53 \cdot 10^{-5}$ mol/mol	$270 \cdot 10^{-9}$ mol/mol	2.00	manual
$Rd_{240Pu/239Pu}$	0.0224154 mol/mol	$5.1 \cdot 10^{-6}$ mol/mol	2.00	manual
$Rd_{241Pu/239Pu}$	$147.8 \cdot 10^{-5}$ mol/mol	$1.9 \cdot 10^{-6}$ mol/mol	2.00	manual
$Rd_{242Pu/239Pu}$	$75.72 \cdot 10^{-5}$ mol/mol	$780 \cdot 10^{-9}$ mol/mol	2.00	manual
$fdnorm_{238Pu}$	$27.90 \cdot 10^{-5}$ mol/mol	$260 \cdot 10^{-9}$ mol/mol	2.00	manual
$fdnorm_{239Pu}$	0.9778349 mol/mol	$5.3 \cdot 10^{-6}$ mol/mol	2.00	manual
$fdnorm_{240Pu}$	0.0219186 mol/mol	$4.9 \cdot 10^{-6}$ mol/mol	2.00	manual
$fdnorm_{241Pu}$	$144.5 \cdot 10^{-5}$ mol/mol	$1.9 \cdot 10^{-6}$ mol/mol	2.00	manual
$fdnorm_{242Pu}$	$74.04 \cdot 10^{-5}$ mol/mol	$760 \cdot 10^{-9}$ mol/mol	2.00	manual
Md_{Pu}	239.0746027 g/mol	$7.5 \cdot 10^{-5}$ g/mol	2.00	manual
$wdnorm_{238Pu}$	$27.78 \cdot 10^{-5}$ g/g	$260 \cdot 10^{-9}$ g/g	2.00	manual
$wdnorm_{239Pu}$	0.9777432 g/g	$5.3 \cdot 10^{-6}$ g/g	2.00	manual
$wdnorm_{240Pu}$	0.0220084 g/g	$4.9 \cdot 10^{-6}$ g/g	2.00	manual
$wdnorm_{241Pu}$	$145.7 \cdot 10^{-5}$ g/g	$1.9 \cdot 10^{-6}$ g/g	2.00	manual
$wdnorm_{242Pu}$	$74.97 \cdot 10^{-5}$ g/g	$770 \cdot 10^{-9}$ g/g	2.00	manual

Annex 16 The weighing certificate of the blend mixtures for the characterisation of ^{235}U, ^{238}U and ^{239}Pu amount content by ID-TIMS using IRMM-046c

Joint Research Centre

Directorate G – Nuclear Safety and Security
Standards for Nuclear Safety, Security and Safeguards Unit

Certificate of weighing

Reg. No. E.3892 **Date of issue**: 24 May 2017 **Page 1 of 1**

Applicant: R. Jakopič **Project:** IRMM-1027s

Description: Verification of IRMM-1027s vials with IRMM-046c

Request for analysis number: 3740 **ID number**: 25937

Date of request: 27 January 2017 **Weighing dates**: 7 February 2017

The reported results apply only to the objects/samples described in this certificate.

Blend	IRMM-046c Mass [g]	IRMM-046c Uncertainty [g]
IRMM-1027s-53/046c-15-1	2.50025	0.00011
IRMM-1027s-134/046c-15-2	2.49239	0.00011
IRMM-1027s-208/046c-15-3	2.49688	0.00044
IRMM-1027s-341/046c-15-4	2.51159	0.00047
IRMM-1027s-418/046c-58-1	3.01383	0.00010
IRMM-1027s-498/046c-58-2	2.99935	0.00016
IRMM-1027s-617/046c-58-3	3.00151	0.00017
IRMM-1027s-730/046c-86-1	3.00315	0.00014
IRMM-1027s-794/046c-86-2	3.00249	0.00018
IRMM-1027s-888/046c-86-3	3.06050	0.00016

Observations:
Masses were determined by substitution weighing on balances AT 261 with an inventory No. 1999 00337 27.

Traceability:
The certified mass values are traceable to the International Kilogram Prototype via regular calibrations of the JRC principal kilogram. The set of working mass standards M 3 was used as reference in the mass determination.

Uncertainty:
All reported uncertainties are expanded uncertainties $U = k \cdot u_c$ where u_c is the combined standard uncertainty calculated according to the ISO/IEC Guide to the expression of Uncertainty in Measurement. The coverage factor $k = 2$ corresponds to a coverage probability of about 95 %.

Rožle Jakopič
Nuclear Chemistry Laboratory Responsible

Carmel Hennessy
Analyst

Retieseweg, B-2440 Geel, Belgium; Tel.: +32-(0)14-571 211 • Fax: +32-(0)14-571 978•

Annex 17 The internal test report (3802) for the selected units of IRMM-1027s

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Directorate G - Nuclear Safety and Security
Unit G.2 - Standards for Nuclear Safety, Security and Safeguards (SN3S)

INTERNAL TEST REPORT # 3802

Requested by: R. Jakopic, SN3S Unit

Samples

Sample ID	Applicant sample identification
26589	IRMM-1027s LSD Spikes

Date of receipt of samples: 01/11/2016

Condition of the samples: U and Pu nitrate solutions, Radioactive material. Chemical separation and purification of samples prior to isotopic measurements was done following working instructions WI-D-00352, WI-D-00353 and WI-D-00352

Sub-sample ID	Analyte	Result (± expanded uncertainty[1])	Unit	Method[2]
Date:	04/04/2017			
1027s-134	$n(^{242}Pu)/n(^{239}Pu)$	0.12860(13)	mol / mol	WI-D-00360
1027s-496	$n(^{242}Pu)/n(^{239}Pu)$	0.15459(18)	mol / mol	WI-D-00360
1027s-888	$n(^{242}Pu)/n(^{239}Pu)$	0.15796(16)	mol / mol	WI-D-00360
1027s-341	$n(^{242}Pu)/n(^{239}Pu)$	0.12937(14)	mol / mol	WI-D-00360
1027s-730	$n(^{242}Pu)/n(^{239}Pu)$	0.15498(22)	mol / mol	WI-D-00360
Date:	19/05/2017			
1027s-53	$n(^{242}Pu)/n(^{239}Pu)$	0.12851(13)	mol / mol	WI-D-00360
1027s-617	$n(^{242}Pu)/n(^{239}Pu)$	0.15478(16)	mol / mol	WI-D-00360
1027s-208	$n(^{242}Pu)/n(^{239}Pu)$	0.12864(13)	mol / mol	WI-D-00360
1027s-794	$n(^{242}Pu)/n(^{239}Pu)$	0.15486(16)	mol / mol	WI-D-00360
1027s-418	$n(^{242}Pu)/n(^{239}Pu)$	0.15535(16)	mol / mol	WI-D-00360
Date:	24/03/2017			
1027s-134	$n(^{233}U)/n(^{235}U)$	0.261495(73)	mol / mol	WI-D-00348
1027s-134	$n(^{233}U)/n(^{238}U)$	0.062291(41)	mol / mol	WI-D-00348
1027s-496	$n(^{233}U)/n(^{235}U)$	0.314388 (97)	mol / mol	WI-D-00348
1027s-496	$n(^{233}U)/n(^{238}U)$	0.074899(58)	mol / mol	WI-D-00348
1027s-888	$n(^{233}U)/n(^{235}U)$	0.321187(85)	mol / mol	WI-D-00348
1027s-888	$n(^{233}U)/n(^{238}U)$	0.076511(51)	mol / mol	WI-D-00348

1027s-341	$n(^{233}U)/n(^{235}U)$	0.262970(74)	mol / mol	WI-D-00348
1027s-341	$n(^{233}U)/n(^{238}U)$	0.062653(42)	mol / mol	WI-D-00348
1027s-730	$n(^{233}U)/n(^{235}U)$	0.314951(74)	mol / mol	WI-D-00348
1027s-730	$n(^{233}U)/n(^{238}U)$	0.075014(46)	mol / mol	WI-D-00348
Date:	02/05/2017			
1027s-53	$n(^{233}U)/n(^{235}U)$	0.261340(83)	mol / mol	WI-D-00348
1027s-53	$n(^{233}U)/n(^{238}U)$	0.062262(48)	mol / mol	WI-D-00348
1027s-617	$n(^{233}U)/n(^{235}U)$	0.314794(79)	mol / mol	WI-D-00348
1027s-617	$n(^{233}U)/n(^{238}U)$	0.074999(47)	mol / mol	WI-D-00348
1027s-208	$n(^{233}U)/n(^{235}U)$	0.261680(58)	mol / mol	WI-D-00348
1027s-208	$n(^{233}U)/n(^{238}U)$	0.062354(33)	mol / mol	WI-D-00348
1027s-794	$n(^{233}U)/n(^{235}U)$	0.315021(66)	mol / mol	WI-D-00348
1027s-794	$n(^{233}U)/n(^{238}U)$	0.075063(38)	mol / mol	WI-D-00348
1027s-418	$n(^{233}U)/n(^{235}U)$	0.316026(84)	mol / mol	WI-D-00348
1027s-418	$n(^{233}U)/n(^{238}U)$	0.075286(50)	mol / mol	WI-D-00348

Sub-sample ID	Analyte	Result (± expanded uncertainty[2])	Unit	Method[2]
Date:	04/04/2017			
1027s-134	$n(^{242}Pu)/n(^{239}Pu)$	0.128598(38)	mol / mol	WI-D-00360
1027s-496	$n(^{242}Pu)/n(^{239}Pu)$	0.154593(83)	mol / mol	WI-D-00360
1027s-888	$n(^{242}Pu)/n(^{239}Pu)$	0.157955(40)	mol / mol	WI-D-00360
1027s-341	$n(^{242}Pu)/n(^{239}Pu)$	0.129369(58)	mol / mol	WI-D-00360
1027s-730	$n(^{242}Pu)/n(^{239}Pu)$	0.15498(15)	mol / mol	WI-D-00360
Date:	19/05/2017			
1027s-53	$n(^{242}Pu)/n(^{239}Pu)$	0.128514(33)	mol / mol	WI-D-00360
1027s-617	$n(^{242}Pu)/n(^{239}Pu)$	0.154776(39)	mol / mol	WI-D-00360
1027s-208	$n(^{242}Pu)/n(^{239}Pu)$	0.128645(32)	mol / mol	WI-D-00360
1027s-794	$n(^{242}Pu)/n(^{239}Pu)$	0.154862(48)	mol / mol	WI-D-00360
1027s-418	$n(^{242}Pu)/n(^{239}Pu)$	0.155354(46)	mol / mol	WI-D-00360
Date:	24/03/2017			
1027s-134	$n(^{233}U)/n(^{235}U)$	0.261495(68)	mol / mol	WI-D-00348
1027s-134	$n(^{233}U)/n(^{238}U)$	0.062291(38)	mol / mol	WI-D-00348
1027s-496	$n(^{233}U)/n(^{235}U)$	0.314388(92)	mol / mol	WI-D-00348
1027s-496	$n(^{233}U)/n(^{238}U)$	0.074899(55)	mol / mol	WI-D-00348
1027s-888	$n(^{233}U)/n(^{235}U)$	0.321187(79)	mol / mol	WI-D-00348
1027s-888	$n(^{233}U)/n(^{238}U)$	0.076511(47)	mol / mol	WI-D-00348
1027s-341	$n(^{233}U)/n(^{235}U)$	0.262970(69)	mol / mol	WI-D-00348
1027s-341	$n(^{233}U)/n(^{238}U)$	0.062653(39)	mol / mol	WI-D-00348
1027s-730	$n(^{233}U)/n(^{235}U)$	0.314951(67)	mol / mol	WI-D-00348

1027s-730	$n(^{233}U)/n(^{238}U)$	0.075014(42)	mol / mol	WI-D-00348
Date:	02/05/2017			
1027s-53	$n(^{233}U)/n(^{235}U)$	0.261340(79)	mol / mol	WI-D-00348
1027s-53	$n(^{233}U)/n(^{238}U)$	0.062262(46)	mol / mol	WI-D-00348
1027s-617	$n(^{233}U)/n(^{235}U)$	0.314794(72)	mol / mol	WI-D-00348
1027s-617	$n(^{233}U)/n(^{238}U)$	0.074999(43)	mol / mol	WI-D-00348
1027s-208	$n(^{233}U)/n(^{235}U)$	0.261680(52)	mol / mol	WI-D-00348
1027s-208	$n(^{233}U)/n(^{238}U)$	0.062354(29)	mol / mol	WI-D-00348
1027s-794	$n(^{233}U)/n(^{235}U)$	0.315021(58)	mol / mol	WI-D-00348
1027s-794	$n(^{233}U)/n(^{238}U)$	0.075063(33)	mol / mol	WI-D-00348
1027s-418	$n(^{233}U)/n(^{235}U)$	0.316026(77)	mol / mol	WI-D-00348
1027s-418	$n(^{233}U)/n(^{238}U)$	0.075286(47)	mol / mol	WI-D-00348

Notes:

Notes *(to be deleted if not applicable, also the logo!)*		
	1	Uncertainties are given as *(e.g. expanded (k=2) uncertainties according to the ISO Guide to the Expression of Uncertainty (GUM), corresponding to an approximate 95% confidence interval). The uncertainties include contributions from the certified reference materials used for mass fractionation correction, IRMM-074/10 for U and IRMM-290A3 for Pu*
	2	Uncertainties are given as *(e.g. expanded (k=2) uncertainties according to the ISO Guide to the Expression of Uncertainty (GUM), corresponding to an approximate 95% confidence interval). The uncertainties do NOT include contributions from the certified reference materials used for mass fractionation correction.*

Files name(s) of raw data:

Results of mass spectrometric measurements for Pu are stored in:
" G:\JRC.G.2\Nuclear Safeguards\Nuclear\PUTON DATA - SHARED\IRMM LSD 1027s"
The relevant data files are:
"P170403 1027s IDMS Pu vials Rev 9.xls "
"P170403 1027s IDMS Pu vials Rev 9 - without IRMM-290A3-uncertainty.xls "
"P170519 1027s IDMS Pu vials Rev 9.xls"
"P170519 1027s IDMS Pu vials Rev 9 - without IRMM-290A3-uncertainty.xls"

Results of mass spectrometric measurements for U are stored in:
"G:\JRC.G.2\Nuclear Safeguards\Nuclear\TRITON DATA - SHARED\LSD 1027s"
The relevant data files are:
"T170323 1027s IDMS U vials Rev 8.xls"
"T170323 1027s IDMS U vials Rev 8 - without IRMM-074-uncertainty.xls"
"T170428 1027s IDMS U vials Rev 8.xls"
"T170428 1027s IDMS U vials Rev 8 - without IRMM-074-uncertainty.xls"

02/06/2017 ..... Date

..... Signature
Analyst

..... Signature
Laboratory Responsible

Annex 18 Determination of ^{235}U in 10 randomly selected vials (turrets A and B) for the characterisation in IRMM-1027s by ID-TIMS with IRMM-046c (reference date November 1, 2016)

U235 IDMS IRMM-1027s single vials with 046c spike COMBINED

Author: Jakopic Date: Elements: U

simplified equation spike ^{233}U, sample ^{235}U, ratio $^{233}U/^{235}U$

Isotope amount ratios: Internal test report 3740

input data from GUM files (set A and B)

IRMM-1027s vials (3 replicates per blend mixture): set A: 134, 341, 496, 730 and 888

set B: 53, 208, 418, 617 and 794

Model Equation:

{----------isotope IDMS equation----------}

$f_{c233U}(c_x)=c_x$;

{turret A, 24 March 2017}

$c_{235U134}=f_{c233U}(c_{x1})+\delta_1$;
$c_{235U341}=f_{c233U}(c_{x2})+\delta_2$;
$c_{235U496}=f_{c233U}(c_{x3})+\delta_3$;
$c_{235U730}=f_{c233U}(c_{x4})+\delta_4$;
$c_{235U888}=f_{c233U}(c_{x5})+\delta_5$;

{turret B, 2 May 2017}

$c_{235U53}=f_{c233U}(c_{x6})+\delta_6$;
$c_{235U208}=f_{c233U}(c_{x7})+\delta_7$;
$c_{235U418}=f_{c233U}(c_{x8})+\delta_8$;
$c_{235U617}=f_{c233U}(c_{x9})+\delta_9$;
$c_{235U794}=f_{c233U}(c_{x10})+\delta_{10}$;

{----------amount content and mass fraction calculations----------}

$c_{235U}=(c_{235U134}+c_{235U341}+c_{235U496}+c_{235U730}+c_{235U888}+c_{235U53}+c_{235U208}+c_{235U418}+c_{235U617}+c_{235U794})/10$;

$c_U=c_{235U}/f_{235U}$;

$\gamma_{235U}=c_{235U}*M_{235U}$;

$\gamma_U=\gamma_{235U}/w_{235U}$;

$m_{235Uvial53}=\gamma_{235U}*m_{aliquot53}$;

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

$\varepsilon_1 = c_{235U} - c_{235U134}$;
$\varepsilon_2 = c_{235U} - c_{235U341}$;
$\varepsilon_3 = c_{235U} - c_{235U496}$;
$\varepsilon_4 = c_{235U} - c_{235U730}$;
$\varepsilon_5 = c_{235U} - c_{235U888}$;

$\varepsilon_6 = c_{235U} - c_{235U53}$;

$\varepsilon_7 = c_{235U} - c_{235U208}$;

$\varepsilon_8 = c_{235U} - c_{235U418}$;

$\varepsilon_9 = c_{235U} - c_{235U617}$;

$\varepsilon_{10} = c_{235U} - c_{235U794}$;

{----------gravimetric versus IDMS values----------}

$diff_{rel}=(c_{235U}-c_{235Umetr})/c_{235Umetr}*100$;

List of Quantities:

Quantity	Unit	Definition
c_{235U}	mol/g	mean amount content of ^{235}U in IRMM-1027s
$c_{235U134}$	mol/g	amount of content ^{235}U in vial 134
$c_{235U341}$	mol/g	amount of content ^{235}U in vial 341
$c_{235U496}$	mol/g	amount of content ^{235}U in vial 496
$c_{235U730}$	mol/g	amount of content ^{235}U in vial 730
$c_{235U888}$	mol/g	amount of content ^{235}U in vial 888
c_{235U53}	mol/g	amount of content ^{235}U in vial 53
$c_{235U208}$	mol/g	amount of content ^{235}U in vial 208
$c_{235U418}$	mol/g	amount of content ^{235}U in vial 418
$c_{235U617}$	mol/g	amount of content ^{235}U in vial 617
$c_{235U794}$	mol/g	amount of content ^{235}U in vial 794
$diff_{rel}$	%	relative difference (IDMS-gravimetric/gravimetric)
c_U	mol/g	mean amount content of U in IRMM-1027s
ε_1		
ε_2		
ε_3		
ε_4		
ε_5		
ε_6		
ε_7		
ε_8		
ε_9		
ε_{10}		
$c_{235Umetr}$	mol/g	gravimetric amount content of ^{235}U in mother solution IRMM-1027s
c_{x1}	mol/g	vial 134

Quantity	Unit	Definition
c_{x2}	mol/g	vial 341
c_{x3}	mol/g	vial 496
c_{x4}	mol/g	vial 730
c_{x5}	mol/g	vial 888
c_{x6}	mol/g	vial 53
c_{x7}	mol/g	vial 208
c_{x8}	mol/g	vial 418
c_{x9}	mol/g	vial 617
c_{x10}	mol/g	vial 794
δ_1	mol/g	
δ_2	mol/g	
δ_3	mol/g	
δ_4	mol/g	
δ_5	mol/g	
δ_6	mol/g	
δ_7	mol/g	
δ_8	mol/g	
δ_9	mol/g	
δ_{10}	mol/g	
M_{235U}	g/mol	atom mass of ^{235}U
$m_{aliquot53}$	g	mass of an aliquot of IRMM-1027s dispensed in vial 53
f_{235U}	mol/mol	^{235}U amount fraction in IRMM-1027s
w_{235U}	g/g	^{235}U mass fraction in IRMM-1027s
γ_{235U}	g/g	mean mass fraction of ^{235}U in IRMM-1027s
γ_U	g/g	mean mass fraction of U in IRMM-1027s
$m_{235Uvial53}$	g	mass of ^{235}U in vial 53

$c_{235Umetr}$: Import
Filename: ..\..\Processing\GUM calculations\IRMM-1027s Uranium gravimetric mixture.smu
Symbol: $c_{235Umixture}$

c_{x1}: Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set A.SMU
Symbol: $c_{235U134}$

c_{x2}: Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set A.SMU
Symbol: $c_{235U341}$

c_{x3}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set A.SMU
Symbol: $c_{235U496}$

c_{x4}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set A.SMU
Symbol: $c_{235U730}$

c_{x5}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set A.SMU
Symbol: $c_{235U888}$

c_{x6}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set B.SMU
Symbol: c_{235U53}

c_{x7}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set B.SMU
Symbol: $c_{235U208}$

c_{x8}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set B.SMU
Symbol: $c_{235U418}$

c_{x9}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set B.SMU
Symbol: $c_{235U617}$

c_{x10}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-235_set B.SMU
Symbol: $c_{235U794}$

δ_1:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_2:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_3:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_4:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_5:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_6:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_7:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_8:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_9:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_{10}:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

M_{235U}:
Type B normal distribution
Value: 235.0439301 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

$m_{aliquot53}$:
Type B normal distribution
Value: 2.51224 g
Expanded Uncertainty: 0.00060 g
Coverage Factor: 2

f_{235U}:
Import
Filename: ..\..\..\Processing\GUM calculations\IRMM-1027s Uranium gravimetric mixture.smu
Symbol: f_{235U}

w_{235U}:
Import
Filename: ..\..\..\Processing\GUM calculations\IRMM-1027s Uranium gravimetric mixture.smu
Symbol: w_{235U}

Input Correlation:

	c_{x1}	c_{x2}	c_{x3}	c_{x4}	c_{x5}
c_{x1}	1	0.5032	0.5225	0.5831	0.5570
c_{x2}	0.5032	1	0.4796	0.5352	0.5113
c_{x3}	0.5225	0.4796	1	0.5557	0.5309
c_{x4}	0.5831	0.5352	0.5557	1	0.5924
c_{x5}	0.5570	0.5113	0.5309	0.5924	1

	c_{x6}	c_{x7}	c_{x8}	c_{x9}	c_{x10}
c_{x6}	1	0.4342	0.4461	0.4530	0.4788
c_{x7}	0.4342	1	0.4715	0.4788	0.5060
c_{x8}	0.4461	0.4715	1	0.4919	0.5198
c_{x9}	0.4530	0.4788	0.4919	1	0.5279
c_{x10}	0.4788	0.5060	0.5198	0.5279	1

	f_{235U}	w_{235U}
f_{235U}	1	1.0000
w_{235U}	1.0000	1

Uncertainty Budgets:

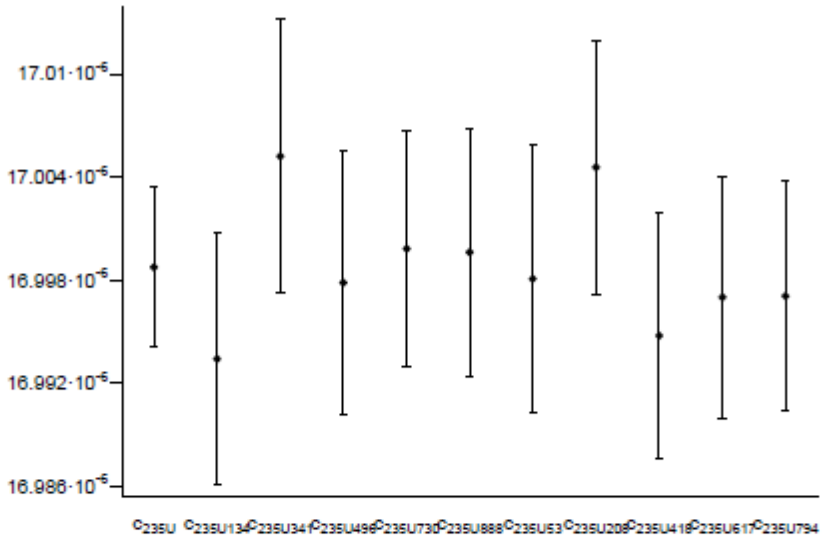
$m_{235Uvial53}$: **mass of ^{235}U in vial 53**

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
c_{x1}	$16.99341 \cdot 10^{-6}$ mol/g	$3.67 \cdot 10^{-9}$ mol/g		59	$220 \cdot 10^{-9}$ g	5.3 %
c_{x2}	$17.00522 \cdot 10^{-6}$ mol/g	$4.00 \cdot 10^{-9}$ mol/g		59	$240 \cdot 10^{-9}$ g	5.6 %
c_{x3}	$16.99786 \cdot 10^{-6}$ mol/g	$3.85 \cdot 10^{-9}$ mol/g		59	$230 \cdot 10^{-9}$ g	5.4 %
c_{x4}	$16.99982 \cdot 10^{-6}$ mol/g	$3.45 \cdot 10^{-9}$ mol/g		59	$200 \cdot 10^{-9}$ g	5.1 %
c_{x5}	$16.99962 \cdot 10^{-6}$ mol/g	$3.62 \cdot 10^{-9}$ mol/g		59	$210 \cdot 10^{-9}$ g	5.2 %
c_{x6}	$16.99807 \cdot 10^{-6}$ mol/g	$3.90 \cdot 10^{-9}$ mol/g		59	$230 \cdot 10^{-9}$ g	4.9 %
c_{x7}	$17.00457 \cdot 10^{-6}$ mol/g	$3.69 \cdot 10^{-9}$ mol/g		59	$220 \cdot 10^{-9}$ g	4.7 %
c_{x8}	$16.99477 \cdot 10^{-6}$ mol/g	$3.59 \cdot 10^{-9}$ mol/g		59	$210 \cdot 10^{-9}$ g	4.6 %
c_{x9}	$16.99700 \cdot 10^{-6}$ mol/g	$3.54 \cdot 10^{-9}$ mol/g		59	$210 \cdot 10^{-9}$ g	4.6 %
c_{x10}	$16.99706 \cdot 10^{-6}$ mol/g	$3.35 \cdot 10^{-9}$ mol/g		59	$200 \cdot 10^{-9}$ g	4.4 %
δ_1	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_2	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_3	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_4	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_5	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_6	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_7	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_8	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_9	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_{10}	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
M_{235U}	235.04393010 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$43 \cdot 10^{-6}$	$81 \cdot 10^{-12}$ g	0.0 %
$m_{aliquot53}$	2.512240 g	$300 \cdot 10^{-6}$ g	normal	$4.0 \cdot 10^{-3}$	$1.2 \cdot 10^{-6}$ g	50.3 %
$m_{235Uvial53}$	0.01003753 g	$1.69 \cdot 10^{-6}$ g				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
c_{235U}	$16.9987 \cdot 10^{-6}$ mol/g	$4.6 \cdot 10^{-9}$ mol/g	2.30	manual
$c_{235U134}$	$16.9934 \cdot 10^{-6}$ mol/g	$7.3 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235U341}$	$17.0052 \cdot 10^{-6}$ mol/g	$8.0 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235U496}$	$16.9979 \cdot 10^{-6}$ mol/g	$7.7 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235U730}$	$16.9998 \cdot 10^{-6}$ mol/g	$6.9 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235U888}$	$16.9996 \cdot 10^{-6}$ mol/g	$7.2 \cdot 10^{-9}$ mol/g	2.00	manual
c_{235U53}	$16.9981 \cdot 10^{-6}$ mol/g	$7.8 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235U208}$	$17.0046 \cdot 10^{-6}$ mol/g	$7.4 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235U418}$	$16.9948 \cdot 10^{-6}$ mol/g	$7.2 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235U617}$	$16.9970 \cdot 10^{-6}$ mol/g	$7.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235U794}$	$16.9971 \cdot 10^{-6}$ mol/g	$6.7 \cdot 10^{-9}$ mol/g	2.00	manual
$diff_{rel}$	-0.076 %	0.027 %	2.00	manual
c_U	$88.727 \cdot 10^{-6}$ mol/g	$27 \cdot 10^{-9}$ mol/g	2.30	manual
ε_1	$5.3 \cdot 10^{-9}$	$6.0 \cdot 10^{-9}$	2.00	manual
ε_2	$-6.5 \cdot 10^{-9}$	$6.6 \cdot 10^{-9}$	2.00	manual
ε_3	$900 \cdot 10^{-12}$	$6.3 \cdot 10^{-9}$	2.00	manual
ε_4	$-1.1 \cdot 10^{-9}$	$5.6 \cdot 10^{-9}$	2.00	manual
ε_5	$-900 \cdot 10^{-12}$	$5.9 \cdot 10^{-9}$	2.00	manual
ε_6	$700 \cdot 10^{-12}$	$6.7 \cdot 10^{-9}$	2.00	manual
ε_7	$-5.8 \cdot 10^{-9}$	$6.3 \cdot 10^{-9}$	2.00	manual
ε_8	$4.0 \cdot 10^{-9}$	$6.1 \cdot 10^{-9}$	2.00	manual
ε_9	$1.7 \cdot 10^{-9}$	$6.0 \cdot 10^{-9}$	2.00	manual
ε_{10}	$1.7 \cdot 10^{-9}$	$5.7 \cdot 10^{-9}$	2.00	manual
γ_{235U}	$3.9955 \cdot 10^{-3}$ g/g	$1.1 \cdot 10^{-6}$ g/g	2.30	manual
γ_U	0.0210693 g/g	$6.3 \cdot 10^{-6}$ g/g	2.30	manual
$m_{235Uvial53}$	0.0100375 g	$3.9 \cdot 10^{-6}$ g	2.30	manual

U235 IDMS IRMM-1027s single vials with 046c spike COMBINED



Date: 03/19/2018	File: U-IDMS IRMM-1027s vialswith 046c using 233-235_ combined.SMU	Page 9 of 9

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Annex 19 Determination of ^{238}U in 10 randomly selected vials (turrets A and B) for the characterisation IRMM-1027s by ID-TIMS with IRMM-046c (reference date November 1, 2016)

U238 IDMS IRMM-1027s single vials with 046c spike COMBINED

Author: Jakopic Date: Elements: U

simplified equation spike ^{233}U, sample ^{238}U, ratio $^{233}U/^{238}U$

input data from GUM files (set A and B)

IRMM-1027s vials (3 replicates per blend mixture): set A: 134, 341, 496, 730 and 888

set B: 53, 208, 418, 617 and 794

Model Equation:

{----------simplified equation----------}

$f_{c233U}(c_x)=c_x$;

{turret A, 24 March 2017}

$c_{238U134}=f_{c233U}(c_{x1})+\delta_1$;

$c_{238U341}=f_{c233U}(c_{x2})+\delta_2$;

$c_{238U496}=f_{c233U}(c_{x3})+\delta_3$;

$c_{238U730}=f_{c233U}(c_{x4})+\delta_4$;

$c_{238U888}=f_{c233U}(c_{x5})+\delta_5$;

{turret B, 2 May 2017}

$c_{238U53}=f_{c233U}(c_{x6})+\delta_6$;

$c_{238U208}=f_{c233U}(c_{x7})+\delta_7$;

$c_{238U418}=f_{c233U}(c_{x8})+\delta_8$;

$c_{238U617}=f_{c233U}(c_{x9})+\delta_9$;

$c_{238U794}=f_{c233U}(c_{x10})+\delta_{10}$;

{----------amount content and mass fraction calculations----------}

$c_{238U}=(c_{238U134}+c_{238U341}+c_{238U496}+c_{238U730}+c_{238U888}+c_{238U53}+c_{238U208}+c_{238U418}+c_{238U617}+c_{238U794})/10$;

$c_U=c_{238U}/f_{238U}$;

$\gamma_{238U}=c_{238U}*M_{238U}$;

$\gamma_U=\gamma_{238U}/w_{238U}$;

$m_{238Uvial53}=\gamma_{238U}*m_{aliquot53}$;

{----------gravimetric versus IDMS values----------}

$diff_{rel}=(c_{238U}-c_{238Umetr})/c_{238Umetr}*100$;

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

$\varepsilon_1 = c_{238U} - c_{238U134}$;

$\varepsilon_2 = c_{238U} - c_{238U341}$;

$\varepsilon_3 = c_{238U} - c_{238U496}$;

$\varepsilon_4 = c_{238U} - c_{238U730}$;

$\varepsilon_5 = c_{238U} - c_{238U888}$;

$\varepsilon_6 = c_{238U} - c_{238U53}$;

$\varepsilon_7 = c_{238U} - c_{238U208}$;

$\varepsilon_8 = c_{238U} - c_{238U418}$;

$\varepsilon_9 = c_{238U} - c_{238U617}$;

$\varepsilon_{10} = c_{238U} - c_{238U794}$;

List of Quantities:

Quantity	Unit	Definition
c_{238U}	mol/g	mean amount content of ^{238}U in IRMM-1027s
$c_{238U134}$	mol/g	amount of content ^{238}U in vial 134
$c_{238U341}$	mol/g	amount of content ^{238}U in vial 341
$c_{238U496}$	mol/g	amount of content ^{238}U in vial 496
$c_{238U730}$	mol/g	amount of content ^{238}U in vial 730
$c_{238U888}$	mol/g	amount of content ^{238}U in vial 888
c_{238U53}	mol/g	amount of content ^{238}U in vial 53
$c_{238U208}$	mol/g	amount of content ^{238}U in vial 208
$c_{238U418}$	mol/g	amount of content ^{238}U in vial 418
$c_{238U617}$	mol/g	amount of content ^{238}U in vial 617
$c_{238U794}$	mol/g	amount of content ^{238}U in vial 794
ε_1		
ε_2		
ε_3		
ε_4		
ε_5		
ε_6		
ε_7		
ε_8		
ε_9		
ε_{10}		
$c_{238Umetr}$	mol/g	metrological amount content of ^{238}U in mother solution IRMM-1027s
c_{x1}	mol/g	vial 134
c_{x2}	mol/g	vial 341
c_{x3}	mol/g	vial 496
c_{x4}	mol/g	vial 730

Quantity	Unit	Definition
c_{x5}	mol/g	vial 888
c_{x6}	mol/g	vial 53
c_{x7}	mol/g	vial 208
c_{x8}	mol/g	vial 418
c_{x9}	mol/g	vial 617
c_{x10}	mol/g	vial 794
δ_1	mol/g	
δ_2	mol/g	
δ_3	mol/g	
δ_4	mol/g	
δ_5	mol/g	
δ_6	mol/g	
δ_7	mol/g	
δ_8	mol/g	
δ_9	mol/g	
δ_{10}	mol/g	
$diff_{rel}$	%	relative difference (IDMS-gravimetric/gravimetric)
γ_{238U}	g/g	mean mass fraction of ^{238}U in IRMM-1027s
M_{238U}	g/mol	atom mass of ^{238}U
$m_{238Uvial53}$	g	mass of ^{238}U in vial 53
$m_{aliquot53}$	g	mass of an aliquot of IRMM-1027s dispensed in vial 53
γ_U	g/g	mean mass fraction of U in IRMM-1027s
w_{238U}	g/g	mass fraction of ^{238}U in IRMM-1027s
c_U	mol/g	mean amount content of U in IRMM-1027s
f_{238U}	mol/mol	amount fraction of ^{238}U in IRMM-1027s

$c_{238Umetr}$: Import
Filename: ..\..\Processing\GUM calculations\IRMM-1027s Uranium gravimetric mixture.smu
Symbol: $c_{238Umixture}$

c_{x1}: Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set A.SMU
Symbol: $c_{238U134}$

c_{x2}: Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set A.SMU
Symbol: $c_{238U341}$

c_{x3}: Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set A.SMU
Symbol: $c_{238U496}$

c_{x4}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set A.SMU
Symbol: $c_{238U730}$

c_{x5}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set A.SMU
Symbol: $c_{238U888}$

c_{x6}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set B.SMU
Symbol: c_{238U53}

c_{x7}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set B.SMU
Symbol: $c_{238U208}$

c_{x8}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set B.SMU
Symbol: $c_{238U418}$

c_{x9}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set B.SMU
Symbol: $c_{238U517}$

c_{x10}:
Import
Filename: U-IDMS IRMM-1027s vials with 046c using 233-238_set B.SMU
Symbol: $c_{238U794}$

δ_1:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_2:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_3:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_4:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_5:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_6:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_7:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_8:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_9:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

δ_{10}:
Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: 0 mol/g
Coverage Factor: 1

M_{238U}:
Type B normal distribution
Value: 238.0507884 g/mol
Expanded Uncertainty: 0.0000020 g/mol
Coverage Factor: 1

$m_{aliquot53}$:
Type B normal distribution
Value: 2.51224 g
Expanded Uncertainty: 0.00060 g
Coverage Factor: 2

w_{238U}:
Import
Filename: ..\..\..\Processing\GUM calculations\IRMM-1027s Uranium gravimetric mixture.smu
Symbol: w_{238U}

f_{238U}:
Import
Filename: ..\..\..\Processing\GUM calculations\IRMM-1027s Uranium gravimetric mixture.smu
Symbol: f_{238U}

Input Correlation:

	c_{x1}	c_{x2}	c_{x3}	c_{x4}	c_{x5}
c_{x1}	1	0.6639	0.6076	0.7411	0.6865
c_{x2}	0.6639	1	0.5795	0.7068	0.6547
c_{x3}	0.6076	0.5795	1	0.6470	0.5992
c_{x4}	0.7411	0.7068	0.6470	1	0.7309
c_{x5}	0.6865	0.6547	0.5992	0.7309	1

	c_{x6}	c_{x7}	c_{x8}	c_{x9}	c_{x10}
c_{x6}	1	0.5074	0.4395	0.4662	0.5394
c_{x7}	0.5074	1	0.5736	0.6083	0.7039
c_{x8}	0.4395	0.5736	1	0.5270	0.6098
c_{x9}	0.4662	0.6083	0.5270	1	0.6467
c_{x10}	0.5394	0.7039	0.6098	0.6467	1

	w_{238U}	f_{238U}
w_{238U}	1	1.0000
f_{238U}	1.0000	1

Interim Results:

Quantity	Value	Standard Uncertainty
γ_U	0.02105935 g/g	$4.54 \cdot 10^{-6}$ g/g
c_U	$88.6850 \cdot 10^{-6}$ mol/g	$19.1 \cdot 10^{-9}$ mol/g

Uncertainty Budgets:

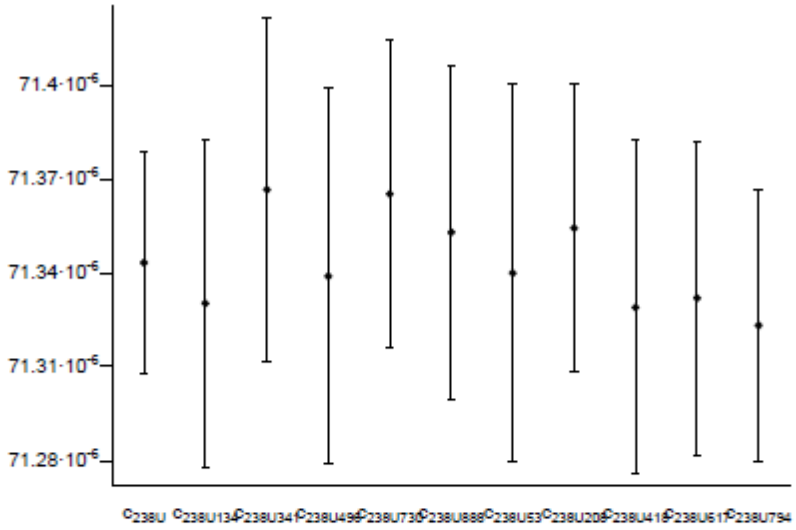
$m_{238Uvial53}$: mass of ^{238}U in vial 53

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
c_{x1}	71.3302·10^{-6} mol/g	26.2·10^{-9} mol/g		60	1.6·10^{-6} g	8.5 %
c_{x2}	71.3666·10^{-6} mol/g	27.5·10^{-9} mol/g		60	1.6·10^{-6} g	8.7 %
c_{x3}	71.3389·10^{-6} mol/g	30.1·10^{-9} mol/g		60	1.8·10^{-6} g	9.2 %
c_{x4}	71.3652·10^{-6} mol/g	24.7·10^{-9} mol/g		60	1.5·10^{-6} g	8.2 %
c_{x5}	71.3529·10^{-6} mol/g	26.6·10^{-9} mol/g		60	1.6·10^{-6} g	8.5 %
c_{x6}	71.3399·10^{-6} mol/g	30.1·10^{-9} mol/g		60	1.8·10^{-6} g	7.5 %
c_{x7}	71.3543·10^{-6} mol/g	23.1·10^{-9} mol/g		60	1.4·10^{-6} g	6.3 %
c_{x8}	71.3289·10^{-6} mol/g	26.6·10^{-9} mol/g		60	1.6·10^{-6} g	6.9 %
c_{x9}	71.3319·10^{-6} mol/g	25.1·10^{-9} mol/g		60	1.5·10^{-6} g	6.6 %
c_{x10}	71.3232·10^{-6} mol/g	21.7·10^{-9} mol/g		60	1.3·10^{-6} g	6.1 %
δ_1	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_2	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_3	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_4	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_5	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_6	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_7	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_8	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_9	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
δ_{10}	0.0 mol/g	0.0 mol/g	normal	0.0	0.0 g	0.0 %
M_{238U}	238.05078840 g/mol	2.00·10^{-6} g/mol	normal	180·10^{-6}	360·10^{-12} g	0.0 %
$m_{aliquot53}$	2.512240 g	300·10^{-6} g	normal	0.017	5.1·10^{-6} g	23.6 %
$m_{238Uvial53}$	0.0426661 g	10.5·10^{-6} g				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
c_{238U}	$71.343 \cdot 10^{-6}$ mol/g	$35 \cdot 10^{-9}$ mol/g	2.30	manual
$c_{238U134}$	$71.330 \cdot 10^{-6}$ mol/g	$52 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238U341}$	$71.367 \cdot 10^{-6}$ mol/g	$55 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238U496}$	$71.339 \cdot 10^{-6}$ mol/g	$60 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238U730}$	$71.365 \cdot 10^{-6}$ mol/g	$49 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238U888}$	$71.353 \cdot 10^{-6}$ mol/g	$53 \cdot 10^{-9}$ mol/g	2.00	manual
c_{238U53}	$71.340 \cdot 10^{-6}$ mol/g	$60 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238U208}$	$71.354 \cdot 10^{-6}$ mol/g	$46 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238U418}$	$71.329 \cdot 10^{-6}$ mol/g	$53 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238U617}$	$71.332 \cdot 10^{-6}$ mol/g	$50 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238U794}$	$71.323 \cdot 10^{-6}$ mol/g	$43 \cdot 10^{-9}$ mol/g	2.00	manual
ε_1	$13 \cdot 10^{-9}$	$40 \cdot 10^{-9}$	2.00	manual
ε_2	$-23 \cdot 10^{-9}$	$43 \cdot 10^{-9}$	2.00	manual
ε_3	$4 \cdot 10^{-9}$	$48 \cdot 10^{-9}$	2.00	manual
ε_4	$-22 \cdot 10^{-9}$	$37 \cdot 10^{-9}$	2.00	manual
ε_5	$-10 \cdot 10^{-9}$	$41 \cdot 10^{-9}$	2.00	manual
ε_6	$3 \cdot 10^{-9}$	$52 \cdot 10^{-9}$	2.00	manual
ε_7	$-11 \cdot 10^{-9}$	$39 \cdot 10^{-9}$	2.00	manual
ε_8	$14 \cdot 10^{-9}$	$46 \cdot 10^{-9}$	2.00	manual
ε_9	$11 \cdot 10^{-9}$	$43 \cdot 10^{-9}$	2.00	manual
ε_{10}	$20 \cdot 10^{-9}$	$36 \cdot 10^{-9}$	2.00	manual
$diff_{rel}$	-0.123 %	0.043 %	2.00	manual
γ_{238U}	0.0169833 g/g	$8.4 \cdot 10^{-5}$ g/g	2.30	manual
$m_{238Uvial53}$	0.042666 g	$24 \cdot 10^{-6}$ g	2.30	manual

U238 IDMS IRMM-1027s single vials with 046c spike COMBINED



Date: 02/12/2018	File: U-IDMS IRMM-1027s vials with 046c using 233-238 _ combined.SMU	Page 9 of 9

Generated with GUM Workbench Pro Version 2.4.1.458

Annex 20 Determination of ^{239}Pu in 10 randomly selected vials (turrets C and D) for the characterisation in IRMM-1027s by ID-TIMS with IRMM-046c (reference date November 1, 2016)

Pu IDMS IRMM-1027s VIALS with IRMM-046c using 242-239 COMBINED 1 Nov 2016

Author: Rozle Jakopic Elements: Pu

Date of reference: 1 November 2016

Isotope amount ratios internal test report 3740 to 1st November 2016

input data from GUM files turret A and B:

magazine C (vials): 134, 341, 496, 730, 888, 4 April 2017

magazine D (vials): 53, 208, 418, 617, 794, 19 May 2017

Model Equation:

{----------amount content calculations----------}

$f_{c242Pu}(c_x)=c_x$;

{turret C 4 April 2017}

$c_{239Pu134}=f_{c242Pu}(c_{x1})*e^{(-\lambda_{239}\cdot\Delta t_1)}$;

$c_{239Pu341}=f_{c242Pu}(c_{x2})*e^{(-\lambda_{239}\cdot\Delta t_1)}$;

$c_{239Pu496}=f_{c242Pu}(c_{x3})*e^{(-\lambda_{239}\cdot\Delta t_1)}$;

$c_{239Pu730}=f_{c242Pu}(c_{x4})*e^{(-\lambda_{239}\cdot\Delta t_1)}$;

$c_{239Pu888}=f_{c242Pu}(c_{x5})*e^{(-\lambda_{239}\cdot\Delta t_1)}$;

{turret D 19 May 2017}

$c_{239Pu53}=f_{c242Pu}(c_{x6})*e^{(-\lambda_{239}\cdot\Delta t_2)}$;

$c_{239Pu208}=f_{c242Pu}(c_{x7})*e^{(-\lambda_{239}\cdot\Delta t_2)}$;

$c_{239Pu418}=f_{c242Pu}(c_{x8})*e^{(-\lambda_{239}\cdot\Delta t_2)}$;

$c_{239Pu617}=f_{c242Pu}(c_{x9})*e^{(-\lambda_{239}\cdot\Delta t_2)}$;

$c_{239Pu794}=f_{c242Pu}(c_{x10})*e^{(-\lambda_{239}\cdot\Delta t_2)}$;

{----------amount content and mass fraction calculations----------}

$c_{239Pu}=(c_{239Pu134}+c_{239Pu341}+c_{239Pu496}+c_{239Pu730}+c_{239Pu888}+c_{239Pu53}+c_{239Pu208}+c_{239Pu418}+c_{239Pu617}+c_{239Pu794})/10$;

$c_{Pu}=c_{239Pu}/fdnorm_{239Pu}$;

$\gamma_{239Pu}=c_{239Pu}*M_{239Pu}$;

$\gamma_{Pu}=\gamma_{239Pu}/wdnorm_{239Pu}$;

$m_{239Puvial53}=\gamma_{239Pu}*m_{aliquot53}$;

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

$\varepsilon_1=c_{239Pu}-c_{239Pu134}$;

$\varepsilon_2=c_{239Pu}-c_{239Pu341}$;

$\varepsilon_3=c_{239Pu}-c_{239Pu496}$;

$\varepsilon_4=c_{239Pu}-c_{239Pu730}$;

$\varepsilon_5=c_{239Pu}-c_{239Pu888}$;

$\varepsilon_6 = c_{239Pu} - c_{239Pu53}$;

$\varepsilon_7 = c_{239Pu} - c_{239Pu208}$;

$\varepsilon_8 = c_{239Pu} - c_{239Pu418}$;

$\varepsilon_9 = c_{239Pu} - c_{239Pu617}$;

$\varepsilon_{10} = c_{239Pu} - c_{239Pu794}$;

{----------gravimetric value vs. IDMS----------}

$diff_{rel} = (c_{239Pu} - c_{239Pumetr}) / c_{239Pumetr} * 100$;

$ln_2 = ln(2)$;

$\lambda_{238} = ln_2 / \tau_{238}$;

$\lambda_{239} = ln_2 / \tau_{239}$;

$\lambda_{240} = ln_2 / \tau_{240}$;

$\lambda_{241} = ln_2 / \tau_{241}$;

$\lambda_{242} = ln_2 / \tau_{242}$;

$\lambda_{244} = ln_2 / \tau_{244}$;

List of Quantities:

Quantity	Unit	Definition
c_{239Pu}	mol/g	mean amount content of ^{239}Pu in IRMM-1027s
Δt_1	a	time difference measurement date 4 April 2017 (IDMS) and reference date 1 November 2016
Δt_2	a	time difference measurement date 19 May 2017 (IDMS) and reference date 1 November 2016
e		
ln_2		
τ_{238}	a	half life ^{238}Pu
τ_{239}	a	half life ^{239}Pu
τ_{240}	a	half life ^{240}Pu
τ_{241}	a	half life ^{241}Pu
τ_{242}	a	half life ^{242}Pu
τ_{244}	a	half life ^{244}Pu
λ_{238}	a^{-1}	decay constant ^{238}Pu
λ_{239}	a^{-1}	decay constant ^{239}Pu
λ_{240}	a^{-1}	decay constant ^{240}Pu
λ_{241}	a^{-1}	decay constant ^{241}Pu
λ_{242}	a^{-1}	decay constant ^{242}Pu
λ_{244}	a^{-1}	decay constant ^{244}Pu
c_{x1}	mol/g	import from respective GUMWB amount content of ^{239}Pu
c_{x2}	mol/g	import from respective GUMWB amount content of ^{239}Pu
c_{x3}	mol/g	import from respective GUMWB amount content of ^{239}Pu

Quantity	Unit	Definition
c_{x4}	mol/g	import from respective GUMWB amount content of ^{239}Pu
c_{x5}	mol/g	import from respective GUMWB amount content of ^{239}Pu
c_{x6}	mol/g	import from respective GUMWB amount content of ^{239}Pu
c_{x7}	mol/g	import from respective GUMWB amount content of ^{239}Pu
c_{x8}	mol/g	import from respective GUMWB amount content of ^{239}Pu
c_{x9}	mol/g	import from respective GUMWB amount content of ^{239}Pu
c_{x10}	mol/g	import from respective GUMWB amount content of ^{239}Pu
ε_1		
ε_2		
ε_3		
ε_4		
ε_5		
ε_6		
ε_7		
ε_8		
ε_9		
ε_{10}		
$c_{239Pu134}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu341}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu496}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu730}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu888}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu53}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu208}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu418}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu617}$	mol/g	normalised ^{239}Pu amount content in vial
$c_{239Pu794}$	mol/g	normalised ^{239}Pu amount content in vial
$diff_{rel}$	%	relative difference between the measured (IDMS) and gravimetric value
$c_{239Pumetr}$	mol/g	amount content of ^{239}Pu in IRMM-1027s from gravimetric preparation, 1 November 2016
c_{Pu}	mol/g	mean amount content of Pu in IRMM-1027s
γ_{239Pu}	g/g	mean mass fraction of ^{239}Pu in IRMM-1027s
γ_{Pu}	g/g	mean mass fraction of Pu in IRMM-1027s
M_{239Pu}	g/mol	atom mass of ^{239}Pu
$m_{239Puvial53}$	g	mass of ^{239}Pu in vial 53
$m_{aliquot53}$	g	mass of an aliquot of IRMM-1027s dispensed in vial 53
$fdnorm_{239Pu}$	mol/mol	amount fraction of ^{239}Pu in IRMM-1027s, 1 November 2016
$wdnorm_{239Pu}$	g/g	mass fraction of ^{239}Pu in IRMM-1027s, 1 November 2016

Δt_1: Constant
Value: -0.42163 a

04/04/2017, 01/11/2016,-154 days/365.25 =-0.42163

Δt_2: Constant
Value: -0.54483 a

19/05/2017, 1/11/2016, -199 days/365.25 = 0.54483 a

e: Constant
Value: 2.71828182845904523536

τ_{238}: Type B normal distribution
Value: 87.74 a
Expanded Uncertainty: 0.03 a
Coverage Factor: 1

τ_{239}: Type B normal distribution
Value: 24100 a
Expanded Uncertainty: 11 a
Coverage Factor: 1

τ_{240}: Type B normal distribution
Value: 6564 a
Expanded Uncertainty: 7 a
Coverage Factor: 1

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

τ_{242}: Type B normal distribution
Value: 373000 a
Expanded Uncertainty: 3000 a
Coverage Factor: 1

τ_{244}: Type B normal distribution
Value: $8 \cdot 10^7$ a
Expanded Uncertainty: $0.09 \cdot 10^7$ a
Coverage Factor: 1

c_{x1}: Import
Filename: U:\Nuclear Safeguards\Secure Data\Project Data\LSD spikes\IRMM-1027s ISO 17034\characterisation assessment\individual vials\GUM files\Pu-IDMS IRMM-1027s with 046c spike using 242-239_set C.smu
Symbol: $c_{239Pu134}$

c_{x2}: Import
Filename: U:\Nuclear Safeguards\Secure Data\Project Data\LSD spikes\IRMM-1027s ISO 17034\characterisation assessment\individual vials\GUM files\Pu-IDMS IRMM-1027s with 046c spike using 242-239_set C.smu
Symbol: $c_{239Pu341}$

c_{x3}:
Import
Filename: U:\Nuclear Safeguards\Secure Data\Project Data\LSD spikes\IRMM-1027s ISO 17034\characterisation assessment\individual vials\GUM files\Pu-IDMS IRMM-1027s with 046c spike using 242-239_set C.smu
Symbol: $c_{239Pu496}$

c_{x4}:
Import
Filename: U:\Nuclear Safeguards\Secure Data\Project Data\LSD spikes\IRMM-1027s ISO 17034\characterisation assessment\individual vials\GUM files\Pu-IDMS IRMM-1027s with 046c spike using 242-239_set C.smu
Symbol: $c_{239Pu730}$

c_{x5}:
Import
Filename: U:\Nuclear Safeguards\Secure Data\Project Data\LSD spikes\IRMM-1027s ISO 17034\characterisation assessment\individual vials\GUM files\Pu-IDMS IRMM-1027s with 046c spike using 242-239_set C.smu
Symbol: $c_{239Pu888}$

c_{x6}:
Import
Filename: Pu-IDMS IRMM-1027s with 046c spike using 242-239_set D.smu
Symbol: $c_{239Pu53}$

c_{x7}:
Import
Filename: Pu-IDMS IRMM-1027s with 046c spike using 242-239_set D.smu
Symbol: $c_{239Pu208}$

c_{x8}:
Import
Filename: Pu-IDMS IRMM-1027s with 046c spike using 242-239_set D.smu
Symbol: $c_{239Pu418}$

c_{x9}:
Import
Filename: Pu-IDMS IRMM-1027s with 046c spike using 242-239_set D.smu
Symbol: $c_{239Pu617}$

c_{x10}:
Import
Filename: Pu-IDMS IRMM-1027s with 046c spike using 242-239_set D.smu
Symbol: $c_{239Pu794}$

$c_{239Pumetr}$:
Import
Filename: ..\..\Processing\GUM calculations\IRMM-1027s Plutonium gravimetric mixture_1_Nov_2016.smu
Symbol: $c_{Pumixture239}$

M_{239Pu}:
Type B normal distribution
Value: 239.0521636 g/mol
Expanded Uncertainty: 0.0000019 g/mol
Coverage Factor: 1

$m_{aliquot53}$:
Type B normal distribution
Value: 2.51224 g
Expanded Uncertainty: 0.00060 g
Coverage Factor: 2

$fdnorm_{239Pu}$: Import
Filename: ..\..\..\Processing\GUM calculations\IRMM-1027s Plutonium gravimetric mixture_1_Nov_2016.smu
Symbol: $fdnorm_{239Pu}$

$wdnorm_{239Pu}$: Import
Filename: ..\..\..\Processing\GUM calculations\IRMM-1027s Plutonium gravimetric mixture_1_Nov_2016.smu
Symbol: $wdnorm_{239Pu}$

Input Correlation:

	c_{x1}	c_{x2}	c_{x3}	c_{x4}	c_{x5}
c_{x1}	1	0.8741	0.8584	0.7154	0.9296
c_{x2}	0.8741	1	0.8134	0.6779	0.8808
c_{x3}	0.8584	0.8134	1	0.6657	0.8650
c_{x4}	0.7154	0.6779	0.6657	1	0.7209
c_{x5}	0.9296	0.8808	0.8650	0.7209	1

	c_{x6}	c_{x7}	c_{x8}	c_{x9}	c_{x10}
c_{x6}	1	0.9376	0.9402	0.9480	0.9352
c_{x7}	0.9376	1	0.9298	0.9374	0.9248
c_{x8}	0.9402	0.9298	1	0.9400	0.9273
c_{x9}	0.9480	0.9374	0.9400	1	0.9350
c_{x10}	0.9352	0.9248	0.9273	0.9350	1

	$fdnorm_{239Pu}$	$wdnorm_{239Pu}$
$fdnorm_{239Pu}$	1	1.0000
$wdnorm_{239Pu}$	1.0000	1

The abundance set for Pu is assumed as uncorrelated.

Interim Results:

Quantity	Value	Standard Uncertainty
λ_{238}	$7.90001 \cdot 10^{-3}$ a^{-1}	$2.70 \cdot 10^{-6}$ a^{-1}
λ_{239}	$28.7613 \cdot 10^{-6}$ a^{-1}	$13.1 \cdot 10^{-9}$ a^{-1}
λ_{240}	$105.598 \cdot 10^{-6}$ a^{-1}	$113 \cdot 10^{-9}$ a^{-1}
λ_{241}	0.0483872 a^{-1}	$40.5 \cdot 10^{-6}$ a^{-1}
λ_{242}	$1.8583 \cdot 10^{-6}$ a^{-1}	$14.9 \cdot 10^{-9}$ a^{-1}
λ_{244}	$8.6643 \cdot 10^{-9}$ a^{-1}	$97.5 \cdot 10^{-12}$ a^{-1}

Uncertainty Budgets:

γ_{239Pu}: mean mass fraction of ^{239}Pu in IRMM-1027s

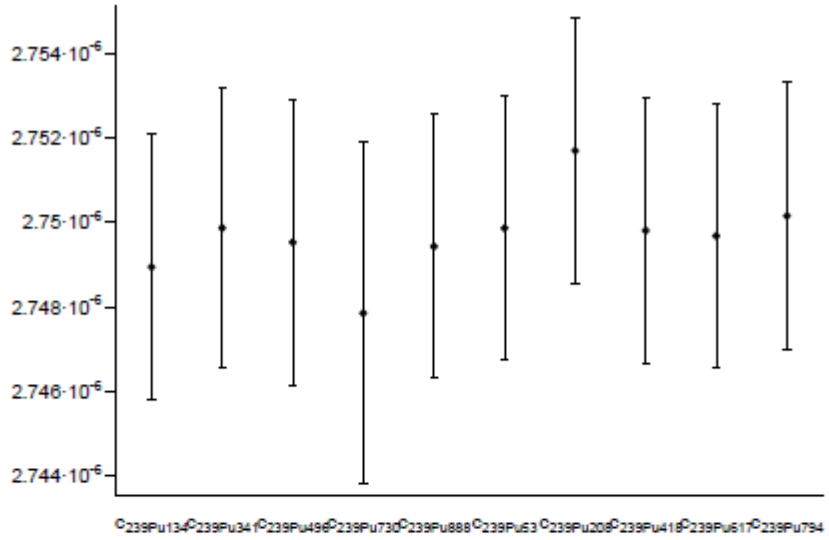
Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
Δt_1	-0.42163 a					
Δt_2	-0.54483 a					
e	2.718281828459					
τ_{239}	24100.0 a	11.0 a	normal	$-380 \cdot 10^{-15}$	$-4.2 \cdot 10^{-12}$ g/g	0.0 %
c_{x1}	$2.74892 \cdot 10^{-6}$ mol/g	$1.57 \cdot 10^{-9}$ mol/g		24	$37 \cdot 10^{-9}$ g/g	9.8 %
c_{x2}	$2.74984 \cdot 10^{-6}$ mol/g	$1.66 \cdot 10^{-9}$ mol/g		24	$40 \cdot 10^{-9}$ g/g	10.0 %
c_{x3}	$2.74950 \cdot 10^{-6}$ mol/g	$1.68 \cdot 10^{-9}$ mol/g		24	$40 \cdot 10^{-9}$ g/g	10.1 %
c_{x4}	$2.74783 \cdot 10^{-6}$ mol/g	$2.02 \cdot 10^{-9}$ mol/g		24	$48 \cdot 10^{-9}$ g/g	11.1 %
c_{x5}	$2.74941 \cdot 10^{-6}$ mol/g	$1.56 \cdot 10^{-9}$ mol/g		24	$37 \cdot 10^{-9}$ g/g	9.7 %
c_{x6}	$2.74983 \cdot 10^{-6}$ mol/g	$1.55 \cdot 10^{-9}$ mol/g		24	$37 \cdot 10^{-9}$ g/g	9.8 %
c_{x7}	$2.75166 \cdot 10^{-6}$ mol/g	$1.57 \cdot 10^{-9}$ mol/g		24	$38 \cdot 10^{-9}$ g/g	9.9 %
c_{x8}	$2.74977 \cdot 10^{-6}$ mol/g	$1.57 \cdot 10^{-9}$ mol/g		24	$37 \cdot 10^{-9}$ g/g	9.9 %
c_{x9}	$2.74964 \cdot 10^{-6}$ mol/g	$1.55 \cdot 10^{-9}$ mol/g		24	$37 \cdot 10^{-9}$ g/g	9.8 %
c_{x10}	$2.75012 \cdot 10^{-6}$ mol/g	$1.58 \cdot 10^{-9}$ mol/g		24	$38 \cdot 10^{-9}$ g/g	9.9 %
M_{239Pu}	239.05216360 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$2.7 \cdot 10^{-6}$	$5.2 \cdot 10^{-12}$ g/g	0.0 %
γ_{239Pu}	$657.319 \cdot 10^{-6}$ g/g	$260 \cdot 10^{-9}$ g/g				

$m_{239Puvial53}$: **mass of ^{239}Pu in vial 53**

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
Δt_1	-0.42163 a					
Δt_2	-0.54483 a					
e	2.718281828459					
τ_{239}	24100.0 a	11.0 a	normal	$-950 \cdot 10^{-15}$	$-10 \cdot 10^{-12}$ g	0.0 %
c_{x1}	$2.74892 \cdot 10^{-6}$ mol/g	$1.57 \cdot 10^{-9}$ mol/g		60	$94 \cdot 10^{-9}$ g	9.0 %
c_{x2}	$2.74984 \cdot 10^{-6}$ mol/g	$1.66 \cdot 10^{-9}$ mol/g		60	$99 \cdot 10^{-9}$ g	9.2 %
c_{x3}	$2.74950 \cdot 10^{-6}$ mol/g	$1.68 \cdot 10^{-9}$ mol/g		60	$100 \cdot 10^{-9}$ g	9.2 %
c_{x4}	$2.74783 \cdot 10^{-6}$ mol/g	$2.02 \cdot 10^{-9}$ mol/g		60	$120 \cdot 10^{-9}$ g	10.2 %
c_{x5}	$2.74941 \cdot 10^{-6}$ mol/g	$1.56 \cdot 10^{-9}$ mol/g		60	$93 \cdot 10^{-9}$ g	8.9 %
c_{x6}	$2.74983 \cdot 10^{-6}$ mol/g	$1.55 \cdot 10^{-9}$ mol/g		60	$93 \cdot 10^{-9}$ g	9.0 %
c_{x7}	$2.75166 \cdot 10^{-6}$ mol/g	$1.57 \cdot 10^{-9}$ mol/g		60	$94 \cdot 10^{-9}$ g	9.0 %
c_{x8}	$2.74977 \cdot 10^{-6}$ mol/g	$1.57 \cdot 10^{-9}$ mol/g		60	$94 \cdot 10^{-9}$ g	9.0 %
c_{x9}	$2.74964 \cdot 10^{-6}$ mol/g	$1.55 \cdot 10^{-9}$ mol/g		60	$93 \cdot 10^{-9}$ g	9.0 %
c_{x10}	$2.75012 \cdot 10^{-6}$ mol/g	$1.58 \cdot 10^{-9}$ mol/g		60	$95 \cdot 10^{-9}$ g	9.0 %
M_{239Pu}	239.05216360 g/mol	$1.90 \cdot 10^{-6}$ g/mol	normal	$6.9 \cdot 10^{-6}$	$13 \cdot 10^{-12}$ g	0.0 %
$m_{aliquot53}$	2.512240 g	$300 \cdot 10^{-6}$ g	normal	$660 \cdot 10^{-6}$	$200 \cdot 10^{-9}$ g	8.4 %
$m_{239Puvial 53}$	$1.651343 \cdot 10^{-3}$ g	$681 \cdot 10^{-9}$ g				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
c_{239Pu}	$2.7497 \cdot 10^{-6}$ mol/g	$2.5 \cdot 10^{-9}$ mol/g	2.30	manual
ε_1	$700 \cdot 10^{-12}$	$2.3 \cdot 10^{-9}$	2.00	manual
ε_2	$-200 \cdot 10^{-12}$	$2.5 \cdot 10^{-9}$	2.00	manual
ε_3	$200 \cdot 10^{-12}$	$2.6 \cdot 10^{-9}$	2.00	manual
ε_4	$1.8 \cdot 10^{-9}$	$3.2 \cdot 10^{-9}$	2.00	manual
ε_5	$200 \cdot 10^{-12}$	$2.3 \cdot 10^{-9}$	2.00	manual
ε_6	$-200 \cdot 10^{-12}$	$2.3 \cdot 10^{-9}$	2.00	manual
ε_7	$-2.0 \cdot 10^{-9}$	$2.3 \cdot 10^{-9}$	2.00	manual
ε_8	$-100 \cdot 10^{-12}$	$2.3 \cdot 10^{-9}$	2.00	manual
ε_9	0.0	$2.3 \cdot 10^{-9}$	2.00	manual
ε_{10}	$-500 \cdot 10^{-12}$	$2.3 \cdot 10^{-9}$	2.00	manual
$c_{239Pu134}$	$2.7490 \cdot 10^{-6}$ mol/g	$3.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu341}$	$2.7499 \cdot 10^{-6}$ mol/g	$3.3 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu496}$	$2.7495 \cdot 10^{-6}$ mol/g	$3.4 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu730}$	$2.7479 \cdot 10^{-6}$ mol/g	$4.0 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu888}$	$2.7494 \cdot 10^{-6}$ mol/g	$3.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu53}$	$2.7499 \cdot 10^{-6}$ mol/g	$3.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu208}$	$2.7517 \cdot 10^{-6}$ mol/g	$3.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu418}$	$2.7498 \cdot 10^{-6}$ mol/g	$3.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu617}$	$2.7497 \cdot 10^{-6}$ mol/g	$3.1 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{239Pu794}$	$2.7502 \cdot 10^{-6}$ mol/g	$3.2 \cdot 10^{-9}$ mol/g	2.00	manual
$diff_{rel}$	-0.122 %	0.089 %	2.00	manual
c_{Pu}	$2.8120 \cdot 10^{-6}$ mol/g	$2.6 \cdot 10^{-9}$ mol/g	2.30	manual
γ_{239Pu}	$657.32 \cdot 10^{-6}$ g/g	$600 \cdot 10^{-9}$ g/g	2.30	manual
γ_{Pu}	$672.28 \cdot 10^{-6}$ g/g	$610 \cdot 10^{-9}$ g/g	2.30	manual
$m_{239Puvial53}$	$1.6513 \cdot 10^{-3}$ g	$1.6 \cdot 10^{-5}$ g	2.30	manual



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