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CERTIFICATION REPORT

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

R. Jakopič, J. Bauwens, C. Hennessy, F. Kehoe, U. Jacobsson, S. Richter and Y. Aregbe

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Abstract

IRMM Large-Sized Dried (LSD) Spikes are widely 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-1027q is a dried nitrate material in cellulose acetate butyrate (CAB), certified for the mass of uranium and plutonium and isotope amount ratios per unit. The material was produced following ISO Guide 34:2009.
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 by means of an automated robot system into individual units 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. Between unit-homogeneity was quantified and stability during dispatch and storage were assessed in accordance with ISO Guide 35:2006.
The certified values for the uranium and plutonium isotope amount ratios and for the mass of uranium per unit were obtained from the gravimetric preparation of the mother solution, taking into account the mass, purity and isotopic abundances of the starting materials, the mass of the mother solution, and the mass of an aliquot in each individual unit. The certified values for the mass of plutonium per unit were established by isotope dilution thermal ionisation mass spectrometry (ID-TIMS). Confirmatory measurements were performed by isotope dilution thermal ionisation mass spectrometry (ID-TIMS) and thermal ionisation mass spectrometry (TIMS).
Uncertainties of the certified values were estimated in compliance with the Guide to the Expression of Uncertainty in Measurement (GUM) and include uncertainties related to possible inhomogeneity and to characterisation.
This spike CRM is applied as a calibrant to measure the uranium and plutonium amount content of dissolved spent nuclear fuel solutions using isotope dilution mass spectrometry (IDMS). Each unit contains about 55 mg of uranium with a relative mass fraction m(^{235}U)/m(U) of 17.7 % and 1.9 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.

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Disclaimer

Certain commercial equipment, instruments, and materials are identified in this paper to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the European Commission, nor does it imply that the material or equipment is necessarily the best available for the purpose.

Summary

IRMM Large-Sized Dried (LSD) Spikes are widely 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-1027q is a dried nitrate material in cellulose acetate butyrate (CAB), certified for the mass of uranium and plutonium and isotope amount ratios per unit. The material was produced following ISO Guide 34:2009 [1].

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 by means of an automated robot system into individual units 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.

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 and for the mass of uranium per unit were obtained from the gravimetric preparation of the mother solution, taking into account the mass, purity and isotopic abundances of the starting materials, the mass of the mother solution, and the mass of an aliquot in each individual unit. The certified values for the mass of plutonium per unit were established by isotope dilution thermal ionisation mass spectrometry (ID-TIMS). Confirmatory measurements were performed by isotope dilution thermal ionisation mass spectrometry (ID-TIMS) and thermal ionisation mass spectrometry (TIMS).

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.

This spike CRM is applied as a calibrant to measure the uranium and plutonium amount content of dissolved spent nuclear fuel solutions using isotope dilution mass spectrometry (IDMS). Each unit contains about 55 mg of uranium with a relative mass fraction $m(^{235}U)/m(U)$ of 17.7 % and 1.9 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]
$n(^{234}U)/n(^{238}U)$	0.0025009	0.0000030
$n(^{235}U)/n(^{238}U)$	0.21834	0.00009
$n(^{240}Pu)/n(^{239}Pu)$	0.022419	0.000008
$n(^{241}Pu)/n(^{239}Pu)$	0.0001628	0.0000024
$n(^{242}Pu)/n(^{239}Pu)$	0.0000757	0.0000021
The certified masses and the uncertainties of ^{235}U, ^{238}U and ^{239}Pu per unit are listed on pages 3 to 25 of the certificate 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 plutonium and uranium isotope amount ratios is November 1, 2014.

[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.

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Glossary

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
CRM	Certified reference material
EC	European Commission
ESARDA	European Safeguards Research and Development Association
GUM	Guide to the Expression of Uncertainty in Measurements
IAEA	International Atomic Energy Agency
IDMS	Isotope dilution mass spectrometry
ID-TIMS	Isotope dilution thermal ionisation mass spectrometry
IRMM	Institute for Reference Materials and Measurements of the JRC
ITU	Institute for Transuranium Elements of the JRC
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	Mass spectrometry
$MS_{between}$	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
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
SDS	Safety data sheet
s_{wb}	Within-unit standard deviation

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
$\overline{y}$	Arithmetic mean
α	Significance level
$\nu_{MSwithin}$	Degrees of freedom of MS_{within}

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 material, 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 [4]. 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 IRMM to meet the existing requirement for reliable isotope reference materials for the accountancy measurements of uranium and plutonium by 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 1.9 mg Pu), isotopically different to the uranium and plutonium in the test sample and are in dried nitrate form. About 1200 units of IRMM-1027 LSD spikes are prepared annually to fulfil the demands for fissile material control from European Safeguards Authorities and industry [5].

1.2 Choice of the material

The IRMM-1027q 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 contains about 55 mg of uranium with a relative mass fraction $m(^{235}U)/m(U)$ of 17.7 % and 1.9 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 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 fuel is needed before measurement by IDMS. 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 vial.

1.3 Design of the project

The individual units of IRMM-1027q LSD spikes were prepared by dispensing aliquots of the mother solution into vials and dried down. This solution was prepared gravimetrically by dissolving uranium and plutonium certified reference metals in nitric acid. Finally, the dried nitrate was treated with CAB for preservation during storage and transport. The certified mass values of uranium and the plutonium and uranium isotope amount ratios are based on the data given by the weighing certificates and the certificate of the starting materials. The certified mass values of plutonium are established by ID-TIMS. Confirmation measurements, along with the assessment of homogeneity and stability were made using IDMS analysis on 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, Institute for Reference Materials and Measurements (IRMM), Geel, Belgium.

3 Material processing and process control

3.1 Origin and purity of the starting materials

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-1027q LSD spikes. The isotopic composition and the purity of the metals are given in Annexes 2 - 6.

3.2 Processing

Five units of plutonium MP2 metal for the preparation of the IRMM-1027q mother solution were weighed and transferred into a pre-cleaned 3 L borosilicate flask. The metal was dissolved by addition of a solution prepared from concentrated nitric acid (*p.a.*, Merck, Darmstadt, Germany), a few drops of concentrated hydrofluoric acid (*p.a.*, Merck, Darmstadt, Germany) and deionised water. After heating on a hot plate at 90 °C for several days, the addition of the solution and the heating step were repeated until the plutonium metal dissolved. The dissolution of plutonium metal was monitored by visual inspection. A small amount of a fine precipitate was observed at the bottom of the flask which did not disappear after further heating. In order to provide IRMM-1027q in a timely manner to the customers it was decided to add the uranium metals to the solution despite the incomplete plutonium dissolution. The respective units of enriched uranium metal (NBL CRM 116-A) and of natural uranium metal (EC NRM 101) were weighed and added into the above solution. Prior to weighing, the units of NBL CRM 116-A metal were etched with nitric acid (c = 1 mol L^{-1}) to remove surface oxidation products, and subsequently rinsed with deionised water and acetone (*p.a.*, Merck, Darmstadt, Germany) and dried down. Finally, a solution prepared from concentrated nitric acid and deionised water was added to adjust the concentration of the nitric acid solution (c = 5 mol L^{-1}). The solution was left to homogenise for a few days with occasionally stirring by hand, and weighed to determine the final amount contents of the uranium and plutonium in the solution, taking into account the necessary corrections for air buoyancy effects.

Prior to dispensing the mother solution into individual vials four aliquots were analysed by ID-TIMS to confirm the gravimetrically determined amount contents of plutonium and uranium (see Section 3.3).

Dispensing and weighing of the solution into individual vials were performed by a validated automated system, which was installed at IRMM in collaboration with Nucomat (Lokeren, Belgium) [6]. 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 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 1126 units over five consecutive working days.

The drying of the dispensed solution contained in the units was carried out on a hot plate equipped with a sensor for controlling the surface temperature. 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. CAB was added to retain the dried material at the bottom of the 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). 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. The processing steps are shown in Figure 1.

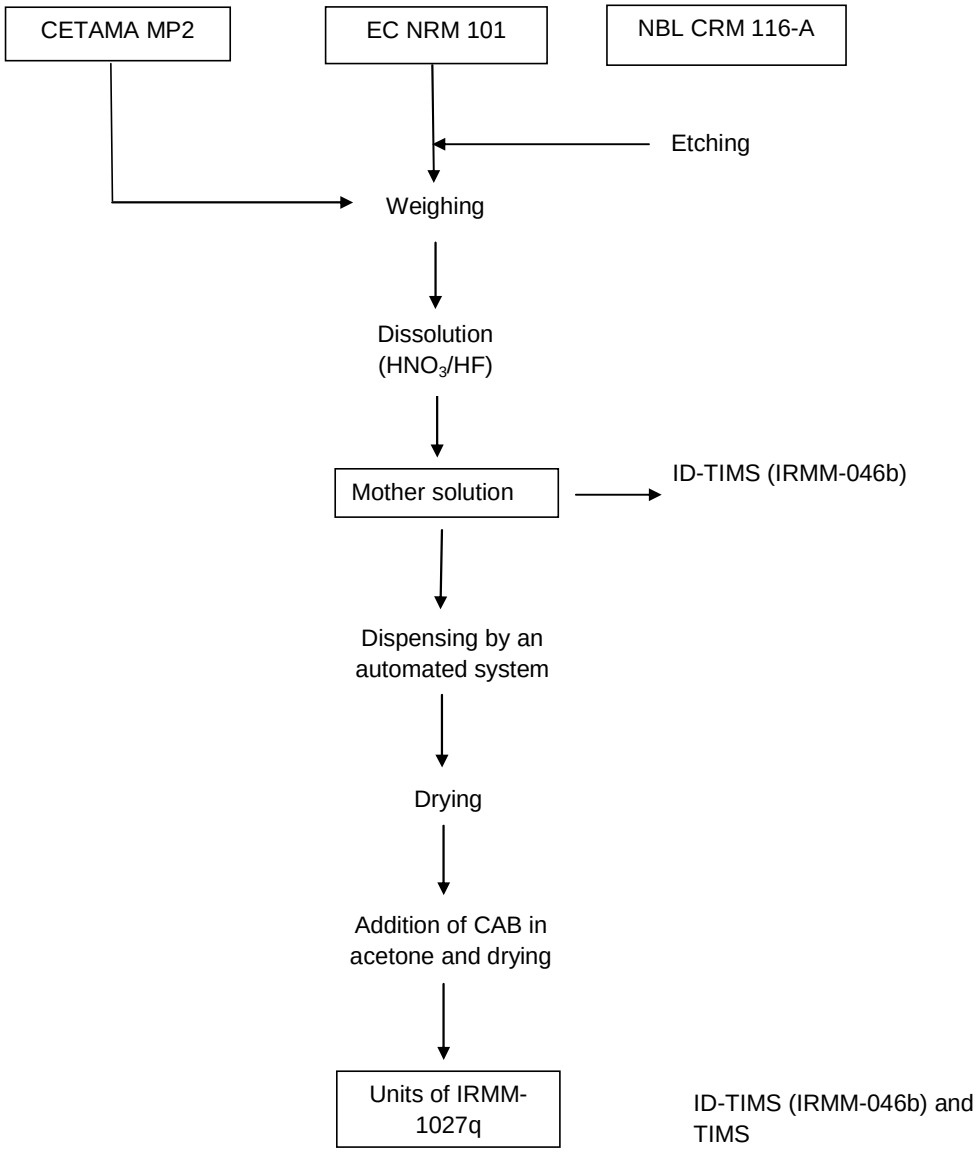

Fig. 1 Preparation of IRMM-1027q LSD spikes

3.3 Process control

This section describes the confirmation measurements performed on the mother solution prior to dispensing into individual vials.

Four aliquots (about 2.5 g each) were individually spiked with a mixed U/Pu spike CRM (IRMM-046b) for ID-TIMS analysis to confirm the amount contents of uranium and plutonium in the solution from gravimetric preparation. The IRMM-046b certificate can be found in Annex 7. Two unspiked aliquots were analysed to confirm the isotopic composition (e.g. uranium and plutonium amount ratios) by thermal ionisation mass spectrometry (TIMS).

The spiked and unspiked solutions were evaporated to dryness and dissolved in 200 µL nitric acid (c = 2 mol L^{-1}, *p.a.*, Merck, Darmstadt, Germany). To achieve isotopic equilibrium between the spike and the sample, first 50 µL iron(II) chloride solution (c = 1.25 mol L^{-1}, *p.a.*, Merck, Darmstadt, Germany) was added to reduce plutonium to Pu(III) and then 100 µL hydroxyl ammonium chloride solution (c = 1 mol L^{-1}, *p.a.*, Merck, Darmstadt, Germany) and 100 µL sodium nitrite (c = 1 mol L^{-1}, *p.a.*, Merck, Darmstadt, Germany) to oxidise Pu(III) to Pu(IV). Finally 430 µL concentrated nitric acid were added to obtain Pu(IV) in nitric acid with an amount of substance concentration of 8 mol L^{-1}. The U/Pu separation was performed using anion-exchange columns (Bio-Rad AG1-X4, 100-200 mesh, Bio-Rad, Hercules, USA). Uranium was eluted with nitric acid (c = 8 mol L^{-1}) and plutonium with nitric acid (c = 0.35 mol L^{-1}). The separation was repeated once for uranium and twice for plutonium to avoid isobaric interference in the TIMS measurement. Both purified fractions were evaporated and re-dissolved in nitric acid (c = 1 mol L^{-1}) to give concentrations of 0.05 mg Pu mL^{-1} and 0.1 mg U mL^{-1} for loading the rhenium filaments. The isotopic measurements of the uranium and plutonium were performed on a Triton TIMS (Thermo Fischer Scientific, Bremen, Germany) [7].

The results of the confirmation measurements for ^{238}U and ^{235}U amount contents in the mother solution of IRMM-1027q agreed within the uncertainties with the values from the gravimetric preparation. On the other hand a relative deviation of about -0.35 % from the gravimetric value was observed for the ^{239}Pu amount content. This was due to an incomplete dissolution of the Pu metal. The results of the confirmation measurements for the mother solution of IRMM-1027q are shown in Annex 8.

A unit of IRMM-1027q LSD spike can be seen in Figure 2.

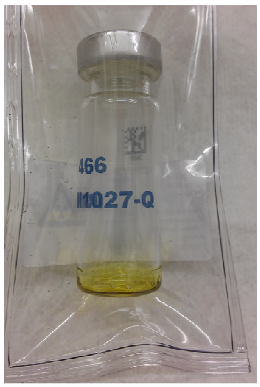

Fig. 2 Unit of IRMM-1027q LSD spike

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 Guide 34 [1] requires RM producers to quantify the between unit variation. This aspect is covered in between-unit homogeneity studies. The homogeneity study was combined together with the measurements to confirm the gravimetric preparation of the IRMM-1027q LSD spikes.

4.1 Between-unit homogeneity

The between-unit homogeneity was evaluated to ensure that the certified values of the CRM are valid for all 1126 units of the material, within the stated uncertainty.

The number of selected units corresponds to approximately the cubic root of the total number of the produced units (1126). Ten units were selected to assess the homogeneity for the amount content and ten units for the isotope amount ratios using a random stratified sampling scheme covering the whole batch for the between-unit homogeneity test. The batch was divided into ten groups (with a similar number of units) and one unit was selected randomly from each group. The whole amount of sample per unit (equals minimum sample intake) was taken, chemically separated and the isotopic measurements were performed on a fraction of the purified sample. Each sample was measured in three replicates together with the isotopic standards to correct for instrumental mass fractionation. This enabled five independent samples to be measured on the same TIMS sample turret on the same day. Therefore, the measurements for all twenty units of IRMM-1027q were performed under intermediate precision conditions rather than repeatability conditions. 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. Some measurement results had to be excluded from the evaluation due to technical reasons, such as e.g. loss of sample prior to total evaporation measurement, high background from the filament due to unusually high filament temperatures or very low signal intensity. The results of the homogeneity study are shown in Annex 9 and Annex 10.

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.

Quantification of between-unit inhomogeneity was accomplished by analysis of variance (ANOVA), which can separate the between-unit variation (s_{bb}) from the within-unit variation (s_{wb}). The latter is equivalent to the method repeatability 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. 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 and Table 2.

Table 1: Results of the statistical evaluation of the homogeneity studies of the amount content in IRMM-1027q at 99 % confidence level

	Trends		Outliers		Distribution	
	Analytical sequence	Filling sequence	Individual results	Unit means	Individual results	Unit means
^{235}U	no	no	none	none	unimodal	unimodal
^{238}U	no	no	none	none	unimodal	unimodal
^{239}Pu	no	no	none	none	unimodal	unimodal

Table 2: Results of the statistical evaluation of the homogeneity studies of the isotope amount ratios in IRMM-1027q at 99 % confidence level

	Trends		Outliers		Distribution	
	Analytical sequence	Filling sequence	Individual results	Unit means	Individual results	Unit means
$n(^{234}U)/n(^{238}U)$	no	no	one	none	unimodal	unimodal
$n(^{235}U)/n(^{238}U)$	no	no	none	none	unimodal	unimodal
$n(^{240}Pu)/n(^{239}Pu)$	no	no	none	none	unimodal	unimodal
$n(^{241}Pu)/n(^{239}Pu)$	no	no	none	none	unimodal	unimodal
$n(^{242}Pu)/n(^{239}Pu)$	no	no	none	none	unimodal	unimodal

One outlying individual result was found for the $n(^{234}U)/n(^{238}U)$ amount ratio (Grubbs single and double test at $\alpha = 0.01$). Since no technical reason was identified for the outlying results, the data was retained for statistical analysis.

One has to bear in mind that $s_{bb,rel}$ and $s_{wb,rel}$ 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.* [8]. 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.

Method repeatability ($s_{wb,rel}$), between–unit standard deviation ($s_{bb,rel}$) and $u^*_{bb,rel}$ were calculated as:

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

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

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

MS_{within} mean square within a 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 because the isotopic measurements for all selected units of IRMM-1027q could not be carried out on the same day. 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 ^{235}U and ^{239}Pu amount contents, and for $n(^{241}\text{Pu})/n(^{239}\text{Pu})$ amount ratio. For that reason, the data were first normalised by the respective day mean and the resulting data were evaluated using one way-ANOVA. The results of the evaluation of the between-unit variation are summarised in Table 3 and Table 4. The resulting values from the above equations were converted into relative uncertainties.

Table 3: Results of the homogeneity studies of the amount content in IRMM-1027q

	$s_{wb,rel}$ [1)] [%]	$s_{bb,rel}$ [1)] [%]	$u^*_{bb,rel}$ [1)] [%]
^{235}U content	0.0181	0.0204	0.00589
^{238}U content	0.0457	0.0303	0.0148
^{239}Pu content	0.0321	n.c.	0.0107

[1)] Rounding rules not applicable to the intermediate results

n.c. cannot be calculated, $MS_{between} < MS_{within}$

Table 4: Results of the homogeneity studies of the isotope amount ratios in IRMM-1027q

	$s_{wb,rel}$ [1)] [%]	$s_{bb,rel}$ [1)] [%]	$u^*_{bb,rel}$ [1)] [%]
$n(^{234}\text{U})/n(^{238}\text{U})$	0.108	n.c.	0.0361
$n(^{235}\text{U})/n(^{238}\text{U})$	0.0363	n.c.	0.0122
$n(^{240}\text{Pu})/n(^{239}\text{Pu})$	0.0108	0.00158	0.00349
$n(^{241}\text{Pu})/n(^{239}\text{Pu})$	0.989	n.c.	0.321
$n(^{242}\text{Pu})/n(^{239}\text{Pu})$	3.99	n.c.	1.30

[1)] Rounding rules not applicable to the intermediate results

n.c. cannot be calculated, $MS_{between} < MS_{within}$

The homogeneity study showed no outlying unit means and no trends in the filling sequence. 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} and u^*_{bb} is adopted as uncertainty contribution to account for potential inhomogeneity.

4.2 Within-unit homogeneity and minimum sample intake

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. Sample sizes equal to or above the minimum sample intake guarantee the certified value within its stated uncertainty. The uranium and plutonium amount content in a single IRMM-1027 LSD spike is such that no dilution of a typical sample

of dissolved fuel is needed. The only quantitative step needed at the reprocessing plant laboratory is to weigh as accurately as possible an aliquot of the dissolved fuel solution onto the spike and ensure complete mixing of spike and sample. 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-1027q 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-1027q is a mixed U/Pu reference material, consisting of U and Pu radionuclides. Therefore, the certified isotope amount ratios and amount contents of this reference material are unstable by nature following the law of radioactive decay, depending on the respective half-lives [9, 10].

Temperatures up to 60 °C could be reached for regular shipment of reference materials. Therefore, stability under these conditions had to be demonstrated. The shipment of nuclear material follows the legal requirements related to radioprotection measures for transport of radioactive materials. The packing of radioactive material is divided into two parts, the packing of the inner package and the packing of the container according to regulations and respective procedures [11]. Units of IRMM-1027q LSD spikes are sealed in plastic bags, put in a plastic Type A container for radioactive materials and are transported finally in large sealed containers. From the package material specification and the fact that the transport of radioactive material does not take longer than one week, the IRMM-1027q units packed as described above are never exposed to temperatures outside the range of 4 to 60 °C.

Taking into account that

1) Certified values of IRMM-1027q are valid for a specific reference date given on the certificate only;
2) The dried uranyl and plutonium nitrates are embedded in an organic substance providing a stable layer at the bottom of the vial to preserve the integrity during transport;
3) Preparation time of a batch of the IRMM-1027 series from dispensing of the mother solution until confirmation measurements on the completed LSD spikes in CAB takes about 6-10 months;
4) The packing of IRMM-1027q is such that the units are never exposed to temperatures outside the range of 4 to 60 °C;
5) Transport of IRMM-1027q does not exceed one week;
6) IRMM has provided IRMM-1027 series of LSD spikes for more than 10 years to customers

the short-term and long-term stability for the IRMM-1027 series are demonstrated in combination with confirmation measurements of the gravimetrically certified values and from experience in preparing the same kind of reference material over years, as described in detail in the certification report of IRMM-1027o by Jakopič et *al*. [7].

5.1 Short-term stability study

In the scope of the certification and preparation of IRMM-1027q a thorough short-term stability study of the CAB applied was demonstrated using a modified isochronous design [12]. To assess the short-term stability of the CAB with 35-39 (g/100g) butyryl content used in the preparation of IRMM-1027q, samples were stored at 4 °C and 60 °C for one week at

each temperature. The reference temperature was set to 18 °C. The test samples contained only CAB with 35-39 (g/100g) butyryl content without plutonium and uranyl nitrate. The same vials and the same CAB preparation procedure were used for IRMM-1027q. Ten units were prepared for each temperature (30 units in total). The samples could not be analysed by direct measurements to assess deterioration. Therefore a visual observation was made of the selected units before and at the end of the study. No visual differences in the appearance of the CAB layers (flaking or hair cracks) were observed before and after the test. This short-term stability study demonstrated that IRMM-1027q LSD spikes show no sign of deterioration during transport period and can be shipped to customers under normal temperature conditions [7].

5.2 Long-term stability study

The long-term stability for IRMM-1027q is demonstrated in combination with confirmation measurements of the gravimetrically certified values and in addition underpinned by measurement results carried out using IRMM-1027m LSD spikes over a period of 4 years [13]. The applied approach for IRMM-1027q of combining confirmation and homogeneity IDMS measurements already demonstrated the stability for the IRMM-1027 LSD series from the time of starting the dispensing until the time of performing confirmation measurements on randomly selected units. This time span is for each of the LSD batches about 6-10 months. Furthermore, long-term stability of the certified properties of IRMM-1027q is underpinned by confirmation measurements from the previous batch as part of the post certification monitoring, such as IRMM-1027o which has the same characteristics as IRMM-1027q. The results are shown in Annex 11. In addition, the compatibility study carried out using IRMM-1027m also proves the long-term stability of the IRMM-1027 series LSD spikes [14, 15].

Furthermore, IRMM, ITU and the IAEA are engaged in mutual verification measurements of mixed uranium plutonium spike reference materials via an EC support task to the IAEA. In the frame of this support task verification measurements of randomly selected IRMM-1027 LSD spikes from different batches are performed sometimes up to two years after the certificate was issued, which 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. As a further proof of the long-term stability of the IRMM-1027 series, selected units of IRMM-1027m were set aside and stored under room temperature conditions for already almost six years. Regular visual inspection showed that the CAB in these units stayed intact for five years. Some sign of deterioration (hair cracks and flaking) appeared in some of the vials after the storage time of more than five years. This has no consequence on the certified values since the certificate is valid for three years.

5.3 Estimation of uncertainties

Due to the chosen approach of demonstrating the stability by combining confirmation and homogeneity assessment and taking into account points 1) – 6) as listed in section 5, no additional contribution from the stability study to the expanded uncertainty of the certified values of IRMM-1027q is taken into account.

Underpinned by internal confirmation, external verification and long-term monitoring of the IRMM-1027 series of LSD spikes in CAB, short- and long-term stability have been demonstrated. The IRMM-1027q certificate is valid for three years from the date of signature. The validity may be extended after further tests on the stability of the spike material are carried out. The material has to be transported according to the legal requirements related to radioprotection measures for the transport of radioactive materials. It is recommended to store the units of IRMM-1027q at + 18 °C ± 5 °C in an upright position.

After the certification campaign, the material will be subjected to IRMM's regular stability monitoring programme to control its stability. At least two units per year will be analysed in the IRMM nuclear laboratories to confirm the certified values.

6 Characterisation

The material characterisation is the process of determining the property values of a reference material.

The material characterisation was based on gravimetric preparation for uranium and on isotope dilution mass spectrometry for plutonium. The IRMM-1027q series of LSD spikes was prepared by dispensing an aliquot (about 2.5 g) of the mother solution into individual units by an automated robot 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 and Annexes 13). Each individual unit of IRMM-1027q LSD spike is certified for the mass of ^{239}Pu, ^{235}U and ^{238}U and the $n(^{234}U)/n(^{238}U)$, $n(^{235}U)/n(^{238}U)$, $n(^{240}Pu)/n(^{239}Pu)$, $n(^{241}Pu)/n(^{239}Pu)$, 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 (see Annexes 2 - 4). The purity of Pu MP2 metal was calculated for November 1, 2014 from the original purity of the CETAMA certificate (Annex 4).

6.2 Masses of ^{235}U and ^{238}U, U amount ratios and their uncertainties

The mass of ^{235}U and ^{238}U and the U isotope amount ratios in each individual unit of IRMM-1027q are calculated from the mass fraction of uranium in the mother solution, taking into account the mass of the metals and the solution, their purity and isotopic composition (e.g. isotope amount ratios), and the mass of an aliquot dispensed into each vial. In Table 5 the data supporting the calculation of the masses of ^{235}U and ^{238}U and Pu and U amount ratios per unit of IRMM-1027q are summarised.

Table 5: Gravimetric mixing to prepare the mother solution of IRMM-1027q

	MP2	EC NRM 101	NBL CRM116-A	Mother solution
Mass [1] [g]	2.35230	54.87388	12.32612	3097.50
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 $n(^{241}Pu)/n(^{239}Pu)$ 0.0002378 $n(^{242}Pu)/n(^{239}Pu)$ 0.00007570	$n(^{234}U)/n(^{238}U)$ 0.00005548 $n(^{235}U)/n(^{238}U)$ 0.0072593 $n(^{236}U)/n(^{238}U)$ 0.000000151	$n(^{233}U)/n(^{235}U)$ 0.0000003863 $n(^{234}U)/n(^{235}U)$ 0.0115836 $n(^{238}U)/n(^{235}U)$ 0.051277 $n(^{236}U)/n(^{235}U)$ 0.0094713	

[1] The masses of the metals are obtained from the weighing certificate, see Annex 14.

[2] The purity of the metals is obtained from the certificates, see Annexes 2 - 4.

[3] Amount ratios are obtained from the certificates, see Annexes 3 and 5 – 6.

The uncertainties on the certified mass (u_{char}) of ^{235}U and ^{238}U in the vial are composed of several contributions (Table 6), i.e. the uncertainty on the mass determination ($u_{char,1}$, $u_{char,2}$ and $u_{char,3}$), the uncertainty on the purity of the metals ($u_{char,4}$), and the uncertainties on the amount ratios ($u_{char,5}$). The complete and detailed calculations of the mass fractions, amount ratios and their uncertainty budgets are given in Annex 13.

Table 6: Uncertainty budgets for the masses of ^{235}U and ^{238}U in the vials of IRMM-1027q

	Standard uncertainty contribution					Combined relative uncertainty
	$u_{char,1}$ [1)] [g]	$u_{char,2}$ [2)] [g]	$u_{char,3}$ [3)] [g]	$u_{char,4}$ [4)] [g/g]	$u_{char,5}$ [5)] [mol/mol]	$u_{char,rel}$ [6)] [%]
^{235}U	0.000035	0.02	0.0003	0.00007	0.0000205	0.0125
^{238}U	0.000055	0.02	0.0003	0.000025	0.0000018	0.0121

[1)] Standard uncertainty of the mass determination of the metals, see Annex 14.

[2)] Standard uncertainty of the mass determination of the mother solution, see Annex 14.

[3)] Standard uncertainty of the mass determination of an aliquot, see Annex 12.

[4)] Standard uncertainty of the purity of the metals, see Annexes 2 - 3.

[5)] Standard uncertainty of the largest amount ratio, for other amount ratios, see Annex 3 and 6.

[6)] Rounding rules not applicable to the intermediate results.

6.3 Masses of ^{239}Pu, Pu amount ratios and their uncertainties

The mass of ^{239}Pu in each individual unit of IRMM-1027q is calculated from the mass fraction of the plutonium established by ID-TIMS analysis using IRMM-046b as spike reference material on 8 randomly selected vials, taking into account the mass of the solution (Annex 12), the mass of the spike in each blend (Annex 15), the amount content and isotopic composition of the spike (see Annex 7), and the isotope ratio measurements of the blend mixture (R_b). The uncertainties on the certified mass (u_{char}) of ^{239}Pu in the vial are composed of several contributions, i.e. the uncertainties on the mass determination of the sample and the spike ($u_{char,1}$ and $u_{char,2}$), the uncertainties on the amount content and isotope amount ratio of the spike ($u_{char,3}$ and $u_{char,4}$), and the uncertainty on the isotope ratio measurements of the blend ($u_{char,5}$). In Table 7 the uncertainty contributions for one blend mixture (vial No. 176) are summarised. The complete and detailed calculations of the mass fractions, amount contents and their uncertainty budgets in the selected units of IRMM-1027q are given in Annex 16 and Annex 17.

Table 7: Uncertainty budgets for the masses of ^{239}Pu in vial no. 176 of IRMM-1027q

	Standard uncertainty contribution					Combined relative uncertainty
	$u_{char,1}$ [1)] [g]	$u_{char,2}$ [2)] [g]	$u_{char,3}$ [3)] [µmol/g]	$u_{char,4}$ [4)] [mol/mol]	$u_{char,5}$ [5)] [mol/mol]	$u_{char,\ rel}$ [6)] [%]
^{239}Pu	0.0003	0.0001	0.00009	0.000008	0.000036	0.0241

[1)] Standard uncertainty of the mass determination of an aliquot, see Annex 12.

[2)] Standard uncertainty of the mass determination of the spike, see Annex 15.

[3)] Standard uncertainty of the ^{242}Pu amount content in IRMM-046b, see Annex 7.

[4)] Standard uncertainty of the $n(^{239}Pu)/n(^{242}Pu)$ ratio in IRMM-046b, see Annex 7.

[5)] Standard uncertainty of the $n(^{239}Pu)/n(^{242}Pu)$ ratio in the blend see Annexes 16 and 17.

[6)] Rounding rules not applicable to the intermediate results.

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 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 weights (certificate), air buoyancy correction and the variability of the balance used in "SUUS" method.

6.5 Confirmation measurements

Ten units of IRMM-1027q were randomly selected from the whole batch and analysed by ID-TIMS to confirm the uranium and plutonium amount contents obtained from the gravimetric preparation and isotope dilution thermal ionisation mass spectrometry, respectively. To each of these vials, about 3 g of IRMM-046b mixed U/Pu spike in nitric acid (c = 5 mol L^{-1}) was weighed in and evaporated to dryness. In addition, ten units of IRMM-1027q were randomly selected for the confirmation of the uranium and plutonium isotope amount ratios. To each of these vials about, 5 mL of nitric acid (c = 8 mol L^{-1}) was added and evaporated to dryness. Subsequently, the isotopic equilibrium, chemical separation and isotopic measurements on Triton TIMS were carried out [7].

The results of the confirmation measurements of the uranium amount contents and uranium and plutonium isotope amount ratios agreed well with the values from the gravimetrical preparation, except for the $n(^{238}Pu)/n(^{239}Pu)$ and $n(^{236}U)/n(^{238}U)$ amount ratios. These two amount ratios were therefore not certified and are given only as additional information in the certification report. The results of the confirmation measurements of the plutonium amount contents agreed well with the ID-TIMS results. All the results are shown as graphs in Annex 18 and Annex 19.

7 Value Assignment

Certified values are values that fulfil the highest standards of accuracy. Certified values for IRMM-1027q were assigned on the basis of gravimetric preparation and isotope dilution mass spectrometry as primary methods of measurement. 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 certified values (masses of ^{239}Pu, ^{235}U and ^{238}U and Pu and U isotope amount ratios) are based on the masses of the metals, their purity and isotopic composition, the mass of the mother solution and the mass of an aliquot dispensed into the vials. All weighings were carried out with a set of calibrated weights, directly traceable to the kg prototype at BIPM, Paris, with the necessary corrections for air buoyancy effects.

The assigned uncertainty consists of uncertainties related to characterisation, u_{char} (Section 6), potential between-unit inhomogeneity, s_{bb} (Section 4.1) 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, relative uncertainty of the certified value ($U_{CRM, rel}$) with a coverage factor k as:

$$U_{CRM,rel} = k \cdot \sqrt{u_{char,rel}^2 + s_{bb,rel}^2} \qquad \textbf{Equation 4}$$

- u_{char} was estimated as described in Section 6
- s_{bb} was estimated as described in Section 4.1.

Because of sufficient degrees of freedom of the different uncertainty contributions**,** a coverage factor k of 2 was applied to obtain the expanded uncertainties. The certified masses and their uncertainties for unit No. 1 are summarised in Table 8. The certified values of all 1126 units are given in Annex 1.

Table 8: Certified masses and their uncertainties for unit No.1 of IRMM-1027q as an example

Mass	Certified value [mg]	$u_{char, rel}$ [1)] [%]	$s_{bb, rel}$ [1)] [%]	$U_{CRM, rel}$ [2)] [%]	U_{CRM} [2)] [mg]
^{239}Pu	1.9394	0.0241	0.0107	0.052	0.0010
^{235}U	10.063	0.0125	0.0204	0.049	0.005
^{238}U	46.678	0.0121	0.0303	0.065	0.030

1) Rounding rules not applicable to the intermediate results.

2) Expanded (k = 2) and rounded uncertainty.

The certified plutonium and uranium isotope amount ratios are summarised in Table 9.

Table 9: Certified isotope amount ratios and their uncertainties for IRMM-1027q LSD spikes

Isotope amount ratios	Certified value [1] [mol/mol]	$u_{char, rel}$ [2] [%]	$u^*_{bb, rel}$ [2] [%]	$U_{CRM, rel}$ [%]	U_{CRM} [3] [mol/mol]
$n(^{234}U)/n(^{238}U)$	0.0025009	0.0433	0.0361	0.11272	0.0000030
$n(^{235}U)/n(^{238}U)$	0.21834	0.0142	0.0122	0.03741	0.00009
$n(^{240}Pu)/n(^{239}Pu)$	0.022419	0.0165	0.00349	0.03380	0.000008
$n(^{241}Pu)/n(^{239}Pu)$	0.0001628	0.664	0.321	1.4741	0.0000024
$n(^{242}Pu)/n(^{239}Pu)$	0.0000757	0.515	1.30	2.7902	0.0000021

[1] The reference date for the plutonium and uranium isotope amount ratios is November 1, 2014.

[2] Rounding rules not applicable to the intermediate results.

[3] Expanded (k = 2) and rounded 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 from gravimetric preparation and from ID-TIMS are summarised in Table 10 and Table 11 (see also Annex 20).

Table 10: Plutonium and uranium isotopic mass fractions (expressed as $^{xxx}U/^{tot}U$ and $^{xxx}Pu/^{tot}Pu$) in the mother solution used for IRMM-1027q

	Isotopic mass fraction	
	Value [1] [%]	Uncertainty [2] [%]
$m(^{234}U)/m(U)\times100$	0.20153	0.00017
$m(^{235}U)/m(U)\times100$	17.6704	0.0022
$m(^{236}U)/m(U)\times100$	0.16256	0.00013
$m(^{238}U)/m(U)\times100$	81.9655	0.0022
$m(^{238}Pu)/m(Pu)\times100$	0.002822	0.000030
$m(^{239}Pu)/m(Pu)\times100$	97.7725	0.0006
$m(^{240}Pu)/m(Pu)\times100$	2.2011	0.0005
$m(^{241}Pu)/m(Pu)\times100$	0.01605	0.00021
$m(^{242}Pu)/m(Pu)\times100$	0.00750	0.00008
	Isotope amount ratios	
	Value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{238}Pu)/n(^{239}Pu)$	0.00002899	0.00000030
$n(^{236}U)/n(^{238}U)$	0.0020001	0.0000016

[1] The reference date for the plutonium and uranium isotopic mass fractions and amount ratios is November 1, 2014. These are not certified values.

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

Table 11: Plutonium and uranium amount contents and mass fractions in the mother solution (sol) used for IRMM-1027q

IRMM-1027q	Amount content		Mass fraction	
	Value [1] [µmol/g sol]	Uncertainty [2] [µmol/g sol]	Value [1] [mg/g sol]	Uncertainty [2] [mg/g sol]
^{235}U	16.3064	0.0023	3.8327	0.0006
^{238}U	74.683	0.004	17.7784	0.0010
U	91.326	0.005	21.6901	0.0011
^{239}Pu	3.0899	0.0013	0.7387	0.0004
Pu	3.1600	0.0012	0.7555	0.0004

[1] The reference date for the plutonium and uranium isotopic mass fractions and amount ratios is November 1, 2014. These are not certified values.

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

8 Metrological traceability and commutability

8.1 Metrological traceability

Quantity value

The certified values are traceable to the values on the respective metal certificate (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 (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 CSLI Guideline C-53A [16] 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-1027q 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 IRMM for its intended use and serves as calibrant for uranium and plutonium 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-1027q 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 of 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 assist 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 applied as a calibrant to measure the uranium and plutonium amount content in an unknown sample of dissolved nuclear fuel solution using isotope dilution mass spectrometry (IDMS). The amount of plutonium or uranium can be calculated using the following IDMS equation:

$$C_x = C_y \frac{m_y}{m_x} \frac{R_y - R_b}{R_b - R_x} \frac{\Sigma(R_i)_x}{\Sigma(R_i)_y} \quad , \qquad \textbf{Equation 5}$$

where C_y is the element content of the spike, 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.

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Annex 1: The certificate of analysis of IRMM-1027q

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Institute for Reference Materials and Measurements (Geel)

CERTIFIED REFERENCE MATERIAL
IRMM – 1027q

CERTIFICATE OF ANALYSIS

Uranium and Plutonium in Cellulose Acetate Butyrate (CAB)		
	Isotope amount ratio	
	Certified value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{234}U)/n(^{238}U)$	0.0025009	0.0000030
$n(^{235}U)/n(^{238}U)$	0.21834	0.00009
$n(^{240}Pu)/n(^{239}Pu)$	0.022419	0.000008
$n(^{241}Pu)/n(^{239}Pu)$	0.0001628	0.0000024
$n(^{242}Pu)/n(^{239}Pu)$	0.0000757	0.0000021
The certified masses and uncertainties of ^{235}U, ^{238}U and ^{239}Pu per unit are listed in Annex 1 on pages 3 to 25 of this certificate.		

1) The certified values are traceable to the values on the respective metal certificates (EC NRM 101, NBL CRM 116-A and CETAMA MP2). The reference date for the plutonium and uranium isotope amount ratios is November 1, 2014.
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 spike material are carried out.

Geel, March 2015

Signed: _____

Prof. Dr. Hendrik Emons
European Commission
Joint Research Centre
Institute for Reference Materials and Measurements
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DESCRIPTION OF THE MATERIAL

The IRMM-1027q series of Large-Sized Dried (LSD) spikes consists of 1126 units, each containing approximately 55 mg of uranium and 1.9 mg of Pu in dried form. Units were prepared by aliquoting of about 2.5 g of a gravimetrically prepared nitrate solution of uranium (EC NRM 101 and NBL CRM 116-A) and plutonium (CETAMA MP2) into individual vials. The solution in each vial was dried down, re-dissolved in cellulose acetate butyrate (CAB) and dried again to produce a stable layer at the bottom of the vial. Each unit contains a unique quantity of uranium and plutonium and is assigned a serial number for identification and reference.

ANALYTICAL METHODS USED FOR CERTIFICATION

The certified values for the uranium and plutonium isotope amount ratios and for the mass of uranium per unit are based on the gravimetric preparation of the mother solution taking into account the isotopic composition and the purity of the starting materials, their masses and the mass of the solution. The certified values for the mass of plutonium per unit were established by isotope dilution thermal ionisation mass spectrometry (ID-TIMS). Confirmatory measurements were performed by isotope dilution thermal ionisation mass spectrometry (ID-TIMS) and thermal ionisation mass spectrometry (TIMS).

All the work related to the preparation and certification of this CRM has been performed at the European Commission, Joint Research Centre, Institute for Reference Materials and Measurement (IRMM) in Geel, Belgium.

SAFETY INFORMATION

The IRMM-1027q 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.

INSTRUCTIONS FOR USE AND INTENDED USE

This Certified Reference Material (CRM) is used as a calibrant in the analysis of plutonium and uranium materials by isotope dilution mass spectrometry (IDMS). The spike 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 assist the dissolution process. The whole amount of sample per unit has to be used for analysis.

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.

LEGAL NOTICE

Neither IRMM, its subsidiaries, its contractors nor any person acting on their behalf,
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(b) assume any liability with respect to, or for damages resulting from, the use of any information, material, apparatus, method or process disclosed in this document save for loss or damage arising solely and directly from the negligence of IRMM or any of its subsidiaries.

NOTE

A technical report on the production of IRMM-1027q is available on the internet (www.irmm.jrc.be).
A paper copy can be obtained from IRMM on request.

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

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]
0001	46.678	0.030	10.063	0.005	1.9394	0.0010
0002	46.403	0.030	10.004	0.005	1.9279	0.0010
0003	46.399	0.030	10.003	0.005	1.9278	0.0010
0004	46.364	0.030	9.995	0.005	1.9263	0.0010
0005	45.597	0.030	9.830	0.005	1.8944	0.0010
0006	44.839	0.029	9.667	0.005	1.8629	0.0010
0007	45.588	0.030	9.828	0.005	1.8941	0.0010
0008	45.419	0.030	9.792	0.005	1.8870	0.0010
0009	45.335	0.030	9.774	0.005	1.8836	0.0010
0010	45.298	0.030	9.765	0.005	1.8820	0.0010
0011	45.308	0.030	9.768	0.005	1.8825	0.0010
0012	45.298	0.030	9.765	0.005	1.8820	0.0010
0013	45.305	0.030	9.767	0.005	1.8823	0.0010
0014	45.303	0.030	9.767	0.005	1.8822	0.0010
0015	45.305	0.030	9.767	0.005	1.8823	0.0010
0016	45.307	0.030	9.767	0.005	1.8824	0.0010
0017	45.301	0.030	9.766	0.005	1.8822	0.0010
0018	45.305	0.030	9.767	0.005	1.8823	0.0010
0019	45.303	0.030	9.767	0.005	1.8822	0.0010
0020	45.305	0.030	9.767	0.005	1.8823	0.0010
0021	45.308	0.030	9.768	0.005	1.8825	0.0010
0022	45.305	0.030	9.767	0.005	1.8823	0.0010
0023	45.308	0.030	9.768	0.005	1.8825	0.0010
0024	45.308	0.030	9.768	0.005	1.8825	0.0010
0025	45.305	0.030	9.767	0.005	1.8823	0.0010
0026	45.305	0.030	9.767	0.005	1.8823	0.0010
0027	45.308	0.030	9.768	0.005	1.8825	0.0010
0028	45.305	0.030	9.767	0.005	1.8823	0.0010
0029	45.301	0.030	9.766	0.005	1.8822	0.0010
0030	45.308	0.030	9.768	0.005	1.8825	0.0010
0031	45.298	0.030	9.765	0.005	1.8820	0.0010
0032	45.303	0.030	9.767	0.005	1.8822	0.0010
0033	45.301	0.030	9.766	0.005	1.8822	0.0010
0034	45.305	0.030	9.767	0.005	1.8823	0.0010
0035	45.294	0.030	9.765	0.005	1.8819	0.0010
0036	45.308	0.030	9.768	0.005	1.8825	0.0010
0037	45.296	0.030	9.765	0.005	1.8819	0.0010
0038	45.296	0.030	9.765	0.005	1.8819	0.0010
0039	45.291	0.030	9.764	0.005	1.8817	0.0010
0040	45.296	0.030	9.765	0.005	1.8819	0.0010
0041	45.287	0.030	9.763	0.005	1.8816	0.0010
0042	45.275	0.030	9.760	0.005	1.8810	0.0010
0043	45.273	0.030	9.760	0.005	1.8810	0.0010
0044	45.248	0.029	9.755	0.005	1.8799	0.0010
0045	45.250	0.029	9.755	0.005	1.8800	0.0010
0046	45.253	0.029	9.756	0.005	1.8802	0.0010
0047	45.266	0.030	9.759	0.005	1.8807	0.0010
0048	45.244	0.029	9.754	0.005	1.8798	0.0010
0049	45.230	0.029	9.751	0.005	1.8792	0.0010
0050	45.230	0.029	9.751	0.005	1.8792	0.0010

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

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]
0051	45.268	0.030	9.759	0.005	1.8808	0.0010
0052	45.243	0.029	9.754	0.005	1.8797	0.0010
0053	45.739	0.030	9.861	0.005	1.9003	0.0010
0054	45.220	0.029	9.749	0.005	1.8788	0.0010
0055	45.264	0.029	9.758	0.005	1.8806	0.0010
0056	45.223	0.029	9.749	0.005	1.8789	0.0010
0057	45.269	0.030	9.759	0.005	1.8808	0.0010
0058	45.291	0.030	9.764	0.005	1.8817	0.0010
0059	45.296	0.030	9.765	0.005	1.8819	0.0010
0060	45.264	0.029	9.758	0.005	1.8806	0.0010
0061	45.275	0.030	9.760	0.005	1.8810	0.0010
0062	45.723	0.030	9.857	0.005	1.8997	0.0010
0063	45.230	0.029	9.751	0.005	1.8792	0.0010
0064	45.241	0.029	9.753	0.005	1.8796	0.0010
0065	45.244	0.029	9.754	0.005	1.8798	0.0010
0066	45.236	0.029	9.752	0.005	1.8794	0.0010
0067	45.266	0.030	9.759	0.005	1.8807	0.0010
0068	45.292	0.030	9.764	0.005	1.8818	0.0010
0069	45.264	0.029	9.758	0.005	1.8806	0.0010
0070	45.275	0.030	9.760	0.005	1.8810	0.0010
0071	45.276	0.030	9.761	0.005	1.8811	0.0010
0072	45.757	0.030	9.864	0.005	1.9011	0.0010
0073	45.275	0.030	9.760	0.005	1.8810	0.0010
0074	45.246	0.029	9.754	0.005	1.8799	0.0010
0075	45.255	0.029	9.756	0.005	1.8802	0.0010
0076	45.259	0.029	9.757	0.005	1.8804	0.0010
0077	45.246	0.029	9.754	0.005	1.8799	0.0010
0078	45.246	0.029	9.754	0.005	1.8799	0.0010
0079	45.264	0.029	9.758	0.005	1.8806	0.0010
0080	45.264	0.029	9.758	0.005	1.8806	0.0010
0081	45.273	0.030	9.760	0.005	1.8810	0.0010
0082	45.284	0.030	9.762	0.005	1.8814	0.0010
0083	45.260	0.029	9.757	0.005	1.8805	0.0010
0084	45.275	0.030	9.760	0.005	1.8810	0.0010
0085	45.737	0.030	9.860	0.005	1.9003	0.0010
0086	45.234	0.029	9.752	0.005	1.8793	0.0010
0087	45.253	0.029	9.756	0.005	1.8802	0.0010
0088	45.252	0.029	9.755	0.005	1.8801	0.0010
0089	45.234	0.029	9.752	0.005	1.8793	0.0010
0090	45.255	0.029	9.756	0.005	1.8802	0.0010
0091	45.269	0.030	9.759	0.005	1.8808	0.0010
0092	45.269	0.030	9.759	0.005	1.8808	0.0010
0093	45.271	0.030	9.760	0.005	1.8809	0.0010
0094	45.280	0.030	9.762	0.005	1.8813	0.0010
0095	45.757	0.030	9.864	0.005	1.9011	0.0010
0096	45.244	0.029	9.754	0.005	1.8798	0.0010
0097	45.252	0.029	9.755	0.005	1.8801	0.0010
0098	45.753	0.030	9.864	0.005	1.9009	0.0010
0099	45.252	0.029	9.755	0.005	1.8801	0.0010
0100	45.287	0.030	9.763	0.005	1.8816	0.0010

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

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]
0101	45.266	0.030	9.759	0.005	1.8807	0.0010
0102	45.223	0.029	9.749	0.005	1.8789	0.0010
0103	45.216	0.029	9.748	0.005	1.8786	0.0010
0104	45.727	0.030	9.858	0.005	1.8998	0.0010
0105	45.195	0.029	9.743	0.005	1.8777	0.0010
0106	45.207	0.029	9.746	0.005	1.8782	0.0010
0107	45.205	0.029	9.746	0.005	1.8782	0.0010
0108	45.712	0.030	9.855	0.005	1.8992	0.0010
0109	45.150	0.029	9.734	0.005	1.8759	0.0010
0110	45.129	0.029	9.729	0.005	1.8750	0.0010
0111	45.744	0.030	9.862	0.005	1.9006	0.0010
0112	45.129	0.029	9.729	0.005	1.8750	0.0010
0113	45.134	0.029	9.730	0.005	1.8752	0.0010
0114	45.739	0.030	9.861	0.005	1.9003	0.0010
0115	45.141	0.029	9.732	0.005	1.8755	0.0010
0116	45.090	0.029	9.721	0.005	1.8734	0.0010
0117	45.791	0.030	9.872	0.005	1.9025	0.0010
0118	45.104	0.029	9.724	0.005	1.8740	0.0010
0119	45.100	0.029	9.723	0.005	1.8738	0.0010
0120	45.810	0.030	9.876	0.005	1.9033	0.0010
0121	45.138	0.029	9.731	0.005	1.8754	0.0010
0122	45.095	0.029	9.722	0.005	1.8736	0.0010
0123	45.762	0.030	9.866	0.005	1.9013	0.0010
0124	45.236	0.029	9.752	0.005	1.8794	0.0010
0125	45.438	0.030	9.796	0.005	1.8878	0.0010
0126	45.236	0.029	9.752	0.005	1.8794	0.0010
0127	45.300	0.030	9.766	0.005	1.8821	0.0010
0128	45.412	0.030	9.790	0.005	1.8867	0.0010
0129	45.373	0.030	9.782	0.005	1.8851	0.0010
0130	45.195	0.029	9.743	0.005	1.8777	0.0010
0131	45.177	0.029	9.739	0.005	1.8770	0.0010
0132	45.248	0.029	9.755	0.005	1.8799	0.0010
0133	45.664	0.030	9.844	0.005	1.8972	0.0010
0134	45.236	0.029	9.752	0.005	1.8794	0.0010
0135	45.307	0.030	9.767	0.005	1.8824	0.0010
0136	45.289	0.030	9.764	0.005	1.8816	0.0010
0137	45.298	0.030	9.765	0.005	1.8820	0.0010
0138	45.264	0.029	9.758	0.005	1.8806	0.0010
0139	45.289	0.030	9.764	0.005	1.8816	0.0010
0140	45.305	0.030	9.767	0.005	1.8823	0.0010
0141	45.305	0.030	9.767	0.005	1.8823	0.0010
0142	45.634	0.030	9.838	0.005	1.8960	0.0010
0143	45.171	0.029	9.738	0.005	1.8768	0.0010
0144	45.319	0.030	9.770	0.005	1.8829	0.0010
0145	45.298	0.030	9.765	0.005	1.8820	0.0010
0146	45.296	0.030	9.765	0.005	1.8819	0.0010
0147	45.266	0.030	9.759	0.005	1.8807	0.0010
0148	45.252	0.029	9.755	0.005	1.8801	0.0010
0149	45.289	0.030	9.764	0.005	1.8816	0.0010
0150	45.296	0.030	9.765	0.005	1.8819	0.0010

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

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]
0151	45.659	0.030	9.843	0.005	1.8970	0.0010
0152	45.341	0.030	9.775	0.005	1.8838	0.0010
0153	45.307	0.030	9.767	0.005	1.8824	0.0010
0154	45.241	0.029	9.753	0.005	1.8796	0.0010
0155	45.168	0.029	9.737	0.005	1.8766	0.0010
0156	45.241	0.029	9.753	0.005	1.8796	0.0010
0157	45.180	0.029	9.740	0.005	1.8771	0.0010
0158	45.728	0.030	9.858	0.005	1.8999	0.0010
0159	45.200	0.029	9.744	0.005	1.8779	0.0010
0160	45.205	0.029	9.746	0.005	1.8782	0.0010
0161	45.212	0.029	9.747	0.005	1.8785	0.0010
0162	45.154	0.029	9.734	0.005	1.8760	0.0010
0163	45.319	0.030	9.770	0.005	1.8829	0.0010
0164	45.312	0.030	9.769	0.005	1.8826	0.0010
0165	45.732	0.030	9.859	0.005	1.9000	0.0010
0166	45.154	0.029	9.734	0.005	1.8760	0.0010
0167	45.376	0.030	9.782	0.005	1.8853	0.0010
0168	45.294	0.030	9.765	0.005	1.8819	0.0010
0169	45.177	0.029	9.739	0.005	1.8770	0.0010
0170	45.383	0.030	9.784	0.005	1.8856	0.0010
0171	45.276	0.030	9.761	0.005	1.8811	0.0010
0172	45.444	0.030	9.797	0.005	1.8881	0.0010
0173	45.335	0.030	9.774	0.005	1.8836	0.0010
0174	45.303	0.030	9.767	0.005	1.8822	0.0010
0175	45.271	0.030	9.760	0.005	1.8809	0.0010
0176	45.314	0.030	9.769	0.005	1.8827	0.0010
0177	45.131	0.029	9.729	0.005	1.8751	0.0010
0178	45.225	0.029	9.750	0.005	1.8790	0.0010
0179	45.250	0.029	9.755	0.005	1.8800	0.0010
0180	45.236	0.029	9.752	0.005	1.8794	0.0010
0181	45.631	0.030	9.837	0.005	1.8958	0.0010
0182	45.268	0.030	9.759	0.005	1.8808	0.0010
0183	45.143	0.029	9.732	0.005	1.8756	0.0010
0184	45.139	0.029	9.731	0.005	1.8754	0.0010
0185	45.289	0.030	9.764	0.005	1.8816	0.0010
0186	45.262	0.029	9.758	0.005	1.8805	0.0010
0187	45.670	0.030	9.846	0.005	1.8975	0.0010
0188	45.282	0.030	9.762	0.005	1.8813	0.0010
0189	45.289	0.030	9.764	0.005	1.8816	0.0010
0190	45.289	0.030	9.764	0.005	1.8816	0.0010
0191	45.280	0.030	9.762	0.005	1.8813	0.0010
0192	45.111	0.029	9.725	0.005	1.8742	0.0010
0193	45.090	0.029	9.721	0.005	1.8734	0.0010
0194	45.780	0.030	9.869	0.005	1.9020	0.0010
0195	44.842	0.029	9.667	0.005	1.8631	0.0010
0196	45.090	0.029	9.721	0.005	1.8734	0.0010
0197	45.784	0.030	9.870	0.005	1.9022	0.0010
0198	45.056	0.029	9.713	0.005	1.8720	0.0010
0199	45.081	0.029	9.719	0.005	1.8730	0.0010
0200	45.721	0.030	9.857	0.005	1.8996	0.0010

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

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]
0201	45.091	0.029	9.721	0.005	1.8734	0.0010
0202	45.100	0.029	9.723	0.005	1.8738	0.0010
0203	45.668	0.030	9.845	0.005	1.8974	0.0010
0204	45.083	0.029	9.719	0.005	1.8731	0.0010
0205	45.095	0.029	9.722	0.005	1.8736	0.0010
0206	45.702	0.030	9.853	0.005	1.8988	0.0010
0207	45.072	0.029	9.717	0.005	1.8726	0.0010
0208	45.091	0.029	9.721	0.005	1.8734	0.0010
0209	45.711	0.030	9.854	0.005	1.8992	0.0010
0210	45.049	0.029	9.712	0.005	1.8717	0.0010
0211	45.072	0.029	9.717	0.005	1.8726	0.0010
0212	45.755	0.030	9.864	0.005	1.9010	0.0010
0213	45.059	0.029	9.714	0.005	1.8721	0.0010
0214	45.086	0.029	9.720	0.005	1.8732	0.0010
0215	45.723	0.030	9.857	0.005	1.8997	0.0010
0216	45.063	0.029	9.715	0.005	1.8723	0.0010
0217	45.067	0.029	9.716	0.005	1.8724	0.0010
0218	45.744	0.030	9.862	0.005	1.9006	0.0010
0219	45.070	0.029	9.716	0.005	1.8725	0.0010
0220	45.081	0.029	9.719	0.005	1.8730	0.0010
0221	45.714	0.030	9.855	0.005	1.8993	0.0010
0222	45.045	0.029	9.711	0.005	1.8715	0.0010
0223	45.059	0.029	9.714	0.005	1.8721	0.0010
0224	45.769	0.030	9.867	0.005	1.9016	0.0010
0225	45.056	0.029	9.713	0.005	1.8720	0.0010
0226	45.020	0.029	9.706	0.005	1.8705	0.0010
0227	45.364	0.030	9.780	0.005	1.8847	0.0010
0228	45.259	0.029	9.757	0.005	1.8804	0.0010
0229	45.262	0.029	9.758	0.005	1.8805	0.0010
0230	45.744	0.030	9.862	0.005	1.9006	0.0010
0231	45.298	0.030	9.765	0.005	1.8820	0.0010
0232	45.282	0.030	9.762	0.005	1.8813	0.0010
0233	45.285	0.030	9.763	0.005	1.8815	0.0010
0234	45.280	0.030	9.762	0.005	1.8813	0.0010
0235	45.303	0.030	9.767	0.005	1.8822	0.0010
0236	45.314	0.030	9.769	0.005	1.8827	0.0010
0237	45.269	0.030	9.759	0.005	1.8808	0.0010
0238	45.259	0.029	9.757	0.005	1.8804	0.0010
0239	45.294	0.030	9.765	0.005	1.8819	0.0010
0240	45.298	0.030	9.765	0.005	1.8820	0.0010
0241	45.248	0.029	9.755	0.005	1.8799	0.0010
0242	45.287	0.030	9.763	0.005	1.8816	0.0010
0243	45.298	0.030	9.765	0.005	1.8820	0.0010
0244	45.259	0.029	9.757	0.005	1.8804	0.0010
0245	45.264	0.029	9.758	0.005	1.8806	0.0010
0246	45.298	0.030	9.765	0.005	1.8820	0.0010
0247	45.236	0.029	9.752	0.005	1.8794	0.0010
0248	45.310	0.030	9.768	0.005	1.8825	0.0010
0249	45.307	0.030	9.767	0.005	1.8824	0.0010
0250	45.264	0.029	9.758	0.005	1.8806	0.0010

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

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]
0251	45.296	0.030	9.765	0.005	1.8819	0.0010
0252	45.278	0.030	9.761	0.005	1.8812	0.0010
0253	45.275	0.030	9.760	0.005	1.8810	0.0010
0254	45.287	0.030	9.763	0.005	1.8816	0.0010
0255	45.275	0.030	9.760	0.005	1.8810	0.0010
0256	45.280	0.030	9.762	0.005	1.8813	0.0010
0257	45.284	0.030	9.762	0.005	1.8814	0.0010
0258	45.278	0.030	9.761	0.005	1.8812	0.0010
0259	45.280	0.030	9.762	0.005	1.8813	0.0010
0260	45.278	0.030	9.761	0.005	1.8812	0.0010
0261	45.282	0.030	9.762	0.005	1.8813	0.0010
0262	45.284	0.030	9.762	0.005	1.8814	0.0010
0263	45.276	0.030	9.761	0.005	1.8811	0.0010
0264	45.285	0.030	9.763	0.005	1.8815	0.0010
0265	45.282	0.030	9.762	0.005	1.8813	0.0010
0266	45.278	0.030	9.761	0.005	1.8812	0.0010
0267	45.280	0.030	9.762	0.005	1.8813	0.0010
0268	45.273	0.030	9.760	0.005	1.8810	0.0010
0269	45.282	0.030	9.762	0.005	1.8813	0.0010
0270	45.280	0.030	9.762	0.005	1.8813	0.0010
0271	45.280	0.030	9.762	0.005	1.8813	0.0010
0272	45.284	0.030	9.762	0.005	1.8814	0.0010
0273	45.282	0.030	9.762	0.005	1.8813	0.0010
0274	45.276	0.030	9.761	0.005	1.8811	0.0010
0275	45.278	0.030	9.761	0.005	1.8812	0.0010
0276	45.276	0.030	9.761	0.005	1.8811	0.0010
0277	45.276	0.030	9.761	0.005	1.8811	0.0010
0278	45.276	0.030	9.761	0.005	1.8811	0.0010
0279	45.280	0.030	9.762	0.005	1.8813	0.0010
0280	45.278	0.030	9.761	0.005	1.8812	0.0010
0281	45.276	0.030	9.761	0.005	1.8811	0.0010
0282	45.278	0.030	9.761	0.005	1.8812	0.0010
0283	45.282	0.030	9.762	0.005	1.8813	0.0010
0284	45.282	0.030	9.762	0.005	1.8813	0.0010
0285	45.276	0.030	9.761	0.005	1.8811	0.0010
0286	45.287	0.030	9.763	0.005	1.8816	0.0010
0287	45.278	0.030	9.761	0.005	1.8812	0.0010
0288	45.284	0.030	9.762	0.005	1.8814	0.0010
0289	45.378	0.030	9.783	0.005	1.8853	0.0010
0290	45.282	0.030	9.762	0.005	1.8813	0.0010
0291	45.148	0.029	9.733	0.005	1.8758	0.0010
0292	45.287	0.030	9.763	0.005	1.8816	0.0010
0293	45.296	0.030	9.765	0.005	1.8819	0.0010
0294	45.284	0.030	9.762	0.005	1.8814	0.0010
0295	45.277	0.030	9.761	0.005	1.8811	0.0010
0296	45.266	0.030	9.759	0.005	1.8807	0.0010
0297	45.255	0.029	9.756	0.005	1.8802	0.0010
0298	45.269	0.030	9.759	0.005	1.8808	0.0010
0299	45.280	0.030	9.762	0.005	1.8813	0.0010
0300	45.278	0.030	9.761	0.005	1.8812	0.0010

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

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]
0301	45.289	0.030	9.764	0.005	1.8816	0.0010
0302	45.296	0.030	9.765	0.005	1.8819	0.0010
0303	45.301	0.030	9.766	0.005	1.8822	0.0010
0304	45.296	0.030	9.765	0.005	1.8819	0.0010
0305	45.285	0.030	9.763	0.005	1.8815	0.0010
0306	45.284	0.030	9.762	0.005	1.8814	0.0010
0307	45.293	0.030	9.764	0.005	1.8818	0.0010
0308	45.294	0.030	9.765	0.005	1.8819	0.0010
0309	45.300	0.030	9.766	0.005	1.8821	0.0010
0310	45.300	0.030	9.766	0.005	1.8821	0.0010
0311	45.294	0.030	9.765	0.005	1.8819	0.0010
0312	45.287	0.030	9.763	0.005	1.8816	0.0010
0313	45.275	0.030	9.760	0.005	1.8811	0.0010
0314	45.298	0.030	9.765	0.005	1.8820	0.0010
0315	45.314	0.030	9.769	0.005	1.8827	0.0010
0316	45.316	0.030	9.769	0.005	1.8828	0.0010
0317	45.634	0.030	9.838	0.005	1.8960	0.0010
0318	44.890	0.029	9.678	0.005	1.8651	0.0010
0319	45.623	0.030	9.836	0.005	1.8955	0.0010
0320	44.921	0.029	9.684	0.005	1.8663	0.0010
0321	45.579	0.030	9.826	0.005	1.8937	0.0010
0322	45.382	0.030	9.784	0.005	1.8855	0.0010
0323	45.278	0.030	9.761	0.005	1.8812	0.0010
0324	45.282	0.030	9.762	0.005	1.8813	0.0010
0325	45.326	0.030	9.772	0.005	1.8832	0.0010
0326	45.264	0.029	9.758	0.005	1.8806	0.0010
0327	45.312	0.030	9.769	0.005	1.8826	0.0010
0328	45.293	0.030	9.764	0.005	1.8818	0.0010
0329	45.287	0.030	9.763	0.005	1.8816	0.0010
0330	45.282	0.030	9.762	0.005	1.8813	0.0010
0331	45.278	0.030	9.761	0.005	1.8812	0.0010
0332	45.282	0.030	9.762	0.005	1.8813	0.0010
0333	45.287	0.030	9.763	0.005	1.8816	0.0010
0334	45.298	0.030	9.765	0.005	1.8820	0.0010
0335	45.273	0.030	9.760	0.005	1.8810	0.0010
0336	45.291	0.030	9.764	0.005	1.8817	0.0010
0337	45.280	0.030	9.762	0.005	1.8813	0.0010
0338	45.277	0.030	9.761	0.005	1.8811	0.0010
0339	45.277	0.030	9.761	0.005	1.8811	0.0010
0340	45.289	0.030	9.764	0.005	1.8816	0.0010
0341	45.268	0.030	9.759	0.005	1.8808	0.0010
0342	45.284	0.030	9.762	0.005	1.8814	0.0010
0343	45.291	0.030	9.764	0.005	1.8817	0.0010
0344	45.293	0.030	9.764	0.005	1.8818	0.0010
0345	45.282	0.030	9.762	0.005	1.8813	0.0010
0346	45.280	0.030	9.762	0.005	1.8813	0.0010
0347	45.202	0.029	9.745	0.005	1.8780	0.0010
0348	45.250	0.029	9.755	0.005	1.8800	0.0010
0349	45.284	0.030	9.762	0.005	1.8814	0.0010
0350	45.259	0.029	9.757	0.005	1.8804	0.0010

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

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]
0351	45.278	0.030	9.761	0.005	1.8812	0.0010
0352	45.241	0.029	9.753	0.005	1.8796	0.0010
0353	45.259	0.029	9.757	0.005	1.8804	0.0010
0354	45.243	0.029	9.754	0.005	1.8797	0.0010
0355	45.205	0.029	9.746	0.005	1.8782	0.0010
0356	45.173	0.029	9.739	0.005	1.8768	0.0010
0357	45.166	0.029	9.737	0.005	1.8765	0.0010
0358	45.696	0.030	9.851	0.005	1.8986	0.0010
0359	45.218	0.029	9.748	0.005	1.8787	0.0010
0360	45.202	0.029	9.745	0.005	1.8780	0.0010
0361	45.175	0.029	9.739	0.005	1.8769	0.0010
0362	45.132	0.029	9.730	0.005	1.8751	0.0010
0363	45.704	0.030	9.853	0.005	1.8989	0.0010
0364	45.168	0.029	9.737	0.005	1.8766	0.0010
0365	45.189	0.029	9.742	0.005	1.8775	0.0010
0366	45.134	0.029	9.730	0.005	1.8752	0.0010
0367	45.615	0.030	9.834	0.005	1.8952	0.0010
0368	45.221	0.029	9.749	0.005	1.8788	0.0010
0369	45.216	0.029	9.748	0.005	1.8786	0.0010
0370	45.148	0.029	9.733	0.005	1.8758	0.0010
0371	45.125	0.029	9.728	0.005	1.8748	0.0010
0372	45.753	0.030	9.864	0.005	1.9009	0.0010
0373	45.179	0.029	9.740	0.005	1.8771	0.0010
0374	45.168	0.029	9.737	0.005	1.8766	0.0010
0375	45.141	0.029	9.732	0.005	1.8755	0.0010
0376	45.583	0.030	9.827	0.005	1.8938	0.0010
0377	45.161	0.029	9.736	0.005	1.8763	0.0010
0378	45.081	0.029	9.719	0.005	1.8730	0.0010
0379	45.122	0.029	9.728	0.005	1.8747	0.0010
0380	45.672	0.030	9.846	0.005	1.8975	0.0010
0381	45.152	0.029	9.734	0.005	1.8759	0.0010
0382	45.145	0.029	9.732	0.005	1.8757	0.0010
0383	45.122	0.029	9.728	0.005	1.8747	0.0010
0384	45.729	0.030	9.858	0.005	1.8999	0.0010
0385	45.211	0.029	9.747	0.005	1.8784	0.0010
0386	45.147	0.029	9.733	0.005	1.8757	0.0010
0387	45.113	0.029	9.726	0.005	1.8743	0.0010
0388	45.664	0.030	9.845	0.005	1.8972	0.0010
0389	45.140	0.029	9.731	0.005	1.8754	0.0010
0390	45.147	0.029	9.733	0.005	1.8757	0.0010
0391	45.125	0.029	9.728	0.005	1.8748	0.0010
0392	45.615	0.030	9.834	0.005	1.8952	0.0010
0393	45.204	0.029	9.745	0.005	1.8781	0.0010
0394	45.248	0.029	9.755	0.005	1.8799	0.0010
0395	45.232	0.029	9.751	0.005	1.8793	0.0010
0396	45.168	0.029	9.737	0.005	1.8766	0.0010
0397	45.563	0.030	9.823	0.005	1.8930	0.0010
0398	45.207	0.029	9.746	0.005	1.8782	0.0010
0399	45.211	0.029	9.747	0.005	1.8784	0.0010
0400	45.154	0.029	9.734	0.005	1.8760	0.0010

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

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]
0401	45.138	0.029	9.731	0.005	1.8754	0.0010
0402	45.753	0.030	9.864	0.005	1.9009	0.0010
0403	45.143	0.029	9.732	0.005	1.8756	0.0010
0404	45.173	0.029	9.739	0.005	1.8768	0.0010
0405	45.109	0.029	9.725	0.005	1.8742	0.0010
0406	45.677	0.030	9.847	0.005	1.8978	0.0010
0407	45.205	0.029	9.746	0.005	1.8782	0.0010
0408	45.113	0.029	9.726	0.005	1.8743	0.0010
0409	45.111	0.029	9.725	0.005	1.8743	0.0010
0410	45.714	0.030	9.855	0.005	1.8993	0.0010
0411	45.191	0.029	9.742	0.005	1.8776	0.0010
0412	45.113	0.029	9.726	0.005	1.8743	0.0010
0413	45.545	0.030	9.819	0.005	1.8923	0.0010
0414	45.132	0.029	9.730	0.005	1.8751	0.0010
0415	45.077	0.029	9.718	0.005	1.8728	0.0010
0416	45.664	0.030	9.845	0.005	1.8972	0.0010
0417	45.124	0.029	9.728	0.005	1.8748	0.0010
0418	45.083	0.029	9.719	0.005	1.8731	0.0010
0419	45.640	0.030	9.839	0.005	1.8962	0.0010
0420	45.188	0.029	9.742	0.005	1.8774	0.0010
0421	45.122	0.029	9.728	0.005	1.8747	0.0010
0422	45.131	0.029	9.729	0.005	1.8751	0.0010
0423	45.712	0.030	9.855	0.005	1.8992	0.0010
0424	45.124	0.029	9.728	0.005	1.8748	0.0010
0425	45.088	0.029	9.720	0.005	1.8733	0.0010
0426	45.559	0.030	9.822	0.005	1.8929	0.0010
0427	45.106	0.029	9.724	0.005	1.8740	0.0010
0428	45.141	0.029	9.732	0.005	1.8755	0.0010
0429	45.636	0.030	9.838	0.005	1.8961	0.0010
0430	45.129	0.029	9.729	0.005	1.8750	0.0010
0431	45.079	0.029	9.718	0.005	1.8729	0.0010
0432	45.647	0.030	9.841	0.005	1.8965	0.0010
0433	45.116	0.029	9.726	0.005	1.8745	0.0010
0434	45.052	0.029	9.713	0.005	1.8718	0.0010
0435	45.654	0.030	9.842	0.005	1.8968	0.0010
0436	45.104	0.029	9.724	0.005	1.8740	0.0010
0437	45.077	0.029	9.718	0.005	1.8728	0.0010
0438	45.622	0.030	9.835	0.005	1.8955	0.0010
0439	45.161	0.029	9.736	0.005	1.8763	0.0010
0440	45.077	0.029	9.718	0.005	1.8728	0.0010
0441	45.609	0.030	9.833	0.005	1.8950	0.0010
0442	45.127	0.029	9.729	0.005	1.8749	0.0010
0443	45.154	0.029	9.734	0.005	1.8760	0.0010
0444	45.508	0.030	9.811	0.005	1.8907	0.0010
0445	45.332	0.030	9.773	0.005	1.8834	0.0010
0446	45.200	0.029	9.744	0.005	1.8779	0.0010
0447	45.232	0.029	9.751	0.005	1.8793	0.0010
0448	45.223	0.029	9.749	0.005	1.8789	0.0010
0449	45.113	0.029	9.726	0.005	1.8743	0.0010
0450	45.230	0.029	9.751	0.005	1.8792	0.0010

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

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]
0451	45.193	0.029	9.743	0.005	1.8777	0.0010
0452	45.088	0.029	9.720	0.005	1.8733	0.0010
0453	45.624	0.030	9.836	0.005	1.8955	0.0010
0454	45.111	0.029	9.725	0.005	1.8743	0.0010
0455	45.088	0.029	9.720	0.005	1.8733	0.0010
0456	45.572	0.030	9.825	0.005	1.8934	0.0010
0457	45.120	0.029	9.727	0.005	1.8746	0.0010
0458	45.058	0.029	9.714	0.005	1.8720	0.0010
0459	45.691	0.030	9.850	0.005	1.8984	0.0010
0460	45.095	0.029	9.722	0.005	1.8736	0.0010
0461	45.136	0.029	9.731	0.005	1.8753	0.0010
0462	45.600	0.030	9.831	0.005	1.8946	0.0010
0463	45.086	0.029	9.720	0.005	1.8732	0.0010
0464	45.115	0.029	9.726	0.005	1.8744	0.0010
0465	45.056	0.029	9.713	0.005	1.8720	0.0010
0466	45.723	0.030	9.857	0.005	1.8997	0.0010
0467	45.113	0.029	9.726	0.005	1.8743	0.0010
0468	45.061	0.029	9.714	0.005	1.8722	0.0010
0469	45.575	0.030	9.825	0.005	1.8935	0.0010
0470	45.083	0.029	9.719	0.005	1.8731	0.0010
0471	45.074	0.029	9.717	0.005	1.8727	0.0010
0472	45.673	0.030	9.846	0.005	1.8976	0.0010
0473	45.109	0.029	9.725	0.005	1.8742	0.0010
0474	45.054	0.029	9.713	0.005	1.8719	0.0010
0475	45.686	0.030	9.849	0.005	1.8981	0.0010
0476	45.122	0.029	9.728	0.005	1.8747	0.0010
0477	45.070	0.029	9.716	0.005	1.8726	0.0010
0478	45.618	0.030	9.835	0.005	1.8953	0.0010
0479	45.092	0.029	9.721	0.005	1.8734	0.0010
0480	45.052	0.029	9.713	0.005	1.8718	0.0010
0481	45.720	0.030	9.856	0.005	1.8995	0.0010
0482	45.093	0.029	9.721	0.005	1.8735	0.0010
0483	45.040	0.029	9.710	0.005	1.8713	0.0010
0484	45.668	0.030	9.845	0.005	1.8974	0.0010
0485	45.108	0.029	9.724	0.005	1.8741	0.0010
0486	45.027	0.029	9.707	0.005	1.8708	0.0010
0487	45.661	0.030	9.844	0.005	1.8971	0.0010
0488	45.092	0.029	9.721	0.005	1.8734	0.0010
0489	45.084	0.029	9.719	0.005	1.8731	0.0010
0490	45.072	0.029	9.717	0.005	1.8726	0.0010
0491	45.737	0.030	9.860	0.005	1.9003	0.0010
0492	45.115	0.029	9.726	0.005	1.8744	0.0010
0493	45.118	0.029	9.727	0.005	1.8745	0.0010
0494	45.097	0.029	9.722	0.005	1.8737	0.0010
0495	45.743	0.030	9.861	0.005	1.9005	0.0010
0496	45.127	0.029	9.729	0.005	1.8749	0.0010
0497	45.148	0.029	9.733	0.005	1.8758	0.0010
0498	45.095	0.029	9.722	0.005	1.8736	0.0010
0499	45.700	0.030	9.852	0.005	1.8987	0.0010
0500	45.129	0.029	9.729	0.005	1.8750	0.0010

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

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]
0501	44.928	0.029	9.686	0.005	1.8666	0.0010
0502	45.106	0.029	9.724	0.005	1.8740	0.0010
0503	45.745	0.030	9.862	0.005	1.9006	0.0010
0504	45.077	0.029	9.718	0.005	1.8728	0.0010
0505	45.031	0.029	9.708	0.005	1.8709	0.0010
0506	45.711	0.030	9.854	0.005	1.8992	0.0010
0507	45.070	0.029	9.716	0.005	1.8726	0.0010
0508	45.029	0.029	9.708	0.005	1.8709	0.0010
0509	45.696	0.030	9.851	0.005	1.8986	0.0010
0510	45.077	0.029	9.718	0.005	1.8728	0.0010
0511	45.040	0.029	9.710	0.005	1.8713	0.0010
0512	45.679	0.030	9.848	0.005	1.8978	0.0010
0513	45.088	0.029	9.720	0.005	1.8733	0.0010
0514	45.054	0.029	9.713	0.005	1.8719	0.0010
0515	45.682	0.030	9.848	0.005	1.8980	0.0010
0516	45.077	0.029	9.718	0.005	1.8728	0.0010
0517	45.047	0.029	9.711	0.005	1.8716	0.0010
0518	45.664	0.030	9.845	0.005	1.8972	0.0010
0519	45.065	0.029	9.715	0.005	1.8723	0.0010
0520	45.049	0.029	9.712	0.005	1.8717	0.0010
0521	45.695	0.030	9.851	0.005	1.8985	0.0010
0522	45.065	0.029	9.715	0.005	1.8723	0.0010
0523	45.052	0.029	9.713	0.005	1.8718	0.0010
0524	45.654	0.030	9.842	0.005	1.8968	0.0010
0525	45.065	0.029	9.715	0.005	1.8723	0.0010
0526	45.042	0.029	9.710	0.005	1.8714	0.0010
0527	45.705	0.030	9.853	0.005	1.8989	0.0010
0528	45.065	0.029	9.715	0.005	1.8723	0.0010
0529	45.001	0.029	9.701	0.005	1.8697	0.0010
0530	45.476	0.030	9.804	0.005	1.8894	0.0010
0531	45.074	0.029	9.717	0.005	1.8727	0.0010
0532	45.060	0.029	9.714	0.005	1.8721	0.0010
0533	45.746	0.030	9.862	0.005	1.9006	0.0010
0534	45.061	0.029	9.714	0.005	1.8722	0.0010
0535	45.054	0.029	9.713	0.005	1.8719	0.0010
0536	45.648	0.030	9.841	0.005	1.8966	0.0010
0537	45.051	0.029	9.712	0.005	1.8717	0.0010
0538	45.045	0.029	9.711	0.005	1.8715	0.0010
0539	45.581	0.030	9.826	0.005	1.8938	0.0010
0540	45.058	0.029	9.714	0.005	1.8720	0.0010
0541	45.049	0.029	9.712	0.005	1.8717	0.0010
0542	45.689	0.030	9.850	0.005	1.8983	0.0010
0543	45.076	0.029	9.718	0.005	1.8728	0.0010
0544	45.058	0.029	9.714	0.005	1.8720	0.0010
0545	45.654	0.030	9.842	0.005	1.8968	0.0010
0546	45.070	0.029	9.716	0.005	1.8726	0.0010
0547	45.051	0.029	9.712	0.005	1.8717	0.0010
0548	45.638	0.030	9.839	0.005	1.8961	0.0010
0549	45.035	0.029	9.709	0.005	1.8711	0.0010
0550	45.045	0.029	9.711	0.005	1.8715	0.0010

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

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]
0551	45.698	0.030	9.852	0.005	1.8986	0.0010
0552	44.992	0.029	9.700	0.005	1.8693	0.0010
0553	45.490	0.030	9.807	0.005	1.8900	0.0010
0554	44.979	0.029	9.697	0.005	1.8688	0.0010
0555	45.554	0.030	9.821	0.005	1.8927	0.0010
0556	44.951	0.029	9.691	0.005	1.8676	0.0010
0557	45.583	0.030	9.827	0.005	1.8938	0.0010
0558	44.899	0.029	9.680	0.005	1.8655	0.0010
0559	45.613	0.030	9.833	0.005	1.8951	0.0010
0560	44.928	0.029	9.686	0.005	1.8666	0.0010
0561	45.579	0.030	9.826	0.005	1.8937	0.0010
0562	44.910	0.029	9.682	0.005	1.8659	0.0010
0563	45.600	0.030	9.831	0.005	1.8946	0.0010
0564	44.899	0.029	9.680	0.005	1.8655	0.0010
0565	45.615	0.030	9.834	0.005	1.8952	0.0010
0566	44.928	0.029	9.686	0.005	1.8666	0.0010
0567	45.581	0.030	9.826	0.005	1.8938	0.0010
0568	44.930	0.029	9.686	0.005	1.8667	0.0010
0569	45.567	0.030	9.823	0.005	1.8932	0.0010
0570	44.906	0.029	9.681	0.005	1.8658	0.0010
0571	45.615	0.030	9.834	0.005	1.8952	0.0010
0572	44.905	0.029	9.681	0.005	1.8657	0.0010
0573	45.611	0.030	9.833	0.005	1.8950	0.0010
0574	44.917	0.029	9.683	0.005	1.8662	0.0010
0575	45.592	0.030	9.829	0.005	1.8942	0.0010
0576	44.899	0.029	9.680	0.005	1.8655	0.0010
0577	45.620	0.030	9.835	0.005	1.8954	0.0010
0578	44.883	0.029	9.676	0.005	1.8648	0.0010
0579	45.604	0.030	9.831	0.005	1.8947	0.0010
0580	44.878	0.029	9.675	0.005	1.8646	0.0010
0581	45.618	0.030	9.835	0.005	1.8953	0.0010
0582	44.892	0.029	9.678	0.005	1.8652	0.0010
0583	45.618	0.030	9.835	0.005	1.8953	0.0010
0584	44.910	0.029	9.682	0.005	1.8659	0.0010
0585	45.670	0.030	9.846	0.005	1.8975	0.0010
0586	44.821	0.029	9.663	0.005	1.8622	0.0010
0587	45.600	0.030	9.831	0.005	1.8946	0.0010
0588	45.339	0.030	9.774	0.005	1.8837	0.0010
0589	44.846	0.029	9.668	0.005	1.8632	0.0010
0590	45.618	0.030	9.835	0.005	1.8953	0.0010
0591	45.312	0.030	9.769	0.005	1.8826	0.0010
0592	44.853	0.029	9.670	0.005	1.8635	0.0010
0593	45.627	0.030	9.836	0.005	1.8957	0.0010
0594	44.835	0.029	9.666	0.005	1.8628	0.0010
0595	45.620	0.030	9.835	0.005	1.8954	0.0010
0596	45.280	0.030	9.762	0.005	1.8813	0.0010
0597	44.848	0.029	9.668	0.005	1.8633	0.0010
0598	45.629	0.030	9.837	0.005	1.8958	0.0010
0599	44.848	0.029	9.668	0.005	1.8633	0.0010
0600	45.611	0.030	9.833	0.005	1.8950	0.0010

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

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]
0601	44.823	0.029	9.663	0.005	1.8623	0.0010
0602	45.616	0.030	9.834	0.005	1.8952	0.0010
0603	44.826	0.029	9.664	0.005	1.8624	0.0010
0604	45.604	0.030	9.831	0.005	1.8947	0.0010
0605	45.312	0.030	9.769	0.005	1.8826	0.0010
0606	44.835	0.029	9.666	0.005	1.8628	0.0010
0607	45.602	0.030	9.831	0.005	1.8947	0.0010
0608	44.823	0.029	9.663	0.005	1.8623	0.0010
0609	45.604	0.030	9.831	0.005	1.8947	0.0010
0610	45.227	0.029	9.750	0.005	1.8791	0.0010
0611	45.261	0.029	9.757	0.005	1.8805	0.0010
0612	44.850	0.029	9.669	0.005	1.8634	0.0010
0613	45.615	0.030	9.834	0.005	1.8952	0.0010
0614	44.825	0.029	9.663	0.005	1.8624	0.0010
0615	45.593	0.030	9.829	0.005	1.8943	0.0010
0616	44.835	0.029	9.666	0.005	1.8628	0.0010
0617	45.602	0.030	9.831	0.005	1.8947	0.0010
0618	45.293	0.030	9.764	0.005	1.8818	0.0010
0619	44.809	0.029	9.660	0.005	1.8617	0.0010
0620	45.581	0.030	9.826	0.005	1.8938	0.0010
0621	44.848	0.029	9.668	0.005	1.8633	0.0010
0622	45.581	0.030	9.826	0.005	1.8938	0.0010
0623	44.805	0.029	9.659	0.005	1.8615	0.0010
0624	45.597	0.030	9.830	0.005	1.8944	0.0010
0625	45.278	0.030	9.761	0.005	1.8812	0.0010
0626	44.855	0.029	9.670	0.005	1.8636	0.0010
0627	45.575	0.030	9.825	0.005	1.8935	0.0010
0628	44.809	0.029	9.660	0.005	1.8617	0.0010
0629	45.593	0.030	9.829	0.005	1.8943	0.0010
0630	45.237	0.029	9.752	0.005	1.8795	0.0010
0631	45.220	0.029	9.749	0.005	1.8788	0.0010
0632	45.229	0.029	9.751	0.005	1.8791	0.0010
0633	45.213	0.029	9.747	0.005	1.8785	0.0010
0634	45.250	0.029	9.755	0.005	1.8800	0.0010
0635	45.191	0.029	9.742	0.005	1.8776	0.0010
0636	45.253	0.029	9.756	0.005	1.8802	0.0010
0637	44.803	0.029	9.659	0.005	1.8615	0.0010
0638	45.565	0.030	9.823	0.005	1.8931	0.0010
0639	45.385	0.030	9.784	0.005	1.8856	0.0010
0640	44.780	0.029	9.654	0.005	1.8605	0.0010
0641	45.568	0.030	9.824	0.005	1.8933	0.0010
0642	45.291	0.030	9.764	0.005	1.8817	0.0010
0643	44.793	0.029	9.657	0.005	1.8610	0.0010
0644	45.565	0.030	9.823	0.005	1.8931	0.0010
0645	45.341	0.030	9.775	0.005	1.8838	0.0010
0646	44.796	0.029	9.657	0.005	1.8612	0.0010
0647	45.563	0.030	9.823	0.005	1.8930	0.0010
0648	45.326	0.030	9.772	0.005	1.8832	0.0010
0649	44.786	0.029	9.655	0.005	1.8607	0.0010
0650	45.558	0.030	9.821	0.005	1.8928	0.0010

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

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]
0651	45.307	0.030	9.767	0.005	1.8824	0.0010
0652	44.778	0.029	9.653	0.005	1.8604	0.0010
0653	45.568	0.030	9.824	0.005	1.8933	0.0010
0654	45.339	0.030	9.774	0.005	1.8837	0.0010
0655	44.784	0.029	9.655	0.005	1.8606	0.0010
0656	45.542	0.030	9.818	0.005	1.8921	0.0010
0657	45.353	0.030	9.777	0.005	1.8843	0.0010
0658	44.791	0.029	9.656	0.005	1.8609	0.0010
0659	45.538	0.030	9.817	0.005	1.8920	0.0010
0660	45.312	0.030	9.769	0.005	1.8826	0.0010
0661	44.787	0.029	9.655	0.005	1.8608	0.0010
0662	45.552	0.030	9.820	0.005	1.8926	0.0010
0663	45.300	0.030	9.766	0.005	1.8821	0.0010
0664	44.793	0.029	9.657	0.005	1.8610	0.0010
0665	45.542	0.030	9.818	0.005	1.8921	0.0010
0666	45.358	0.030	9.779	0.005	1.8845	0.0010
0667	44.780	0.029	9.654	0.005	1.8605	0.0010
0668	45.547	0.030	9.819	0.005	1.8924	0.0010
0669	45.373	0.030	9.782	0.005	1.8851	0.0010
0670	44.782	0.029	9.654	0.005	1.8606	0.0010
0671	45.524	0.030	9.814	0.005	1.8914	0.0010
0672	45.342	0.030	9.775	0.005	1.8839	0.0010
0673	44.793	0.029	9.657	0.005	1.8610	0.0010
0674	45.540	0.030	9.818	0.005	1.8921	0.0010
0675	45.339	0.030	9.774	0.005	1.8837	0.0010
0676	44.777	0.029	9.653	0.005	1.8604	0.0010
0677	45.563	0.030	9.823	0.005	1.8930	0.0010
0678	45.296	0.030	9.765	0.005	1.8819	0.0010
0679	44.780	0.029	9.654	0.005	1.8605	0.0010
0680	45.561	0.030	9.822	0.005	1.8930	0.0010
0681	45.321	0.030	9.770	0.005	1.8830	0.0010
0682	44.786	0.029	9.655	0.005	1.8607	0.0010
0683	45.572	0.030	9.825	0.005	1.8934	0.0010
0684	45.204	0.029	9.745	0.005	1.8781	0.0010
0685	44.798	0.029	9.658	0.005	1.8612	0.0010
0686	45.547	0.030	9.819	0.005	1.8924	0.0010
0687	45.341	0.030	9.775	0.005	1.8838	0.0010
0688	44.800	0.029	9.658	0.005	1.8613	0.0010
0689	45.547	0.030	9.819	0.005	1.8924	0.0010
0690	45.350	0.030	9.777	0.005	1.8842	0.0010
0691	44.793	0.029	9.657	0.005	1.8610	0.0010
0692	45.556	0.030	9.821	0.005	1.8927	0.0010
0693	45.337	0.030	9.774	0.005	1.8836	0.0010
0694	44.810	0.029	9.660	0.005	1.8618	0.0010
0695	45.533	0.030	9.816	0.005	1.8918	0.0010
0696	45.339	0.030	9.774	0.005	1.8837	0.0010
0697	44.794	0.029	9.657	0.005	1.8611	0.0010
0698	45.551	0.030	9.820	0.005	1.8925	0.0010
0699	45.335	0.030	9.774	0.005	1.8836	0.0010
0700	44.810	0.029	9.660	0.005	1.8618	0.0010

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

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]
0701	45.567	0.030	9.823	0.005	1.8932	0.0010
0702	45.269	0.030	9.759	0.005	1.8808	0.0010
0703	44.807	0.029	9.660	0.005	1.8616	0.0010
0704	45.631	0.030	9.837	0.005	1.8958	0.0010
0705	45.261	0.029	9.757	0.005	1.8805	0.0010
0706	44.816	0.029	9.662	0.005	1.8620	0.0010
0707	45.579	0.030	9.826	0.005	1.8937	0.0010
0708	45.318	0.030	9.770	0.005	1.8828	0.0010
0709	44.812	0.029	9.661	0.005	1.8618	0.0010
0710	45.577	0.030	9.826	0.005	1.8936	0.0010
0711	45.364	0.030	9.780	0.005	1.8847	0.0010
0712	44.809	0.029	9.660	0.005	1.8617	0.0010
0713	45.549	0.030	9.820	0.005	1.8924	0.0010
0714	45.326	0.030	9.772	0.005	1.8832	0.0010
0715	44.798	0.029	9.658	0.005	1.8612	0.0010
0716	45.584	0.030	9.827	0.005	1.8939	0.0010
0717	45.205	0.029	9.746	0.005	1.8782	0.0010
0718	45.245	0.029	9.754	0.005	1.8798	0.0010
0719	44.812	0.029	9.661	0.005	1.8618	0.0010
0720	45.563	0.030	9.823	0.005	1.8930	0.0010
0721	45.326	0.030	9.772	0.005	1.8832	0.0010
0722	44.796	0.029	9.657	0.005	1.8612	0.0010
0723	45.570	0.030	9.824	0.005	1.8933	0.0010
0724	45.255	0.029	9.756	0.005	1.8802	0.0010
0725	45.209	0.029	9.746	0.005	1.8783	0.0010
0726	45.216	0.029	9.748	0.005	1.8786	0.0010
0727	45.257	0.029	9.757	0.005	1.8803	0.0010
0728	44.821	0.029	9.663	0.005	1.8622	0.0010
0729	45.556	0.030	9.821	0.005	1.8927	0.0010
0730	45.374	0.030	9.782	0.005	1.8852	0.0010
0731	44.803	0.029	9.659	0.005	1.8615	0.0010
0732	45.567	0.030	9.823	0.005	1.8932	0.0010
0733	45.259	0.029	9.757	0.005	1.8804	0.0010
0734	45.232	0.029	9.751	0.005	1.8793	0.0010
0735	44.819	0.029	9.662	0.005	1.8621	0.0010
0736	45.608	0.030	9.832	0.005	1.8949	0.0010
0737	45.229	0.029	9.751	0.005	1.8791	0.0010
0738	45.241	0.029	9.753	0.005	1.8796	0.0010
0739	44.805	0.029	9.659	0.005	1.8615	0.0010
0740	45.592	0.030	9.829	0.005	1.8942	0.0010
0741	45.332	0.030	9.773	0.005	1.8834	0.0010
0742	44.787	0.029	9.655	0.005	1.8608	0.0010
0743	45.565	0.030	9.823	0.005	1.8931	0.0010
0744	45.337	0.030	9.774	0.005	1.8836	0.0010
0745	44.818	0.029	9.662	0.005	1.8621	0.0010
0746	45.535	0.030	9.817	0.005	1.8918	0.0010
0747	44.796	0.029	9.657	0.005	1.8612	0.0010
0748	45.606	0.030	9.832	0.005	1.8948	0.0010
0749	45.188	0.029	9.742	0.005	1.8774	0.0010
0750	45.269	0.030	9.759	0.005	1.8808	0.0010

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

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]
0751	44.805	0.029	9.659	0.005	1.8615	0.0010
0752	45.535	0.030	9.817	0.005	1.8918	0.0010
0753	45.346	0.030	9.776	0.005	1.8840	0.0010
0754	44.798	0.029	9.658	0.005	1.8612	0.0010
0755	45.599	0.030	9.830	0.005	1.8945	0.0010
0756	44.803	0.029	9.659	0.005	1.8615	0.0010
0757	45.570	0.030	9.824	0.005	1.8933	0.0010
0758	45.334	0.030	9.773	0.005	1.8835	0.0010
0759	44.770	0.029	9.652	0.005	1.8601	0.0010
0760	45.565	0.030	9.823	0.005	1.8931	0.0010
0761	45.266	0.030	9.759	0.005	1.8807	0.0010
0762	44.810	0.029	9.660	0.005	1.8618	0.0010
0763	45.551	0.030	9.820	0.005	1.8925	0.0010
0764	45.346	0.030	9.776	0.005	1.8840	0.0010
0765	44.793	0.029	9.657	0.005	1.8610	0.0010
0766	45.535	0.030	9.817	0.005	1.8918	0.0010
0767	45.360	0.030	9.779	0.005	1.8846	0.0010
0768	44.803	0.029	9.659	0.005	1.8615	0.0010
0769	45.567	0.030	9.823	0.005	1.8932	0.0010
0770	45.316	0.030	9.769	0.005	1.8828	0.0010
0771	44.802	0.029	9.658	0.005	1.8614	0.0010
0772	45.561	0.030	9.822	0.005	1.8930	0.0010
0773	45.223	0.029	9.749	0.005	1.8789	0.0010
0774	44.802	0.029	9.658	0.005	1.8614	0.0010
0775	45.552	0.030	9.820	0.005	1.8926	0.0010
0776	45.337	0.030	9.774	0.005	1.8836	0.0010
0777	44.798	0.029	9.658	0.005	1.8612	0.0010
0778	45.568	0.030	9.824	0.005	1.8933	0.0010
0779	45.250	0.029	9.755	0.005	1.8800	0.0010
0780	44.800	0.029	9.658	0.005	1.8613	0.0010
0781	45.554	0.030	9.821	0.005	1.8927	0.0010
0782	45.250	0.029	9.755	0.005	1.8800	0.0010
0783	44.775	0.029	9.653	0.005	1.8603	0.0010
0784	45.588	0.030	9.828	0.005	1.8941	0.0010
0785	45.271	0.030	9.760	0.005	1.8809	0.0010
0786	44.793	0.029	9.657	0.005	1.8610	0.0010
0787	45.558	0.030	9.822	0.005	1.8928	0.0010
0788	45.241	0.029	9.753	0.005	1.8796	0.0010
0789	44.803	0.029	9.659	0.005	1.8615	0.0010
0790	45.602	0.030	9.831	0.005	1.8947	0.0010
0791	44.796	0.029	9.657	0.005	1.8612	0.0010
0792	45.474	0.030	9.803	0.005	1.8893	0.0010
0793	45.293	0.030	9.764	0.005	1.8818	0.0010
0794	44.796	0.029	9.657	0.005	1.8612	0.0010
0795	45.577	0.030	9.826	0.005	1.8936	0.0010
0796	45.289	0.030	9.764	0.005	1.8816	0.0010
0797	44.784	0.029	9.655	0.005	1.8607	0.0010
0798	45.560	0.030	9.822	0.005	1.8929	0.0010
0799	45.225	0.029	9.750	0.005	1.8790	0.0010
0800	45.172	0.029	9.738	0.005	1.8768	0.0010

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

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]
0801	45.257	0.029	9.757	0.005	1.8803	0.0010
0802	44.826	0.029	9.664	0.005	1.8624	0.0010
0803	45.551	0.030	9.820	0.005	1.8925	0.0010
0804	45.310	0.030	9.768	0.005	1.8825	0.0010
0805	44.794	0.029	9.657	0.005	1.8611	0.0010
0806	45.602	0.030	9.831	0.005	1.8947	0.0010
0807	45.186	0.029	9.741	0.005	1.8774	0.0010
0808	45.237	0.029	9.752	0.005	1.8795	0.0010
0809	44.800	0.029	9.658	0.005	1.8613	0.0010
0810	45.556	0.030	9.821	0.005	1.8927	0.0010
0811	45.305	0.030	9.767	0.005	1.8823	0.0010
0812	44.787	0.029	9.655	0.005	1.8608	0.0010
0813	45.549	0.030	9.820	0.005	1.8924	0.0010
0814	45.318	0.030	9.770	0.005	1.8828	0.0010
0815	44.736	0.029	9.644	0.005	1.8587	0.0010
0816	45.544	0.030	9.818	0.005	1.8922	0.0010
0817	44.809	0.029	9.660	0.005	1.8617	0.0010
0818	45.556	0.030	9.821	0.005	1.8927	0.0010
0819	45.291	0.030	9.764	0.005	1.8817	0.0010
0820	44.775	0.029	9.653	0.005	1.8603	0.0010
0821	45.547	0.030	9.819	0.005	1.8924	0.0010
0822	44.793	0.029	9.657	0.005	1.8610	0.0010
0823	45.568	0.030	9.824	0.005	1.8933	0.0010
0824	45.195	0.029	9.743	0.005	1.8777	0.0010
0825	45.213	0.029	9.747	0.005	1.8785	0.0010
0826	45.204	0.029	9.745	0.005	1.8781	0.0010
0827	44.771	0.029	9.652	0.005	1.8601	0.0010
0828	45.540	0.030	9.818	0.005	1.8921	0.0010
0829	45.310	0.030	9.768	0.005	1.8825	0.0010
0830	44.791	0.029	9.656	0.005	1.8609	0.0010
0831	45.570	0.030	9.824	0.005	1.8933	0.0010
0832	45.234	0.029	9.752	0.005	1.8794	0.0010
0833	44.816	0.029	9.662	0.005	1.8620	0.0010
0834	45.337	0.030	9.774	0.005	1.8836	0.0010
0835	45.417	0.030	9.791	0.005	1.8870	0.0010
0836	44.761	0.029	9.650	0.005	1.8597	0.0010
0837	45.558	0.030	9.822	0.005	1.8928	0.0010
0838	45.280	0.030	9.762	0.005	1.8813	0.0010
0839	44.732	0.029	9.644	0.005	1.8585	0.0010
0840	45.572	0.030	9.825	0.005	1.8934	0.0010
0841	44.802	0.029	9.658	0.005	1.8614	0.0010
0842	45.478	0.030	9.804	0.005	1.8895	0.0010
0843	45.245	0.029	9.754	0.005	1.8798	0.0010
0844	44.805	0.029	9.659	0.005	1.8615	0.0010
0845	45.565	0.030	9.823	0.005	1.8931	0.0010
0846	45.278	0.030	9.761	0.005	1.8812	0.0010
0847	44.805	0.029	9.659	0.005	1.8615	0.0010
0848	45.558	0.030	9.822	0.005	1.8928	0.0010
0849	45.319	0.030	9.770	0.005	1.8829	0.0010
0850	44.821	0.029	9.663	0.005	1.8622	0.0010

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

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]
0851	45.560	0.030	9.822	0.005	1.8929	0.0010
0852	44.802	0.029	9.658	0.005	1.8614	0.0010
0853	45.576	0.030	9.825	0.005	1.8935	0.0010
0854	44.839	0.029	9.667	0.005	1.8629	0.0010
0855	45.378	0.030	9.783	0.005	1.8853	0.0010
0856	44.825	0.029	9.663	0.005	1.8624	0.0010
0857	45.583	0.030	9.827	0.005	1.8938	0.0010
0858	44.810	0.029	9.660	0.005	1.8618	0.0010
0859	45.586	0.030	9.828	0.005	1.8940	0.0010
0860	44.818	0.029	9.662	0.005	1.8621	0.0010
0861	45.576	0.030	9.825	0.005	1.8935	0.0010
0862	44.828	0.029	9.664	0.005	1.8625	0.0010
0863	45.568	0.030	9.824	0.005	1.8933	0.0010
0864	45.229	0.029	9.751	0.005	1.8791	0.0010
0865	45.085	0.029	9.719	0.005	1.8731	0.0010
0866	45.417	0.030	9.791	0.005	1.8870	0.0010
0867	44.768	0.029	9.651	0.005	1.8600	0.0010
0868	45.528	0.030	9.815	0.005	1.8916	0.0010
0869	44.823	0.029	9.663	0.005	1.8623	0.0010
0870	45.542	0.030	9.818	0.005	1.8921	0.0010
0871	45.207	0.029	9.746	0.005	1.8782	0.0010
0872	45.200	0.029	9.744	0.005	1.8780	0.0010
0873	45.175	0.029	9.739	0.005	1.8769	0.0010
0874	45.218	0.029	9.748	0.005	1.8787	0.0010
0875	44.782	0.029	9.654	0.005	1.8606	0.0010
0876	45.561	0.030	9.822	0.005	1.8930	0.0010
0877	45.238	0.029	9.752	0.005	1.8795	0.0010
0878	44.793	0.029	9.657	0.005	1.8610	0.0010
0879	45.547	0.030	9.819	0.005	1.8924	0.0010
0880	45.198	0.029	9.744	0.005	1.8779	0.0010
0881	45.206	0.029	9.746	0.005	1.8782	0.0010
0882	44.784	0.029	9.655	0.005	1.8607	0.0010
0883	45.561	0.030	9.822	0.005	1.8930	0.0010
0884	44.782	0.029	9.654	0.005	1.8606	0.0010
0885	45.542	0.030	9.818	0.005	1.8921	0.0010
0886	45.206	0.029	9.746	0.005	1.8782	0.0010
0887	45.191	0.029	9.743	0.005	1.8776	0.0010
0888	45.193	0.029	9.743	0.005	1.8777	0.0010
0889	44.803	0.029	9.659	0.005	1.8615	0.0010
0890	45.611	0.030	9.833	0.005	1.8950	0.0010
0891	44.786	0.029	9.655	0.005	1.8607	0.0010
0892	45.567	0.030	9.823	0.005	1.8932	0.0010
0893	45.216	0.029	9.748	0.005	1.8786	0.0010
0894	44.793	0.029	9.657	0.005	1.8610	0.0010
0895	45.577	0.030	9.826	0.005	1.8936	0.0010
0896	45.220	0.029	9.749	0.005	1.8788	0.0010
0897	45.186	0.029	9.741	0.005	1.8774	0.0010
0898	44.809	0.029	9.660	0.005	1.8617	0.0010
0899	45.556	0.030	9.821	0.005	1.8927	0.0010
0900	44.841	0.029	9.667	0.005	1.8630	0.0010

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

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]
0901	45.547	0.030	9.819	0.005	1.8924	0.0010
0902	44.798	0.029	9.658	0.005	1.8612	0.0010
0903	45.560	0.030	9.822	0.005	1.8929	0.0010
0904	44.791	0.029	9.656	0.005	1.8610	0.0010
0905	45.558	0.030	9.822	0.005	1.8928	0.0010
0906	45.275	0.030	9.761	0.005	1.8811	0.0010
0907	44.787	0.029	9.655	0.005	1.8608	0.0010
0908	45.547	0.030	9.819	0.005	1.8924	0.0010
0909	44.805	0.029	9.659	0.005	1.8615	0.0010
0910	45.560	0.030	9.822	0.005	1.8929	0.0010
0911	45.277	0.030	9.761	0.005	1.8811	0.0010
0912	44.807	0.029	9.660	0.005	1.8616	0.0010
0913	45.558	0.030	9.822	0.005	1.8928	0.0010
0914	44.809	0.029	9.660	0.005	1.8617	0.0010
0915	45.558	0.030	9.822	0.005	1.8928	0.0010
0916	45.238	0.029	9.752	0.005	1.8795	0.0010
0917	44.796	0.029	9.657	0.005	1.8612	0.0010
0918	45.551	0.030	9.820	0.005	1.8925	0.0010
0919	45.291	0.030	9.764	0.005	1.8817	0.0010
0920	44.793	0.029	9.657	0.005	1.8610	0.0010
0921	45.565	0.030	9.823	0.005	1.8931	0.0010
0922	44.800	0.029	9.658	0.005	1.8613	0.0010
0923	45.508	0.030	9.811	0.005	1.8907	0.0010
0924	44.798	0.029	9.658	0.005	1.8612	0.0010
0925	45.551	0.030	9.820	0.005	1.8925	0.0010
0926	44.798	0.029	9.658	0.005	1.8612	0.0010
0927	45.561	0.030	9.822	0.005	1.8930	0.0010
0928	44.807	0.029	9.660	0.005	1.8616	0.0010
0929	45.579	0.030	9.826	0.005	1.8937	0.0010
0930	44.802	0.029	9.659	0.005	1.8614	0.0010
0931	45.592	0.030	9.829	0.005	1.8942	0.0010
0932	44.816	0.029	9.662	0.005	1.8620	0.0010
0933	45.560	0.030	9.822	0.005	1.8929	0.0010
0934	45.241	0.029	9.753	0.005	1.8797	0.0010
0935	44.835	0.029	9.666	0.005	1.8628	0.0010
0936	45.563	0.030	9.823	0.005	1.8930	0.0010
0937	44.812	0.029	9.661	0.005	1.8618	0.0010
0938	45.581	0.030	9.827	0.005	1.8938	0.0010
0939	44.825	0.029	9.663	0.005	1.8624	0.0010
0940	45.590	0.030	9.828	0.005	1.8941	0.0010
0941	44.818	0.029	9.662	0.005	1.8621	0.0010
0942	45.602	0.030	9.831	0.005	1.8947	0.0010
0943	44.816	0.029	9.662	0.005	1.8620	0.0010
0944	45.599	0.030	9.830	0.005	1.8945	0.0010
0945	44.835	0.029	9.666	0.005	1.8628	0.0010
0946	45.649	0.030	9.841	0.005	1.8966	0.0010
0947	44.835	0.029	9.666	0.005	1.8628	0.0010
0948	45.601	0.030	9.831	0.005	1.8946	0.0010
0949	44.834	0.029	9.665	0.005	1.8627	0.0010
0950	45.581	0.030	9.827	0.005	1.8938	0.0010

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

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]
0951	44.827	0.029	9.664	0.005	1.8624	0.0010
0952	45.590	0.030	9.828	0.005	1.8941	0.0010
0953	44.828	0.029	9.664	0.005	1.8625	0.0010
0954	45.581	0.030	9.827	0.005	1.8938	0.0010
0955	44.816	0.029	9.662	0.005	1.8620	0.0010
0956	45.588	0.030	9.828	0.005	1.8941	0.0010
0957	44.827	0.029	9.664	0.005	1.8624	0.0010
0958	45.590	0.030	9.828	0.005	1.8941	0.0010
0959	44.832	0.029	9.665	0.005	1.8627	0.0010
0960	45.595	0.030	9.830	0.005	1.8944	0.0010
0961	44.853	0.029	9.670	0.005	1.8635	0.0010
0962	45.577	0.030	9.826	0.005	1.8936	0.0010
0963	44.707	0.029	9.638	0.005	1.8575	0.0010
0964	45.606	0.030	9.832	0.005	1.8948	0.0010
0965	44.827	0.029	9.664	0.005	1.8624	0.0010
0966	45.593	0.030	9.829	0.005	1.8943	0.0010
0967	44.763	0.029	9.650	0.005	1.8598	0.0010
0968	45.588	0.030	9.828	0.005	1.8941	0.0010
0969	44.832	0.029	9.665	0.005	1.8627	0.0010
0970	45.586	0.030	9.828	0.005	1.8940	0.0010
0971	44.821	0.029	9.663	0.005	1.8622	0.0010
0972	45.586	0.030	9.828	0.005	1.8940	0.0010
0973	44.832	0.029	9.665	0.005	1.8627	0.0010
0974	45.581	0.030	9.827	0.005	1.8938	0.0010
0975	44.827	0.029	9.664	0.005	1.8624	0.0010
0976	45.590	0.030	9.828	0.005	1.8941	0.0010
0977	44.839	0.029	9.667	0.005	1.8629	0.0010
0978	45.585	0.030	9.827	0.005	1.8939	0.0010
0979	44.830	0.029	9.665	0.005	1.8626	0.0010
0980	45.581	0.030	9.827	0.005	1.8938	0.0010
0981	44.871	0.029	9.673	0.005	1.8643	0.0010
0982	45.576	0.030	9.825	0.005	1.8936	0.0010
0983	44.805	0.029	9.659	0.005	1.8615	0.0010
0984	45.588	0.030	9.828	0.005	1.8941	0.0010
0985	45.232	0.029	9.751	0.005	1.8793	0.0010
0986	44.809	0.029	9.660	0.005	1.8617	0.0010
0987	45.520	0.030	9.813	0.005	1.8913	0.0010
0988	44.821	0.029	9.663	0.005	1.8622	0.0010
0989	45.581	0.030	9.827	0.005	1.8938	0.0010
0990	44.811	0.029	9.660	0.005	1.8618	0.0010
0991	45.588	0.030	9.828	0.005	1.8941	0.0010
0992	44.821	0.029	9.663	0.005	1.8622	0.0010
0993	45.581	0.030	9.827	0.005	1.8938	0.0010
0994	44.832	0.029	9.665	0.005	1.8627	0.0010
0995	45.576	0.030	9.825	0.005	1.8936	0.0010
0996	44.828	0.029	9.664	0.005	1.8625	0.0010
0997	45.577	0.030	9.826	0.005	1.8936	0.0010
0998	44.825	0.029	9.663	0.005	1.8624	0.0010
0999	45.586	0.030	9.828	0.005	1.8940	0.0010
1000	44.818	0.029	9.662	0.005	1.8621	0.0010

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

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]
1001	45.576	0.030	9.825	0.005	1.8936	0.0010
1002	44.827	0.029	9.664	0.005	1.8624	0.0010
1003	45.586	0.030	9.828	0.005	1.8940	0.0010
1004	44.843	0.029	9.667	0.005	1.8631	0.0010
1005	45.581	0.030	9.827	0.005	1.8938	0.0010
1006	45.044	0.029	9.711	0.005	1.8714	0.0010
1007	44.811	0.029	9.660	0.005	1.8618	0.0010
1008	45.581	0.030	9.827	0.005	1.8938	0.0010
1009	44.818	0.029	9.662	0.005	1.8621	0.0010
1010	45.588	0.030	9.828	0.005	1.8941	0.0010
1011	44.816	0.029	9.662	0.005	1.8620	0.0010
1012	45.583	0.030	9.827	0.005	1.8938	0.0010
1013	44.803	0.029	9.659	0.005	1.8615	0.0010
1014	45.592	0.030	9.829	0.005	1.8942	0.0010
1015	44.812	0.029	9.661	0.005	1.8618	0.0010
1016	45.561	0.030	9.822	0.005	1.8930	0.0010
1017	45.227	0.029	9.750	0.005	1.8791	0.0010
1018	44.807	0.029	9.660	0.005	1.8616	0.0010
1019	45.558	0.030	9.822	0.005	1.8928	0.0010
1020	44.734	0.029	9.644	0.005	1.8586	0.0010
1021	45.569	0.030	9.824	0.005	1.8933	0.0010
1022	44.812	0.029	9.661	0.005	1.8618	0.0010
1023	45.579	0.030	9.826	0.005	1.8937	0.0010
1024	44.823	0.029	9.663	0.005	1.8623	0.0010
1025	45.565	0.030	9.823	0.005	1.8931	0.0010
1026	44.807	0.029	9.660	0.005	1.8616	0.0010
1027	45.595	0.030	9.830	0.005	1.8944	0.0010
1028	44.816	0.029	9.662	0.005	1.8620	0.0010
1029	45.561	0.030	9.822	0.005	1.8930	0.0010
1030	44.821	0.029	9.663	0.005	1.8622	0.0010
1031	45.576	0.030	9.825	0.005	1.8936	0.0010
1032	44.825	0.029	9.663	0.005	1.8624	0.0010
1033	45.549	0.030	9.820	0.005	1.8924	0.0010
1034	45.266	0.030	9.759	0.005	1.8807	0.0010
1035	44.812	0.029	9.661	0.005	1.8618	0.0010
1036	45.572	0.030	9.825	0.005	1.8934	0.0010
1037	44.814	0.029	9.661	0.005	1.8619	0.0010
1038	45.554	0.030	9.821	0.005	1.8927	0.0010
1039	44.827	0.029	9.664	0.005	1.8624	0.0010
1040	45.631	0.030	9.837	0.005	1.8958	0.0010
1041	44.809	0.029	9.660	0.005	1.8617	0.0010
1042	45.567	0.030	9.823	0.005	1.8932	0.0010
1043	44.811	0.029	9.660	0.005	1.8618	0.0010
1044	45.579	0.030	9.826	0.005	1.8937	0.0010
1045	44.816	0.029	9.662	0.005	1.8620	0.0010
1046	45.565	0.030	9.823	0.005	1.8931	0.0010
1047	44.812	0.029	9.661	0.005	1.8618	0.0010
1048	45.570	0.030	9.824	0.005	1.8933	0.0010
1049	44.818	0.029	9.662	0.005	1.8621	0.0010
1050	45.560	0.030	9.822	0.005	1.8929	0.0010

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

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]
1051	44.814	0.029	9.661	0.005	1.8619	0.0010
1052	45.531	0.030	9.816	0.005	1.8917	0.0010
1053	44.837	0.029	9.666	0.005	1.8629	0.0010
1054	45.549	0.030	9.820	0.005	1.8924	0.0010
1055	44.818	0.029	9.662	0.005	1.8621	0.0010
1056	45.565	0.030	9.823	0.005	1.8931	0.0010
1057	45.305	0.030	9.767	0.005	1.8823	0.0010
1058	45.189	0.029	9.742	0.005	1.8775	0.0010
1059	45.204	0.029	9.745	0.005	1.8781	0.0010
1060	44.697	0.029	9.636	0.005	1.8570	0.0010
1061	45.510	0.030	9.811	0.005	1.8908	0.0010
1062	45.136	0.029	9.731	0.005	1.8753	0.0010
1063	45.246	0.029	9.754	0.005	1.8799	0.0010
1064	44.750	0.029	9.647	0.005	1.8592	0.0010
1065	45.567	0.030	9.823	0.005	1.8932	0.0010
1066	45.255	0.029	9.756	0.005	1.8802	0.0010
1067	44.741	0.029	9.645	0.005	1.8589	0.0010
1068	45.551	0.030	9.820	0.005	1.8925	0.0010
1069	45.259	0.029	9.757	0.005	1.8804	0.0010
1070	44.723	0.029	9.642	0.005	1.8581	0.0010
1071	45.577	0.030	9.826	0.005	1.8936	0.0010
1072	45.092	0.029	9.721	0.005	1.8734	0.0010
1073	45.164	0.029	9.737	0.005	1.8765	0.0010
1074	45.172	0.029	9.738	0.005	1.8768	0.0010
1075	45.186	0.029	9.741	0.005	1.8774	0.0010
1076	44.972	0.029	9.695	0.005	1.8685	0.0010
1077	45.410	0.030	9.790	0.005	1.8867	0.0010
1078	44.736	0.029	9.644	0.005	1.8587	0.0010
1079	45.577	0.030	9.826	0.005	1.8936	0.0010
1080	44.762	0.029	9.650	0.005	1.8598	0.0010
1081	45.572	0.030	9.825	0.005	1.8934	0.0010
1082	45.177	0.029	9.739	0.005	1.8770	0.0010
1083	45.182	0.029	9.741	0.005	1.8772	0.0010
1084	45.232	0.029	9.751	0.005	1.8793	0.0010
1085	45.186	0.029	9.741	0.005	1.8774	0.0010
1086	45.209	0.029	9.746	0.005	1.8783	0.0010
1087	45.189	0.029	9.742	0.005	1.8775	0.0010
1088	45.198	0.029	9.744	0.005	1.8779	0.0010
1089	45.196	0.029	9.744	0.005	1.8778	0.0010
1090	45.189	0.029	9.742	0.005	1.8775	0.0010
1091	45.202	0.029	9.745	0.005	1.8780	0.0010
1092	45.063	0.029	9.715	0.005	1.8723	0.0010
1093	44.841	0.029	9.667	0.005	1.8630	0.0010
1094	45.474	0.030	9.803	0.005	1.8893	0.0010
1095	44.755	0.029	9.649	0.005	1.8595	0.0010
1096	45.567	0.030	9.823	0.005	1.8932	0.0010
1097	45.271	0.030	9.760	0.005	1.8809	0.0010
1098	45.143	0.029	9.732	0.005	1.8756	0.0010
1099	45.241	0.029	9.753	0.005	1.8796	0.0010
1100	45.157	0.029	9.735	0.005	1.8762	0.0010

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

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]
1101	45.230	0.029	9.751	0.005	1.8792	0.0010
1102	45.189	0.029	9.742	0.005	1.8775	0.0010
1103	45.207	0.029	9.746	0.005	1.8782	0.0010
1104	45.177	0.029	9.739	0.005	1.8770	0.0010
1105	45.211	0.029	9.747	0.005	1.8784	0.0010
1106	45.173	0.029	9.739	0.005	1.8768	0.0010
1107	45.209	0.029	9.746	0.005	1.8783	0.0010
1108	45.216	0.029	9.748	0.005	1.8786	0.0010
1109	45.140	0.029	9.731	0.005	1.8754	0.0010
1110	45.275	0.030	9.761	0.005	1.8811	0.0010
1111	45.141	0.029	9.732	0.005	1.8755	0.0010
1112	45.232	0.029	9.751	0.005	1.8793	0.0010
1113	45.191	0.029	9.742	0.005	1.8776	0.0010
1114	45.202	0.029	9.745	0.005	1.8780	0.0010
1115	45.209	0.029	9.746	0.005	1.8783	0.0010
1116	44.686	0.029	9.634	0.005	1.8566	0.0010
1117	45.586	0.030	9.828	0.005	1.8940	0.0010
1118	44.793	0.029	9.657	0.005	1.8610	0.0010
1119	45.583	0.030	9.827	0.005	1.8938	0.0010
1120	44.800	0.029	9.658	0.005	1.8613	0.0010
1121	45.625	0.030	9.836	0.005	1.8956	0.0010
1122	44.761	0.029	9.650	0.005	1.8597	0.0010
1123	45.520	0.030	9.813	0.005	1.8913	0.0010
1124	45.333	0.030	9.773	0.005	1.8835	0.0010
1125	45.111	0.029	9.725	0.005	1.8743	0.0010
1126	45.442	0.030	9.797	0.005	1.8880	0.0010

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Annex 2: The certificate of EC NRM 101 uranium metal

Certified Nuclear Reference Material

Certificate of Analysis

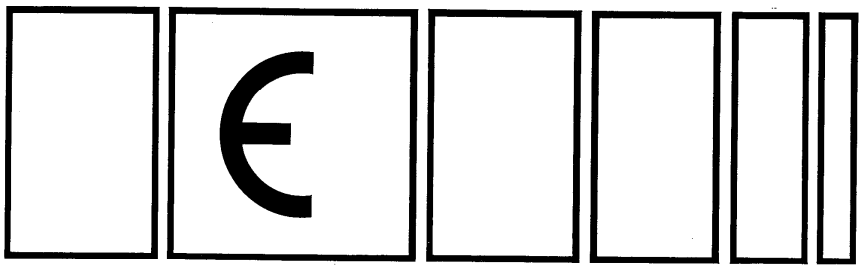
EC NUCLEAR REFERENCE MATERIAL NO. 101

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

Page 1 of 3

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
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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) $g \cdot mol^{-1}$

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 +32-14-571 883

European Commission - JRC

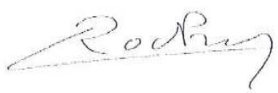
30207 BAGNOLS SUR CEZE CEDEX
Téléphone 04.66.79.69.88 - Télécopie 04.66.79.69.89

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
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Annex 5: The certificate of isotopic abundances of CETAMA MP2 by IRMM

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)
$n(^{242}Pu)/\ n(^{239}Pu)$	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 by IRMM

European Commission
JOINT
RESEARCH
CENTRE

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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)	0.007293		+/- 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

CERTIFICATE
SPIKE ISOTOPIC REFERENCE MATERIAL IRMM-046b

4.650 4(18) · 10^{-7} mol (^{242}Pu) · g^{-1} (solution)
4.115 38(85) · 10^{-6} mol (^{233}U) · g^{-1} (solution)

The Spike Isotopic Reference Material is supplied with an isotope amount content of ^{233}U and ^{242}Pu as certified above.

The amount of other uranium and plutonium isotopes present are related to the ^{233}U and ^{242}Pu content through the following certified amount ratios:

$n(^{238}Pu)/n(^{242}Pu)$	:	0.005 332(20)
$n(^{239}Pu)/n(^{242}Pu)$	:	0.002 212(16)
$n(^{240}Pu)/n(^{242}Pu)$	:	0.046 066(63)
$n(^{241}Pu)/n(^{242}Pu)$	:	0.002 9998(86)
$n(^{244}Pu)/n(^{242}Pu)$	:	0.000 237(31)

$n(^{234}U)/n(^{233}U)$	:	0.009 396(12)
$n(^{235}U)/n(^{233}U)$	:	0.002 252 0(60)
$n(^{236}U)/n(^{233}U)$	:	0.000 280 0(40)
$n(^{238}U)/n(^{233}U)$	:	0.008 186(11)

This corresponds to an isotopic composition with the following abundances:

	amount fraction (·100)		mass fraction (·100)
$n(^{238}Pu)/n(Pu)$	0.504 5(18)	$m(^{238}Pu)/m(Pu)$	0.496 4(18)
$n(^{239}Pu)/n(Pu)$	0.209 3(15)	$m(^{239}Pu)/m(Pu)$	0.206 8(15)
$n(^{240}Pu)/n(Pu)$	4.358 9(57)	$m(^{240}Pu)/m(Pu)$	4.324 8(57)
$n(^{241}Pu)/n(Pu)$	0.283 85(81)	$m(^{241}Pu)/m(Pu)$	0.282 81(81)
$n(^{242}Pu)/n(Pu)$	94.621 0(67)	$m(^{242}Pu)/m(Pu)$	94.666 5(67)
$n(^{244}Pu)/n(Pu)$	0.022 4(29)	$m(^{244}Pu)/m(Pu)$	0.022 6(30)

The molar mass of the plutonium in this sample is 241.942 44(15) $g \cdot mol^{-1}$

06/2010

amount fraction (·100)		mass fraction (·100)	
$n(^{233}U)/n(U)$	98.028 3(17)	$m(^{233}U)/m(U)$	98.005 3(17)
$n(^{234}U)/n(U)$	0.921 1(12)	$m(^{234}U)/m(U)$	0.924 8(12)
$n(^{235}U)/n(U)$	0.220 76(59)	$m(^{235}U)/m(U)$	0.222 61(59)
$n(^{236}U)/n(U)$	0.027 45(39)	$m(^{236}U)/m(U)$	0.027 80(40)
$n(^{238}U)/n(U)$	0.802 5(11)	$m(^{238}U)/m(U)$	0.819 5(11)

The molar mass of the uranium in this sample is 233.094 320(57) $g \cdot mol^{-1}$

From the certified values, the following amount and mass contents are derived:

$4.914\ 7(19) \cdot 10^{-7}$	mol (Pu) · g^{-1} (solution)
$1.125\ 67(43) \cdot 10^{-4}$	g (^{242}Pu) · g^{-1} (solution)
$1.189\ 09(46) \cdot 10^{-4}$	g (Pu) · g^{-1} (solution)

and

$4.198\ 16(87) \cdot 10^{-6}$	mol (U) · g^{-1} (solution)
$0.959\ 05(20) \cdot 10^{-3}$	g (^{233}U) · g^{-1} (solution)
$0.978\ 57(20) \cdot 10^{-3}$	g (U) · g^{-1} (solution)

NOTES

1. All uncertainties indicated are expanded uncertainties $U = k \cdot u_c$ where u_c is the combined standard uncertainty estimated according to the ISO/BIPM Guide to the Expression of Uncertainty in Measurement. They are given in parentheses and include a coverage factor $k = 2$. They apply to the last two digits of the value.
2. Values for isotope ratios, isotopic compositions and for concentrations are valid for 1 June 2010. This certificate is valid until June 2013; the validity may be extended after further tests on the stability of the spike material are carried out.
3. Due to radioactive decay, the Pu element concentration decreases by 0.035 % · a^{-1}.
4. The half lives used in the calculations are

^{238}Pu: 8.77 (03) · 10^1 a[(1)]

^{239}Pu: 2.411 (03) · 10^4 a[(1)]

^{240}Pu: 6.563 (07) · 10^3 a[(1)]

^{241}Pu: 1.432 5(24) · 10^1 a[(2)]

^{242}Pu: 3.735 (11) · 10^5 a[(1)]

^{244}Pu: 8.00 (09) · 10^7 a[(1]

(1) IAEA, Decay data of the Transactinium Nuclides, Technical Reports Series No. 261, 1986
(2) R. Wellum, A. Verbruggen, R. Kessel, J. Anal. At. Spectrom., 2009, 24, 801 - 807

5. The atomic masses, used in the calculations, are[3]

^{233}U : 233.039 635 2 (58) g·mol^{-1}
^{234}U : 234.040 952 1 (40) g·mol^{-1}
^{235}U : 235.043 929 9 (40) g·mol^{-1}
^{236}U : 236.045 568 0 (40) g·mol^{-1}
^{238}U : 238.050 788 2 (40) g·mol^{-1}

^{238}Pu : 238.049 559 9 (40) g·mol^{-1}
^{239}Pu : 239.052 163 4 (40) g·mol^{-1}
^{240}Pu : 240.053 813 5 (40) g·mol^{-1}
^{241}Pu : 241.056 851 5 (40) g·mol^{-1}
^{242}Pu : 242.058 742 6 (40) g·mol^{-1}
^{244}Pu : 244.064 204 (10) g·mol^{-1}

6. A unit of IRMM-046b consists of a flame-sealed glass ampoule containing a chemically stable solution of uranium and plutonium in nitric acid. The solution volume is about 10 mL; the molarity is about 5 M.

7. The ampoule should be handled with great care and by experienced personnel in a laboratory environment suitably equipped for the safe handling of radioactive materials.

8. Using this Spike Isotopic Reference Material, ^{239}Pu concentrations in unknown samples can be determined by Isotope Dilution Mass Spectrometry, through a measurement of the isotope dilution ratio $R_B = n(^{239}\text{Pu})/n(^{242}\text{Pu})$ in the blend. They should be computed with the aid of the following formula which allows an easy identification and quantification of the sources of the uncertainties in the procedure :

$$c\left(^{239}Pu\right)_X = \frac{R_Y - R_B}{R_B - R_X} \cdot R_X \cdot \frac{m_Y}{m_X} \cdot c\left(^{242}Pu\right)_Y$$

$$c(Pu)_X = \frac{R_Y - R_B}{R_B - R_X} \cdot \frac{\sum R_{Xi}}{\sum R_{Yi}} \cdot \frac{m_Y}{m_X} \cdot c(Pu)_Y$$

where

R_X	=	amount ratio $n(^{239}\text{Pu})/n(^{242}\text{Pu})$ in the unknown sample material
R_Y	=	amount ratio $n(^{239}\text{Pu})/n(^{242}\text{Pu})$ in the spike material
m_X	=	mass of the unknown sample
m_Y	=	mass of the sample of spike solution used
$c\left(^{239}Pu\right)_X$	=	number of moles ^{239}Pu · kg^{-1} sample material
$c\left(^{242}Pu\right)_Y$	=	number of moles ^{242}Pu · kg^{-1} spike solution
$c(Pu)_X$	=	number of moles Pu · kg^{-1} sample material
$c(Pu)_Y$	=	number of moles Pu · kg^{-1} spike solution.

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

9. Using this Spike Isotopic Reference Material, ^{235}U concentrations in unknown samples can be determined by Isotope Dilution Mass Spectrometry, through a measurement of the isotope dilution ratio $R_B = n(^{233}U)/n(^{235}U)$ in the blend. They should be computed with the aid of the following formula which allows an easy identification and quantification of the sources of the uncertainties in the procedure :

$$c\left(^{235}U\right)_X = \frac{R_Y - R_B}{R_B - R_X} \cdot \frac{1}{R_Y} \cdot \frac{m_Y}{m_X} \cdot c\left(^{233}U\right)_Y$$

$$c(U)_X = \frac{R_Y - R_B}{R_B - R_X} \cdot \frac{\sum R_{Xi}}{\sum R_{Yi}} \cdot \frac{m_Y}{m_X} \cdot c(U)_Y$$

where

R_X	=	amount ratio $n(^{233}U)/n(^{235}U)$ in the unknown sample material
R_Y	=	amount ratio $n(^{233}U)/n(^{235}U)$ in the spike material
m_X	=	mass of the unknown sample
m_Y	=	mass of the sample of spike solution used
$c\left(^{235}U\right)_X$	=	number of moles $^{235}U \cdot kg^{-1}$ sample material
$c\left(^{233}U\right)_Y$	=	number of moles $^{233}U \cdot kg^{-1}$ spike solution
$c(U)_X$	=	number of moles $U \cdot kg^{-1}$ sample material
$c(U)_Y$	=	number of moles $U \cdot kg^{-1}$ spike solution.

10. The certified values of this Spike Isotopic Reference Material are metrologically traceable to the SI. Measurements calibrated with this Isotopic Reference Materials can therefore provide SI-traceable results.

11. The isotopic measurements by Thermal Ionisation Mass Spectrometry were performed by H. Kühn, F. Kehoe and S. Richter for uranium and for plutonium. Isotopic measurements were calibrated against synthetic plutonium isotope mixtures prepared by J. Broothaerts. Chemical preparation of the samples for isotope measurements was performed by F. Kehoe and R. Jakopič.

Metrological weighings for the preparation and certification were performed by U. Jacobsson and R. Eykens. The ampoulation of this Spike Isotopic Reference Material was accomplished by G. Van Baelen and A. Verbruggen.

The overall co-ordination leading to the establishment, certification and issuance of this Spike Isotopic Reference Material was performed by A. Verbruggen.

Geel, June 2010

H. Emons
Head
Reference Materials Unit

Annex 8: Results of the IDMS confirmation measurements (4 blends, 4 replicates) for ^{235}U, ^{238}U and ^{239}Pu amount contents in the mother solution of IRMM-1027q.

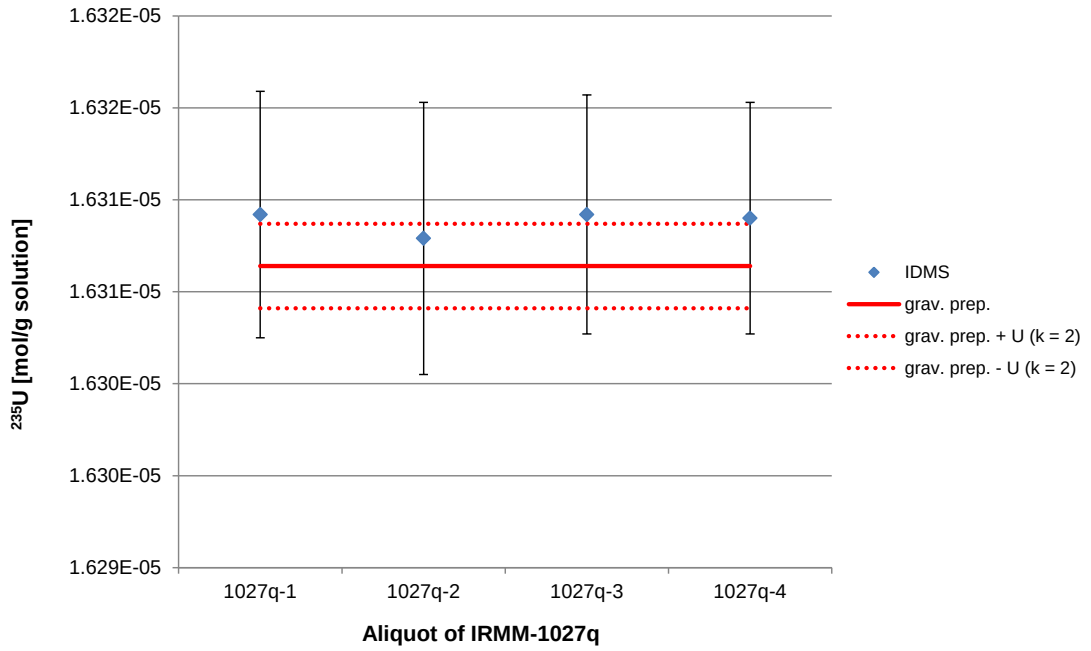

Fig. 3 The amount content of ^{235}U in the solution of IRMM-1027q prepared by gravimetric mixing compared with the measured values by IDMS (with expanded uncertainties, coverage factor k = 2).

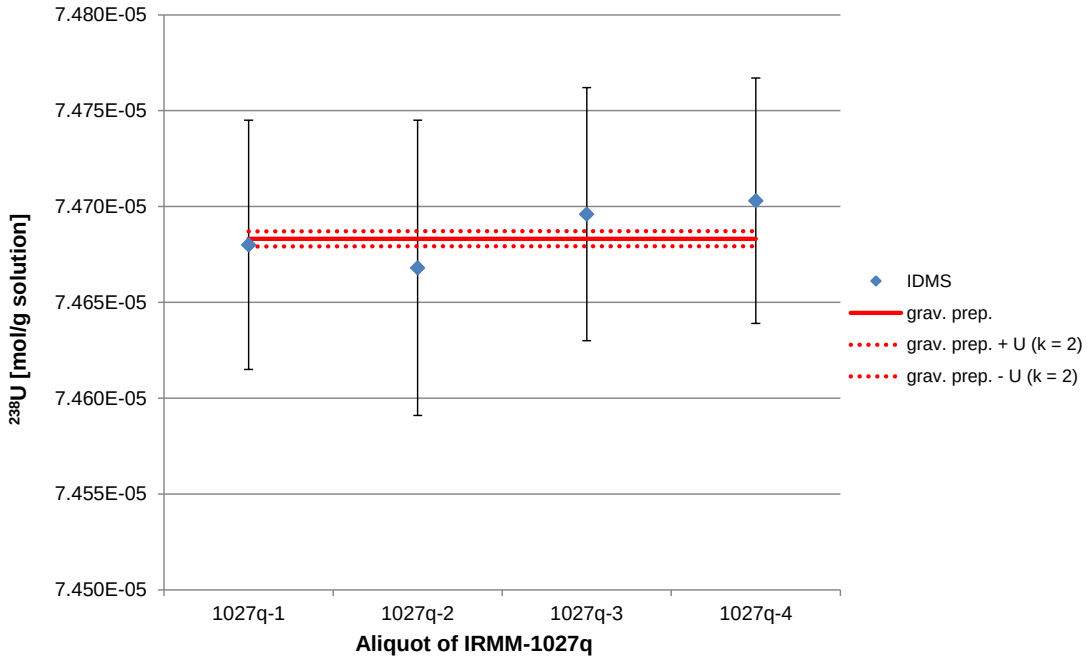

Fig. 4 The amount content of ^{238}U in the solution of IRMM-1027q prepared by gravimetric mixing compared with the measured values by IDMS (with expanded uncertainties, coverage factor k = 2).

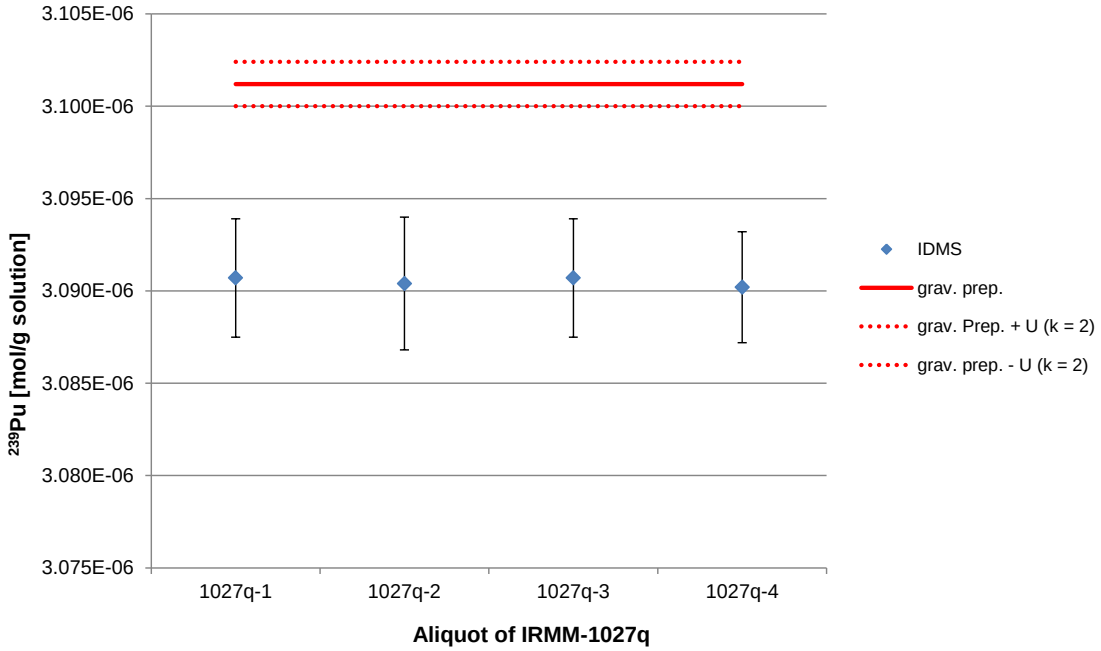

Fig. 5 The amount content of ^{239}Pu in the solution of IRMM-1027q prepared by gravimetric mixing compared with the measured values by IDMS (with expanded uncertainties, coverage factor *k* = 2).

Annex 9: Results of the homogeneity assessment (single value, mean and standard deviation) of the ^{239}Pu, ^{238}U and ^{235}U amount contents in the selected vials of IRMM-1027q.

Unit	^{235}U [µmol/g]			
	Rep.1	Rep.2	Rep.3	Mean ± s
37	16.3049	16.3067	16.3084	16.3067 ± 0.0018
314	16.3042	16.3037	16.3031	16.3037 ± 0.0005
538	16.3040	16.3055	16.3113	16.3069 ± 0.0040
188	16.3088	16.3078	16.3109	16.3092 ± 0.0016
412	16.3106	16.3096	16.3128	16.3110 ± 0.0017
638	16.3048	16.3086	16.3103	16.3079 ± 0.0028
855	16.3082	16.3169	16.3084	16.3112 ± 0.0050
1110	16.3219	16.3184	16.3210	16.3205 ± 0.0018
665	16.3057	16.3147	16.3116	16.3107 ± 0.0046
999	16.3074	16.3119	16.3118	16.3104 ± 0.0026

Unit	^{238}U [µmol/g]			
	Rep.1	Rep.2	Rep.3	Mean ± s
37	74.689	74.710	74.722	74.708 ± 0.018
314	74.666	74.666	74.670	74.667 ± 0.002
538	74.631	74.642	74.721	74.665 ± 0.049
188	74.698	74.693	74.719	74.703 ± 0.014
412	74.720	74.708	74.745	74.724 ± 0.019
638	74.618	74.658	74.676	74.651 ± 0.030
855	74.615	74.713	74.623	74.650 ± 0.054
1110	74.731	74.696	74.732	74.720 ± 0.021
665	74.598	74.710	74.678	74.662 ± 0.058
999	74.621	74.664	74.672	74.652 ± 0.027

Unit	^{239}Pu [µmol/g]			
	Rep.1	Rep.2	Rep.3	Mean ± *s*
37	3.09057	3.08845	3.08899	3.08934 ± 0.00110
314	3.08946	3.08984	/	3.08965 ± 0.00027
538	3.08843	3.09077	3.09033	3.08984 ± 0.00124
188	3.09029	3.09017	3.09003	3.09016 ± 0.00013
412	3.08968	3.09034	3.08835	3.08946 ± 0.00112
638	3.08953	3.089964	3.09149	3.09022 ± 0.00110
855	3.09006	3.09069	3.09211	3.09095 ± 0.00105
1110	3.09151	3.09293	3.09049	3.09164 ± 0.00122
665	3.09121	3.09096	3.09000	3.09072 ± 0.00064
999	3.08948	3.09175	3.09084	3.09069 ± 0.00114

Annex 10: Results of the homogeneity assessment of the uranium and plutonium isotope amount ratios in the selected vials of IRMM-1027q.

Unit	$n(^{234}U)/n(^{238}U)$			
	Rep.1	Rep.2	Rep.3	Mean ± *s*
23	0.0025030	0.0025036	0.0024995	0.0025020 ± 0.000022
392	0.0025009	0.0025023	0.0025025	0.0025019 ± 0.0000008
147	0.0025033	0.0025004	0.0025118	0.0025052 ± 0.0000059
484	0.0025038	0.0025035	0.0025033	0.0025035 ± 0.0000002
235	0.0025049	0.0025022	/	0.0025036 ± 0.0000019
576	0.0025030	0.0025075	0.0025064	0.0025056 ± 0.0000023
847	0.0025005	0.0024988	0.0025043	0.0025012 ± 0.0000028
1034	0.0025031	0.0025035	0.0025047	0.0025038 ± 0.0000009
712	0.0025023	0.0025076	0.0025013	0.0025037 ± 0.0000034
922	0.0025049	0.0025046	0.002503	0.0025042 ± 0.0000010

Unit	$n(^{235}U)/n(^{238}U)$			
	Rep.1	Rep.2	Rep.3	Mean ± *s*
23	0.218451	0.218450	0.218446	0.218449 ± 0.000002
392	0.218366	0.218442	0.218457	0.218422 ± 0.000049
147	0.218505	0.218398	0.218211	0.218371 ± 0.000149
484	0.218341	0.218485	0.218633	0.218486 ± 0.000146
235	0.218553	0.218412	/	0.218482 ± 0.000099
576	0.218341	0.218405	0.218404	0.218383 ± 0.000037
847	0.218434	0.218400	0.218400	0.218411 ± 0.000020
1034	0.218498	0.218443	0.218436	0.218459 ± 0.000034
712	0.218493	0.218394	0.218452	0.218446 ± 0.000050
922	0.218494	0.218465	0.218379	0.218446 ± 0.000060

Unit	$n(^{240}Pu)/n(^{239}Pu)$			
	Rep.1	Rep.2	Rep.3	Mean ± *s*
23	0.0224095	0.0224155	0.0224180	0.0224143 ± 0.0000044
392	0.0224139	0.0224153	0.0224143	0.0224145 ± 0.0000007
147	0.0224134	0.0224150	0.0224148	0.0224144 ± 0.0000009
484	0.0224182	0.0224127	0.0224188	0.0224166 ± 0.0000034
235	0.0224172	0.0224179	0.0224141	0.0224164 ± 0.0000020
576	0.0224150	0.0224173	0.0224190	0.0224171 ± 0.0000021
847	0.0224148	0.0224214	0.0224203	0.0224188 ± 0.0000035
1034	0.0224153	0.0224193	0.0224161	0.0224169 ± 0.0000021
712	0.0224174	0.0224153	0.0224159	0.0224162 ± 0.0000011
922	0.0224153	0.0224158	0.0224149	0.0224153 ± 0.0000005

Unit	$n(^{241}Pu)/n(^{239}Pu)$			
	Rep.1	Rep.2	Rep.3	Mean ± *s*
23	0.0001654	0.0001645	0.0001677	0.0001659 ± 0.0000017
392	0.0001633	0.0001647	0.0001632	0.0001637 ± 0.0000008
147	0.0001632	0.0001622	0.0001659	0.0001637 ± 0.0000019
484	0.0001655	0.0001658	0.0001637	0.0001650 ± 0.0000011
235	0.0001626	0.0001648	0.0001671	0.0001649 ± 0.0000023
576	0.0001644	0.0001608	0.0001622	0.0001625 ± 0.0000018
847	0.0001635	0.0001638	0.0001631	0.0001635 ± 0.0000004
1034	0.0001631	0.0001639	0.0001656	0.0001642 ± 0.0000013
712	0.0001646	0.0001612	0.0001662	0.0001640 ± 0.0000026
922	0.0001637	0.0001639	0.0001620	0.0001632 ± 0.0000010

Unit	$n(^{242}Pu)/n(^{239}Pu)$			
	Rep. 1	Rep.2	Rep.3	Mean ± *s*
23	0.0000750	0.0000761	0.0000751	0.0000754 ± 0.0000006
392	0.0000717	0.0000753	0.0000744	0.0000738 ± 0.0000019
147	0.0000834	0.0000745	0.0000690	0.0000757 ± 0.0000072
484	0.0000741	0.0000756	0.0000765	0.0000754 ± 0.0000012
235	0.0000761	0.0000784	0.0000752	0.0000766 ± 0.0000016
576	0.0000760	0.0000778	0.0000773	0.0000770 ± 0.0000009
847	0.0000727	0.0000735	0.0000772	0.0000745 ± 0.0000024
1034	0.0000728	0.0000747	0.0000717	0.0000730 ± 0.0000015
712	0.0000732	0.0000756	0.0000787	0.0000759 ± 0.0000027
922	0.0000710	0.0000778	0.0000771	0.0000753 ± 0.0000037

Annex 11: Post certification monitoring of the uranium and plutonium mass fraction in IRMM-1027o.

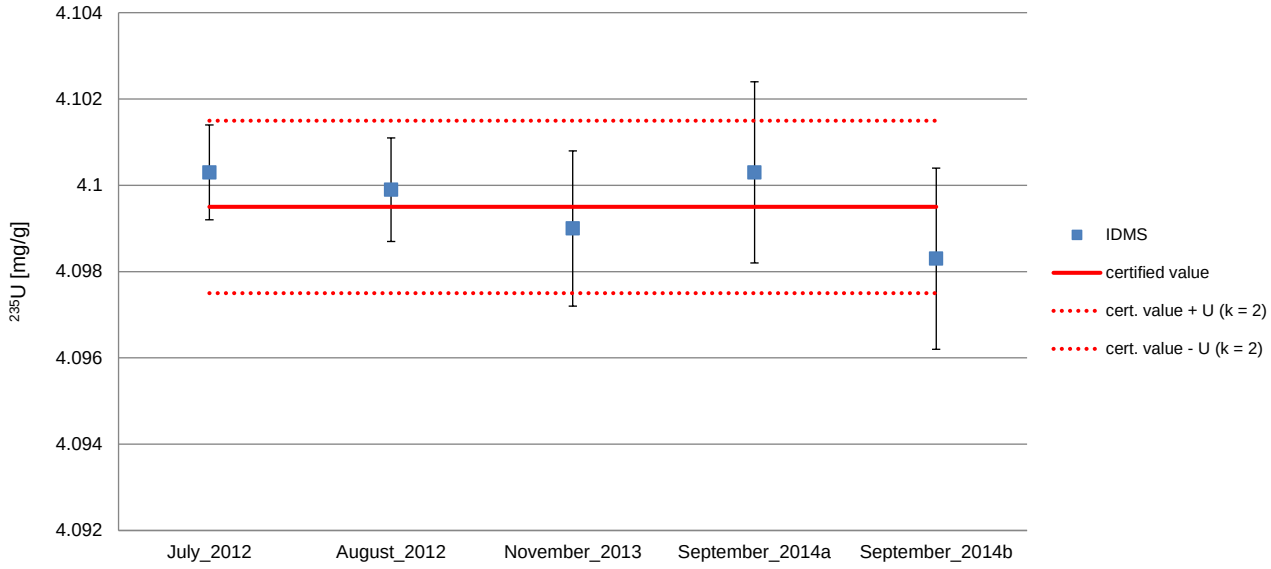

Fig. 6 The mass fraction of ^{235}U in IRMM-1027o compared with the certified values for the post certification monitoring (with expanded uncertainties, coverage factor k = 2).

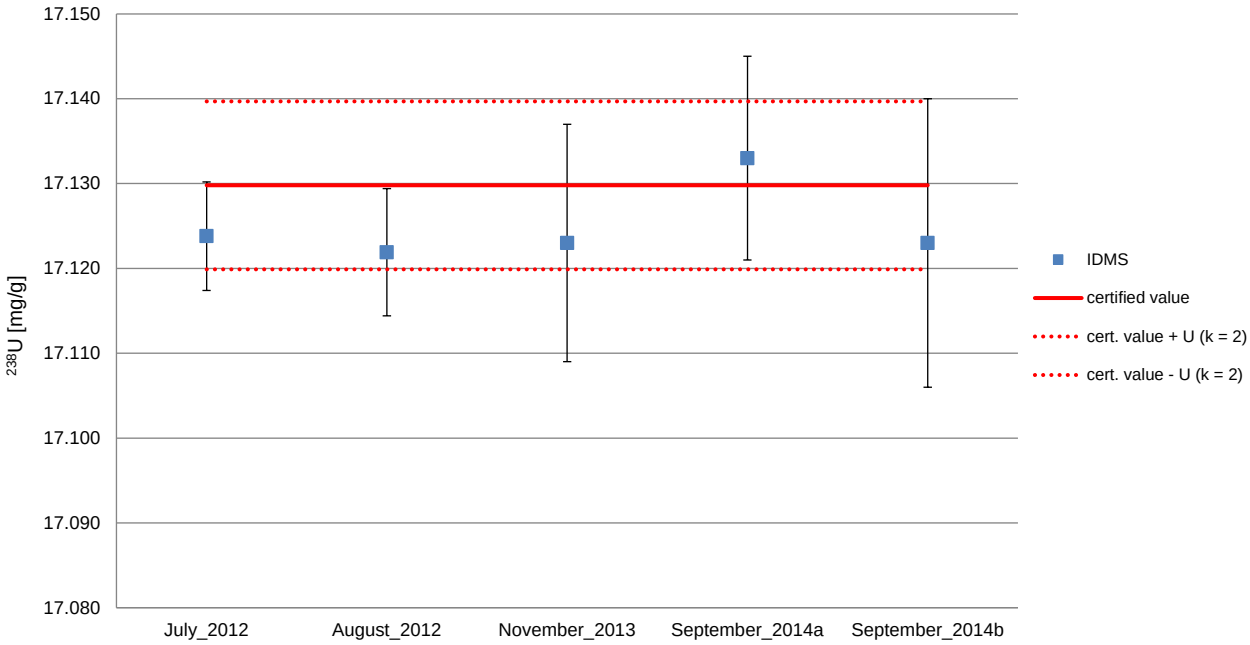

Fig. 7 The mass fraction of ^{238}U in IRMM-1027o compared with the certified values for the post certification monitoring (with expanded uncertainties, coverage factor k = 2).

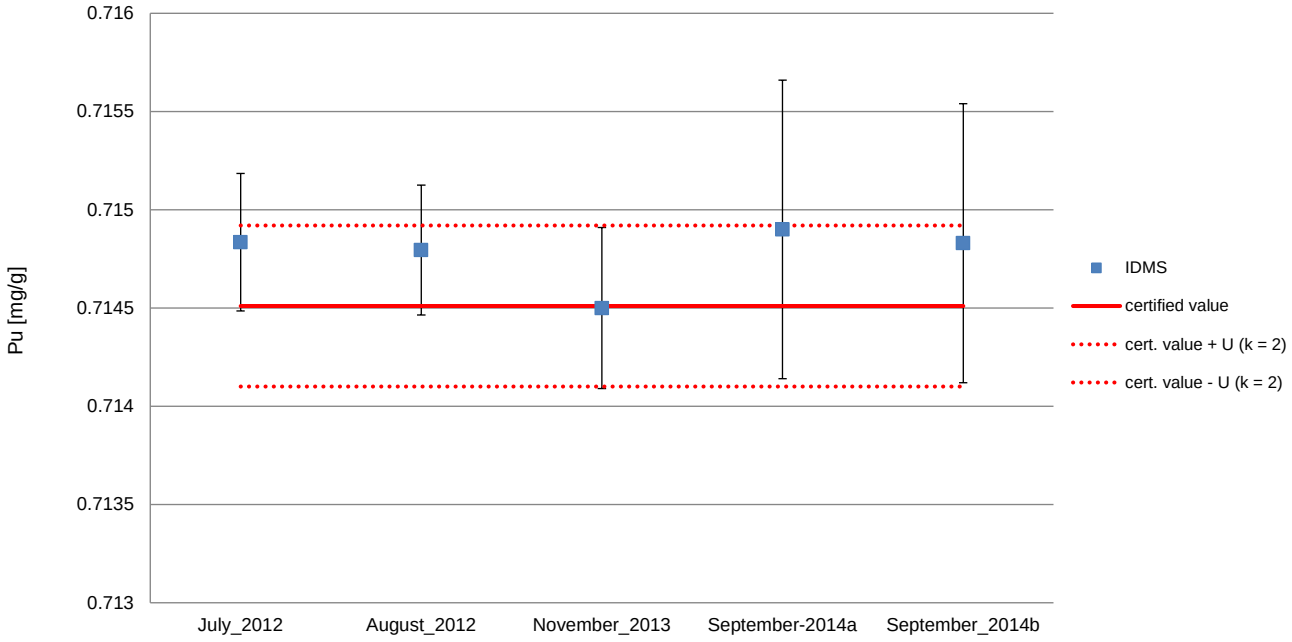

Fig. 8 The mass fraction of Pu in IRMM-1027o compared with the certified values for the post certification monitoring (with expanded uncertainties, coverage factor $k = 2$).

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

European Commission	**Certificate of weighing**	Institute for Reference Materials and Measurements

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Applicant:	R. Jakopič	**Unit**: SN3S
Project:	Preparation and certification of IRMM-1027q	
Description:	Dispensing of IRMM-1027q mother solution into single vials	
Weighing date: 29 September - 03 October 2014		

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-00368 / 2 "LSD automated system equipment manual" on balance Sartorius TE124 installed in the dispensing robot box with IRMM inventory No. 2006 00290 17.

Traceability:
The certified masses are traceable to the International Kilogram Prototype via regular calibrations of the IRMM principal mass standards. The mass standard identified as H208 (cylinder + vial certificate IRMM 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

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
001	2.6256	051	2.5462	101	2.5461	151	2.5682
002	2.6101	052	2.5448	102	2.5437	152	2.5503
003	2.6099	053	2.5727	103	2.5433	153	2.5484
004	2.6079	054	2.5435	104	2.5720	154	2.5447
005	2.5647	055	2.5460	105	2.5421	155	2.5406
006	2.5221	056	2.5437	106	2.5428	156	2.5447
007	2.5642	057	2.5463	107	2.5427	157	2.5413
008	2.5547	058	2.5475	108	2.5712	158	2.5721
009	2.5500	059	2.5478	109	2.5396	159	2.5424
010	2.5479	060	2.5460	110	2.5384	160	2.5427
011	2.5485	061	2.5466	111	2.5730	161	2.5431
012	2.5479	062	2.5718	112	2.5384	162	2.5398
013	2.5483	063	2.5441	113	2.5387	163	2.5491
014	2.5482	064	2.5447	114	2.5727	164	2.5487
015	2.5483	065	2.5449	115	2.5391	165	2.5723
016	2.5484	066	2.5444	116	2.5362	166	2.5398
017	2.5481	067	2.5461	117	2.5756	167	2.5523
018	2.5483	068	2.5476	118	2.5370	168	2.5477
019	2.5482	069	2.5460	119	2.5368	169	2.5411
020	2.5483	070	2.5466	120	2.5767	170	2.5527
021	2.5485	071	2.5467	121	2.5389	171	2.5467
022	2.5483	072	2.5737	122	2.5365	172	2.5561
023	2.5485	073	2.5466	123	2.5740	173	2.5500
024	2.5485	074	2.5450	124	2.5444	174	2.5482
025	2.5483	075	2.5455	125	2.5558	175	2.5464
026	2.5483	076	2.5457	126	2.5444	176	2.5488
027	2.5485	077	2.5450	127	2.5480	177	2.5385
028	2.5483	078	2.5450	128	2.5543	178	2.5438
029	2.5481	079	2.5460	129	2.5521	179	2.5452
030	2.5485	080	2.5460	130	2.5421	180	2.5444
031	2.5479	081	2.5465	131	2.5411	181	2.5666
032	2.5482	082	2.5471	132	2.5451	182	2.5462
033	2.5481	083	2.5458	133	2.5685	183	2.5392
034	2.5483	084	2.5466	134	2.5444	184	2.5390
035	2.5477	085	2.5726	135	2.5484	185	2.5474
036	2.5485	086	2.5443	136	2.5474	186	2.5459
037	2.5478	087	2.5454	137	2.5479	187	2.5688
038	2.5478	088	2.5453	138	2.5460	188	2.5470
039	2.5475	089	2.5443	139	2.5474	189	2.5474
040	2.5478	090	2.5455	140	2.5483	190	2.5474
041	2.5473	091	2.5463	141	2.5483	191	2.5469
042	2.5466	092	2.5463	142	2.5668	192	2.5374
043	2.5465	093	2.5464	143	2.5408	193	2.5362
044	2.5451	094	2.5469	144	2.5491	194	2.5750
045	2.5452	095	2.5737	145	2.5479	195	2.5223
046	2.5454	096	2.5449	146	2.5478	196	2.5362
047	2.5461	097	2.5453	147	2.5461	197	2.5752
048	2.5449	098	2.5735	148	2.5453	198	2.5343
049	2.5441	099	2.5453	149	2.5474	199	2.5357
050	2.5441	100	2.5473	150	2.5478	200	2.5717

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
201	2.5363	251	2.5478	301	2.5474	351	2.5468
202	2.5368	252	2.5468	302	2.5478	352	2.5447
203	2.5687	253	2.5466	303	2.5481	353	2.5457
204	2.5358	254	2.5473	304	2.5478	354	2.5448
205	2.5365	255	2.5466	305	2.5472	355	2.5427
206	2.5706	256	2.5469	306	2.5471	356	2.5409
207	2.5352	257	2.5471	307	2.5476	357	2.5405
208	2.5363	258	2.5468	308	2.5477	358	2.5703
209	2.5711	259	2.5469	309	2.5480	359	2.5434
210	2.5339	260	2.5468	310	2.5480	360	2.5425
211	2.5352	261	2.5470	311	2.5477	361	2.5410
212	2.5736	262	2.5471	312	2.5473	362	2.5386
213	2.5345	263	2.5467	313	2.5466	363	2.5707
214	2.5360	264	2.5472	314	2.5479	364	2.5406
215	2.5718	265	2.5470	315	2.5488	365	2.5418
216	2.5347	266	2.5468	316	2.5489	366	2.5387
217	2.5349	267	2.5469	317	2.5668	367	2.5657
218	2.5730	268	2.5465	318	2.5250	368	2.5436
219	2.5351	269	2.5470	319	2.5662	369	2.5433
220	2.5357	270	2.5469	320	2.5267	370	2.5395
221	2.5713	271	2.5469	321	2.5637	371	2.5382
222	2.5337	272	2.5471	322	2.5526	372	2.5735
223	2.5345	273	2.5470	323	2.5468	373	2.5412
224	2.5744	274	2.5467	324	2.5470	374	2.5406
225	2.5343	275	2.5468	325	2.5495	375	2.5391
226	2.5323	276	2.5467	326	2.5460	376	2.5639
227	2.5516	277	2.5467	327	2.5487	377	2.5402
228	2.5457	278	2.5467	328	2.5476	378	2.5357
229	2.5459	279	2.5469	329	2.5473	379	2.5380
230	2.5730	280	2.5468	330	2.5470	380	2.5689
231	2.5479	281	2.5467	331	2.5468	381	2.5397
232	2.5470	282	2.5468	332	2.5470	382	2.5393
233	2.5472	283	2.5470	333	2.5473	383	2.5380
234	2.5469	284	2.5470	334	2.5479	384	2.5721
235	2.5482	285	2.5467	335	2.5465	385	2.5430
236	2.5488	286	2.5473	336	2.5475	386	2.5394
237	2.5463	287	2.5468	337	2.5469	387	2.5375
238	2.5457	288	2.5471	338	2.5467	388	2.5685
239	2.5477	289	2.5524	339	2.5467	389	2.5390
240	2.5479	290	2.5470	340	2.5474	390	2.5394
241	2.5451	291	2.5395	341	2.5462	391	2.5382
242	2.5473	292	2.5473	342	2.5471	392	2.5657
243	2.5479	293	2.5478	343	2.5475	393	2.5426
244	2.5457	294	2.5471	344	2.5476	394	2.5451
245	2.5460	295	2.5467	345	2.5470	395	2.5442
246	2.5479	296	2.5461	346	2.5469	396	2.5406
247	2.5444	297	2.5455	347	2.5425	397	2.5628
248	2.5486	298	2.5463	348	2.5452	398	2.5428
249	2.5484	299	2.5469	349	2.5471	399	2.5430
250	2.5460	300	2.5468	350	2.5457	400	2.5398

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
0401	2.5389	451	2.5420	501	2.5271	551	2.5704
0402	2.5735	452	2.5361	502	2.5371	552	2.5307
0403	2.5392	453	2.5662	503	2.5730	553	2.5587
0404	2.5409	454	2.5374	504	2.5355	554	2.5300
0405	2.5373	455	2.5361	505	2.5329	555	2.5623
0406	2.5692	456	2.5633	506	2.5711	556	2.5284
0407	2.5427	457	2.5379	507	2.5351	557	2.5639
0408	2.5375	458	2.5344	508	2.5328	558	2.5255
0409	2.5374	459	2.5700	509	2.5703	559	2.5656
0410	2.5713	460	2.5365	510	2.5355	560	2.5271
0411	2.5419	461	2.5388	511	2.5334	561	2.5637
0412	2.5375	462	2.5649	512	2.5693	562	2.5261
0413	2.5618	463	2.5360	513	2.5361	563	2.5649
0414	2.5386	464	2.5376	514	2.5342	564	2.5255
0415	2.5355	465	2.5343	515	2.5695	565	2.5657
0416	2.5685	466	2.5718	516	2.5355	566	2.5271
0417	2.5381	467	2.5375	517	2.5338	567	2.5638
0418	2.5358	468	2.5346	518	2.5685	568	2.5272
0419	2.5671	469	2.5635	519	2.5348	569	2.5630
0420	2.5417	470	2.5358	520	2.5339	570	2.5259
0421	2.5380	471	2.5353	521	2.5702	571	2.5657
422	2.5385	472	2.5690	522	2.5348	572	2.5258
423	2.5712	473	2.5373	523	2.5341	573	2.5655
424	2.5381	474	2.5342	524	2.5679	574	2.5265
425	2.5361	475	2.5697	525	2.5348	575	2.5644
426	2.5626	476	2.5380	526	2.5335	576	2.5255
427	2.5371	477	2.5351	527	2.5708	577	2.5660
428	2.5391	478	2.5659	528	2.5348	578	2.5246
429	2.5669	479	2.5363	529	2.5312	579	2.5651
430	2.5384	480	2.5341	530	2.5579	580	2.5243
431	2.5356	481	2.5716	531	2.5353	581	2.5659
432	2.5675	482	2.5364	532	2.5345	582	2.5251
433	2.5377	483	2.5334	533	2.5731	583	2.5659
434	2.5341	484	2.5687	534	2.5346	584	2.5261
435	2.5679	485	2.5372	535	2.5342	585	2.5688
436	2.5370	486	2.5327	536	2.5676	586	2.5211
437	2.5355	487	2.5683	537	2.5340	587	2.5649
438	2.5661	488	2.5363	538	2.5337	588	2.5502
439	2.5402	489	2.5359	539	2.5638	589	2.5225
440	2.5355	490	2.5352	540	2.5344	590	2.5659
441	2.5654	491	2.5726	541	2.5339	591	2.5487
442	2.5383	492	2.5376	542	2.5699	592	2.5229
443	2.5398	493	2.5378	543	2.5354	593	2.5664
444	2.5597	494	2.5366	544	2.5344	594	2.5219
445	2.5498	495	2.5729	545	2.5679	595	2.5660
446	2.5424	496	2.5383	546	2.5351	596	2.5469
447	2.5442	497	2.5395	547	2.5340	597	2.5226
448	2.5437	498	2.5365	548	2.5670	598	2.5665
449	2.5375	499	2.5705	549	2.5331	599	2.5226
450	2.5441	500	2.5384	550	2.5337	600	2.5655

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
601	2.5212	651	2.5484	701	2.5630	751	2.5202
602	2.5658	652	2.5187	702	2.5463	752	2.5612
603	2.5214	653	2.5631	703	2.5203	753	2.5506
604	2.5651	654	2.5502	704	2.5666	754	2.5198
605	2.5487	655	2.5190	705	2.5458	755	2.5648
606	2.5219	656	2.5616	706	2.5208	756	2.5201
607	2.5650	657	2.5510	707	2.5637	757	2.5632
608	2.5212	658	2.5194	708	2.5490	758	2.5499
609	2.5651	659	2.5614	709	2.5206	759	2.5182
610	2.5439	660	2.5487	710	2.5636	760	2.5629
611	2.5458	661	2.5192	711	2.5516	761	2.5461
612	2.5227	662	2.5622	712	2.5204	762	2.5205
613	2.5657	663	2.5480	713	2.5620	763	2.5621
614	2.5213	664	2.5195	714	2.5495	764	2.5506
615	2.5645	665	2.5616	715	2.5198	765	2.5195
616	2.5219	666	2.5513	716	2.5640	766	2.5612
617	2.5650	667	2.5188	717	2.5427	767	2.5514
618	2.5476	668	2.5619	718	2.5449	768	2.5201
619	2.5204	669	2.5521	719	2.5206	769	2.5630
620	2.5638	670	2.5189	720	2.5628	770	2.5489
621	2.5226	671	2.5606	721	2.5495	771	2.5200
622	2.5638	672	2.5504	722	2.5197	772	2.5627
623	2.5202	673	2.5195	723	2.5632	773	2.5437
624	2.5647	674	2.5615	724	2.5455	774	2.5200
625	2.5468	675	2.5502	725	2.5429	775	2.5622
626	2.5230	676	2.5186	726	2.5433	776	2.5501
627	2.5635	677	2.5628	727	2.5456	777	2.5198
628	2.5204	678	2.5478	728	2.5211	778	2.5631
629	2.5645	679	2.5188	729	2.5624	779	2.5452
630	2.5445	680	2.5627	730	2.5522	780	2.5199
631	2.5435	681	2.5492	731	2.5201	781	2.5623
632	2.5440	682	2.5191	732	2.5630	782	2.5452
633	2.5431	683	2.5633	733	2.5457	783	2.5185
634	2.5452	684	2.5426	734	2.5442	784	2.5642
635	2.5419	685	2.5198	735	2.5210	785	2.5464
636	2.5454	686	2.5619	736	2.5653	786	2.5195
637	2.5201	687	2.5503	737	2.5440	787	2.5625
638	2.5629	688	2.5199	738	2.5447	788	2.5447
639	2.5528	689	2.5619	739	2.5202	789	2.5201
640	2.5188	690	2.5508	740	2.5644	790	2.5650
641	2.5631	691	2.5195	741	2.5498	791	2.5197
642	2.5475	692	2.5624	742	2.5192	792	2.5578
643	2.5195	693	2.5501	743	2.5629	793	2.5476
644	2.5629	694	2.5205	744	2.5501	794	2.5197
645	2.5503	695	2.5611	745	2.5209	795	2.5636
646	2.5197	696	2.5502	746	2.5612	796	2.5474
647	2.5628	697	2.5196	747	2.5197	797	2.5190
648	2.5495	698	2.5621	748	2.5652	798	2.5626
649	2.5191	699	2.5500	749	2.5417	799	2.5438
650	2.5625	700	2.5205	750	2.5463	800	2.5408

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
801	2.5456	851	2.5626	901	2.5619	951	2.5214
802	2.5214	852	2.5200	902	2.5198	952	2.5643
803	2.5621	853	2.5635	903	2.5626	953	2.5215
804	2.5486	854	2.5221	904	2.5194	954	2.5638
805	2.5196	855	2.5524	905	2.5625	955	2.5208
806	2.5650	856	2.5213	906	2.5466	956	2.5642
807	2.5416	857	2.5639	907	2.5192	957	2.5214
808	2.5445	858	2.5205	908	2.5619	958	2.5643
809	2.5199	859	2.5641	909	2.5202	959	2.5217
810	2.5624	860	2.5209	910	2.5626	960	2.5646
811	2.5483	861	2.5635	911	2.5467	0961	2.5229
812	2.5192	862	2.5215	912	2.5203	0962	2.5636
813	2.5620	863	2.5631	913	2.5625	0963	2.5147
814	2.5490	864	2.5440	914	2.5204	0964	2.5652
815	2.5163	865	2.5359	915	2.5625	965	2.5214
816	2.5617	866	2.5546	916	2.5445	966	2.5645
817	2.5204	867	2.5181	917	2.5197	967	2.5178
818	2.5624	868	2.5608	918	2.5621	968	2.5642
819	2.5475	869	2.5212	919	2.5475	969	2.5217
820	2.5185	870	2.5616	920	2.5195	970	2.5641
821	2.5619	871	2.5428	921	2.5629	971	2.5211
822	2.5195	872	2.5424	922	2.5199	972	2.5641
823	2.5631	873	2.5410	923	2.5597	973	2.5217
824	2.5421	874	2.5434	924	2.5198	974	2.5638
825	2.5431	875	2.5189	925	2.5621	975	2.5214
826	2.5426	876	2.5627	926	2.5198	976	2.5643
827	2.5183	877	2.5445	927	2.5627	977	2.5221
828	2.5615	878	2.5195	928	2.5203	978	2.5640
829	2.5486	879	2.5619	929	2.5637	979	2.5216
830	2.5194	880	2.5423	930	2.5200	980	2.5638
831	2.5632	881	2.5427	931	2.5644	981	2.5239
832	2.5443	882	2.5190	932	2.5208	982	2.5635
833	2.5208	883	2.5627	933	2.5626	983	2.5202
834	2.5501	884	2.5189	934	2.5447	984	2.5642
835	2.5546	885	2.5616	935	2.5219	985	2.5442
836	2.5177	886	2.5427	936	2.5628	986	2.5204
837	2.5625	887	2.5419	937	2.5206	987	2.5604
838	2.5469	888	2.5420	938	2.5638	988	2.5211
839	2.5161	889	2.5201	939	2.5213	989	2.5638
840	2.5633	890	2.5655	940	2.5643	990	2.5205
841	2.5200	891	2.5191	941	2.5209	991	2.5642
842	2.5580	892	2.5630	942	2.5650	992	2.5211
843	2.5449	893	2.5433	943	2.5208	993	2.5638
844	2.5202	894	2.5195	944	2.5648	994	2.5217
845	2.5629	895	2.5636	945	2.5219	995	2.5635
846	2.5468	896	2.5435	946	2.5676	996	2.5215
847	2.5202	897	2.5416	947	2.5219	997	2.5636
848	2.5625	898	2.5204	948	2.5649	998	2.5213
849	2.5491	899	2.5624	949	2.5218	999	2.5641
850	2.5211	900	2.5222	950	2.5638	1000	2.5209

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
1001	2.5635	1051	2.5207	1101	2.5441
1002	2.5214	1052	2.5610	1102	2.5418
1003	2.5641	1053	2.5220	1103	2.5428
1004	2.5223	1054	2.5620	1104	2.5411
1005	2.5638	1055	2.5209	1105	2.5430
1006	2.5336	1056	2.5629	1106	2.5409
1007	2.5205	1057	2.5483	1107	2.5429
1008	2.5638	1058	2.5418	1108	2.5433
1009	2.5209	1059	2.5426	1109	2.5390
1010	2.5642	1060	2.5141	1110	2.5466
1011	2.5208	1061	2.5598	1111	2.5391
1012	2.5639	1062	2.5388	1112	2.5442
1013	2.5201	1063	2.5450	1113	2.5419
1014	2.5644	1064	2.5171	1114	2.5425
1015	2.5206	1065	2.5630	1115	2.5429
1016	2.5627	1066	2.5455	1116	2.5135
1017	2.5439	1067	2.5166	1117	2.5641
1018	2.5203	1068	2.5621	1118	2.5195
1019	2.5625	1069	2.5457	1119	2.5639
1020	2.5162	1070	2.5156	1120	2.5199
1021	2.5631	1071	2.5636	1121	2.5663
1022	2.5206	1072	2.5363	1122	2.5177
1023	2.5637	1073	2.5404	1123	2.5604
1024	2.5212	1074	2.5408	1124	2.5499
1025	2.5629	1075	2.5416	1125	2.5374
1026	2.5203	1076	2.5296	1126	2.5560
1027	2.5646	1077	2.5542		
1028	2.5208	1078	2.5163		
1029	2.5627	1079	2.5636		
1030	2.5211	1080	2.5178		
1031	2.5635	1081	2.5633		
1032	2.5213	1082	2.5411		
1033	2.5620	1083	2.5414		
1034	2.5461	1084	2.5442		
1035	2.5206	1085	2.5416		
1036	2.5633	1086	2.5429		
1037	2.5207	1087	2.5418		
1038	2.5623	1088	2.5423		
1039	2.5214	1089	2.5422		
1040	2.5666	1090	2.5418		
1041	2.5204	1091	2.5425		
1042	2.5630	1092	2.5347		
1043	2.5205	1093	2.5222		
1044	2.5637	1094	2.5578		
1045	2.5208	1095	2.5174		
1046	2.5629	1096	2.5630		
1047	2.5206	1097	2.5464		
1048	2.5632	1098	2.5392		
1049	2.5209	1099	2.5447		
1050	2.5626	1100	2.5400		

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Annex 13: Uncertainty budget for the uranium gravimetric mixture of IRMM-1027q.

Uranium gravimetric mixture for IRMM-1027q

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 nitric acid solution.

Input parameters: a) masses of the metals and the nitrate solution (E3853) b) purity of the metals (metal certificates) c) uranium isotope amount ratios of the metals (certificate) d) atomic masses for uranium isotopes from G. Audi et al., Nuclear Physics A 729, 337-676, 2003

Model Equation:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$\gamma_{Umixture}=(m_{UCRM116A}*\eta_{purityCRM116A}+m_{UEC101}*\eta_{purityEC101})/m_{solution1027q}$;

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

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

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

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

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

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

{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-1027q
$\gamma_{235Umixture}$	g/g	^{235}U mass fraction in IRMM-1027q
$\gamma_{238Umixture}$	g/g	^{238}U mass fraction in IRMM-1027q
$c_{Umixture}$	mol/g	U amount content in IRMM-1027q
$c_{235Umixture}$	mol/g	^{235}U amount content in IRMM-1027q
$c_{238Umixture}$	mol/g	^{238}U amount content in IRMM-1027q
M_U	g/mol	Molar mass of U in IRMM-1027q
$R_{233U/238U}$	mol/mol	^{233}U/^{238}U amount ratio in IRMM-1027q
$R_{234U/238U}$	mol/mol	^{234}U/^{238}U amount ratio in IRMM-1027q
$R_{235U/238U}$	mol/mol	^{235}U/^{238}U amount ratio in IRMM-1027q
$R_{236U/238U}$	mol/mol	^{236}U/^{238}U amount ratio in IRMM-1027q
f_{233U}	mol/mol	^{233}U amount fraction in IRMM-1027q

Quantity	Unit	Definition
f_{234U}	mol/mol	^{234}U amount fraction in IRMM-1027q
f_{235U}	mol/mol	^{235}U amount fraction in IRMM-1027q
f_{236U}	mol/mol	^{236}U amount fraction in IRMM-1027q
f_{238U}	mol/mol	^{238}U amount fraction in IRMM-1027q
w_{233U}	g/g	^{233}U mass fraction in IRMM-1027q
w_{234U}	g/g	^{234}U mass fraction in IRMM-1027q
w_{235U}	g/g	^{235}U mass fraction in IRMM-1027q
w_{236U}	g/g	^{236}U mass fraction in IRMM-1027q
w_{238U}	g/g	^{238}U mass fraction in IRMM-1027q
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
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
$m_{solution1027q}$	g	Mass of gravimetric mixture, IRMM-1027q
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-116A
$\eta_{purityCRM116A}$	g/g	Purity of enriched uranium metal, NBL CRM-116A
M_{Ua}	g/mol	Molar mass of U in EC NRM 101
f_{233Ua}		^{233}U amount fraction in EC NRM 101
f_{234Ua}		^{234}U amount fraction in EC NRM 101
f_{235Ua}		^{235}U amount fraction in EC NRM 101
f_{236Ua}		^{236}U amount fraction in EC NRM 101
f_{238Ua}		^{238}U amount fraction in EC NRM 101
M_{Ub}	g/mol	Molar mass of U in NBL CRM-116A
f_{233Ub}		^{233}U amount fraction in NBL CRM 116-A
f_{234Ub}		^{234}U amount fraction in NBL CRM 116-A
f_{235Ub}		^{235}U amount fraction in NBL CRM 116-A
f_{236Ub}		^{236}U amount fraction in NBL CRM 116-A

Quantity	Unit	Definition
f_{238Ub}		^{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
$R_{238U/235Ub}$	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-1027q
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

M_{233U}: Type B normal distribution
Value: 233.0396352 g/mol
Expanded Uncertainty: 0.0000058 g/mol
Coverage Factor: 2

G. Audi et al., The AME2003 atomic mass evaluation, Nuclear Physics A 729, 337-676, 2003

M_{234U}: Type B normal distribution
Value: 234.0409521 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al., The AME2003 atomic mass evaluation, Nuclear Physics A 729, 337-676, 2003

M_{235U}: Type B normal distribution
Value: 235.0439299 g/mol
Expanded Uncertainty: 0.00000040 g/mol
Coverage Factor: 2

G. Audi et al., The AME2003 atomic mass evaluation, Nuclear Physics A 729, 337-676, 2003

M_{236U}: Type B normal distribution
Value: 236.0455680 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al., The AME2003 atomic mass evaluation, Nuclear Physics A 729, 337-676, 2003

M_{238U}: Type B normal distribution
Value: 238.0507882 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al., The AME2003 atomic mass evaluation, Nuclear Physics A 729, 337-676, 2003

$m_{solution1027q}$: Type B normal distribution
Value: 3097.50 g
Expanded Uncertainty: 0.04 g
Coverage Factor: 2

E3853

m_{UEC101}: Type B normal distribution
Value: 54.87388 g
Expanded Uncertainty: 0.00011 g
Coverage Factor: 2

E3853

$\eta_{purityEC101}$: 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: 12.32612 g
Expanded Uncertainty: 0.00007 g
Coverage Factor: 2

E3853

$\eta_{purityCRM116A}$: Type B normal distribution
Value: 0.99945 g/g
Expanded Uncertainty: 0.00014 g/g
Coverage Factor: 2

NBL CRM 116-A certificate

$R_{233U/238Ua}$: 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: 0.00000011 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: 0.0000018 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: 0.000000020 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: 2

CRM 116-A certificate

$R_{234U/235Ub}$: 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

Interim Results:

Quantity	Value	Standard Uncertainty
w_{233U}	$65.453 \cdot 10^{-9}$ g/g	$729 \cdot 10^{-12}$ g/g
n_{233U}	$18.870 \cdot 10^{-9}$ mol	$210 \cdot 10^{-12}$ mol
n_{234U}	$578.531 \cdot 10^{-6}$ mol	$239 \cdot 10^{-9}$ mol
n_{235U}	0.05050916 mol	$3.59 \cdot 10^{-5}$ mol
n_{236U}	$462.689 \cdot 10^{-6}$ mol	$189 \cdot 10^{-9}$ mol
n_{238U}	0.23133088 mol	$5.82 \cdot 10^{-5}$ mol
M_{Ua}	238.02889787 g/mol	$5.71 \cdot 10^{-6}$ g/mol
f_{234Ua}	$55.077 \cdot 10^{-6}$	$109 \cdot 10^{-9}$
f_{235Ua}	$7.20658 \cdot 10^{-3}$	$1.77 \cdot 10^{-6}$
f_{236Ua}	$149.9 \cdot 10^{-9}$	$19.9 \cdot 10^{-9}$
f_{238Ua}	0.99273819	$1.78 \cdot 10^{-6}$
M_{Ub}	235.1857242 g/mol	$55.1 \cdot 10^{-6}$ g/mol
f_{233Ub}	$360.24 \cdot 10^{-9}$	$4.01 \cdot 10^{-9}$
f_{234Ub}	0.01080225	$4.48 \cdot 10^{-6}$
f_{235Ub}	0.9325468	$18.6 \cdot 10^{-6}$
f_{236Ub}	$8.83243 \cdot 10^{-3}$	$3.56 \cdot 10^{-6}$
f_{238Ub}	0.0478182	$18.2 \cdot 10^{-6}$
$n_{234.a}$	$12.6953 \cdot 10^{-6}$ mol	$25.2 \cdot 10^{-9}$ mol
$n_{235.a}$	$1.661117 \cdot 10^{-3}$ mol	$411 \cdot 10^{-9}$ mol
$n_{236.a}$	$34.55 \cdot 10^{-9}$ mol	$4.58 \cdot 10^{-9}$ mol
$n_{238.a}$	0.22882610 mol	$5.74 \cdot 10^{-5}$ mol
$n_{233.b}$	$18.870 \cdot 10^{-9}$ mol	$210 \cdot 10^{-12}$ mol
$n_{234.b}$	$565.836 \cdot 10^{-6}$ mol	$238 \cdot 10^{-9}$ mol
$n_{235.b}$	0.04884804 mol	$3.56 \cdot 10^{-5}$ mol
$n_{236.b}$	$462.654 \cdot 10^{-6}$ mol	$189 \cdot 10^{-9}$ mol
$n_{238.b}$	$2.504781 \cdot 10^{-3}$ mol	$969 \cdot 10^{-9}$ mol
ΣR_U	1.2228427 mol/mol	$16.8 \cdot 10^{-6}$ mol/mol
ΣR_{Ua}	1.00731493 mol/mol	$1.80 \cdot 10^{-6}$ mol/mol
ΣR_{Ub}	1.0723323 mol/mol	$21.4 \cdot 10^{-6}$ mol/mol
w_{234Ua}	$54.154 \cdot 10^{-6}$ g/g	$107 \cdot 10^{-9}$ g/g
w_{235Ua}	$7.11621 \cdot 10^{-3}$ g/g	$1.75 \cdot 10^{-6}$ g/g
w_{236Ua}	$148.7 \cdot 10^{-9}$ g/g	$19.7 \cdot 10^{-9}$ g/g
w_{238Ua}	0.99282949 g/g	$1.76 \cdot 10^{-6}$ g/g
w_{233Ub}	$356.96 \cdot 10^{-9}$ g/g	$3.97 \cdot 10^{-9}$ g/g

Quantity	Value	Standard Uncertainty
w_{234Ub}	0.01074967 g/g	$4.46 \cdot 10^{-6}$ g/g
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:

$\gamma_{235Umixture}$: ^{235}U mass fraction in IRMM-1027q

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$m_{solution1027q}$	3097.5000 g	0.0200 g	normal	$-1.2 \cdot 10^{-6}$	$-25 \cdot 10^{-9}$ g/g	0.8 %
$m_{UCRM116A}$	12.3261200 g	$35.0 \cdot 10^{-6}$ g	normal	$300 \cdot 10^{-6}$	$11 \cdot 10^{-9}$ g/g	0.1 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$70.0 \cdot 10^{-6}$ g/g	normal	$3.7 \cdot 10^{-3}$	$260 \cdot 10^{-9}$ g/g	90.2 %
$R_{235U/238Ua}$	$7.25930 \cdot 10^{-3}$ mol/mol	$1.80 \cdot 10^{-6}$ mol/mol	normal	0.017	$31 \cdot 10^{-9}$ g/g	1.3 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85 \cdot 10^{-6}$ mol/mol	normal	$-3.4 \cdot 10^{-3}$	$-17 \cdot 10^{-9}$ g/g	0.4 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	$-3.5 \cdot 10^{-3}$	$-72 \cdot 10^{-9}$ g/g	6.9 %
$R_{236U/235Ub}$	$9.47130 \cdot 10^{-3}$ mol/mol	$3.85 \cdot 10^{-6}$ mol/mol	normal	$-3.5 \cdot 10^{-3}$	$-13 \cdot 10^{-9}$ g/g	0.2 %
$\gamma_{235Umixture}$	$3.832727 \cdot 10^{-3}$ g/g	$273 \cdot 10^{-9}$ g/g				

$\gamma_{238Umixture}$: ^{238}U mass fraction in IRMM-1027q

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$m_{solution1027q}$	3097.5000 g	0.0200 g	normal	$-5.7 \cdot 10^{-6}$	$-110 \cdot 10^{-9}$ g/g	6.2 %
m_{UEC101}	54.8738800 g	$55.0 \cdot 10^{-6}$ g	normal	$320 \cdot 10^{-6}$	$18 \cdot 10^{-9}$ g/g	0.1 %
$\eta_{purityEC101}$	0.9998500 g/g	$25.0 \cdot 10^{-6}$ g/g	normal	0.018	$440 \cdot 10^{-9}$ g/g	90.6 %
$R_{235U/238Ua}$	$7.25930 \cdot 10^{-3}$ mol/mol	$1.80 \cdot 10^{-6}$ mol/mol	normal	-0.017	$-31 \cdot 10^{-9}$ g/g	0.5 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	$3.6 \cdot 10^{-3}$	$73 \cdot 10^{-9}$ g/g	2.5 %
$\gamma_{238Umixture}$	0.017778369 g/g	$462 \cdot 10^{-9}$ g/g				

$c_{235Umixture}$: ^{235}U amount content in IRMM-1027q

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$m_{solution1027q}$	3097.5000 g	0.0200 g	normal	$-5.3 \cdot 10^{-9}$	$-110 \cdot 10^{-12}$ mol/g	0.8 %
$m_{UCRM116A}$	12.3261200 g	$35.0 \cdot 10^{-6}$ g	normal	$1.3 \cdot 10^{-6}$	$45 \cdot 10^{-12}$ mol/g	0.1 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$70.0 \cdot 10^{-6}$ g/g	normal	$16 \cdot 10^{-6}$	$1.1 \cdot 10^{-9}$ mol/g	90.2 %
$R_{235U/238Ua}$	$7.25930 \cdot 10^{-3}$ mol/mol	$1.80 \cdot 10^{-6}$ mol/mol	normal	$73 \cdot 10^{-6}$	$130 \cdot 10^{-12}$ mol/g	1.3 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85 \cdot 10^{-6}$ mol/mol	normal	$-15 \cdot 10^{-6}$	$-71 \cdot 10^{-12}$ mol/g	0.4 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	$-15 \cdot 10^{-6}$	$-310 \cdot 10^{-12}$ mol/g	6.9 %
$R_{236U/235Ub}$	$9.47130 \cdot 10^{-3}$ mol/mol	$3.85 \cdot 10^{-6}$ mol/mol	normal	$-15 \cdot 10^{-6}$	$-57 \cdot 10^{-12}$ mol/g	0.2 %
$c_{235Umixture}$	$16.30643 \cdot 10^{-6}$ mol/g	$1.16 \cdot 10^{-9}$ mol/g				

$c_{238Umixture}$: ^{238}U amount content in IRMM-1027q

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$m_{solution1027q}$	3097.5000 g	0.0200 g	normal	$-24 \cdot 10^{-9}$	$-480 \cdot 10^{-12}$ mol/g	6.2 %
m_{UEC101}	54.8738800 g	$55.0 \cdot 10^{-6}$ g	normal	$1.3 \cdot 10^{-6}$	$74 \cdot 10^{-12}$ mol/g	0.1 %
$\eta_{purityEC101}$	0.9998500 g/g	$25.0 \cdot 10^{-6}$ g/g	normal	$74 \cdot 10^{-6}$	$1.8 \cdot 10^{-9}$ mol/g	90.6 %
$R_{235U/238Ua}$	$7.25930 \cdot 10^{-3}$ mol/mol	$1.80 \cdot 10^{-6}$ mol/mol	normal	$-72 \cdot 10^{-6}$	$-130 \cdot 10^{-12}$ mol/g	0.5 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	$15 \cdot 10^{-6}$	$310 \cdot 10^{-12}$ mol/g	2.5 %
$c_{238Umixture}$	$74.68309 \cdot 10^{-6}$ mol/g	$1.94 \cdot 10^{-9}$ mol/g				

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

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$\eta_{purityEC101}$	0.9998500 g/g	$25.0 \cdot 10^{-6}$ g/g	normal	$-2.4 \cdot 10^{-3}$	$-60 \cdot 10^{-9}$ mol/mol	0.3 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$70.0 \cdot 10^{-6}$ g/g	normal	$2.4 \cdot 10^{-3}$	$170 \cdot 10^{-9}$ mol/mol	2.7 %
$R_{234U/238Ua}$	$55.480 \cdot 10^{-6}$ mol/mol	$110 \cdot 10^{-9}$ mol/mol	normal	0.99	$110 \cdot 10^{-9}$ mol/mol	1.1 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85 \cdot 10^{-6}$ mol/mol	normal	0.21	$1.0 \cdot 10^{-6}$ mol/mol	95.6 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	$-2.8 \cdot 10^{-3}$	$-58 \cdot 10^{-9}$ mol/mol	0.3 %
$R_{234U/238U}$	$2.50088 \cdot 10^{-3}$ mol/mol	$1.04 \cdot 10^{-6}$ mol/mol				

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

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$\eta_{purityEC101}$	0.9998500 g/g	$25.0 \cdot 10^{-6}$ g/g	normal	-0.21	$-5.2 \cdot 10^{-6}$ mol/mol	10.0 %
$m_{UCRM116A}$	12.3261200 g	$35.0 \cdot 10^{-6}$ g	normal	0.017	$590 \cdot 10^{-9}$ mol/mol	0.1 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$70.0 \cdot 10^{-6}$ g/g	normal	0.21	$15 \cdot 10^{-6}$ mol/mol	78.5 %
$R_{235U/238Ua}$	$7.25930 \cdot 10^{-3}$ mol/mol	$1.80 \cdot 10^{-6}$ mol/mol	normal	1.2	$2.1 \cdot 10^{-6}$ mol/mol	1.7 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85 \cdot 10^{-6}$ mol/mol	normal	-0.19	$-940 \cdot 10^{-9}$ mol/mol	0.3 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	-0.24	$-5.0 \cdot 10^{-6}$ mol/mol	9.1 %
$R_{236U/235Ub}$	$9.47130 \cdot 10^{-3}$ mol/mol	$3.85 \cdot 10^{-6}$ mol/mol	normal	-0.20	$-750 \cdot 10^{-9}$ mol/mol	0.2 %
$R_{235U/238U}$	0.2183416 mol/mol	$16.5 \cdot 10^{-6}$ mol/mol				

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

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$\eta_{purityEC101}$	0.9998500 g/g	$25.0 \cdot 10^{-6}$ g/g	normal	$-2.0 \cdot 10^{-3}$	$-49 \cdot 10^{-9}$ mol/mol	0.4 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$70.0 \cdot 10^{-6}$ g/g	normal	$2.0 \cdot 10^{-3}$	$140 \cdot 10^{-9}$ mol/mol	2.8 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5 \cdot 10^{-6}$ mol/mol	normal	$-2.3 \cdot 10^{-3}$	$-47 \cdot 10^{-9}$ mol/mol	0.3 %
$R_{236U/235Ub}$	$9.47130 \cdot 10^{-3}$ mol/mol	$3.85 \cdot 10^{-6}$ mol/mol	normal	0.21	$810 \cdot 10^{-9}$ mol/mol	96.4 %
$R_{236U/238U}$	$2.000118 \cdot 10^{-3}$ mol/mol	$821 \cdot 10^{-9}$ mol/mol				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
$\gamma_{Umixture}$	0.0216901 g/g	$1.1 \cdot 10^{-6}$ g/g	2.00	manual
$\gamma_{235Umixture}$	$3.83273 \cdot 10^{-3}$ g/g	$550 \cdot 10^{-9}$ g/g	2.00	manual
$\gamma_{238Umixture}$	0.01777837 g/g	$920 \cdot 10^{-9}$ g/g	2.00	manual
$c_{Umixture}$	$91.3257 \cdot 10^{-6}$ mol/g	$4.6 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{235Umixture}$	$16.3064 \cdot 10^{-6}$ mol/g	$2.3 \cdot 10^{-9}$ mol/g	2.00	manual
$c_{238Umixture}$	$74.6831 \cdot 10^{-6}$ mol/g	$3.9 \cdot 10^{-9}$ mol/g	2.00	manual
M_U	237.502425 g/mol	$68 \cdot 10^{-6}$ g/mol	2.00	manual
$R_{233U/238U}$	$81.6 \cdot 10^{-9}$ mol/mol	$1.8 \cdot 10^{-9}$ mol/mol	2.00	manual
$R_{234U/238U}$	$2.5009 \cdot 10^{-3}$ mol/mol	$2.1 \cdot 10^{-6}$ mol/mol	2.00	manual
$R_{235U/238U}$	0.218342 mol/mol	$33 \cdot 10^{-6}$ mol/mol	2.00	manual
$R_{236U/238U}$	$2.0001 \cdot 10^{-3}$ mol/mol	$1.6 \cdot 10^{-6}$ mol/mol	2.00	manual
f_{233U}	$66.7 \cdot 10^{-9}$ mol/mol	$1.5 \cdot 10^{-9}$ mol/mol	2.00	manual
f_{234U}	$2.0451 \cdot 10^{-3}$ mol/mol	$1.7 \cdot 10^{-6}$ mol/mol	2.00	manual
f_{235U}	0.178552 mol/mol	$22 \cdot 10^{-6}$ mol/mol	2.00	manual
f_{236U}	$1.6356 \cdot 10^{-3}$ mol/mol	$1.3 \cdot 10^{-6}$ mol/mol	2.00	manual
f_{238U}	0.817767 mol/mol	$22 \cdot 10^{-6}$ mol/mol	2.00	manual
w_{234U}	$2.0153 \cdot 10^{-3}$ g/g	$1.7 \cdot 10^{-6}$ g/g	2.00	manual
w_{235U}	0.176704 g/g	$22 \cdot 10^{-6}$ g/g	2.00	manual
w_{236U}	$1.6256 \cdot 10^{-3}$ g/g	$1.3 \cdot 10^{-6}$ g/g	2.00	manual
w_{238U}	0.819655 g/g	$22 \cdot 10^{-6}$ g/g	2.00	manual

Annex 14: The weighing certificate of the metals and the mother solution for the preparation of IRMM-1027q

Certificate of weighing

Institute for Reference Materials and Measurements

E. 3853 **Issued date**: 12 November 2014 **Page** 1 **of** 1

Applicant: R. Jakopič **Unit**: SN3S

Project: Preparation and certification of IRMM-1027q

Description: Preparation mother solution IRMM-1027q

Date of request: MP2 9 January 2014
EC 101 20 June 2014
CRM 116A 20 June 2014

Weighing date: 18 March 2014, 25 July 2014 and 27 July 2014

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

	Mass [g]	Uncertainty [g]
Mass of Pu metal (MP2)	2.35230	0.00007
Mass of U metal (CRM-116A)	12.32612	0.00007
Mass of U metal (EC 101)	54.87388	0.00011
Mass of IRMM-1027q solution	3097.50	0.04

Observations:
Masses were determined by substitution weighing on balances AT 261 and AT 201 with IRMM inventory No 1999 00337 27 and 1996 00547 73 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 IRMM principal mass standards. 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 %.

R. Jakopič
Nuclear Chemistry Laboratory responsible

J. Bauwens
Analyst

Retieseweg, B-2440 Geel, Belgium; Tel.: +32-(0)14-571 211 - Fax: +32-(0)14-571 978- http://www.irmm.jrc.be

Annex 15: The weighing certificate for the preparation of the blend mixtures the certification measurement of the plutonium in IRMM-1027q.

Certificate of weighing

Institute for Reference Materials and Measurements

Reg. No. E.3860 **Date of issue**: 15 December 2014 **Page** 1 **of** 1

Applicant: R. Jakopic **Project:** IRMM-1027q

Description: Certification of IRMM-1027q LSD vials using IRMM-046b

Request for analysis number: 3134 **Date of request**: 29 Oct 2014

Weighing date: 11 Nov 2014

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

Blend	IRMM-046b mass [g]	Uncertainty [g]
IRMM-1027q-232/046b-15	2.9962	0.0002
IRMM-1027q-176/046b-15	3.0097	0.0002
IRMM-1027q-337/046b-15	3.0145	0.0001
IRMM-1027q-424/046b-16	3.0122	0.0002
IRMM-1027q-622/046b-16	3.0224	0.0002
IRMM-1027q-791/046b-16	3.0344	0.0002
IRMM-1027q-888/046b-17	3.0139	0.0001
IRMM-1027q-1095/046b-17	3.0209	0.0001

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

Traceability:
The certified mass values are traceable to the International Kilogram Prototype via regular calibrations of the IRMM 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

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Annex 16: Uncertainty budget for the plutonium of IRMM-1027q by ID-TIMS (measurement date 16 Jan 2015).

Certification of Pu amount content IRMM-1027q by IDMS with 046b spike

Author: Rozle Jakopic

Isotope amount ratios from MP2 certificate (IRMM, 01/01/2007) decayed to reference date (1 Nov 2014)

Spike IRMM-046b

Date of measurement (IDMS): 16 Jan 2015

mass metrology certificates: E3861 (masses of vials), E3860 (blend mixtures)

IRMM-1027q vials (analytical sequence): 176, 232, 337, 424

no delta uncertainties added

reference date 1 Nov 2014

Model Equation:

$$f_{c242Pu}(m_x,m_y,R_b)=c_{y.IRMM046bdec}*(1/Rd_{242/239})*m_y/m_x*(R_{239/242Pu.IRMM046bdec}-(1/R_b))/(1/R_b-1/Rd_{242/239});$$

$$c_{239Pu1}=f_{c242Pu}(m_{x1},m_{y1},R_{b1})*e^{(\Delta t_{ref}*\lambda_{239})}+\delta_1;$$
$$c_{239Pu2}=f_{c242Pu}(m_{x2},m_{y2},R_{b2})*e^{(\Delta t_{ref}*\lambda_{239})}+\delta_2;$$
$$c_{239Pu3}=f_{c242Pu}(m_{x3},m_{y3},R_{b3})*e^{(\Delta t_{ref}*\lambda_{239})}+\delta_3;$$
$$c_{239Pu4}=f_{c242Pu}(m_{x4},m_{y4},R_{b4})*e^{(\Delta t_{ref}*\lambda_{239})}+\delta_4;$$

{----------concentration calculations----------}

$$c_{239Pu}=(c_{239Pu1}+c_{239Pu2}+c_{239Pu3}+c_{239Pu4})/4;$$

$$c_{Pu1}=c_{239Pu1}/fdnorm_{239};$$
$$c_{Pu2}=c_{239Pu2}/fdnorm_{239};$$
$$c_{Pu3}=c_{239Pu3}/fdnorm_{239};$$
$$c_{Pu4}=c_{239Pu4}/fdnorm_{239};$$

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

$$\gamma_{239Pu1}=c_{239Pu1}*M_{239Pu};$$
$$\gamma_{239Pu2}=c_{239Pu2}*M_{239Pu};$$
$$\gamma_{239Pu3}=c_{239Pu3}*M_{239Pu};$$
$$\gamma_{239Pu4}=c_{239Pu4}*M_{239Pu};$$

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

$\gamma_{Pu1}=Mdnorm_{Pu}*c_{Pu1}$;

$\gamma_{Pu2}=Mdnorm_{Pu}*c_{Pu2}$;

$\gamma_{Pu3}=Mdnorm_{Pu}*c_{Pu3}$;

$\gamma_{Pu4}=Mdnorm_{Pu}*c_{Pu4}$;

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

{----------operator----------}

$\varepsilon_1 = c_{239Pu} - c_{239Pu1}$;

$\varepsilon_2 = c_{239Pu} - c_{239Pu2}$;

$\varepsilon_3 = c_{239Pu} - c_{239Pu3}$;

$\varepsilon_4 = c_{239Pu} - c_{239Pu4}$;

{----------amount fractions on 1 Jan 2007 (MP2)----------}

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

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

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

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

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

$f_{244} = R_{244/239}/\Sigma R_{Pu}$;

$M_{Pu} = M_{238Pu}\cdot f_{238} + M_{239Pu}\cdot f_{239} + M_{240Pu}\cdot f_{240} + M_{241Pu}\cdot f_{241} + M_{242Pu}\cdot f_{242} + M_{244Pu}\cdot f_{244}$;

{----------sum of ratios aon 1 Jan 2007 (MP2)----------}

$\Sigma R_{Pu} = R_{238/239} + 1 + R_{240/239} + R_{241/239} + R_{242/239} + R_{244/239}$;

{----------decayed spike parameters----------}

$R_{239/242Pu.IRMM046bdec} = R_{239/242Pu.IRMM045b} * e^{(-\lambda_{239}\cdot\Delta t_{spike})}/(e^{(-\lambda_{242}\cdot\Delta t_{spike})})$;

$c_{y.IRMM046bdec} = c_{y.IRMM046b} * e^{(-\lambda_{242}\cdot\Delta t_{spike})}$;

{----------decayed isotopic ratios in the sample to 1 Nov 2014 (reference date)----------}

$Rd_{238/239} = R_{238/239}\cdot(e^{(-\lambda_{238}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

$Rd_{240/239} = R_{240/239}\cdot(e^{(-\lambda_{240}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

$Rd_{241/239} = R_{241/239}\cdot(e^{(-\lambda_{241}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

$Rd_{242/239} = R_{242/239}\cdot(e^{(-\lambda_{242}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

$Rd_{244/239} = R_{244/239}\cdot(e^{(-\lambda_{244}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

{----------normalised decayed amount fractions----------}

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

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

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

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

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

$fdnorm_{244} = Rd_{244/239}/\Sigma Rd_{Pu}$;

{----------normalised decayed mass fractions----------}

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

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

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

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

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

$wdnorm_{244} = fdnorm_{244} \cdot M_{244Pu}/Mdnorm_{Pu}$;

$Mdnorm_{Pu} = M_{238Pu} \cdot fdnorm_{238} + M_{239Pu} \cdot fdnorm_{239} + M_{240Pu} \cdot fdnorm_{240} + M_{241Pu} \cdot fdnorm_{241} + M_{242Pu} \cdot fdnorm_{242} + M_{244Pu} \cdot fdnorm_{244}$;

$\Sigma Rd_{Pu} = Rd_{238/239} + 1 + Rd_{240/239} + Rd_{241/239} + Rd_{242/239} + Rd_{244/239}$;

$ln_2 = ln(2)$;

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

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

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

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

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

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

List of Quantities:

Quantity	Unit	Definition
c_{Pu}	mol/g	amount content of Pu in IRMM-1027q
c_{239Pu}	mol/g	amount content of ^{239}Pu in IRMM-1027q
γ_{239Pu}	g/g	mass content of ^{239}Pu in IRMM-1027q
γ_{Pu}	g/g	mass content of Pu in IRMM-1027q
Δt_{norm}	a	time difference Pu MP2 Jan 2007 and reference date 01 Nov 2014

Quantity	Unit	Definition
$Mdnorm_{Pu}$	g/mol	molar mass of decayed Pu
$Rd_{238/239}$	mol/mol	isotope amount ratio n_{238}/n_{239} after decay, IRMM-1027q, 1 Nov 2014
$Rd_{240/239}$	mol/mol	isotope amount ratio n_{240}/n_{239} after decay, IRMM-1027q, 1 Nov 2014
$Rd_{241/239}$	mol/mol	isotope amount ratio n_{241}/n_{239} after decay, IRMM-1027q, 1 Nov 2014
$Rd_{242/239}$	mol/mol	isotope amount ratio n_{242}/n_{239} after decay, IRMM-1027q, 1 Nov 2014
$Rd_{244/239}$	mol/mol	isotope amount ratio n_{244}/n_{239} after decay, IRMM-1027q, 1 Nov 2014
$fdnorm_{238}$		normalised decayed mole fraction of ^{238}Pu , IRMM-1027q, 1 Nov 2014
$fdnorm_{239}$		normalised decayed mole fraction of ^{239}Pu , IRMM-1027q, 1 Nov 2014
$fdnorm_{240}$		normalised decayed mole fraction of ^{240}Pu, IRMM-1027q, 1 Nov 2014
$fdnorm_{241}$		normalised decayed mole fraction of ^{241}Pu, IRMM-1027q, 1 Nov 2014
$fdnorm_{242}$		normalised decayed mole fraction of ^{242}Pu, IRMM-1027q, 1 Nov 2014
$fdnorm_{244}$		normalised decayed mole fraction of ^{244}Pu, IRMM-1027q, 1 Nov 2014
$wdnorm_{238}$		normalised decayed mass fraction of ^{238}Pu, IRMM-1027q, 1 Nov 2014
$wdnorm_{239}$		normalised decayed mass fraction of ^{239}Pu, IRMM-1027q, 1 Nov 2014
$wdnorm_{240}$		normalised decayed mass fraction of ^{240}Pu, IRMM-1027q, 1 Nov 2014
$wdnorm_{241}$		normalised decayed mass fraction of ^{241}Pu, IRMM-1027q, 1 Nov 2014
$wdnorm_{242}$		normalised decayed mass fraction of ^{242}Pu, IRMM-1027q, 1 Nov 2014
$wdnorm_{244}$		normalised decayed mass fraction of ^{244}Pu, IRMM-1027q, 1 Nov 2014
$R_{238/239}$	mol/mol	isotope amount ratio n_{238}/n_{239} of Pu in IRMM-1027q MP2
$R_{240/239}$	mol/mol	isotope amount ratio n_{240}/n_{239} of Pu in IRMM-1027q MP2
$R_{241/239}$	mol/mol	isotope amount ratio n_{241}/n_{239} of Pu in IRMM-1027q MP2
$R_{242/239}$	mol/mol	isotope amount ratio n_{242}/n_{239} of Pu in IRMM-1027q MP2
$R_{244/239}$	mol/mol	isotope amount ratio n_{244}/n_{239} of Pu in IRMM-1027q MP2

Quantity	Unit	Definition
M_{Pu}	g/mol	molar mass of Pu
f_{238}		mole fraction of ^{238}Pu MP2
f_{239}		mole fraction of ^{239}Pu MP2
f_{240}		mole fraction of ^{240}Pu MP2
f_{241}		mole fraction of ^{241}Pu MP2
f_{242}		mole fraction of ^{242}Pu MP2
f_{244}		mole fraction of ^{244}Pu MP2
e		
ln_2		
ΣR_{Pu}		
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
M_{238Pu}	g/mol	atomic mass for ^{238}Pu
M_{239Pu}	g/mol	atomic mass for ^{239}Pu
M_{240Pu}	g/mol	atomic mass for ^{240}Pu
M_{241Pu}	g/mol	atomic mass for ^{241}Pu
M_{242Pu}	g/mol	atomic mass for ^{242}Pu
M_{244Pu}	g/mol	atomic mass for ^{244}Pu
ΣRd_{Pu}		
$c_{y.IRMM046bdec}$	mol/g	decayed amount content of ^{242}Pu in IRMM-046b
$c_{y.IRMM046b}$	mol/g	amount content of ^{242}Pu in IRMM-046b
$R_{239/242Pu.IRMM046bdec}$	mol/mol	decayed isotope amount ratio n_{239}/n_{242} of Pu in IRMM-046b
$R_{239/242Pu.IRMM046b}$		isotope amount ratio n_{239}/n_{242} of Pu in IRMM-046b
Δt_{spike}	a	time difference certificate 046b (1 June 2010) and reference date (01 Nov 2014)

Quantity	Unit	Definition
c_{239Pu1}	mol/g	amount content of ^{239}Pu in vial 176
c_{239Pu2}	mol/g	amount content of ^{239}Pu in vial 232
c_{239Pu3}	mol/g	amount content of ^{239}Pu in vial 337
c_{239Pu4}	mol/g	amount content of ^{239}Pu in vial 424
R_{b1}	mol/mol	measured ^{242}Pu/^{239}Pu ratio in blend 1, vial 176
R_{b2}	mol/mol	measured ^{242}Pu/^{239}Pu ratio in blend 2, vial 232
R_{b3}	mol/mol	measured ^{242}Pu/^{239}Pu ratio in blend 4, vial 337
R_{b4}	mol/mol	measured ^{242}Pu/^{239}Pu ratio in blend 4, vial 424
m_{x1}	g	mass of sample 1027q in vial 176
m_{x2}	g	mass of sample 1027q in vial 232
m_{x3}	g	mass of sample 1027q in vial 337
m_{x4}	g	mass of sample 1027q in vial 424
m_{y1}	g	mass of spike in blend 1, vial 176
m_{y2}	g	mass of spike in blend 2, vial 232
m_{y3}	g	mass of spike in blend 3, vial 337
m_{y4}	g	mass of spike in blend 4, vial 424
ε_1		
ε_2		
ε_3		
ε_4		
δ_1		
δ_2		
δ_3		
δ_4		
c_{Pu1}	mol/g	Pu amount content in vial 176
c_{Pu2}	mol/g	Pu amount content in vial 232
c_{Pu3}	mol/g	Pu amount content in vial 337
c_{Pu4}	mol/g	Pu amount content in vial 424
γ_{Pu1}	g/g	Pu mass content in vial 176
γ_{Pu2}	g/g	Pu mass content in vial 232
γ_{Pu3}	g/g	Pu mass content in vial 337
γ_{Pu4}	g/g	Pu mass content in vial 424
γ_{239Pu1}	g/g	^{239}Pu mass content in vial 176
γ_{239Pu2}	g/g	^{239}Pu mass content in vial 232
γ_{239Pu3}	g/g	^{239}Pu mass content in vial 337

Quantity	Unit	Definition
γ_{239Pu4}	g/g	^{239}Pu mass content in vial 424
Δt_{ref}	y	difference between IDMS measurement and reference date 1 Nov 2014

Δt_{norm}: Type B rectangular distribution
Value: 7.83299 a
Halfwidth of Limits: 0.019 a

01/01/2007, 01/11/2014, delta t= 2861 days/365.25=7.83299

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

MP2 certificate 1 Jan 2007

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

MP2 certificate 1 Jan 2007

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

MP2 certificate 1 Jan 2007

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

MP2 certificate 1 Jan 2007

$R_{244/239}$: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

MP2 certificate 1 Jan 2007

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: 6561 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

M_{238Pu}: Type B normal distribution
Value: 238.0495599 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{239Pu}: Type B normal distribution
Value: 239.0521634 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{240Pu}: Type B normal distribution
Value: 240.0538135 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{241Pu}: Type B normal distribution
Value: 241.0568515 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{242Pu}: Type B normal distribution
Value: 242.0587426 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{244Pu}: Type B normal distribution
Value: 244.064204 g/mol
Expanded Uncertainty: 0.000010 g/mol
Coverage Factor: 2

G. Audi et al, 2003

$c_{y.IRMM046b}$: Type B normal distribution
Value: $4.6504 \cdot 10^{-7}$ mol/g
Expanded Uncertainty: $0.0018 \cdot 10^{-7}$ mol/g
Coverage Factor: 2

IRMM-046b certificate

$R_{239/242Pu.IRMM046b}$ Type B normal distribution
Value: 0.002212
Expanded Uncertainty: 0.000016
Coverage Factor: 2

IRMM-046b certificate

Δt_{spike}: Type B rectangular distribution
Value: 4.41889 a
Halfwidth of Limits: 0.039 a

01/06/2010, 01/11/2014, delta t= 1614 days/365.25=4.41889

R_{b1}: Type B normal distribution
Value: 0.177777 mol/mol
Expanded Uncertainty: 0.000072 mol/mol
Coverage Factor: 2

R_{b2}: Type B normal distribution
Value: 0.177031 mol/mol
Expanded Uncertainty: 0.000067 mol/mol
Coverage Factor: 2

R_{b3}:
Type B normal distribution
Value: 0.178223 mol/mol
Expanded Uncertainty: 0.000104 mol/mol
Coverage Factor: 2

R_{b4}:
Type B normal distribution
Value: 0.178596 mol/mol
Expanded Uncertainty: 0.000067 mol/mol
Coverage Factor: 2

m_{x1}:
Type B normal distribution
Value: 2.5488 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3861

m_{x2}:
Type B normal distribution
Value: 2.5470 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3846

m_{x3}:
Type B normal distribution
Value: 2.5469 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3846

m_{x4}:
Type B normal distribution
Value: 2.5381 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3846

m_{y1}:
Type B normal distribution
Value: 3.0097 g
Expanded Uncertainty: 0.0002 g
Coverage Factor: 2

E3860

m_{y2}:
Type B normal distribution
Value: 2.9962 g
Expanded Uncertainty: 0.0002 g
Coverage Factor: 2

E3860

m_{y3}: Type B normal distribution
Value: 3.0145 g
Expanded Uncertainty: 0.0001 g
Coverage Factor: 2

E3860

m_{y4}: Type B normal distribution
Value: 3.0122 g
Expanded Uncertainty: 0.0002 g
Coverage Factor: 2

E3860

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

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

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

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

Δt_{ref}: Type B rectangular distribution
Value: -0.208077 y
Halfwidth of Limits: 0.00019 y

16/01/2015, 01/11/2014, delta t= 76 dats/365.25 = 0.208077

Input Correlation:

The abundance set for Pu is assumed as uncorrelated.

Interim Results:

Quantity	Value	Standard Uncertainty
c_{Pu}	$3.159566 \cdot 10^{-6}$ mol/g	$731 \cdot 10^{-12}$ mol/g
γ_{Pu}	$755.372 \cdot 10^{-6}$ g/g	$175 \cdot 10^{-9}$ g/g
$Mdnorm_{Pu}$	239.07463448 g/mol	$3.92 \cdot 10^{-6}$ g/mol
$Rd_{238/239}$	$28.987 \cdot 10^{-6}$ mol/mol	$136 \cdot 10^{-9}$ mol/mol
$Rd_{240/239}$	0.02241889 mol/mol	$2.55 \cdot 10^{-6}$ mol/mol
$Rd_{241/239}$	$162.82 \cdot 10^{-6}$ mol/mol	$1.07 \cdot 10^{-6}$ mol/mol
$Rd_{242/239}$	$75.716 \cdot 10^{-6}$ mol/mol	$390 \cdot 10^{-9}$ mol/mol
$fdnorm_{238}$	$28.344 \cdot 10^{-6}$	$133 \cdot 10^{-9}$
$fdnorm_{239}$	0.97781684	$2.67 \cdot 10^{-6}$
$fdnorm_{240}$	0.02192157	$2.44 \cdot 10^{-6}$
$fdnorm_{241}$	$159.21 \cdot 10^{-6}$	$1.04 \cdot 10^{-6}$
$fdnorm_{242}$	$74.036 \cdot 10^{-6}$	$381 \cdot 10^{-9}$
$wdnorm_{238}$	$28.222 \cdot 10^{-6}$	$133 \cdot 10^{-9}$
$wdnorm_{239}$	0.97772493	$2.68 \cdot 10^{-6}$
$wdnorm_{240}$	0.02201136	$2.45 \cdot 10^{-6}$
$wdnorm_{241}$	$160.53 \cdot 10^{-6}$	$1.05 \cdot 10^{-6}$
$wdnorm_{242}$	$74.960 \cdot 10^{-6}$	$386 \cdot 10^{-9}$
M_{Pu}	239.07479084 g/mol	$4.49 \cdot 10^{-6}$ g/mol
f_{238}	$30.143 \cdot 10^{-6}$	$142 \cdot 10^{-9}$
f_{239}	0.97773050	$2.88 \cdot 10^{-6}$
f_{240}	0.02193284	$2.44 \cdot 10^{-6}$
f_{241}	$232.50 \cdot 10^{-6}$	$1.52 \cdot 10^{-6}$
f_{242}	$74.014 \cdot 10^{-6}$	$381 \cdot 10^{-9}$
ΣR_{Pu}	1.02277673	$3.01 \cdot 10^{-6}$
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}
λ_{244}	$8.6643 \cdot 10^{-9}$ a^{-1}	$97.5 \cdot 10^{-12}$ a^{-1}
ΣRd_{Pu}	1.02268642	$2.79 \cdot 10^{-6}$
$c_{y.IRMM046bdec}$	$465.0362 \cdot 10^{-9}$ mol/g	$90.0 \cdot 10^{-12}$ mol/g
$R_{239/242Pu.IRMM046bdec}$	$2.21174 \cdot 10^{-3}$ mol/mol	$8.00 \cdot 10^{-6}$ mol/mol
ε_1	$532 \cdot 10^{-12}$	$648 \cdot 10^{-12}$

Quantity	Value	Standard Uncertainty
ε_2	$-764 \cdot 10^{-12}$	$629 \cdot 10^{-12}$
ε_3	$1.052 \cdot 10^{-9}$	$792 \cdot 10^{-12}$
ε_4	$-819 \cdot 10^{-12}$	$627 \cdot 10^{-12}$
c_{Pu1}	$3.159023 \cdot 10^{-6}$ mol/g	$966 \cdot 10^{-12}$ mol/g
c_{Pu2}	$3.160348 \cdot 10^{-6}$ mol/g	$939 \cdot 10^{-12}$ mol/g
c_{Pu3}	$3.15849 \cdot 10^{-6}$ mol/g	$1.17 \cdot 10^{-9}$ mol/g
c_{Pu4}	$3.160404 \cdot 10^{-6}$ mol/g	$936 \cdot 10^{-12}$ mol/g
γ_{Pu1}	$755.242 \cdot 10^{-6}$ g/g	$231 \cdot 10^{-9}$ g/g
γ_{Pu2}	$755.559 \cdot 10^{-6}$ g/g	$225 \cdot 10^{-9}$ g/g
γ_{Pu3}	$755.115 \cdot 10^{-6}$ g/g	$279 \cdot 10^{-9}$ g/g
γ_{Pu4}	$755.572 \cdot 10^{-6}$ g/g	$224 \cdot 10^{-9}$ g/g

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
c_{239Pu}	$3.0895 \cdot 10^{-6}$ mol/g	$1.4 \cdot 10^{-9}$ mol/g	2.00	manual
γ_{239Pu}	$738.55 \cdot 10^{-6}$ g/g	$340 \cdot 10^{-9}$ g/g	2.00	manual
c_{239Pu1}	$3.0889 \cdot 10^{-6}$ mol/g	$1.9 \cdot 10^{-9}$ mol/g	2.00	manual
c_{239Pu2}	$3.0902 \cdot 10^{-6}$ mol/g	$1.8 \cdot 10^{-9}$ mol/g	2.00	manual
c_{239Pu3}	$3.0884 \cdot 10^{-6}$ mol/g	$2.3 \cdot 10^{-9}$ mol/g	2.00	manual
c_{239Pu4}	$3.0903 \cdot 10^{-6}$ mol/g	$1.8 \cdot 10^{-9}$ mol/g	2.00	manual
γ_{239Pu1}	$738.42 \cdot 10^{-6}$ g/g	$450 \cdot 10^{-9}$ g/g	2.00	manual
γ_{239Pu2}	$738.73 \cdot 10^{-6}$ g/g	$440 \cdot 10^{-9}$ g/g	2.00	manual
γ_{239Pu3}	$738.29 \cdot 10^{-6}$ g/g	$550 \cdot 10^{-9}$ g/g	2.00	manual
γ_{239Pu4}	$738.74 \cdot 10^{-6}$ g/g	$440 \cdot 10^{-9}$ g/g	2.00	manual

Annex 17: Uncertainty budget for the plutonium of IRMM-1027q by ID-TIMS (measurement date 20 Jan 2015).

Certification of Pu amount content IRMM-1027q by IDMS with 046b spike

Author: Rozle Jakopic

Isotope amount ratios from MP2 certificate (IRMM, 01/01/2007) decayed to the reference date (01 Nov 2014)

Spike IRMM-046b

Date of measurement (IDMS): 20 Jan 2015

mass metrology certificates: E3861 (masses of vials), E3860 (blend mixtures)

IRMM-1027q vials (analytical sequence): 622, 791, 888, 1095

no delta uncertainties added

reference date: 01 Nov 2014

Model Equation:

$$f_{c242Pu}(m_x,m_y,R_b)=c_{y.IRMM046bdec}*(1/Rd_{242/239})*m_y/m_x*(R_{239/242Pu.IRMM046bdec}-(1/R_b))/(1/R_b-1/Rd_{242/239});$$

$$c_{239Pu1}=f_{c242Pu}(m_{x1},m_{y1},R_{b1})*e^{(\Delta t_{ref}*\lambda_{239})}+\delta_1;$$
$$c_{239Pu2}=f_{c242Pu}(m_{x2},m_{y2},R_{b2})*e^{(\Delta t_{ref}*\lambda_{239})}+\delta_2;$$
$$c_{239Pu3}=f_{c242Pu}(m_{x3},m_{y3},R_{b3})*e^{(\Delta t_{ref}*\lambda_{239})}+\delta_3;$$
$$c_{239Pu4}=f_{c242Pu}(m_{x4},m_{y4},R_{b4})*e^{(\Delta t_{ref}*\lambda_{239})}+\delta_4;$$

{----------concentration calculations----------}

$$c_{239Pu}=(c_{239Pu1}+c_{239Pu2}+c_{239Pu3}+c_{239Pu4})/4;$$

$$c_{Pu1}=c_{239Pu1}/fdnorm_{239};$$
$$c_{Pu2}=c_{239Pu2}/fdnorm_{239};$$
$$c_{Pu3}=c_{239Pu3}/fdnorm_{239};$$
$$c_{Pu4}=c_{239Pu4}/fdnorm_{239};$$

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

$$\gamma_{239Pu1}=c_{239Pu1}*M_{239Pu};$$
$$\gamma_{239Pu2}=c_{239Pu2}*M_{239Pu};$$
$$\gamma_{239Pu3}=c_{239Pu3}*M_{239Pu};$$
$$\gamma_{239Pu4}=c_{239Pu4}*M_{239Pu};$$

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

$\gamma_{Pu1}=Mdnorm_{Pu}*c_{Pu1}$;

$\gamma_{Pu2}=Mdnorm_{Pu}*c_{Pu2}$;

$\gamma_{Pu3}=Mdnorm_{Pu}*c_{Pu3}$;

$\gamma_{Pu4}=Mdnorm_{Pu}*c_{Pu4}$;

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

{----------operator----------}

$\varepsilon_1 = c_{239Pu} - c_{239Pu1}$;

$\varepsilon_2 = c_{239Pu} - c_{239Pu2}$;

$\varepsilon_3 = c_{239Pu} - c_{239Pu3}$;

$\varepsilon_4 = c_{239Pu} - c_{239Pu4}$;

{----------amount fractions on 1 Jan 2007 (MP2)----------}

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

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

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

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

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

$f_{244} = R_{244/239}/\Sigma R_{Pu}$;

$M_{Pu} = M_{238Pu}\cdot f_{238} + M_{239Pu}\cdot f_{239} + M_{240Pu}\cdot f_{240} + M_{241Pu}\cdot f_{241} + M_{242Pu}\cdot f_{242} + M_{244Pu}\cdot f_{244}$;

{----------sum of ratios aon 1 Jan 2007 (MP2)----------}

$\Sigma R_{Pu} = R_{238/239} + 1 + R_{240/239} + R_{241/239} + R_{242/239} + R_{244/239}$;

{----------decayed spike parameters----------}

$R_{239/242Pu.IRMM046bdec} = R_{239/242Pu.IRMM046b} * e^{(-\lambda_{239}\cdot\Delta t_{spike})}/(e^{(-\lambda_{242}\cdot\Delta t_{spike})})$;

$c_{y.IRMM046bdec} = c_{y.IRMM046b} * e^{(-\lambda_{242}\cdot\Delta t_{spike})}$;

{----------decayed isotopic ratios in the sample to 1 Nov 2014 (reference date)----------}

$Rd_{238/239} = R_{238/239}\cdot(e^{(-\lambda_{238}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

$Rd_{240/239} = R_{240/239}\cdot(e^{(-\lambda_{240}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

$Rd_{241/239} = R_{241/239}\cdot(e^{(-\lambda_{241}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

$Rd_{242/239} = R_{242/239}\cdot(e^{(-\lambda_{242}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

$Rd_{244/239} = R_{244/239}\cdot(e^{(-\lambda_{244}\cdot\Delta t_{norm})}/e^{(-\lambda_{239}\cdot\Delta t_{norm})})$;

{----------normalised decayed amount fractions----------}

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

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

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

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

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

$fdnorm_{244} = Rd_{244/239}/\Sigma Rd_{Pu}$;

{----------normalised decayed mass fractions----------}

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

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

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

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

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

$wdnorm_{244} = fdnorm_{244} \cdot M_{244Pu}/Mdnorm_{Pu}$;

$Mdnorm_{Pu} = M_{238Pu} \cdot fdnorm_{238} + M_{239Pu} \cdot fdnorm_{239} + M_{240Pu} \cdot fdnorm_{240} + M_{241Pu} \cdot fdnorm_{241} + M_{242Pu} \cdot fdnorm_{242} + M_{244Pu} \cdot fdnorm_{244}$;

$\Sigma Rd_{Pu} = Rd_{238/239} + 1 + Rd_{240/239} + Rd_{241/239} + Rd_{242/239} + Rd_{244/239}$;

$ln_2 = ln(2)$;

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

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

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

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

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

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

List of Quantities:

Quantity	Unit	Definition
c_{Pu}	mol/g	amount content of Pu in IRMM-1027q
c_{239Pu}	mol/g	amount content of ^{239}Pu in IRMM-1027q
γ_{239Pu}	g/g	mass content of ^{239}Pu in IRMM-1027q
γ_{Pu}	g/g	mass content of Pu in IRMM-1027q
Δt_{norm}	a	time difference Pu MP2 Jan 2007 and measurement Pu IDMS, 01 Nov 2014

Quantity	Unit	Definition
$Mdnorm_{Pu}$	g/mol	molar mass of decayed Pu
$Rd_{238/239}$	mol/mol	isotope amount ratio n_{238}/n_{239} after decay, IRMM-1027q, 01 Nov 2014
$Rd_{240/239}$	mol/mol	isotope amount ratio n_{240}/n_{239} after decay, IRMM-1027q, 01 Nov 2014
$Rd_{241/239}$	mol/mol	isotope amount ratio n_{241}/n_{239} after decay, IRMM-1027q, 01 Nov 2014
$Rd_{242/239}$	mol/mol	isotope amount ratio n_{242}/n_{239} after decay, IRMM-1027q, 01 Nov 2014
$Rd_{244/239}$	mol/mol	isotope amount ratio n_{244}/n_{239} after decay, IRMM-1027q, 01 Nov 2014
$fdnorm_{238}$		normalised decayed mole fraction of ^{238}Pu , IRMM-1027q, 01 Nov 2014
$fdnorm_{239}$		normalised decayed mole fraction of ^{239}Pu , IRMM-1027q, 01 Nov 2014
$fdnorm_{240}$		normalised decayed mole fraction of ^{240}Pu, IRMM-1027q, 01 Nov 2014
$fdnorm_{241}$		normalised decayed mole fraction of ^{241}Pu, IRMM-1027q, 01 Nov 2014
$fdnorm_{242}$		normalised decayed mole fraction of ^{242}Pu, IRMM-1027q, 01 Nov 2014
$fdnorm_{244}$		normalised decayed mole fraction of ^{244}Pu, IRMM-1027q, 01 Nov 2014
$wdnorm_{238}$		normalised decayed mass fraction of ^{238}Pu, IRMM-1027q, 01 Nov 2014
$wdnorm_{239}$		normalised decayed mass fraction of ^{239}Pu, IRMM-1027q, 01 Nov 2014
$wdnorm_{240}$		normalised decayed mass fraction of ^{240}Pu, IRMM-1027q, 01 Nov 2014
$wdnorm_{241}$		normalised decayed mass fraction of ^{241}Pu, IRMM-1027q, 01 Nov 2014
$wdnorm_{242}$		normalised decayed mass fraction of ^{242}Pu, IRMM-1027q, 01 Nov 2014
$wdnorm_{244}$		normalised decayed mass fraction of ^{244}Pu, IRMM-1027q, 01 Nov 2014
$R_{238/239}$	mol/mol	isotope amount ratio n_{238}/n_{239} of Pu in MP2
$R_{240/239}$	mol/mol	isotope amount ratio n_{240}/n_{239} of Pu in MP2
$R_{241/239}$	mol/mol	isotope amount ratio n_{241}/n_{239} of Pu in MP2
$R_{242/239}$	mol/mol	isotope amount ratio n_{242}/n_{239} of Pu in MP2
$R_{244/239}$	mol/mol	isotope amount ratio n_{244}/n_{239} of Pu in MP2

Quantity	Unit	Definition
M_{Pu}	g/mol	molar mass of Pu
f_{238}		mole fraction of ^{238}Pu MP2
f_{239}		mole fraction of ^{239}Pu MP2
f_{240}		mole fraction of ^{240}Pu MP2
f_{241}		mole fraction of ^{241}Pu MP2
f_{242}		mole fraction of ^{242}Pu MP2
f_{244}		mole fraction of ^{244}Pu MP2
e		
ln_2		
ΣR_{Pu}		
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
M_{238Pu}	g/mol	atomic mass for ^{238}Pu
M_{239Pu}	g/mol	atomic mass for ^{239}Pu
M_{240Pu}	g/mol	atomic mass for ^{240}Pu
M_{241Pu}	g/mol	atomic mass for ^{241}Pu
M_{242Pu}	g/mol	atomic mass for ^{242}Pu
M_{244Pu}	g/mol	atomic mass for ^{244}Pu
ΣRd_{Pu}		
$c_{y.IRMM046bdec}$	mol/g	decayed amount content of ^{242}Pu in IRMM-046b
$c_{y.IRMM046b}$	mol/g	amount content of ^{242}Pu in IRMM-046b
$R_{239/242Pu.IRMM046bdec}$	mol/mol	decayed isotope amount ratio n_{239}/n_{242} of Pu in IRMM-046b
$R_{239/242Pu.IRMM046b}$		isotope amount ratio n_{239}/n_{242} of Pu in IRMM-046b
Δt_{spike}	a	time difference certificate 046b (1 June 2010) and measurement date IRMM-1027q (01 Nov 2014)

Quantity	Unit	Definition
c_{239Pu1}	mol/g	amount content of ^{239}Pu in vial 622
c_{239Pu2}	mol/g	amount content of ^{239}Pu in vial 791
c_{239Pu3}	mol/g	amount content of ^{239}Pu in vial 888
c_{239Pu4}	mol/g	amount content of ^{239}Pu in vial 1095
R_{b1}	mol/mol	measured ^{242}Pu/^{239}Pu ratio in blend 1, vial 622
R_{b2}	mol/mol	measured ^{242}Pu/^{239}Pu ratio in blend 2, vial 791
R_{b3}	mol/mol	measured ^{242}Pu/^{239}Pu ratio in blend 4, vial 888
R_{b4}	mol/mol	measured ^{242}Pu/^{239}Pu ratio in blend 4, vial 1095
m_{x1}	g	mass of sample 1027q in vial 622
m_{x2}	g	mass of sample 1027q in vial 791
m_{x3}	g	mass of sample 1027q in vial 888
m_{x4}	g	mass of sample 1027q in vial 1095
m_{y1}	g	mass of spike in blend 1, vial 622
m_{y2}	g	mass of spike in blend 2, vial 791
m_{y3}	g	mass of spike in blend 3, vial 888
m_{y4}	g	mass of spike in blend 4, vial 1095
ε_1		
ε_2		
ε_3		
ε_4		
δ_1		
δ_2		
δ_3		
δ_4		
c_{Pu1}	mol/g	Pu amount content in vial 622
c_{Pu2}	mol/g	Pu amount content in vial 791
c_{Pu3}	mol/g	Pu amount content in vial 888
c_{Pu4}	mol/g	Pu amount content in vial 1095
γ_{Pu1}	g/g	Pu mass content in vial 622
γ_{Pu2}	g/g	Pu mass content in vial 791
γ_{Pu3}	g/g	Pu mass content in vial 888
γ_{Pu4}	g/g	Pu mass content in vial 1095
γ_{239Pu1}	g/g	^{239}Pu mass content in vial 622
γ_{239Pu2}	g/g	^{239}Pu mass content in vial 791
γ_{239Pu3}	g/g	^{239}Pu mass content in vial 888

Quantity	Unit	Definition
γ_{239Pu4}	g/g	^{239}Pu mass content in vial 1095
Δt_{ref}		difference between IDMS measurement date and reference date (01 Nov 2014)

Δt_{norm}: Type B rectangular distribution
Value: 7.83299 a
Halfwidth of Limits: 0.019 a

01/01/2007, 01/11/2014, delta t= 2861 days/365.25=7.83299

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

MP2 certificate 1 Jan 2007

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

MP2 certificate 1 Jan 2007

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

MP2 certificate 1 Jan 2007

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

MP2 certificate 1 Jan 2007

$R_{244/239}$: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 1

MP2 certificate 1 Jan 2007

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: 6561 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

M_{238Pu}: Type B normal distribution
Value: 238.0495599 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{239Pu}: Type B normal distribution
Value: 239.0521634 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{240Pu}: Type B normal distribution
Value: 240.0538135 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{241Pu}: Type B normal distribution
Value: 241.0568515 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{242Pu}: Type B normal distribution
Value: 242.0587426 g/mol
Expanded Uncertainty: 0.0000040 g/mol
Coverage Factor: 2

G. Audi et al, 2003

M_{244Pu}: Type B normal distribution
Value: 244.064204 g/mol
Expanded Uncertainty: 0.000010 g/mol
Coverage Factor: 2

G. Audi et al, 2003

$c_{y.IRMM046b}$: Type B normal distribution
Value: $4.6504 \cdot 10^{-7}$ mol/g
Expanded Uncertainty: $0.0018 \cdot 10^{-7}$ mol/g
Coverage Factor: 2

IRMM-046b certificate

$R_{239/242Pu.IRMM046b}$: Type B normal distribution
Value: 0.002212
Expanded Uncertainty: 0.000016
Coverage Factor: 2

IRMM-046b certificate

Δt_{spike}: Type B rectangular distribution
Value: 4.41889 a
Halfwidth of Limits: 0.039 a

01/06/2010, 01/11/2014, delta t= 1614 days/365.25=4.41889

R_{b1}: Type B normal distribution
Value: 0.177419 mol/mol
Expanded Uncertainty: 0.000054 mol/mol
Coverage Factor: 2

R_{b2}: Type B normal distribution
Value: 0.181235 mol/mol
Expanded Uncertainty: 0.000049 mol/mol
Coverage Factor: 2

R_{b3}:
Type B normal distribution
Value: 0.178376 mol/mol
Expanded Uncertainty: 0.000049 mol/mol
Coverage Factor: 2

R_{b4}:
Type B normal distribution
Value: 0.180601 mol/mol
Expanded Uncertainty: 0.000061 mol/mol
Coverage Factor: 2

m_{x1}:
Type B normal distribution
Value: 2.5638 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3861

m_{x2}:
Type B normal distribution
Value: 2.5197 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3846

m_{x3}:
Type B normal distribution
Value: 2.5420 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3846

m_{x4}:
Type B normal distribution
Value: 2.5174 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3846

m_{y1}:
Type B normal distribution
Value: 3.0224 g
Expanded Uncertainty: 0.0002 g
Coverage Factor: 2

E3860

m_{y2}:
Type B normal distribution
Value: 3.0344 g
Expanded Uncertainty: 0.0002 g
Coverage Factor: 2

E3860

m_{y3}: Type B normal distribution
Value: 3.0139 g
Expanded Uncertainty: 0.0001 g
Coverage Factor: 2

E3860

m_{y4}: Type B normal distribution
Value: 3.0209 g
Expanded Uncertainty: 0.0001 g
Coverage Factor: 2

E3860

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

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

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

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

Δt_{ref}: Type B rectangular distribution
Value: -0.219028
Halfwidth of Limits: 0.00019

20/1/2015, 01/11/2014, delta t= 80 days/365.25 = 0.219028

Input Correlation:

The abundance set for Pu is assumed as uncorrelated.

Interim Results:

Quantity	Value	Standard Uncertainty
c_{Pu}	$3.160422 \cdot 10^{-6}$ mol/g	$683 \cdot 10^{-12}$ mol/g
γ_{Pu}	$755.577 \cdot 10^{-6}$ g/g	$163 \cdot 10^{-9}$ g/g
$Mdnorm_{Pu}$	239.07463448 g/mol	$3.92 \cdot 10^{-6}$ g/mol
$Rd_{238/239}$	$28.987 \cdot 10^{-6}$ mol/mol	$136 \cdot 10^{-9}$ mol/mol
$Rd_{240/239}$	0.02241889 mol/mol	$2.55 \cdot 10^{-5}$ mol/mol
$Rd_{241/239}$	$162.82 \cdot 10^{-6}$ mol/mol	$1.07 \cdot 10^{-5}$ mol/mol
$Rd_{242/239}$	$75.716 \cdot 10^{-6}$ mol/mol	$390 \cdot 10^{-9}$ mol/mol
$fdnorm_{238}$	$28.344 \cdot 10^{-6}$	$133 \cdot 10^{-9}$
$fdnorm_{239}$	0.97781684	$2.67 \cdot 10^{-5}$
$fdnorm_{240}$	0.02192157	$2.44 \cdot 10^{-5}$
$fdnorm_{241}$	$159.21 \cdot 10^{-6}$	$1.04 \cdot 10^{-5}$
$fdnorm_{242}$	$74.036 \cdot 10^{-6}$	$381 \cdot 10^{-9}$
$wdnorm_{238}$	$28.222 \cdot 10^{-6}$	$133 \cdot 10^{-9}$
$wdnorm_{239}$	0.97772493	$2.68 \cdot 10^{-5}$
$wdnorm_{240}$	0.02201136	$2.45 \cdot 10^{-5}$
$wdnorm_{241}$	$160.53 \cdot 10^{-6}$	$1.05 \cdot 10^{-5}$
$wdnorm_{242}$	$74.960 \cdot 10^{-6}$	$386 \cdot 10^{-9}$
M_{Pu}	239.07479084 g/mol	$4.49 \cdot 10^{-6}$ g/mol
f_{238}	$30.143 \cdot 10^{-6}$	$142 \cdot 10^{-9}$
f_{239}	0.97773050	$2.88 \cdot 10^{-5}$
f_{240}	0.02193284	$2.44 \cdot 10^{-5}$
f_{241}	$232.50 \cdot 10^{-6}$	$1.52 \cdot 10^{-5}$
f_{242}	$74.014 \cdot 10^{-6}$	$381 \cdot 10^{-9}$
ΣR_{Pu}	1.02277673	$3.01 \cdot 10^{-5}$
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}
λ_{244}	$8.6643 \cdot 10^{-9}$ a^{-1}	$97.5 \cdot 10^{-12}$ a^{-1}
ΣRd_{Pu}	1.02268642	$2.79 \cdot 10^{-5}$
$c_{y.IRMM046bdec}$	$465.0362 \cdot 10^{-9}$ mol/g	$90.0 \cdot 10^{-12}$ mol/g
$R_{239/242Pu.IRMM046bdec}$	$2.21174 \cdot 10^{-3}$ mol/mol	$8.00 \cdot 10^{-6}$ mol/mol
ε_1	$256 \cdot 10^{-12}$	$519 \cdot 10^{-12}$

Quantity	Value	Standard Uncertainty
ε_2	$209 \cdot 10^{-12}$	$498 \cdot 10^{-12}$
ε_3	$-792 \cdot 10^{-12}$	$496 \cdot 10^{-12}$
ε_4	$327 \cdot 10^{-12}$	$542 \cdot 10^{-12}$
c_{Pu1}	$3.160160 \cdot 10^{-6}$ mol/g	$868 \cdot 10^{-12}$ mol/g
c_{Pu2}	$3.160209 \cdot 10^{-6}$ mol/g	$842 \cdot 10^{-12}$ mol/g
c_{Pu3}	$3.161232 \cdot 10^{-6}$ mol/g	$840 \cdot 10^{-12}$ mol/g
c_{Pu4}	$3.160087 \cdot 10^{-6}$ mol/g	$897 \cdot 10^{-12}$ mol/g
γ_{Pu1}	$755.514 \cdot 10^{-6}$ g/g	$208 \cdot 10^{-9}$ g/g
γ_{Pu2}	$755.526 \cdot 10^{-6}$ g/g	$201 \cdot 10^{-9}$ g/g
γ_{Pu3}	$755.770 \cdot 10^{-6}$ g/g	$201 \cdot 10^{-9}$ g/g
γ_{Pu4}	$755.497 \cdot 10^{-6}$ g/g	$214 \cdot 10^{-9}$ g/g

Uncertainty Budgets:

γ_{239Pu}: mass content of ^{239}Pu in IRMM-1027q

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$c_{y,IRMM046b}$	$465.0400 \cdot 10^{-9}$ mol/g	$90.0 \cdot 10^{-12}$ mol/g	normal	1600	$140 \cdot 10^{-9}$ g/g	80.2 %
R_{b1}	0.1774190 mol/mol	$27.0 \cdot 10^{-6}$ mol/mol	normal	$-1.0 \cdot 10^{-3}$	$-28 \cdot 10^{-9}$ g/g	3.1 %
R_{b2}	0.1812350 mol/mol	$24.5 \cdot 10^{-6}$ mol/mol	normal	$-1.0 \cdot 10^{-3}$	$-25 \cdot 10^{-9}$ g/g	2.4 %
R_{b3}	0.1783760 mol/mol	$24.5 \cdot 10^{-6}$ mol/mol	normal	$-1.0 \cdot 10^{-3}$	$-25 \cdot 10^{-9}$ g/g	2.5 %
R_{b4}	0.1806010 mol/mol	$30.5 \cdot 10^{-6}$ mol/mol	normal	$-1.0 \cdot 10^{-3}$	$-31 \cdot 10^{-9}$ g/g	3.8 %
m_{x1}	2.563800 g	$300 \cdot 10^{-6}$ g	normal	$-72 \cdot 10^{-6}$	$-22 \cdot 10^{-9}$ g/g	1.8 %
m_{x2}	2.519700 g	$300 \cdot 10^{-6}$ g	normal	$-73 \cdot 10^{-6}$	$-22 \cdot 10^{-9}$ g/g	1.9 %
m_{x3}	2.542000 g	$300 \cdot 10^{-6}$ g	normal	$-73 \cdot 10^{-6}$	$-22 \cdot 10^{-9}$ g/g	1.9 %
m_{x4}	2.517400 g	$300 \cdot 10^{-6}$ g	normal	$-73 \cdot 10^{-6}$	$-22 \cdot 10^{-9}$ g/g	1.9 %
m_{y1}	3.022400 g	$100 \cdot 10^{-6}$ g	normal	$61 \cdot 10^{-6}$	$6.1 \cdot 10^{-9}$ g/g	0.1 %
m_{y2}	3.034400 g	$100 \cdot 10^{-6}$ g	normal	$61 \cdot 10^{-6}$	$6.1 \cdot 10^{-9}$ g/g	0.1 %
γ_{239Pu}	$738.746 \cdot 10^{-6}$ g/g	$160 \cdot 10^{-9}$ g/g				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
c_{239Pu}	$3.0903 \cdot 10^{-6}$ mol/g	$1.3 \cdot 10^{-9}$ mol/g	2.00	manual
γ_{239Pu}	$738.75 \cdot 10^{-6}$ g/g	$320 \cdot 10^{-9}$ g/g	2.00	manual
c_{239Pu1}	$3.0901 \cdot 10^{-6}$ mol/g	$1.7 \cdot 10^{-9}$ mol/g	2.00	manual
c_{239Pu2}	$3.0901 \cdot 10^{-6}$ mol/g	$1.6 \cdot 10^{-9}$ mol/g	2.00	manual
c_{239Pu3}	$3.0911 \cdot 10^{-6}$ mol/g	$1.6 \cdot 10^{-9}$ mol/g	2.00	manual
c_{239Pu4}	$3.0900 \cdot 10^{-6}$ mol/g	$1.8 \cdot 10^{-9}$ mol/g	2.00	manual
γ_{239Pu1}	$738.69 \cdot 10^{-6}$ g/g	$410 \cdot 10^{-9}$ g/g	2.00	manual
γ_{239Pu2}	$738.70 \cdot 10^{-6}$ g/g	$390 \cdot 10^{-9}$ g/g	2.00	manual
γ_{239Pu3}	$738.94 \cdot 10^{-6}$ g/g	$390 \cdot 10^{-9}$ g/g	2.00	manual
γ_{239Pu4}	$738.67 \cdot 10^{-6}$ g/g	$420 \cdot 10^{-9}$ g/g	2.00	manual

Annex 18: Results of the confirmation measurements (10 units, 3 replicates) of ^{235}U, ^{238}U and ^{239}Pu amount contents in the selected vials of IRMM-1027q.

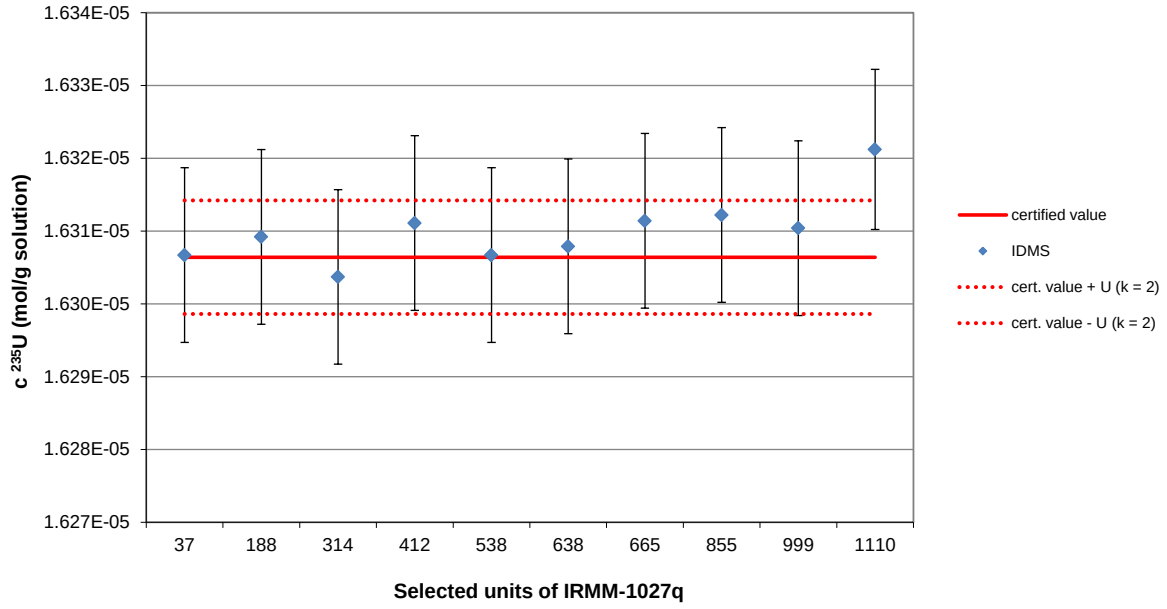

Fig. 9 The certified amount content of ^{235}U in the selected vials of IRMM-1027q prepared by gravimetric mixing compared with the measured values by IDMS (with expanded uncertainties, coverage factor k = 2).

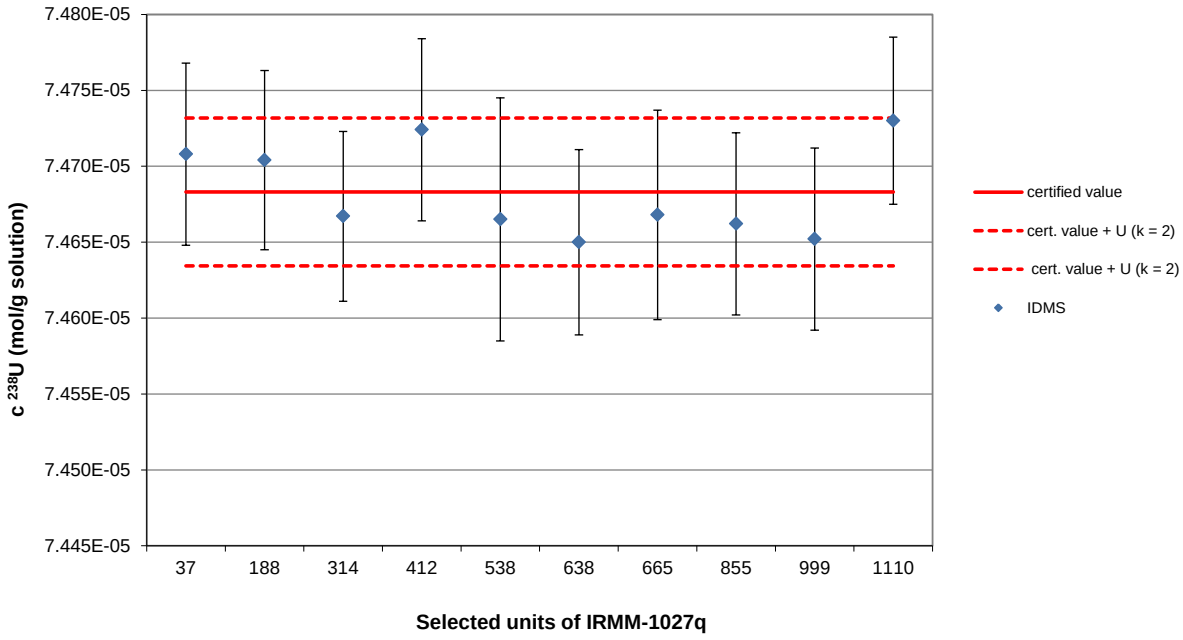

Fig. 10 The certified amount content of ^{238}U in the selected vials of IRMM-1027q prepared by gravimetric mixing compared with the measured values by IDMS (with expanded uncertainties, coverage factor k = 2).

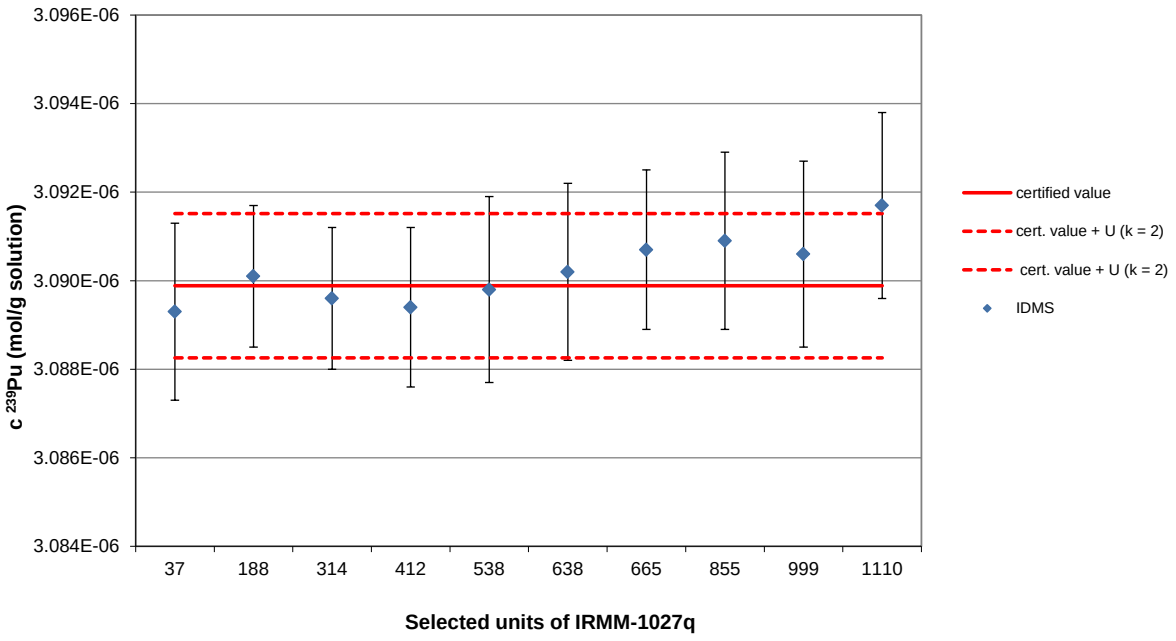

Fig. 11 The certified amount content of ^{239}Pu in the selected vials of IRMM-1027q established by IDMS compared with the measured values by IDMS (with expanded uncertainties, coverage factor k = 2)

Annex 19: Results of the confirmation measurements (10 units, 3 replicates) of the uranium and plutonium isotope amount ratios in the selected vials of IRMM-1027q.

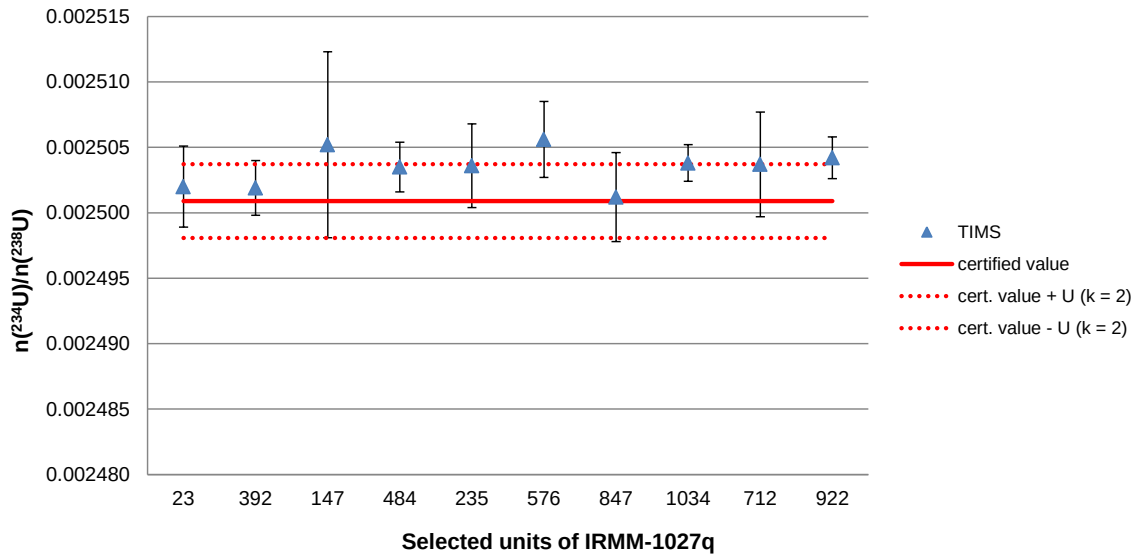

Fig. 12 The certified $n(^{234}U)/n(^{238}U)$ amount ratio in the selected vials of IRMM-1027q prepared by gravimetric mixing compared with the measured values by TIMS (with expanded uncertainties, coverage factor $k = 2$).

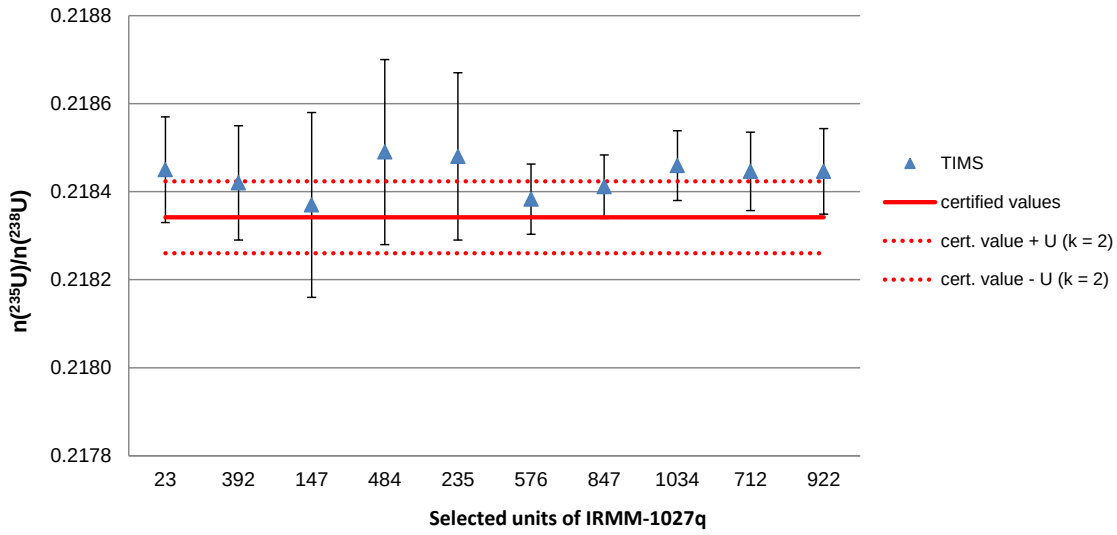

Fig. 13 The certified $n(^{235}U)/n(^{238}U)$ amount ratio in the selected vials of IRMM-1027q prepared by gravimetric mixing compared with the measured values by TIMS (with expanded uncertainties, coverage factor $k = 2$).

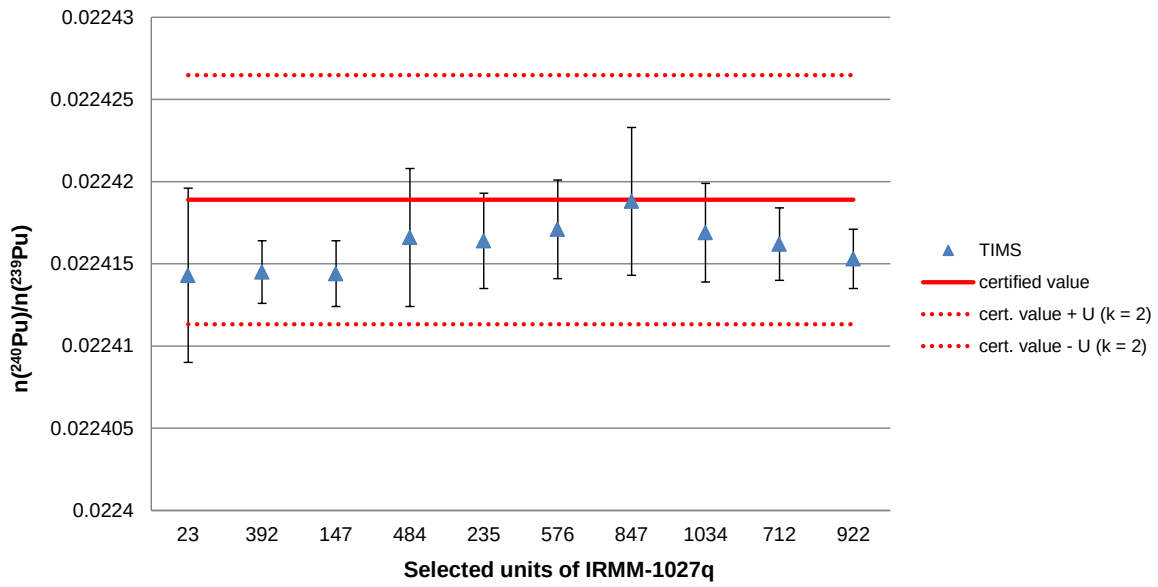

Fig. 14 The certified $n(^{240}Pu)/n(^{239}Pu)$ amount ratio in the selected vials of IRMM-1027q prepared by gravimetric mixing compared with the measured values by TIMS (with expanded uncertainties, coverage factor $k = 2$).

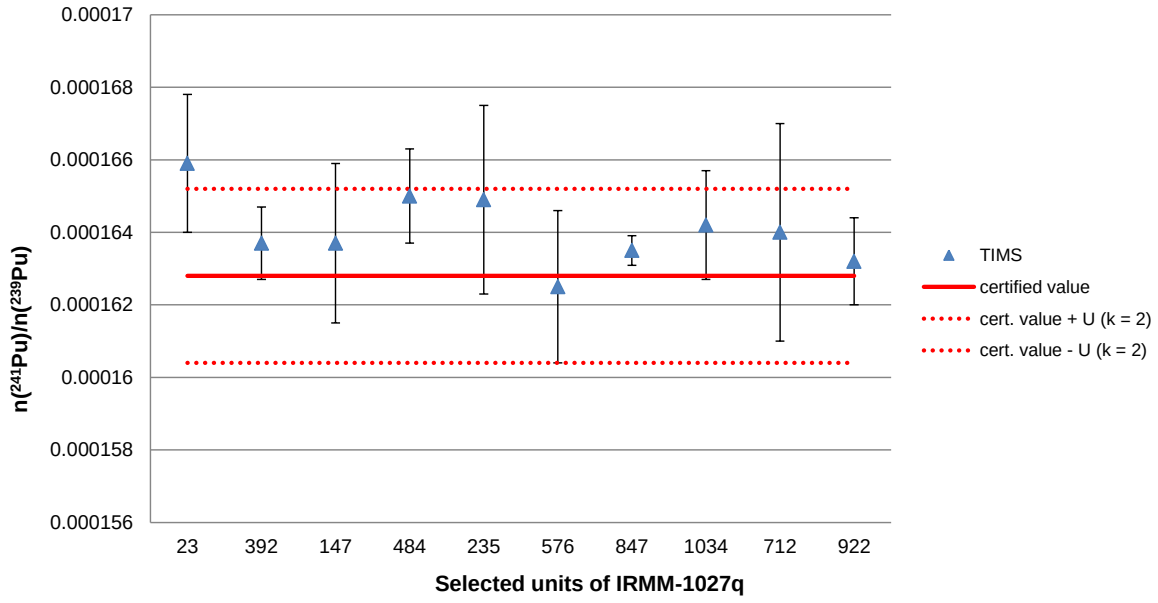

Fig. 15 The certified $n(^{241}Pu)/n(^{239}Pu)$ amount ratio in the selected vials of IRMM-1027q prepared by gravimetric mixing compared with the measured values by TIMS (with expanded uncertainties, coverage factor $k = 2$).

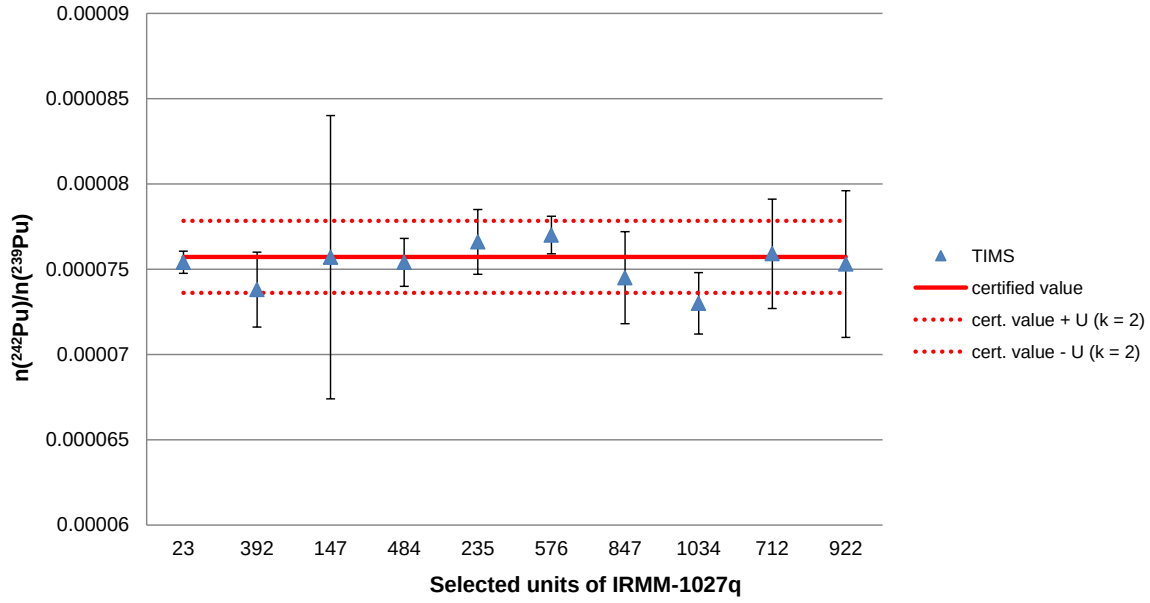

Fig. 16 The certified $n(^{242}Pu)/n(^{239}Pu)$ amount ratio in the selected vials of IRMM-1027q prepared by gravimetric mixing compared with the measured values by TIMS (with expanded uncertainties, coverage factor $k = 2$).

Annex 20: The values for the plutonium and uranium amount contents, mass fractions and isotopic composition of the mother solution for IRMM-1027q from gravimetric preparation and from ID-TIMS.

IRMM-1027q	Amount content		Mass fraction	
	Value [1] [µmol/g sol]	Uncertainty [2] [µmol/g sol]	Value [1] [mg/g sol]	Uncertainty [2] [mg/g sol]
^{235}U	16.3064	0.0023	3.8327	0.0006
^{238}U	74.683	0.004	17.7784	0.0010
U	91.326	0.005	21.6901	0.0011
^{239}Pu	3.0899	0.0013	0.7387	0.0004
Pu	3.1600	0.0012	0.7555	0.0004

IRMM-1027q	Isotopic mass fraction	
	Value [1] [%]	Uncertainty [2] [%]
$m(^{234}U)/m(U)\times100$	0.20153	0.00017
$m(^{235}U)/m(U)\times100$	17.6704	0.0022
$m(^{236}U)/m(U)\times100$	0.16256	0.00013
$m(^{238}U)/m(U)\times100$	81.9655	0.0022
$m(^{238}Pu)/m(Pu)\times100$	0.002822	0.000030
$m(^{239}Pu)/m(Pu)\times100$	97.7725	0.0006
$m(^{240}Pu)/m(Pu)\times100$	2.2011	0.0005
$m(^{241}Pu)/m(Pu)\times100$	0.01605	0.00021
$m(^{242}Pu)/m(Pu)\times100$	0.00750	0.00008
	Isotope amount ratios	
	Value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{238}Pu)/n(^{239}Pu)$	0.00002899	0.00000030
$n(^{236}U)/n(^{238}U)$	0.0020001	0.0000016

[1] The reference date for the plutonium and uranium isotopic mass fractions and amount ratios is November 1, 2014. These are not the certified values.

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

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