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CERTIFICATION REPORT

Preparation and Certification of Large-Sized Dried (LSD) Spike: IRMM-1027w

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

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Abstract

Large-Sized Dried (LSD) spikes are used as a fundamental part of the fissile material control of irradiated nuclear fuel and have been provided on a regular basis to safeguards authorities and industry for 30 years [1]. This report describes the preparation and certification of a new batch of LSD spikes. IRMM-1027w is a dried mixture of uranyl- and plutonium nitrate in carboxymethyl cellulose (CMC). The material is certified for the masses of ^{235}U, ^{238}U and ^{239}Pu and the uranium and plutonium isotope amount ratios per unit. The material was produced in accordance with ISO/IEC 17034:2016 [2]. The homogeneity and stability were assessed in accordance with ISO Guide 35:2017 [3] and the uncertainties of the certified values were calculated in accordance with Guide to the Expression of Uncertainty in Measurement (GUM) [4].

The certified reference materials uranium metal NBL PO CRM 112-A, enriched uranium metal NBL PO CRM 116-A and plutonium metal CETAMA MP2 were used as starting materials to prepare the mother solution. This solution was dispensed into individual vials by means of an automated robot system and subsequently evaporated to dryness. A solution of carboxymethyl cellulose (CMC) was added to the spike material and evaporated and dried. The organic matrix serves as a stabiliser to retain the dried nuclear material at the bottom of the vial. In total, 862 units were produced.

The heterogeneity of the batch was estimated based on the between-unit standard deviation and stability during dispatch and storage was assessed in accordance with ISO Guide 35:2017 [3].

The certified values were obtained from the gravimetric preparation of the mother solution, taking into account the mass, purity and isotopic composition of the starting materials, the mass of the mother solution, and the mass of an aliquot in each individual unit. The certified and indicative values with the exception of the ^{233}U and ^{238}Pu values were confirmed by isotope dilution thermal ionisation mass spectrometry (ID-TIMS) or thermal ionisation mass spectrometry (TIMS) as independent methods on randomly selected units of IRMM-1027w or the mother solution.

The main purpose of this material is the use as a spike isotopic reference material to measure the plutonium and uranium amount content of spent nuclear fuel solutions using IDMS. Each unit contains about 58.5 mg of uranium with a relative mass fraction $m(^{235}\mathrm{U})/m(\mathrm{U})$ of 19.0 % and 1.8 mg of plutonium with a relative mass fraction $m(^{239}\mathrm{Pu})/m(\mathrm{Pu})$ of 97.8 % as dried nitrates in CMC.

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

The following values were assigned:

	Isotope amount ratios	
	Certified value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{234}\mathrm{U})/n(^{238}\mathrm{U})$	0.0027390	0.0000023
$n(^{235}\mathrm{U})/n(^{238}\mathrm{U})$	0.239127	0.000035
$n(^{236}\mathrm{U})/n(^{238}\mathrm{U})$	0.0022000	0.0000018
$n(^{240}\mathrm{Pu})/n(^{239}\mathrm{Pu})$	0.0224065	0.0000051
$n(^{241}\mathrm{Pu})/n(^{239}\mathrm{Pu})$	0.0001151	0.0000015
$n(^{242}\mathrm{Pu})/n(^{239}\mathrm{Pu})$	0.00007573	0.00000078

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

[1] The certified values are considered to be traceable to the SI based on the use of certified metals as source materials (NBL PO CRM 116-A, CETAMA MP2 and NBL PO CRM 112-A), primary methods of measurement (weighing) and calibration of measurement systems. The reference date for the plutonium and uranium isotope amount ratios is January 1, 2022.

[2] The reference material was produced in compliance with ISO/IEC 17034:2016 and certified in accordance with ISO Guide 35:2017. The uncertainty of the certified value is the expanded uncertainty with a coverage factor k = 2 with the exception of $n(^{235}\mathrm{U})/n(^{238}\mathrm{U})$ ratio value, which has a coverage factor k = 2.2 based on the t-distribution for the associated effective degrees of freedom (v = 15). The expanded uncertainties correspond to a level of confidence of about 95 % estimated in accordance with ISO/IEC Guide 98-3:2008:2008, Guide to the Expression of Uncertainty in Measurement (GUM:2008).

The atomic masses of radionuclides were obtained from M. Wang et al. [5]

The half-lives of radionuclides were obtained from DDEP-BIPM (Table of radionuclides) [6] and R. Wellum et al. [7].

The following values for uranium and plutonium isotopic mass fraction, isotope amount ratios, amount content and mass fraction for the nitrate solution of IRMM-1027w were also assigned as indicative values:

Indicative Values		
	Isotope amount ratio	
	Indicative value [3] [mol/mol]	Uncertainty [4] [mol/mol]
$n(^{233}U)/n(^{238}U)$ [1]	0.0000000896	0.0000000020
$n(^{238}Pu)/n(^{239}Pu)$ [2]	0.00002740	0.00000026
	Isotope mass fraction (·100)	
	Indicative value [3] [g/g]	Uncertainty [4] [g/g]
$m(^{233}U)/m(U)$ [1] [5]	0.00000707	0.00000016
$m(^{234}U)/m(U)$ [5]	0.21700	0.00018
$m(^{235}U)/m(U)$ [5]	19.0258	0.0023
$m(^{236}U)/m(U)$ [5]	0.17579	0.00014
$m(^{238}U)/m(U)$ [5]	80.5814	0.0023
$m(^{238}Pu)/m(Pu)$ [5]	0.002668	0.000025
$m(^{239}Pu)/m(Pu)$ [5]	97.77843	0.00052
$m(^{240}Pu)/m(Pu)$ [5]	2.20006	0.00049
$m(^{241}Pu)/m(Pu)$ [5]	0.01135	0.00015
$m(^{242}Pu)/m(Pu)$ [5]	0.007498	0.000077
	Amount content	
	Value [3] [6] [µmol/g solution]	Uncertainty [4] [µmol/g solution]
^{235}U	18.3009	0.0026
^{238}U	76.5324	0.0048
U	95.2113	0.0054
^{239}Pu	2.9644	0.0012
Pu	3.0315	0.0012
	Mass fraction	
	Value [3] [6] [mg/g solution]	Uncertainty [4] [mg/g solution]
^{235}U	4.30153	0.00061
^{238}U	18.2186	0.0011
U	22.6089	0.0013
^{239}Pu	0.70865	0.00029
Pu	0.72475	0.00029

[1] The $n(^{233}U)/n(^{238}U)$ isotope amount ratio and $m(^{233}U)/m(U)$ isotope mass fraction values could not be verified because the signal intensity for the ^{233}U isotope was below the detection limit and therefore are classified as indicative values only.

[2] The $n(^{238}Pu)/n(^{239}Pu)$ isotope amount ratio and $m(^{238}Pu)/m(Pu)$ isotope mass fraction values were not verified for the IRMM-1027w batch.

[3] Indicative values are values that refer to the nitrate solution and are derived from the certified values with the exception of $n(^{233}U)/n(^{238}U)$. The indicative values are considered to be traceable to the SI based on the use of certified metals as source materials (NBL PO CRM 116-A, CETAMA MP2 and NBL PO CRM 112-A), primary methods of measurement (weighing) and calibration of measurement systems. The reference date for the plutonium and uranium isotopic mass fraction, amount content, mass fractions and isotope amount ratios of the mother solution of IRMM-1027w is January 1, 2022.

[4] The reference material was produced in compliance with ISO/IEC 17034:2016 and certified in accordance with ISO Guide 35:2017. The uncertainty of the indicative value is the expanded uncertainty with a coverage factor k = 2 with the exception of $n(^{233}U)/n(^{238}U)$ and $m(^{233}U)/m(U)$ values, which has a coverage factor k = 3.3 (v = 3), ^{235}U amount content and mass fraction values, which have a coverage factor k = 2.3 (v = 9) and the ^{235}U and ^{238}U isotope mass fraction values which have a coverage factor k = 2.2 (v = 15) based on the t-distribution for the associated effective degrees of freedom. The expanded uncertainties correspond to a level of confidence of about 95 % estimated in accordance with ISO/IEC Guide 98-3:2008, Guide to the Expression of Uncertainty in Measurement (GUM:2008)).

[5] Isotope mass fraction is expressed as $m(^{xxx}U)/m(U_{tot})$x100 and $m(^{xxx}Pu)/m(Pu_{tot})$x100.

[6] Nitrate solution before dispensing, drying and application of CMC.

The atomic masses of radionuclides were obtained from M. Wang et al. [5]

The half-lives of radionuclides were obtained from DDEP-BIPM (Table of radionuclides) [6] and R. Wellum et al. [7].

1. Introduction

1.1 Background

The International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials (ITVs) are uncertainties to be considered in judging the reliability of the measurement results of analytical techniques applied to industrial nuclear and fissile materials, which are subject to safeguards verification. ITVs should be achievable under the conditions 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 [8]. 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. Currently these international target values are revised by the IAEA jointly with experts from respective stakeholder domains towards the release of the ITVs-2020.

The series of IRMM-1027 Large-Sized Dried (LSD) spikes were prepared by the Joint Research Centre of the European Commission (EC-JRC) to meet the existing requirements for reliable isotope reference materials for the accountancy measurements of uranium and plutonium by isotope dilution mass spectrometry (IDMS) in compliance with the ITVs-2010 in spent nuclear fuel. These spikes contain about 58.5 mg U and 1.8 mg Pu, isotopically different from the uranium and plutonium in the test sample and are in dried nitrate form. Approximately 1000 units of IRMM-1027 LSD spikes are prepared annually to fulfil the demands for fissile material control from European Safeguards Authorities and industry [9, 10].

1.2 Choice of the material

The IRMM-1027w batch of LSD spikes was prepared from natural uranium (NBL PO CRM 112-A), enriched uranium (NBL PO CRM 116-A) and plutonium (CETAMA MP2) certified reference metals (Annex 2-Annex 5). Each unit of IRMM-1027w contains about 58.5 mg of uranium with a relative isotope mass fraction $m(^{235}U)/m(U)$ of 19.0 % and 1.8 mg of plutonium with a relative isotope mass fraction $m(^{239}Pu)/m(Pu)$ of 97.8 %. The relative isotope mass fraction $m(^{235}U)/m(U)$ is below 20 %, thus the uranium is classified as "low enriched" for accountability purposes.

Individual units are certified for the mass of ^{239}Pu, ^{235}U and ^{238}U and for the plutonium and uranium isotope amount ratios. The uranium and plutonium amount content and mass in a single IRMM-1027 LSD spike is such that no dilution of a typical sample of dissolved nuclear fuel is needed prior to measurement. As the dried nitrates could flake off the vial surface over time or during transport, an organic polymer is added to retain the material at the bottom of the tailor-made headspace vial, in the following referred to as “penicillin vial”, supplied by Euro-Scientific, Belgium.

From the batch IRMM-1027f [11] to the batch IRMM-1027s [12], the cellulose acetate butyrate (CAB) has been used as a stabilising material for the IRMM-1027 LSD spikes for transport, thus for short-term stability purposes. The CAB produces a stable layer at the bottom of the vial and guarantees the integrity of the LSD spikes for about 3 years [13]. Customers, however, require a longer shelf-life of IRMM-1027 LSD spikes, hence JRC-Geel and JRC-Karlsruhe joined their forces to investigate new stabilizing matrices in the framework of the Innovative Nuclear Reference Materials for EURATOM Safeguards and Industry (INS-CRM) exploratory research project [14]. The main objective of the project was to find potential materials that would prolong the shelf-life of LSD spikes from 3 to 5 years or even beyond. The new coatings should fulfil additional requirements such as ready dissolution in nitric acid and a lack of interference with chemical separations or mass spectrometry measurements. Among the tested materials, carboxymethyl cellulose (CMC) showed very promising results [15,16]. Hence it has been applied from the batch IRMM-1027t onwards [17].

As a result of the successful outcome of the exploratory research project and the real application on the IRMM-1027t, u and v [17,18,19] LSD spikes, the same approach was applied when preparing the IRMM-1027w spikes. This time the entire batch was embedded into CMC. CAB-based embedding matrices were not used.

1.3 Design of the project

The mother solution was prepared gravimetrically by dissolving plutonium and uranium certified reference metals in hydrochloric and nitric acid, respectively. Finally, the dried nitrates were treated with CMC for preservation during storage and transport. The individual units of IRMM-1027w LSD spikes were prepared by dispensing aliquots (about 2.5 g) of the mother solution into penicillin vials and were evaporated to dryness at around 55°C, under glovebox conditions (around 50 mm Hg under-pressure).

The certified masses of plutonium and uranium isotopes and the certified values of the uranium and plutonium isotope amount ratios are based on the data from the weighing certificates and the certificates of the starting materials (metals). Confirmation measurements and homogeneity assessment were established by ID-TIMS on the same units selected by stratified random sampling and spiked with IRMM-046c. A mixed, in-house prepared ^{235}U and ^{239}Pu quality control reference material was

measured on the same ID-TIMS turret with each verification set of IRMM-1027w. One set of Pu ID-TIMS measurement was performed with an additional, external QC material LSD-30, obtained from IAEA-SGAS.

2. Participants

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

3. Material processing and process control

3.1 Origin and purity of the starting material

CRMs of high purity metals of uranium (NBL PO CRM 112-A and NBL PO CRM 116-A, Lemont, USA) and plutonium (CETAMA MP2, CEA Marcoule, France) were used as starting materials (Figure 1) for the preparation of the IRMM-1027w LSD spikes. The isotopic composition and the purity of the metals are given in Annex 2 - Annex 6.

Figure 1 Starting materials for the preparation of IRMM-1027w LSD spikes: a) one of the electropolished Pu MP2 metal b) etched U NBL PO CRM 116-A metals and c) etched U NBL PO CRM 112-A metals (Source: EC JRC G.2)

3.2 Processing

Dissolution of the Pu metal

The protocol in use at JRC-Geel for the dissolution of Pu MP2 metal consists in applying an electro-polishing of the Pu metal before weighing and dissolution [12]. This protocol does not comply with MP2 certificate and associated recommendation for use as the mass of the MP2 ingot is certified (see Annex 4).

After electro-polishing the 3 selected units of the MP2 metal were rinsed with deionised water and acetone (*p.a.*, Merck, Darmstadt, Germany) and dried. The units were precisely weighed (by substitution method) in a dedicated glovebox on a Mettler Toledo AT 261 DR balance (readability = 0.1/0.01 mg) and subsequently transferred to another glovebox for dissolution. They were dissolved in about 20-25 mL of hydrochloric acid (c = 6 mol L^{-1}, Suprapur®, Merck). The reaction was vigorous and fast and undissolved Pu particles could not be detected by visual observation. Then, nitric acid solution (c = 8 mol L^{-1}, *p.a.*, Merck) was added to the dissolved Pu solution. The flask with the plutonium solution was closed with a stopper and kept in a dedicated glovebox to prevent any potential contamination. The dissolution of Pu MP2 metal is shown in Figure 2.

Dissolution of the U metals

The respective units of enriched uranium metal (NBL PO CRM 116-A) and natural uranium metal (NBL PO CRM 112-A) were weighed (by substitution method) on a Mettler Toledo XPE 205 balance (Mettler Toledo, Vienna, Austria) (readability = 0.01mg) and added into the prepared plutonium solution. Prior to weighing, the units of both metals were etched with nitric acid (c = 8 mol L^{-1}) to remove surface oxidation products as described in the certificate, subsequently rinsed with deionised water and acetone (*p.a.*, Merck, Darmstadt, Germany) and dried, according to the manufacturer's recommendation. The final amounts of concentrated nitric acid and deionised water were added to adjust the concentration of the nitric acid solution (c = 5-6 mol L^{-1}). The solution was left to homogenise for a few days with occasional swirling by hand, and it was weighed to determine the final mass of the mother solution on a Mettler Toledo PR 5002 balance (readability = 0.01 g). Corrections for air buoyancy effects were applied at each weighing step. The dissolution of the uranium metals is shown in Figure 2.

The conventional mass values of most the weights used for the mass determination of the metals and the mother solution were in accordance with the maximum permissible error of class E2 according to OIML-R 111:2004 [20]. The conventional mass

values of some of the larger weights were in accordance with the maximum permissible error of class F1. More detailed information on the weights is available upon request.

Prior to dispensing the mother solution into individual penicillin vials, four aliquots were analysed by isotope dilution (ID) technique on a TRITON thermal ionisation mass spectrometer (TIMS, Thermo-Fisher, Bremen, Germany) to verify the gravimetrically determined amount contents of plutonium and uranium. Additionally, four aliquots were analysed by TIMS to verify the uranium and plutonium isotope amount ratios (see Section 3.3 Process Control). The uranium isotope ratios were determined by both the total evaporation (TE) [21] and modified total evaporation (MTE) [22] TIMS methods.

Figure 2 Dissolution of Pu and U metals: a) MP2 dissolution in HCl, b) flask from a) after adding HNO_3 and U NBL PO CRM 116-A, c) flask from b) after adding U NBL PO CRM 112-A (Source: EC JRC G.2)

Dispensing, drying and application of CMC

Dispensing and weighing of the mother solution into individual penicillin vials were performed by a validated automated system, which was installed at the JRC Geel in collaboration with Nucomat (Lokeren, Belgium) [23]. 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 glovebox, such as identifying the vial with a barcode reader, dispensing and weighing of an aliquot of the solution (2.5 g) into the penicillin vials. The weighing component is equipped with an analytical balance (Sartorius TE124S, Göttingen, Germany) and a 5 kg balance (Sartorius TE6101) to monitor the mass of the mother solution during dispensing. The whole solution (about 2.3 kg) was dispensed into 862 vials over five consecutive working days.

The drying of the dispensed solution contained in the vials was carried out on a hot plate. The temperature of the solution was kept below 60 °C for several days (typically 4-5 days continuous heating) to evaporate the solution completely.

For the preparation of the IRMM-1027w LSD spikes carboxymethyl cellulose (CMC) stabilizing matrix was used.

CMC protocol

10 g of low viscosity CMC sodium salt (Merck) was slowly added into 90 g of nitric acid solution (c = 2 mol L^{-1}, p.a., Merck) at 70-75 °C under continuous stirring. The mixture was stirred and heated until the dissolution of CMC was complete (usually 2-3 hours) and then allowed to cool to room temperature. A colourless to slightly yellow, transparent solution was obtained. 1.5 mL of this solution was added to the dried nitrates and heated up to about 52-54 °C. The solution in the vials was kept at this temperature to evaporate the nitric acid solution. Once the nitric acid had evaporated completely and the foams were produced, the vials were removed from the hotplate, cooled and closed with butyl rubber caps. This protocol allows the preparation of up to 24 units per day in one glovebox.

CMC was added to retain the dried material at the bottom of the penicillin vials in order to resist physical shocks that might be encountered during transport and to avoid flaking of the material during long-term storage. CMC dissolves readily in warm nitric acid and have no effect on the subsequent IDMS analysis.

One example each of IRMM-1027w LSD spike is shown in Figure 3. The processing steps are shown in Figure 4.

Figure 3 One unit of IRMM-1027w LSD spike treated with CMC (Source: EC JRC G.2)

Figure 4 Preparation of IRMM-1027w LSD spikes

3.3 Process control

This section describes the measurements performed on the mother solution of IRMM-1027w prior to dispensing into vials to verify the amount contents of uranium and plutonium in the solution from gravimetric preparation. Detailed GUM Workbench calculations of the uranium and plutonium amount contents, mass fractions, isotopic compositions and their associated uncertainties from the gravimetric preparation of IRMM-1027w are shown in Annex 13 and Annex 14.

Four aliquots of the mother solution (about 2.5 g each) were individually spiked with a mixed $^{233}U/^{242}Pu$ spike CRM (*ca.* 2 g IRMM-046c) for ID-TIMS analysis. The certificate of IRMM-046c can be found in Annex 7.

The U-Pu separation of the samples was performed using anion-exchange columns (Bio-Rad AG1-X4, 100-200 mesh, Bio-Rad, Hercules, USA) as described in detail in [24].

The ID-TIMS results of the process control measurements for ^{235}U, ^{238}U and ^{239}Pu amount contents in the mother solution of IRMM-1027w were metrologically compatible with the values from the gravimetric preparation (Annex 8, Figure 10). The expanded uncertainty ranges of the measured and gravimetrically defined values also overlap. Therefore, both of our verification requirements were fulfilled (for the definition of requirements see section 6.4) even though the uncertainty contribution associated with homogeneity was considered negligible and set to zero when the combined standard uncertainty of the gravimetric value was determined. The ID-TIMS results showed a slight negative bias compared to the gravimetrical value, -0.04%, -0.06% and -0.04% for ^{235}U, ^{238}U and ^{239}Pu amount contents, respectively. The biases are so small that they do not limit the usability of the spikes in any way.

The CRM 116-A and the NBL-126 reference materials are used in the JRC G.2 laboratory as quality control (QC) materials for uranium and plutonium IDMS, respectively. These stock solutions were prepared and verified independently from the IRMM-1027w mother solution. [25] An aliquot of CRM 116-A and NBL-126 (ID-QC) material solutions were weighed into a vial and this mixture was spiked with the IRMM-046c ($^{242}Pu/^{233}U$) spike CRM, and measured together with the aliquots of the IRMM-1027w mother solution. One ID-QC was measured on the same sample turret and the result was used for bias correction of the corresponding IRMM-1027w mother solution samples (see Section 6.5 for details).

4. Homogeneity

A key requirement for any reference material is homogeneity. In this respect, it is relevant whether the variation between units is significant compared to the uncertainty of the certified value but most importantly, whether the combined uncertainty remains fit for purpose. In contrast to that, it is not relevant if this variation between units is significant compared to the analytical variation. Consequently, ISO/IEC 17034:2016 [2] requires reference material (RM) producers to assess the homogeneity of any candidate RM. This aspect is covered in between-unit homogeneity studies.

The within-unit inhomogeneity does not influence the uncertainty of the certified value when the minimum sample intake is respected. In case of the IRMM-1027 LSD CRM series, the whole amount of sample per unit is used for analysis. Thus, there is no contribution to the combined uncertainty from the within-unit homogeneity unless the relative maximum inhomogeneity ($u^*_{bb,rel}$) equation (Eq 3) is used for the assessment of uncertainty associated with inhomogeneity.

4.1 Between-unit homogeneity

The between-unit homogeneity was evaluated to ensure that the certified values of the CRM are valid for all 862 units of the material, within the stated uncertainty.

In the course of the certification of IRMM-1027w, 16-19 single spiked units were selected and used to assess the homogeneity for the amount content of ^{235}U, ^{238}U and ^{239}Pu using a random stratified sampling scheme covering the whole batch for the between-unit homogeneity test. Random stratified sampling involves dividing the batch into *n* groups (with a similar number of units in each group) and randomly selecting one unit from each group, where *n* represents the number of selected units. This number for the between-unit homogeneity study was determined in accordance with ISO Guide 35:2017 [3].

In this project, the homogeneity study and the confirmation measurements were performed on the same set of units (see Section 6).

The whole amount of sample of each randomly selected unit of IRMM-1027w was spiked and dissolved with around 2g of an accurately weighed, mixed $^{233}U/^{242}Pu$ spike CRM (IRMM-046c) in 5 mol L^{-1} HNO_3 solution. The solution was evaporated to dryness in the vials. The U-Pu separation was carried out prior to isotope ratio measurements on each unit in the same way as for the process control measurements (see Section 3.3).

Each sample was measured in three replicates (one measurement data of #772 for U was rejected for technical reasons thus only two replicates were used for this unit). Three aliquots were taken from the same spiked, separated and diluted subsample, loaded on the filaments and measured on the same turret together with isotopic standards (IRMM-074/10 for U and IRMM-290/A3 for Pu) to correct for instrumental mass fractionation. The selected units were measured together with the in-house ID-QC (U/Pu) sample. This allowed four IRMM-1027w units plus one QC material to be measured on the same TIMS turret on the same day (with the exception of the last Pu measurement that contained three IRMM-1027w units and two QC samples). Four turrets were prepared for uranium and five turrets for plutonium measurements. Due to technical reason, unit #340 had to be re-analysed for U with the same QC that was originally used. Therefore, the ID-TIMS analysis for all 16-19 units of IRMM-1027w were performed under intermediate precision conditions over five instrument runs for both uranium and plutonium.

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.

Given the intermediate precision conditions of the sample preparations, day-to-day effects can occur that could inflate the between-unit variation. Significant differences between the day means were checked using one-way ANOVA. Significant day-to-day effects were found for ^{235}U and ^{238}U isotope amount content values at the 95% confidence level. (Annex 10, Figure 20) If no significant day-to-day differences are found it does not necessarily mean that they do not exist. With such a small number of groups (days) as five, the statistical power of the F-test (used by ANOVA) is often very low that can lead to Type II error i.e. the failure of detecting differences when they exist. In these situations, we assumed that the day-to-day differences are negligible and accepted the potentially overestimated between-unit variances.

Due to the ageing of the IRMM-046c spike material and potential evaporation loss during long-term storage, significant ampoule-to-ampoule differences may occur. The F-test of one-way ANOVA was used to check whether the mean of the results obtained with the different spike ampoules are equal. Four randomly selected IRMM-1027w units and one randomly selected QC sample was spiked with the same spike ampoule. Then the samples were analysed in such way that each spike ampoule was represented on each ID-TIMS turret with at least one sample. This planning allowed us to be able to separate day-to-day and spike ampoule-to-ampoule differences. (The only exception was the last Pu set, where the three IRMM-1027w units and the two QC samples were spiked with the same IRMM-046c ampoule and measured on the same day.) Ampoule-to-ampoule differences are less likely to occur if the data were bias corrected based on the observed QC bias, since this correction was applied to all four IRMM-1027w samples spiked with the same spike ampoule as the given QC sample (instead of the four IRMM-1027w samples that were measured on the same day as the QC sample) (Section 6.5, Equation 6). For the U amount

content no significant ampoule-to-ampoule differences were observed at the 95% CL. On the other hand, for the ^{239}Pu amount content values, that could not be bias corrected, blatantly obvious spike ampoule-to-ampoule differences were detected. (Annex 10, Figure 21)

Regression analyses were performed to evaluate potential trends in the analytical sequence as well as trends in the filling sequence. No trend was detected for the ^{239}Pu isotope amount content. If significant day-to-day effects and strong correlation between this effect and the analytical sequence occurred, then the regression analysis was performed on normalised dataset. This was the case for ^{235}U (correlation coefficient = 0.98) and ^{238}U (correlation coefficient = 0.98) isotope amount content data. The data that was first normalised by the respective day mean did not show any trend at the 95% CL. (Annex 10, Figure 14-Figure 19)

The data were tested for consistency using the Grubbs outlier test at a confidence level of 95 % on the individual results and on the unit means. In the case of ^{235}U and ^{238}U amount contents, single outliers were detected among the individual results however, no technical reason was found to exclude the data thus it was kept and included in the evaluation of homogeneity. No outliers among the unit means were detected.

Each subset (3-4 units) of the randomly selected units were spiked with a single ampoule of IRMM-046c CRM and analysed on a single day. Due to the significant day-to-day differences for the U and significant ampoule-to-ampoule difference for the ^{239}Pu amount contents the quantification of between-unit inhomogeneity was accomplished by nested ANOVA. Nested or hierarchical ANOVA can separate the between-unit, between-day and/or between-spike-ampoule and residual effects. It is an extension of a one-way ANOVA for experiments where each group is divided into disjoint subgroups or subsets. These subgroups could be for example the units that were measured on the same day or units that were spiked with the same ampoule. The former was applied for the U and the latter for the ^{239}Pu isotope amount content data because those effects were identified as significant at the 95% CL. In any case, the between-unit standard deviation (s_{bb}) is separated from the within-unit standard deviation (s_{wb}), which is equivalent to the method intermediate precision.

The essence of ANOVA is the partitioning of the total sum of squares (SS) into components related to the effects defined in the model. It allows the overall variance of the data to be attributed to different sources of variation, with the relative importance of each being quantified by the size of each component of the overall sum of squares. Dividing the SS by their associated degrees of freedom results in mean squares (MS) that can be used as or for calculating variance estimates. In order to calculate MS and variance components, the method assumes that a) the observations are obtained independently and randomly, b) the variances of the groups (e.g. units) are equal (homoscedasticity). The residuals *vs* fitted values graph and the Levene's test was used to check the homoscedasticity assumption. If the *F*-test of ANOVA is used to compare multiple group means and to check their equivalence (e.g. day-to-day or ampoule-to-ampoule variance), one more assumption has to be fulfilled, namely that each group sample is drawn from a normally distributed population. Normality testing for small sample sizes is problematic and can lead to inadequate estimation of the dispersion of the data. The quantiles of the residuals can be plotted against the quantiles of the normal distribution on a normal Q-Q plot to visualize and the statistical tests (e.g. the Shapiro-Wilk test) can be used to check at the 95% CL the assumption for normality. However, judgement based on the evaluation of Q-Q plots is subjective and statistical tests for normality are often underpowered for small data sets. Based on the knowledge of how the batch was prepared and how the samples were selected and analysed we assumed that the normality assumption holds. Nevertheless, if the statistical test required, we tested the normality assumption by both, analysing Q-Q plots and performing the Shapiro-Wilk test. There was no significant deviation from normality observed.

The results of the statistical evaluations for the isotope amount contents are given in Table 1.

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

	Trends 1)		Outliers 2)		Homoscedasticity 3)
	Analytical sequence	Filling sequence	Individual results	Unit means	
^{235}U amount content	no4)	no	yes	none	OK (p=1)
^{238}U amount content	no4)	no	yes	none	OK (p=1)
^{239}Pu amount content	no	no	none	none	OK (p=0.5)

1) Linear regression at CL= 95 %
2) Grubb's test at CL= 95 %
3) Levene's test at CL= 95 %
4) Regression analysis was performed on normalised data

The between-unit standard deviation was used to assess the homogeneity of the IRMM-1027w batch in accordance with ISO Guide 35 [3]. Although the ANOVA method provides unbiased variance estimates, it does not prevent negative variance estimates if the mean square between units ($MS_{between}$) is smaller than the mean squares within groups (MS_{within}). This results in negative arguments under the square root used for the estimation of the between-unit variation, whereas the true variance is a non-negative value by definition. In this case, u^*_{bb}, the maximum inhomogeneity that could be hidden by method repeatability (intermediate precision), was calculated as described by Linsinger et al. [26] and recommended by ISO Guide 35[3]. u^*_{bb} is comparable to the limit of detection of an analytical method, yielding the maximum inhomogeneity that might be undetected by the given study setup (alpha risk). Please, note that the definition of u^*_{bb} assumes normality.

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

$$s_{\mathrm{wb,rel}} = \frac{\sqrt{MS_{\mathrm{within}}}}{\bar{y}}$$

Equation 1

$$\boldsymbol{s_{\mathrm{bb,rel}}} = \frac{\sqrt{\frac{\boldsymbol{MS_{\mathrm{between}} - MS_{\mathrm{within}}}}{\boldsymbol{N}}}}{\bar{\boldsymbol{y}}}$$

Equation 2

$$\boldsymbol{u^*_{\mathrm{bb,rel}}} = \frac{\sqrt{\frac{\boldsymbol{MS_{\mathrm{within}}}}{\boldsymbol{N}}}\boldsymbol{4}\sqrt{\frac{\boldsymbol{2}}{\boldsymbol{\nu_{MS_{\mathrm{within}}}}}}}{\bar{\boldsymbol{y}}}$$

Equation 3

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

The results of the evaluation of the between-unit variation are summarised in Table 2.

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

	$s_{wb,rel}$ [%]	$s_{bb,rel}$ [%]	$u^*_{bb,rel}$ [%]
^{235}U amount content	0.015	**0.012**	0.004
^{238}U amount content	0.034	**0.020**	0.010
^{239}Pu amount content	0.025	**0.021**	0.007

The homogeneity studies showed no outlying unit means or trends in the filling sequence. Therefore, the between-unit standard deviation can be used as estimate of u_{hom}. As u^*_{bb} sets the limits of the study to detect inhomogeneity, the larger value of s_{bb} or u^*_{bb} is adopted as uncertainty contribution to account for potential inhomogeneity. In case of the IRMM-1027w, the s_{bb} could be used to assess the contribution of uncertainty from the homogeneity study. These values remained below 0.05% for all the three dominant isotopes, thus; it can be concluded that the batch is sufficiently homogeneous and fit for purpose.

The uncertainty associated with homogeneity was assessed and the method assumptions were tested via the accredited software SoftCRM® [27] and/or the open-source statistical software R [28].

4.2 Homogeneity of the U and Pu isotope ratios

The homogeneity assessment of the uranium and plutonium isotope amount ratios was deemed unnecessary. The IRMM-1027w LSD spikes were prepared by dissolution of the plutonium and uranium metals, dispensing of the solution into individual units and drying. Any differences in the isotope amount ratios could only stem from a contamination with plutonium and uranium of a different isotopic composition, from the isotope fractionation during the evaporation of the nitrate solution in the vial and

from an incomplete mixing of the uranium metals. Dedicated gloveboxes were used for the preparation of the spikes with no other sources of uranium and plutonium, so the contamination can be excluded. The drying temperature was less than 60 °C, where the fractionation effects are negligible. Moreover, the results of the process control measurements (see Section 3.3) for the uranium and plutonium isotope amount ratios agreed with the values from the gravimetric preparation, confirming the isotope mixing of the metals. For these reasons, no heterogeneity of the plutonium and uranium isotope amount ratios is to be expected in the vials of IRMM-1027w. This has been confirmed in the certification of previous batches of the IRMM-1027 LSD series.

4.3 Minimum sample intake

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

The whole amount of sample per unit has to be used and thus equals the minimum sample intake. Quantification of within-unit inhomogeneity to determine the minimum sample intake for IRMM-1027w 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-1027w is a mixed U/Pu reference material, consisting of U and Pu radionuclides. It should be noted that the term 'stability' in this context does not refer to radioactive decay. Radionuclides are naturally decaying according to their half-lives, a process which is quantitatively predictable using the decay data [6, 7].

5.1 Short-term stability

In the scope of the preparation and certification IRMM-1027t batch, a thorough short-term stability study of CMC was carried out [17].

The test samples contained CMC without any plutonium and uranyl nitrates. They were stored at 4 °C and 60 °C for one week at each temperature. The reference temperature was set to 18 °C. Six units for each temperature were prepared (36 units in total). Only visual inspection of the selected units was made before and after the test to assess any detachment of the coating/foam.

No flaking and/or fluid material could be observed before and after the test. An ongoing reaction accelerated by the temperature (at 60°C) was observed. As the foam still contains unreacted HNO_3 or nitrous gases – being the origin of the brownish colour of the fresh foams – the foam has even further matured, and discoloration can be noticed. However, this colour change of the foam does not affect the integrity or the stability of the material as demonstrated during the INS-CRM project [14].

Transport is often referred to as short-term stability. The transport does not affect the stability of the actinide matrix but it can have an influence on the cellulose based stabilizing matrices hence on the shelf-life and usability of the CRMs. The behaviour of LSD spikes in CMC stabilizing matrix was tested during the certification of the IRMM-1027v batch. [19] 10 units were packed identically to the ones that are shipped to customers and the test sample (Type A package) was placed on a random vibration testing machine. All units remained intact after performing a random vibration module according to the ISTA 2A procedure. [29]

IRMM-1027w LSD spikes are packed and shipped to customers following the legal requirements related to radioprotection measures for transport of radioactive materials [30]. IRMM-1027w LSD spikes are considered stable regarding its isotopic composition and the amount content during dispatch and can be shipped to customers under normal temperature conditions. No additional uncertainty component ($u_{sts,\ rel}$ = 0) was applied.

5.2 Long-term stability

The change of the reference values with time of the U/Pu CRM IRMM-1027 batches can be perfectly described by radioactive decay equations and therefore have to be compared to the given reference date on the certificate. These decay-corrected certified values are valid as long as the stabilizing organic matrix remains sufficiently intact that allows full sample intake without the risk of loss of the material when opening the vial. Therefore, no additional uncertainty component ($u_{lts,\ rel}$ = 0) has to be applied to the certified values but the degradation process investigated in prior exploratory research of the stabilizing matrix limits the shelf-life of the IRMM-1027 series of LSD spikes to 5 years.

The long-term stability of IRMM-1027 LSD spikes prepared with CAB has been demonstrated via the results of the stability monitoring of previous batches of LSD spikes for the period of three years [31] and the verification results of IRMM-1027m over a period of four years after the certification in the context of the inter-calibration of JRC-IRMM spike CRMs [32, 33, 34]. Furthermore, the JRC-Geel (Belgium), the JRC-Karlsruhe (Germany) and the IAEA at Seibersdorf (Austria) are engaged in mutual verification measurements of mixed uranium-plutonium spike reference materials via EC support task to the IAEA [35]. In the frame of this support task, verification measurements of randomly selected IRMM-1027 LSD spikes from different batches are performed up to two years after the issuance of the certificate. This is not only an external verification of the certified values but also a demonstration of the long-term stability of the IRMM-1027 series of LSD spikes.

The long-term stability of the LSD spikes prepared with CMC and CAB/DOP can be demonstrated via the results of the INS-CRM exploratory research project [14, 15, 16]. In the study, the stability of the CMC foams is visually inspected at regular time intervals. Discoloration, cavity formation or collapsing of the CMC foam may occur with time. However, as long as the foam adheres to the vial; these effects do not influence the quality of the LSD spikes and therefore, the certified values can be guaranteed. The main findings of the shelf-life of the IRMM-1027 series of LSD spikes were summarized in the previous certification report, IRMM-1027u [18]. A more detailed discussion of the topic has been submitted for publication.

6. Characterisation

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

The material characterisation for the uranium and plutonium isotope amount ratios and for the mass of uranium and plutonium was based on gravimetric preparation of the mother solution, confirmed by independent analysis. The IRMM-1027w series of LSD spikes was prepared by dispensing an aliquot (about 2.5 g) of the mother solution into individual units by an automated system and subsequent drying. The masses of dispensed aliquots per unit before drying are given in Annex 12. The mother solution was prepared by gravimetric mixing of uranium and plutonium metals (see Section 3.2).

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

6.1 Purity of the starting materials

The purity of the starting U materials (metals) was taken from the corresponding certificates (Annex 2 Annex 3). The purity of the Pu MP2 metal was calculated for January 1, 2022 (Annex 14) from the original purity of the CETAMA certificate (Annex 4).

6.2 Masses of ^{235}U, ^{238}U, ^{239}Pu , U and Pu isotope amount ratios and their uncertainties

The mass of ^{235}U, ^{238}U, ^{239}Pu and the U and Pu isotope amount ratios in each individual unit of IRMM-1027w are calculated from the gravimetric preparation of the mother solution. The following parameters were taken into account: the mass of the metals, their purity and isotopic composition (e.g. isotope amount ratios), the mass of the mother solution and the mass of an aliquot dispensed into each vial. In Table 3, the data supporting the calculation of the masses of ^{235}U, ^{238}U, ^{239}Pu and Pu and U amount ratios of IRMM-1027w are summarised.

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

	MP2[5]	NBL PO CRM 112-A [5]	NBL PO CRM 116-A[5]	Mother solution[5]
Mass [1)] [g]	1.64765 (07)	41.15558 (08)	10.16332 (06)	2269.23 (04)
Purity [2)] [g/g]	0.99817(40)	0.99975(06)	0.99945(14)	
Isotope amount ratios [3)] [mol/mol]	$n(^{238}Pu)/n(^{239}Pu)$ 0.00002740(26) $n(^{240}Pu)/n(^{239}Pu)$ 0.0224065(51) $n(^{241}Pu)/n(^{239}Pu)$ 0.0001151(15) $n(^{242}Pu)/n(^{239}Pu)$ 0.00007573(78)	$n(^{234}U)/n(^{238}U)$ 0.000052841(82) $n(^{235}U)/n(^{238}U)$ 0.0072543(40)	$n(^{233}U)/n(^{235}U)$ 0.0000003863(86) $n(^{234}U)/n(^{235}U)$ 0.0115836(97) $n(^{236}U)/n(^{235}U)$ 0.0094713(77) $n(^{238}U)/n(^{235}U)$ 0.051277(41)	
U amount content [4)] [µmol/g]	4.8267(34)			
Isotope amount fraction [4)] [mol/mol]	$n(^{235}U)/n(U)$ 0.916552(72)			

[1)] The masses of the metals are obtained from the weighing certificate, see Annex 12.
[2)] The decay-corrected purity of the Pu metal (see Annex 14) and the purity of the U metals. For the original metal certificates, see Annex 2 - Annex 5.
[3)] The decay-corrected Pu isotope amount ratios and the U isotope amount ratios. For the original certificates, see Annex 2- Annex 5.
[4)] The decay-corrected U isotope amount content and $n(^{235}U)/n(U)$ amount fraction. For the original metal certificate, see Annex 6.
[5)] The numbers in parenthesis are the expanded uncertainties. A coverage factor of k =2 was assigned to all values that corresponds to a CL of about 95%.

The uncertainties associated to the characterisation of the certified masses (u_{char}) of ^{235}U, ^{238}U and ^{239}Pu in the individual units are composed of several contributions, which can be derived from the gravimetric mixture of the mother solution (Table 4). The contributors are the following: the uncertainties on the mass determinations ($u_{char,rel1}$ - metals, $u_{char,rel2}$ - mother solution and $u_{char,rel3}$ – dispensed aliquot into the vial), the uncertainty on the purity of the metals ($u_{char,rel4}$), and the uncertainties on the

isotope amount ratios ($u_{char,rel5}$). The detailed calculations of the mass fractions, amount fractions and the most important uncertainty budgets are given in Annex 13 and Annex 14. The uncertainty of the mass determination of the aliquot (dispensing) is the major contributor to the combined standard uncertainty associated to the characterisation for the U isotope amount contents. It is also an important contributor to the combined standard uncertainty of characterisation for ^{239}Pu isotope amount content, the second largest after the purity of the MP2 metal.

The uncertainties associated to the characterisation of the certified U and Pu isotope amount ratios are also composed of several contributions i.e. the uncertainty on the mass determination of the metals, the uncertainty on the purity of the metals, and the uncertainty on the isotope amount ratios. The detailed calculations of the uranium and plutonium isotope amount ratios and their uncertainty budgets are given in Annex 13 and Annex 14.

Table 4 Uncertainty budgets for the masses of ^{235}U, ^{238}U and ^{239}Pu in the gravimetric mixture in the first unit #1 of IRMM-1027w as an example. The main uncertainty contributions associated to the characterisation are highlighted. (Source: EC JRC G.2)

	Relative standard uncertainty contribution					Combined relative uncertainty
	$u_{char,rel1}$ 1) [%]	$u_{char,rel2}$ 2) [%]	$u_{char,rel3}$ 3) [%]	$u_{char,rel4}$ 4) [%]	$u_{char,rel5}$ 5) [%]	$u_{char,rel}$ 7) [%]
^{235}U	0.00029	0.0009	0.012	0.0057	0.0019	0.013
^{238}U	0.00010	0.0009	0.012	0.0030	0.00050 6)	0.012
^{239}Pu	0.0021	0.0009	0.012	0.020	0.00025	0.023

1) Relative standard uncertainty of the mass determination of the metals, see Annex 13 and Annex 14 denoted as $m_{UCRM116A}$ for ^{235}U, $m_{UNBL112A}$ for ^{238}U and m_{PuMP2} for ^{239}Pu. The respective uncertainties of the mass determinations can be found in Annex 12.

2) Relative standard uncertainty of the mass determination of the mother solution, see Annex 13 and Annex 14 denoted as $m_{solution1027w}$. The respective uncertainty of the mass determination can be found in Annex 12.

3) Relative standard uncertainty of the mass determination of the aliquot in the first vial, see Annex 13 and Annex 14 denoted as $m_{aliquot1}$. The respective uncertainties of the mass determination can be found in Annex 11.

4) Relative standard uncertainty of the purity of the metals, see Annex 13 and Annex 14 denoted as $\eta_{purityNBL112A}$, $\eta_{purityCRM116A}$ and $\eta_{MP2refdate}$. The respective purities can be found in the metal certificates Annex 2 - Annex 4. For the CETAMA MP2 metal, the purity is decayed in a separate GUM file to the 1 January 2007 and from that date ($\eta_{MP2Jan2007}$) is decayed further to the certification date 1 January 2022.

5) Relative standard uncertainty of the major isotope amount ratios, see Annex 13 and Annex 14 denoted as $R_{238U/235U\text{-}b}$ for NBL PO CRM-116-A; and $R_{240Pu/239Pu}$ for CETAMA MP2. The respective isotope amount ratios can be found in Annex 3, Annex 5.

6) For NBL PO CRM 112-A the relative standard uncertainty of the two most important isotope amount ratios $R_{235U/238U\text{-}a}$ and $R_{238U/235U\text{-}b}$ were combined. The respective isotope amount ratios can be found in Annex 2, Annex 3.

7) The final combined relative uncertainty is calculated using $u_{\mathrm{char,rel}} = \sqrt{\sum_{i=1}^{5}(u_{char,rel,i}^2)}$, assuming no correlation between the different uncertainty contributors.

6.3 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 11. 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 glovebox. No evaporation loss was assumed. Traceability of the values to the SI is ensured by weighing a calibrated reference weight before and after dispensing a series of 96 units. A correction factor ($K_{nucomat}$) was applied based on the ratio of the last calibration of the reference weight and the mean value obtained during dispensing according to the following equation:

$$\boldsymbol{K}_{\mathbf{nucomat}} = \frac{\boldsymbol{m}_{\mathbf{ref,cal}}}{\boldsymbol{m}_{\mathbf{ref,readout}}} \qquad \text{Equation 4}$$

$m_{ref,\ readout}$ is the mean value of the reference mass recorded at ambient conditions during dispensing and $m_{ref,\ cal}$ is the mass value of the latest calibration of the same reference object after ambient condition correction.

The uncertainty estimate on the dispensed mass (± 0.0006 g, coverage factor k = 2) is composed of several contributions, i.e. the uncertainty on the mass determination by an automated system, the uncertainty on the buoyancy correction, the uncertainty of the correction factor, and the uncertainty associated with the stability of the balance [23].

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 the unknown (U)

and several reference weights (S). The so called "SUUS" method was applied [20]. The uncertainty contributions in substitution weighing of the metals are the uncertainties associated with the calibrated reference weights (certificate), air buoyancy correction and the stability of the balance used in "SUUS" method.

6.4 Isotope ratio confirmation measurements

Four unspiked aliquots (about 0.5 g each) of the IRMM-1027w mother solution and four randomly selected unspiked units were analysed to verify the uranium and plutonium isotope amount ratios by TIMS. The uranium isotope amount ratios were determined by the modified total evaporation (MTE) method to avoid peak tailing and allow more accurate determination of the minor isotope ratios $n(^{234}U)/n(^{238}U)$ and $n(^{236}U)/n(^{238}U)$. [22] The U-Pu separation of the samples was performed using anion-exchange columns (Bio-Rad AG1-X4, 100-200 mesh, Bio-Rad, Hercules, USA) as described in detail in [24].

All uranium and plutonium isotope amount ratio confirmation measurements were compatible with the values from the gravimetric preparation, except for aliquot no 3 for the $n(^{241}Pu)/n(^{239}Pu)$ amount ratio. However, even in this case, the expanded uncertainty of the measurement overlapped with that of the gravimetrical value and the other seven confirmation measurements passed both of the verification criteria. Therefore, this isotope ratio was also included in the certificate.

As it is apparent from Figure 5 most U isotope ratio verification data show a slight positive bias relative to the gravimetrical value even though they are all within uncertainty. The mean relative differences are +0.02% for $n(^{235}U)/n(^{238}U)$, +0.04% for $n(^{234}U)/n(^{238}U)$ and +0.02% for $n(^{236}U)/n(^{238}U)$ amount ratios. The signal for ^{233}U was below the LOD and therefore the $n(^{233}U)/n(^{238}U)$ ratio could not be determined and certified. The gravimetrical value of this ratio is given on the 'Indicative values' page of the certificate.

Figure 5 Uranium isotope ratio verification measurements for a) $n(^{235}U)/n(^{238}U)$ b) $n(^{234}U)/n(^{238}U)$ and c) $n(^{236}U)/n(^{238}U)$. Error bars show the expanded uncertainties (k = 2 that corresponds to a level of confidence of about 95 %). The blue line shows the mean TIMS value, and the blue shaded area represents expanded uncertainty of the mean with a coverage factor k = 2.

The verification measurements of the Pu isotope ratios are summarized in Figure 6. All expanded uncertainties of the individual measurements overlap with that of the gravimetrical (certified) value and all results pass the compatibility check with one exception: the $n(^{241}Pu)/n(^{239}Pu)$ amount ratio as it was mentioned earlier. The mean relative differences to the gravimetrical value are +0.01% for $n(^{240}Pu)/n(^{239}Pu)$, +1.1% for $n(^{241}Pu)/n(^{239}Pu)$ and -0.37% for $n(^{242}Pu)/n(^{239}Pu)$ amount ratios. Due to an isobaric interference with ^{238}U resulting from the incomplete removal of uranium in the plutonium fraction TIMS would provide

a deviating value for the $n(^{238}Pu)/n(^{239}Pu)$ ratio. This ratio was not certified for the IRMM-1027w batch, and the gravimetrical value is given on the 'Indicative values' page of the certificate.

All isotope ratios and additionally the $n(^{238}Pu)/n(^{239}Pu)$ ratio were verified by JRC-G.II.8 as well (Annex 9).

Figure 6 Plutonium isotope ratio verification measurements for a) $n(^{240}Pu)/n(^{239}Pu)$ b) $n(^{241}Pu)/n(^{239}Pu)$ and c) $n(^{242}Pu)/n(^{239}Pu)$ ratios. Error bars show the expanded uncertainties (coverage factors are based on the *t*-distribution for the associated effective degrees of freedom that corresponds to a level of confidence of about 95 %; some error bars on c) extend outside of the plot region.). The blue line shows the mean TIMS value and the blue shaded area represents expanded uncertainty of the mean with a coverage factor k = 2.

The compatibility check was performed for the results of the confirmation measurements (IDMS/TIMS) using the compatibility equation (equation 5) [36]. We set the following criteria for the compatibility check: compatibility values that are less than or equal to 2 pass, values between 2 and 3 pass with a warning and values larger than or equal to 3 fail to pass the check. We have observed only one value larger than 3 ($n(^{241}Pu)/n(^{239}Pu)$) during the verification exercise and only one between 2 and 3 ($n(^{235}U)/n(^{238}U)$), which are highlighted in the respective tables. The outcome of the compatibility check is summarized in

Table **5**.

$$\textbf{compatibility} = \frac{X_{\text{IDMS/TIMS}} - X_{\text{cert}}}{\sqrt{u^2_{\text{IDMS/TIMS}} + u^2_{\text{cert}}}} \qquad \text{Equation 5}$$

$X_{\text{IDMS/TIMS}}$	individual result obtained by IDMS/TIMS
X_{cert}	gravimetric value established by characterisation
$u_{\text{IDMS/TIMS}}$	standard uncertainty obtained by IDMS/TIMS
u_{cert}	standard uncertainty of the certified value

Table 5 Results of the compatibility evaluation for the isotope ratios

Aliquot or vial No.	**$n(^{235}U)/n(^{238}U)$ ratio**	$n(^{234}U)/n(^{238}U)$ ratio	$n(^{236}U)/n(^{238}U)$ ratio	**$n(^{240}Pu)/n(^{239}Pu)$ ratio**	$n(^{241}Pu)/n(^{239}Pu)$ ratio	$n(^{242}Pu)/n(^{239}Pu)$ ratio
1027w-aliquot 1	**1.51**	1.16	0.38	**0.06**	0.35	1.16
1027w- aliquot 2	**1.95**	1.16	0.34	**0.25**	0.84	0.51
1027w- aliquot 3	**2.15**	1.21	0.33	**0.57**	3.20	0.24
1027w- aliquot 4	**1.35**	0.68	0.20	**0.16**	0.86	0.77
1027w-483	**1.97**	1.16	0.21	**0.18**	0.90	0.85
1027w-56	**0.12**	0.16	0.01	**0.72**	0.25	0.22
1027w-732	**1.03**	0.60	0.07	**0.71**	1.96	1.28
1027w-225	**0.74**	0.36	0.05	**0.00**	1.76	0.93

The relative standard uncertainty contribution of the uranium and plutonium isotope amount ratios from the characterisation assessment (gravimetric preparation) are summarised in Table 6. As uncertainty contribution associated with homogeneity is not assigned to these ratios (see Section 4.2), u_{char} represents the combined standard uncertainty.

Table 6 The U and Pu isotope amount ratios and their relative standard uncertainties from the characterisation assessment of IRMM-1027w (Source: EC JRC G.2)

	Value [1] [mol/mol]	u_{char} [mol/mol]	$u_{char, rel}$ [%]
$n(^{234}U)/n(^{238}U)$	0.0027390	0.0000011	0.041
$n(^{235}U)/n(^{238}U)$	0.239127	0.000016	0.0067
$n(^{236}U)/n(^{238}U)$	0.0022000	0.0000009	0.041
$n(^{238}Pu)/n(^{239}Pu)$ [2]	0.00002740	0.00000013	0.47
$n(^{240}Pu)/n(^{239}Pu)$	0.0224065	0.0000025	0.011
$n(^{241}Pu)/n(^{239}Pu)$	0.0001151	0.0000008	0.65
$n(^{242}Pu)/n(^{239}Pu)$	0.00007573	0.00000039	0.52

1) The reference date for the isotope amount ratios is January 1, 2022.
2) The value was not certified.

Similarly to previous batches [12, 17, 37], it was demonstrated that there are no significant difference between the measured isotope ratios in the mother solution and in the dried spikes (except for the minor U isotope ratios and the $n(^{241}Pu)/n(^{239}Pu)$ isotope ratio that might be due to TIMS run-to-run differences).

6.5 Amount content confirmation measurements

The confirmation measurements and the homogeneity study were performed on the same set of units (see Section 6). 16 units of IRMM-1027w were selected by stratified random sampling from the whole batch and analysed by ID-TIMS to verify the uranium and 19 units to verify the plutonium amount contents from gravimetric preparation. To these units, about 2.0 g of mixed $^{233}U/^{242}Pu$ spike (IRMM-046c) in HNO_3 (c = 5 mol L^{-1}) was weighed in and evaporated to dryness. Subsequently, the isotopic equilibrium, chemical separation and isotopic measurements on Triton TIMS were carried out as described in [24]. The weighing certificates and ID-TIMS reports regarding to the single unit verification of the IRMM-1027w batch can be found in Annex 15 and Annex 16.

Independently prepared and certified uranium (CRM-116A) and plutonium (NBL 126) quality control (QC) materials were measured together with each set of sample turrets as QC samples (the last set of plutonium measurement additionally contained an external QC sample). A correction factor based on the relative bias of the QC measurements was applied to the uranium verification results that were spiked with the same ampoule of IRMM-046c as the respective QC sample. The latter was important because statistically significant ampoule-to-ampoule differences were observed for some of the spike ampoules. The bias correction factor was applied according to Equation 5.

$$c_{\mathrm{IDMS,corr}} = c_{\mathrm{IDMS,uncorr}} * \frac{1}{1+QC_{\mathrm{bias}}} \qquad \text{Equation 6}$$

$c_{\mathrm{IDMS,\ corr}}$ corrected amount content value of the selected isotope

$c_{\mathrm{IDMS,\ uncorr}}$ uncorrected amount content value of the selected isotope

QC_{bias} IDMS QC bias relative to the gravimetrical QC value (expressed as decimal)

The same QC correction was not applicable to the plutonium verification results because the internal Pu QCs showed inconsistency. To verify that the ID-TIMS verification measurements were technically acceptable, another 3 randomly selected units were analysed for plutonium verification and measured together with two independent QC materials: another ampoule of the in-house plutonium QC and one ampoule of IAEA-SGAS LSD-30, which is a mixed U/Pu LSD spike. Not only these two QC results were within the tolerance limit, but the IRMM-1027w verification results were also consistent with previously analysed 16 units. These studies provided sufficient evidence for the technical validation of all Pu verification measurements on the IRMM-1027w batch. Furthermore, external verification by JRC-KA on four randomly selected units confirmed the total U and Pu masses for each unit (Annex 9).

In case it was necessary (compatibility value calculated by Equation 5 was larger than 2), an additional uncertainty contribution was assigned to the IDMS values depending on the results of the consistency check. The consistency check was applied under repeatability conditions i.e. on sample subsets that were measured on the same TIMS turret as described by Kessel et al. [38].

The results of the confirmation measurements and the unit numbers selected by stratified random sampling are shown in Figure 7- Figure 9.

Figure 7 The amount content of ^{235}U in the selected vials of IRMM-1027w measured by ID-TIMS at JRC-GE expressed as the relative difference to the gravimetric value. Error bars show the relative expanded uncertainties (coverage factors are based on the *t*-distribution for the associated effective degrees of freedom that corresponds to a level of confidence of about 95 %). Red dotted lines show the combined relative expanded uncertainty assigned to the gravimetric value (coverage factor *k* = 2 that corresponds to a level of confidence of about 95)

Figure 8 The amount content of ^{238}U in the selected units of IRMM-1027w measured by ID-TIMS. Error bars show the relative expanded uncertainties (coverage factors are based on the *t*-distribution for the associated effective degrees of freedom that corresponds to a level of confidence of about 95 %). Red dotted lines show the combined relative expanded uncertainty assigned to the gravimetric value (coverage factor k = 2 that corresponds to a level of confidence of about 95 %)

Figure 9 The amount content of ^{239}Pu in the selected units of IRMM-1027w measured by ID-TIMS expressed as the relative difference from the gravimetric value. Error bars show the relative expanded uncertainties (coverage factors are based on the *t*-distribution for the associated effective degrees of freedom that corresponds to a level of confidence of about 95 %). Red dotted lines show the combined relative expanded uncertainty assigned to the gravimetric value (coverage factor k = 2 that corresponds to a level of confidence of about 95 %)

The results of the confirmation measurements for the ^{235}U, ^{238}U and ^{239}Pu amount content agreed within measurement uncertainties with the values from the gravimetrical preparation of IRMM-1027w. The results of the compatibility evaluations are summarised in Table 7.

Table 7 Results of the compatibility evaluation for the ^{235}U, ^{238}U and ^{239}Pu amount content

Vial No.	Compatibility check values for:		
	^{235}U amount content	^{238}U amount content	^{239}Pu amount content
1027w-57	-1.00	-0.43	-0.71
1027w-842	-0.79	-1.28	-1.94

1027w-497	-0.80	-1.52	-1.89
1027w-767	-0.70	-1.28	-1.37
1027w-689	-0.48	-1.56	-0.90
1027w-22	-1.76	-2.73	-0.46
1027w-202	-1.06	-2.02	-2.20
1027w-340*	0.14	-0.06	-1.62
1027w-292	-0.79	-1.48	-2.52
1027w-406	-1.17	-1.70	-1.30
1027w-126	-1.30	-1.98	-1.64
1027w-605	-0.78	-1.24	-2.46
1027w-247	-0.30	-0.81	-0.46
1027w-772	-0.49	-0.97	-1.39
1027w-443	-0.12	-0.32	-1.67
1027w-564	-1.18	-2.29	-1.67
1027w-807	-	-	-0.88
1027w-87	-	-	-1.75
1027w-447	-	-	-1.09

* 1027w-340 was re-measured for U verification and its position does not reflect the real analytical sequence

From Table 7 it can be seen that the compatibility is between -2 and +2 at a 95 % CI for all the ^{235}U amount content. The absolute compatibility value is between 2 and 3 for some ^{238}U and ^{239}Pu amount content verification data. These are still below our acceptance limit (3) but they are marked with a warning sign. It can be concluded that the values of the gravimetric preparation are sufficiently verified by results obtained via IDMS and the material is fit for purpose.

Even after correcting for QC bias, all IDMS results of ^{235}U, ^{238}U amount contents show a slight deviance from the gravimetric values (-0.03% and -0.07%, respectively (Figure 7 - Figure 9)). The bias is even larger for ^{239}Pu amount content (-0.11%) where bias correction was not possible. All results of the ID-TIMS measurements confirmed the gravimetrical values within expanded uncertainties. Therefore, these biases do not affect the certified values and their assigned uncertainties.

The quantity values and uncertainties associated with CRM characterisation and the internal verification data were computed via the commercially available software, GUM Workbench [39].

7. Value Assignment

Certified values for IRMM-1027w were assigned on the basis of the gravimetric preparation as a primary method of measurement. Full uncertainty budgets in accordance with the ISO GUM 'Guide to the Expression of Uncertainty in Measurement' [4] were established.

7.1 Certified values and their uncertainties

Certified values for the $n(^{234}U)/n(^{238}U)$, $n(^{235}U)/n(^{238}U)$, $n(^{236}U)/n(^{238}U)$, $n(^{240}Pu)/n(^{239}Pu)$, $n(^{241}Pu)/n(^{239}Pu)$ and $n(^{242}Pu)/n(^{239}Pu)$ isotope ratios and for the ^{235}U, ^{238}U and ^{239}Pu isotope masses per unit were assigned.

Certified values are values that fulfil the highest standards of accuracy. Full uncertainty budget in accordance with ISO 17034 [2] and ISO Guide 35 [3] was established.

Indicative values for the $n(^{233}U)/n(^{238}U)$ and $n(^{238}Pu)/n(^{239}Pu)$ isotope ratios, for the isotope mass fractions and the amount content and mass fraction values associated with the mother solution were also assigned.

Indicative values are as accurate as the certified values but the two minor isotope ratios were not verified with a secondary method.

The uncertainty assigned to isotope masses consists of uncertainties related to characterisation, u_{char} (Section 6), between-unit inhomogeneity, u_{hom} (Section 4) and potential degradation during transport (u_{sts}) and long-term storage, u_{lts} (Section 0). As described in Section 5 the uncertainties related to degradation during transport and long-term storage were found to be negligible. These different contributions were combined to estimate the expanded uncertainty of the certified value (U_{CRM}) with a coverage factor k as:

$$\boldsymbol{U_{CRM} = k \cdot \sqrt{u_{char}^2 + u_{hom}^2}} \qquad \text{Equation 7}$$

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

Because of sufficient degrees of freedom of the different uncertainty contributions, a coverage factor k of 2 was applied to obtain these expanded uncertainties that correspond to a level of confidence of about 95 %.

For the isotope ratios and the indicative values the between-unit inhomogeneity, u_{hom} (Section 4.2) was also considered negligible. Therefore, only the different contributions associated to characterisation, u_{char} (Section 6) were combined to estimate the expanded uncertainty of these certified values (U_{CRM}) with a coverage factor k as:

$$\boldsymbol{U_{CRM} = k \cdot \sqrt{u_{char}^2}} \qquad \text{Equation 8}$$

The coverage factor of these values was based on the t-distribution for the associated effective degrees of freedom and its value k varies between 2 and 3.3 as indicated on the certificate. The expanded uncertainties correspond to a level of confidence of about 95 %.

The certified masses and their uncertainties for unit No. 1 are summarised in Table 8. Its relative standard and expanded uncertainties are representative for all the units of the entire IRMM-1027w batch. The certified values of all 862 units are given in Annex 1.

Table 8 Exemplary representation of certified masses and their uncertainties in unit #1 of IRMM-1027w as an example

Mass	Certified value [mg]	$u_{char, rel}$ [%]	$u_{hom, rel}$ [%]	$U_{CRM, rel}$ 1) [%]	U_{CRM} 1) [mg]
^{235}U mass	11.1496	0.013	0.013	0.037	0.0040
^{238}U mass	47.223	0.012	0.020	0.047	0.022
^{239}Pu mass	1.8368	0.023	0.021	0.062	0.0011

1) Expanded uncertainty, coverage factor k = 2 corresponding to a CL of around 95%

It might be also interesting to know what the main uncertainty contributors of the certified masses are and what percentage of the combined uncertainty can be attributed to each. These values for unit #1, which are also representative for the entire batch, are summarized in Table 9.

Table 9 Exemplary representation of the main uncertainty contributors and their relative contribution to the combined uncertainty in unit #1 of IRMM-1027w

Uncertainty contributor	Contribution to the combined uncertainty of the certified masses [%]		
	^{235}U	^{238}U	^{239}Pu
Uncertainty of the mass determination of the aliquot in the vial (dispensing)	42.4	24.7	14.7
Uncertainty associated with homogeneity	45.7	73.5	43.9
Uncertainty of the purity of the metal	10.1	1.6	40.9
Total	98.2	99.8	99.5

As one can see, three main uncertainty contributors are accountable for more than 98% of the combined uncertainty of the certified masses of unit #1. These are: 1) the uncertainty of the dispensing, 2) the uncertainty associated with homogeneity and 3) uncertainty of the purity of the metal CRM. The remaining less than 2% can be attributed to different quantities that are associated with characterisation (Table 4 gives an idea about the most important ones).

8. Metrological traceability and commutability

8.1 Metrological traceability

Identity

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

Quantity value

Traceability of the obtained results is based on the traceability of all relevant input factors. Investigation of the method and measurement details of the individual results show that all relevant input parameters of each technically accepted dataset have been properly calibrated.

The certified values are considered to be traceable to the SI based on the use of certified metals as source materials (NBL PO CRM 116-A, CETAMA MP2 and NBL PO CRM 112-A), primary methods of measurement (weighing) and calibration of measurement systems. The primary methods and calibration used for establishing the certified values of the metal CRMs can be found on the respective metal certificates or available from the producer upon request. The values associated to the weighing are traceable to the SI via regular calibrations of the JRC G2's principal mass standards. The mass standards used for the calibration of balances and mass determination of the metals and the mother solution are in accordance with the maximum permissible error of class E1, E2 or F1 according to OIML-R 111:2004. More detailed information about the weight sets is available upon request.

8.2 Commutability

Many measurement procedures include one or more steps, which are selecting specific analytes (or specific groups of analytes) from the sample for the subsequent steps of the whole measurement process. Often the complete identity of these 'intermediate analytes' is not fully known or taken into account. Therefore, it is difficult to mimic all analytically relevant properties of real samples within a CRM. The degree of equivalence in the analytical behaviour of real samples and a CRM with respect to various measurement procedures (methods) is summarised in a concept called 'commutability of a reference material'. There are various definitions expressing this concept. For instance, the CLSI Guideline C-53A [40] 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-1027w is a dried nitrate in CMC certified for uranium and plutonium isotope amount ratios and masses of ^{235}U, ^{238}U and ^{239}Pu per unit. This CRM is tailor-made by the JRC for its intended use and serves as a spike for determination of uranium and plutonium content by IDMS measurements of samples from input solutions at reprocessing plants and is not intended to be used for other measurement methods.

9. Instructions for use

9.1 Safety information

The IRMM-1027w series contains radioactive material. The ampoules should be handled with great care and by experienced personnel in a laboratory suitably equipped for the safe handling of radioactive materials.

9.2 Storage conditions

The material should be stored at room temperature in an upright position.

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.

9.3 Instructions for use

The spike has to be dissolved in the appropriate amount of acid (e.g. nitric acid with an amount of substance concentration of about 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.

9.5 Use of the certified value

This spike CRM is for use as a spike isotopic reference material to measure the plutonium and uranium amount content in an unknown sample of dissolved nuclear fuel solution using IDMS. The amount content (C_x) of plutonium or uranium can be calculated using the following IDMS equation 9:

$$C_x = C_y \frac{m_y}{m_x} \frac{R_y - R_b}{R_b - R_x} \frac{\Sigma(R_i)_x}{\Sigma(R_i)_y} \quad , \qquad \text{Equation 9}$$

where C_y is the element amount 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.

10. Conclusions

A new batch of IRMM-1027 series of LSD spike CRMs was prepared and certified in compliance with international guidelines: IRMM-1027w. The material is certified for the U and Pu isotope amount ratios and for the mass of ^{235}U, ^{238}U and ^{239}Pu per unit. This tailor-made CRM is applied for the determination of the U and Pu amount content of dissolved spent nuclear fuel by nuclear safeguards authorities and industry worldwide. A cellulose-based material, CMC was used as stabiliser matrix to fix the dried nitrates at the bottom of the vials. Certified values for the masses of ^{235}U, ^{238}U and ^{239}Pu and for the U and Pu isotope amount ratios were established by gravimetric preparation and confirmed by TIMS and ID-TIMS as independent methods of measurement. The uncertainties of the certified values were established in compliance with the Guide to the Expression of Uncertainty in Measurement (GUM). The IRMM-1027w batch is a state-of-the-art CRM and its certified values fulfil the highest standards of accuracy. It has been proven fit for purpose and enables laboratories to meet the International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials (ITVs) ITV2010. A unit of IRMM-1027w contains about 59 mg of uranium with a relative mass fraction $m(^{235}\mathrm{U})/m(\mathrm{U})$ of 19.0 % and 1.9 mg of plutonium with a relative mass fraction $m(^{239}\mathrm{Pu})/m(\mathrm{Pu})$ of 97.8 % as dried nitrates in CMC matrices.

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List of abbreviations and definitions

ANOVA	Analysis of variance
BIPM	Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
c	amount of substance concentration
CAB	Cellulose acetate butyrate
CETAMA	Commission d'Etablissement des Méthodes d'Analyse
CI	Confidence interval
CLSI	Clinical and Laboratory Standards Institute
CMC	Carboxymethyl cellulose
CRM	Certified reference material
DOP	Dioctyl phthalate
EC	European Commission
ESARDA	European Safeguards Research and Development Association
GUM	Guide to the Expression of Uncertainty in Measurement
IAEA	International Atomic Energy Agency
IDMS	Isotope dilution mass spectrometry
ID-TIMS	Isotope dilution thermal ionisation mass spectrometry
ISO	International Organization for Standardization
ITVs	International Target Values
JRC	Joint Research Centre of the European Commission
k	Coverage factor
LSD	Large-Sized dried
m	Mass
M	Molar mass
$MS_{between}$	Between-unit mean squares from an ANOVA
MS_{within}	Within-unit mean squares from an ANOVA
MTE	Modified total evaporation
n	amount of substance
NBL	New Brunswick laboratory
NML	Nuclear Material Laboratory
p.a.	pro analysis
R_b	Isotope amount ratio in the blend
R_x	Isotope amount ratio in the un-spiked sample
R_y	Isotope amount ratio in the spike
rel	Index denoting relative figures (uncertainties etc.)
RM	Reference material
s	Standard deviation

s_{bb}	Between-unit standard deviation; an additional index "rel" is added if the relative value is meant
SI	International System of Units
s_{ip}	(Standard deviation associated with) Method intermediate precision
$t_{1/2}$	Half life
TE	Total evaporation
TIMS	Thermal Ionisation Mass Spectrometry
u	Standard uncertainty
U	Expanded uncertainty
u^{*}_{bb}	Standard uncertainty related to a maximum between-unit inhomogeneity that could be hidden by method repeatability; an additional index "rel" is added if the relative value is meant
u_{bb}	Standard uncertainty related to a possible between-unit inhomogeneity; an additional index "rel" is added if the relative value is meant
u_{char}	Standard uncertainty of the material characterisation; an additional index "rel" is added if the relative value is meant
u_{CRM}	Combined standard uncertainty of the certified value; an additional index "rel" is added if the relative value is meant
U_{CRM}	Expanded uncertainty of the certified value; an additional index "rel" is added if the relative value is meant
u_{lts}	Standard uncertainty of the long-term stability; an additional index "rel" is added if the relative value is meant
u_{sts}	Standard uncertainty of the short-term stability; an additional index "rel" is added if the relative value is meant
$\overline{y}$	Arithmetic mean
$\nu_{MSwithin}$	Degrees of freedom of MS_{within}

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

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
001	47.223	0.022	11.1496	0.0040	1.8368	0.0012
002	47.239	0.022	11.1534	0.0040	1.8375	0.0012
003	47.155	0.022	11.1337	0.0040	1.8342	0.0011
004	47.179	0.022	11.1392	0.0040	1.8351	0.0012
005	47.152	0.022	11.1328	0.0040	1.8341	0.0011
006	47.219	0.022	11.1487	0.0040	1.8367	0.0012
007	47.173	0.022	11.1380	0.0040	1.8349	0.0012
008	47.166	0.022	11.1362	0.0040	1.8346	0.0012
009	47.193	0.022	11.1427	0.0040	1.8357	0.0012
010	47.175	0.022	11.1384	0.0040	1.8350	0.0012
011	47.232	0.022	11.1517	0.0040	1.8372	0.0012
012	47.135	0.022	11.1289	0.0040	1.8334	0.0011
013	47.250	0.022	11.1560	0.0040	1.8379	0.0012
014	47.204	0.022	11.1453	0.0040	1.8361	0.0012
015	47.183	0.022	11.1401	0.0040	1.8353	0.0012
016	47.210	0.022	11.1466	0.0040	1.8363	0.0012
017	47.235	0.022	11.1526	0.0040	1.8373	0.0012
018	47.152	0.022	11.1328	0.0040	1.8341	0.0011
019	47.175	0.022	11.1384	0.0040	1.8350	0.0012
020	47.214	0.022	11.1474	0.0040	1.8365	0.0012
021	47.244	0.022	11.1547	0.0040	1.8377	0.0012
022	47.193	0.022	11.1427	0.0040	1.8357	0.0012
023	47.228	0.022	11.1509	0.0040	1.8370	0.0012
024	47.190	0.022	11.1418	0.0040	1.8355	0.0012
025	47.208	0.022	11.1461	0.0040	1.8363	0.0012
026	47.106	0.022	11.1220	0.0040	1.8323	0.0011
027	47.188	0.022	11.1414	0.0040	1.8355	0.0012
028	47.203	0.022	11.1448	0.0040	1.8360	0.0012
029	47.206	0.022	11.1457	0.0040	1.8362	0.0012
030	47.221	0.022	11.1491	0.0040	1.8367	0.0012
031	47.230	0.022	11.1513	0.0040	1.8371	0.0012
032	47.184	0.022	11.1405	0.0040	1.8353	0.0012
033	47.203	0.022	11.1448	0.0040	1.8360	0.0012
034	47.172	0.022	11.1375	0.0040	1.8348	0.0012
035	47.162	0.022	11.1354	0.0040	1.8345	0.0012
036	47.170	0.022	11.1371	0.0040	1.8348	0.0012
037	47.183	0.022	11.1401	0.0040	1.8353	0.0012
038	47.199	0.022	11.1440	0.0040	1.8359	0.0012
039	47.206	0.022	11.1457	0.0040	1.8362	0.0012
040	47.232	0.022	11.1517	0.0040	1.8372	0.0012
041	47.188	0.022	11.1414	0.0040	1.8355	0.0012
042	47.179	0.022	11.1392	0.0040	1.8351	0.0012
043	47.164	0.022	11.1358	0.0040	1.8346	0.0012
044	47.175	0.022	11.1384	0.0040	1.8350	0.0012
045	47.210	0.022	11.1466	0.0040	1.8363	0.0012
046	47.162	0.022	11.1354	0.0040	1.8345	0.0012
047	47.221	0.022	11.1491	0.0040	1.8367	0.0012
048	47.186	0.022	11.1410	0.0040	1.8354	0.0012
049	47.190	0.022	11.1418	0.0040	1.8355	0.0012

050	47.135	0.022	11.1289	0.0040	1.8334	0.0011

Unit #	^{238}U Mass [1] [mg]	^{238}U Uncertainty [2] [mg]	^{235}U Mass [1] [mg]	^{235}U Uncertainty [2] [mg]	^{239}Pu Mass [1] [mg]	^{239}Pu Uncertainty [2] [mg]
051	47.188	0.022	11.1414	0.0040	1.8355	0.0012
052	47.172	0.022	11.1375	0.0040	1.8348	0.0012
053	47.254	0.022	11.1569	0.0040	1.8380	0.0012
054	47.119	0.022	11.1250	0.0040	1.8328	0.0011
055	47.190	0.022	11.1418	0.0040	1.8355	0.0012
056	47.197	0.022	11.1435	0.0040	1.8358	0.0012
057	47.193	0.022	11.1427	0.0040	1.8357	0.0012
058	47.184	0.022	11.1405	0.0040	1.8353	0.0012
059	47.177	0.022	11.1388	0.0040	1.8350	0.0012
060	47.159	0.022	11.1345	0.0040	1.8343	0.0011
061	47.234	0.022	11.1521	0.0040	1.8372	0.0012
062	47.214	0.022	11.1474	0.0040	1.8365	0.0012
063	47.155	0.022	11.1337	0.0040	1.8342	0.0011
064	47.201	0.022	11.1444	0.0040	1.8360	0.0012
065	47.232	0.022	11.1517	0.0040	1.8372	0.0012
066	47.111	0.022	11.1233	0.0040	1.8325	0.0011
067	47.197	0.022	11.1435	0.0040	1.8358	0.0012
068	47.217	0.022	11.1483	0.0040	1.8366	0.0012
069	47.164	0.022	11.1358	0.0040	1.8346	0.0012
070	47.153	0.022	11.1332	0.0040	1.8341	0.0011
071	47.155	0.022	11.1337	0.0040	1.8342	0.0011
072	47.193	0.022	11.1427	0.0040	1.8357	0.0012
073	47.268	0.022	11.1603	0.0040	1.8386	0.0012
074	47.117	0.022	11.1246	0.0040	1.8327	0.0011
075	47.203	0.022	11.1448	0.0040	1.8360	0.0012
076	47.223	0.022	11.1496	0.0040	1.8368	0.0012
077	47.175	0.022	11.1384	0.0040	1.8350	0.0012
078	47.168	0.022	11.1367	0.0040	1.8347	0.0012
079	47.166	0.022	11.1362	0.0040	1.8346	0.0012
080	47.217	0.022	11.1483	0.0040	1.8366	0.0012
081	47.195	0.022	11.1431	0.0040	1.8358	0.0012
082	47.121	0.022	11.1255	0.0040	1.8329	0.0011
083	47.195	0.022	11.1431	0.0040	1.8358	0.0012
084	47.208	0.022	11.1461	0.0040	1.8363	0.0012
085	47.170	0.022	11.1371	0.0040	1.8348	0.0012
086	47.237	0.022	11.1530	0.0040	1.8374	0.0012
087	47.152	0.022	11.1328	0.0040	1.8341	0.0011
088	47.168	0.022	11.1367	0.0040	1.8347	0.0012
089	47.162	0.022	11.1354	0.0040	1.8345	0.0012
090	47.150	0.022	11.1324	0.0040	1.8340	0.0011
091	47.175	0.022	11.1384	0.0040	1.8350	0.0012
092	47.208	0.022	11.1461	0.0040	1.8363	0.0012
093	47.177	0.022	11.1388	0.0040	1.8350	0.0012
094	47.146	0.022	11.1315	0.0040	1.8338	0.0011
095	47.181	0.022	11.1397	0.0040	1.8352	0.0012
096	47.168	0.022	11.1367	0.0040	1.8347	0.0012
097	47.172	0.022	11.1375	0.0040	1.8348	0.0012
098	47.148	0.022	11.1319	0.0040	1.8339	0.0011
099	47.126	0.022	11.1268	0.0040	1.8331	0.0011
100	47.183	0.022	11.1401	0.0040	1.8353	0.0012

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
101	47.159	0.022	11.1345	0.0040	1.8343	0.0011
102	47.244	0.022	11.1547	0.0040	1.8377	0.0012
103	47.133	0.022	11.1285	0.0040	1.8333	0.0011
104	47.203	0.022	11.1448	0.0040	1.8360	0.0012
105	47.082	0.022	11.1164	0.0040	1.8314	0.0011
106	47.172	0.022	11.1375	0.0040	1.8348	0.0012
107	47.210	0.022	11.1466	0.0040	1.8363	0.0012
108	47.203	0.022	11.1448	0.0040	1.8360	0.0012
109	47.133	0.022	11.1285	0.0040	1.8333	0.0011
110	47.157	0.022	11.1341	0.0040	1.8343	0.0011
111	47.197	0.022	11.1435	0.0040	1.8358	0.0012
112	47.132	0.022	11.1281	0.0040	1.8333	0.0011
113	47.192	0.022	11.1423	0.0040	1.8356	0.0012
114	47.199	0.022	11.1440	0.0040	1.8359	0.0012
115	47.144	0.022	11.1311	0.0040	1.8338	0.0011
116	47.217	0.022	11.1483	0.0040	1.8366	0.0012
117	47.177	0.022	11.1388	0.0040	1.8350	0.0012
118	47.164	0.022	11.1358	0.0040	1.8346	0.0012
119	47.203	0.022	11.1448	0.0040	1.8360	0.0012
120	47.146	0.022	11.1315	0.0040	1.8338	0.0011
121	47.197	0.022	11.1435	0.0040	1.8358	0.0012
122	47.135	0.022	11.1289	0.0040	1.8334	0.0011
123	47.241	0.022	11.1539	0.0040	1.8375	0.0012
124	47.159	0.022	11.1345	0.0040	1.8343	0.0011
125	47.159	0.022	11.1345	0.0040	1.8343	0.0011
126	47.141	0.022	11.1302	0.0040	1.8336	0.0011
127	47.170	0.022	11.1371	0.0040	1.8348	0.0012
128	47.153	0.022	11.1332	0.0040	1.8341	0.0011
129	47.223	0.022	11.1496	0.0040	1.8368	0.0012
130	47.223	0.022	11.1496	0.0040	1.8368	0.0012
131	47.070	0.022	11.1134	0.0040	1.8309	0.0011
132	47.199	0.022	11.1440	0.0040	1.8359	0.0012
133	47.208	0.022	11.1461	0.0040	1.8363	0.0012
134	47.137	0.022	11.1293	0.0040	1.8335	0.0011
135	47.195	0.022	11.1431	0.0040	1.8358	0.0012
136	47.148	0.022	11.1319	0.0040	1.8339	0.0011
137	47.250	0.022	11.1560	0.0040	1.8379	0.0012
138	47.108	0.022	11.1225	0.0040	1.8324	0.0011
139	47.179	0.022	11.1392	0.0040	1.8351	0.0012
140	47.190	0.022	11.1418	0.0040	1.8355	0.0012
141	47.157	0.022	11.1341	0.0040	1.8343	0.0011
142	47.121	0.022	11.1255	0.0040	1.8329	0.0011
143	47.190	0.022	11.1418	0.0040	1.8355	0.0012
144	47.152	0.022	11.1328	0.0040	1.8341	0.0011
145	47.241	0.022	11.1539	0.0040	1.8375	0.0012
146	47.150	0.022	11.1324	0.0040	1.8340	0.0011
147	47.152	0.022	11.1328	0.0040	1.8341	0.0011
148	47.190	0.022	11.1418	0.0040	1.8355	0.0012
149	47.102	0.022	11.1212	0.0040	1.8321	0.0011
150	47.186	0.022	11.1410	0.0040	1.8354	0.0012

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
151	47.150	0.022	11.1324	0.0040	1.8340	0.0011
152	47.177	0.022	11.1388	0.0040	1.8350	0.0012
153	47.135	0.022	11.1289	0.0040	1.8334	0.0011
154	47.157	0.022	11.1341	0.0040	1.8343	0.0011
155	47.206	0.022	11.1457	0.0040	1.8362	0.0012
156	47.203	0.022	11.1448	0.0040	1.8360	0.0012
157	47.121	0.022	11.1255	0.0040	1.8329	0.0011
158	47.208	0.022	11.1461	0.0040	1.8363	0.0012
159	47.168	0.022	11.1367	0.0040	1.8347	0.0012
160	47.130	0.022	11.1276	0.0040	1.8332	0.0011
161	47.177	0.022	11.1388	0.0040	1.8350	0.0012
162	47.181	0.022	11.1397	0.0040	1.8352	0.0012
163	47.133	0.022	11.1285	0.0040	1.8333	0.0011
164	47.170	0.022	11.1371	0.0040	1.8348	0.0012
165	47.164	0.022	11.1358	0.0040	1.8346	0.0012
166	47.146	0.022	11.1315	0.0040	1.8338	0.0011
167	47.210	0.022	11.1466	0.0040	1.8363	0.0012
168	47.141	0.022	11.1302	0.0040	1.8336	0.0011
169	47.155	0.022	11.1337	0.0040	1.8342	0.0011
170	47.192	0.022	11.1423	0.0040	1.8356	0.0012
171	47.111	0.022	11.1233	0.0040	1.8325	0.0011
172	47.188	0.022	11.1414	0.0040	1.8355	0.0012
173	47.111	0.022	11.1233	0.0040	1.8325	0.0011
174	47.241	0.022	11.1539	0.0040	1.8375	0.0012
175	47.150	0.022	11.1324	0.0040	1.8340	0.0011
176	47.161	0.022	11.1349	0.0040	1.8344	0.0011
177	47.084	0.022	11.1169	0.0040	1.8314	0.0011
178	47.153	0.022	11.1332	0.0040	1.8341	0.0011
179	47.203	0.022	11.1448	0.0040	1.8360	0.0012
180	47.124	0.022	11.1263	0.0040	1.8330	0.0011
181	47.183	0.022	11.1401	0.0040	1.8353	0.0012
182	47.166	0.022	11.1362	0.0040	1.8346	0.0012
183	47.099	0.022	11.1203	0.0040	1.8320	0.0011
184	47.144	0.022	11.1311	0.0040	1.8338	0.0011
185	47.203	0.022	11.1448	0.0040	1.8360	0.0012
186	47.135	0.022	11.1289	0.0040	1.8334	0.0011
187	47.159	0.022	11.1345	0.0040	1.8343	0.0011
188	47.111	0.022	11.1233	0.0040	1.8325	0.0011
189	47.152	0.022	11.1328	0.0040	1.8341	0.0011
190	47.195	0.022	11.1431	0.0040	1.8358	0.0012
191	47.121	0.022	11.1255	0.0040	1.8329	0.0011
192	47.177	0.022	11.1388	0.0040	1.8350	0.0012
193	47.239	0.022	11.1534	0.0040	1.8375	0.0012
194	47.192	0.022	11.1423	0.0040	1.8356	0.0012
195	47.122	0.022	11.1259	0.0040	1.8329	0.0011
196	47.184	0.022	11.1405	0.0040	1.8353	0.0012
197	47.210	0.022	11.1466	0.0040	1.8363	0.0012
198	47.184	0.022	11.1405	0.0040	1.8353	0.0012
199	47.166	0.022	11.1362	0.0040	1.8346	0.0012
200	47.111	0.022	11.1233	0.0040	1.8325	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
201	47.155	0.022	11.1337	0.0040	1.8342	0.0011
202	47.177	0.022	11.1388	0.0040	1.8350	0.0012
203	47.124	0.022	11.1263	0.0040	1.8330	0.0011
204	47.142	0.022	11.1306	0.0040	1.8337	0.0011
205	47.190	0.022	11.1418	0.0040	1.8355	0.0012
206	47.075	0.022	11.1147	0.0040	1.8311	0.0011
207	47.228	0.022	11.1509	0.0040	1.8370	0.0012
208	47.144	0.022	11.1311	0.0040	1.8338	0.0011
209	47.206	0.022	11.1457	0.0040	1.8362	0.0012
210	47.090	0.022	11.1182	0.0040	1.8316	0.0011
211	47.157	0.022	11.1341	0.0040	1.8343	0.0011
212	47.201	0.022	11.1444	0.0040	1.8360	0.0012
213	47.091	0.022	11.1186	0.0040	1.8317	0.0011
214	47.141	0.022	11.1302	0.0040	1.8336	0.0011
215	47.152	0.022	11.1328	0.0040	1.8341	0.0011
216	47.173	0.022	11.1380	0.0040	1.8349	0.0012
217	47.188	0.022	11.1414	0.0040	1.8355	0.0012
218	47.110	0.022	11.1229	0.0040	1.8324	0.0011
219	47.157	0.022	11.1341	0.0040	1.8343	0.0011
220	47.132	0.022	11.1281	0.0040	1.8333	0.0011
221	47.208	0.022	11.1461	0.0040	1.8363	0.0012
222	47.124	0.022	11.1263	0.0040	1.8330	0.0011
223	47.170	0.022	11.1371	0.0040	1.8348	0.0012
224	47.155	0.022	11.1337	0.0040	1.8342	0.0011
225	47.142	0.022	11.1306	0.0040	1.8337	0.0011
226	47.162	0.022	11.1354	0.0040	1.8345	0.0012
227	47.142	0.022	11.1306	0.0040	1.8337	0.0011
228	47.173	0.022	11.1380	0.0040	1.8349	0.0012
229	47.095	0.022	11.1195	0.0040	1.8319	0.0011
230	47.166	0.022	11.1362	0.0040	1.8346	0.0012
231	47.126	0.022	11.1268	0.0040	1.8331	0.0011
232	47.139	0.022	11.1298	0.0040	1.8336	0.0011
233	47.135	0.022	11.1289	0.0040	1.8334	0.0011
234	47.144	0.022	11.1311	0.0040	1.8338	0.0011
235	47.130	0.022	11.1276	0.0040	1.8332	0.0011
236	47.168	0.022	11.1367	0.0040	1.8347	0.0012
237	47.157	0.022	11.1341	0.0040	1.8343	0.0011
238	47.093	0.022	11.1190	0.0040	1.8318	0.0011
239	47.159	0.022	11.1345	0.0040	1.8343	0.0011
240	47.228	0.022	11.1509	0.0040	1.8370	0.0012
241	47.070	0.022	11.1134	0.0040	1.8309	0.0011
242	47.175	0.022	11.1384	0.0040	1.8350	0.0012
243	47.150	0.022	11.1324	0.0040	1.8340	0.0011
244	47.117	0.022	11.1246	0.0040	1.8327	0.0011
245	47.135	0.022	11.1289	0.0040	1.8334	0.0011
246	47.186	0.022	11.1410	0.0040	1.8354	0.0012
247	47.175	0.022	11.1384	0.0040	1.8350	0.0012
248	47.110	0.022	11.1229	0.0040	1.8324	0.0011
249	47.133	0.022	11.1285	0.0040	1.8333	0.0011
250	47.152	0.022	11.1328	0.0040	1.8341	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
251	47.155	0.022	11.1337	0.0040	1.8342	0.0011
252	47.108	0.022	11.1225	0.0040	1.8324	0.0011
253	47.162	0.022	11.1354	0.0040	1.8345	0.0012
254	47.144	0.022	11.1311	0.0040	1.8338	0.0011
255	47.142	0.022	11.1306	0.0040	1.8337	0.0011
256	47.161	0.022	11.1349	0.0040	1.8344	0.0011
257	47.157	0.022	11.1341	0.0040	1.8343	0.0011
258	47.137	0.022	11.1293	0.0040	1.8335	0.0011
259	47.121	0.022	11.1255	0.0040	1.8329	0.0011
260	47.183	0.022	11.1401	0.0040	1.8353	0.0012
261	47.142	0.022	11.1306	0.0040	1.8337	0.0011
262	47.115	0.022	11.1242	0.0040	1.8326	0.0011
263	47.153	0.022	11.1332	0.0040	1.8341	0.0011
264	47.146	0.022	11.1315	0.0040	1.8338	0.0011
265	47.173	0.022	11.1380	0.0040	1.8349	0.0012
266	47.108	0.022	11.1225	0.0040	1.8324	0.0011
267	47.139	0.022	11.1298	0.0040	1.8336	0.0011
268	47.101	0.022	11.1207	0.0040	1.8321	0.0011
269	47.144	0.022	11.1311	0.0040	1.8338	0.0011
270	47.117	0.022	11.1246	0.0040	1.8327	0.0011
271	47.155	0.022	11.1337	0.0040	1.8342	0.0011
272	47.168	0.022	11.1367	0.0040	1.8347	0.0012
273	47.183	0.022	11.1401	0.0040	1.8353	0.0012
274	47.088	0.022	11.1177	0.0040	1.8316	0.0011
275	47.166	0.022	11.1362	0.0040	1.8346	0.0012
276	47.162	0.022	11.1354	0.0040	1.8345	0.0012
277	47.126	0.022	11.1268	0.0040	1.8331	0.0011
278	47.132	0.022	11.1281	0.0040	1.8333	0.0011
279	47.166	0.022	11.1362	0.0040	1.8346	0.0012
280	47.122	0.022	11.1259	0.0040	1.8329	0.0011
281	47.084	0.022	11.1169	0.0040	1.8314	0.0011
282	47.141	0.022	11.1302	0.0040	1.8336	0.0011
283	47.192	0.022	11.1423	0.0040	1.8356	0.0012
284	47.115	0.022	11.1242	0.0040	1.8326	0.0011
285	47.150	0.022	11.1324	0.0040	1.8340	0.0011
286	47.133	0.022	11.1285	0.0040	1.8333	0.0011
287	47.135	0.022	11.1289	0.0040	1.8334	0.0011
288	47.150	0.022	11.1324	0.0040	1.8340	0.0011
289	47.117	0.022	11.1246	0.0040	1.8327	0.0011
290	47.192	0.022	11.1423	0.0040	1.8356	0.0012
291	47.144	0.022	11.1311	0.0040	1.8338	0.0011
292	47.110	0.022	11.1229	0.0040	1.8324	0.0011
293	47.121	0.022	11.1255	0.0040	1.8329	0.0011
294	47.093	0.022	11.1190	0.0040	1.8318	0.0011
295	47.210	0.022	11.1466	0.0040	1.8363	0.0012
296	47.104	0.022	11.1216	0.0040	1.8322	0.0011
297	47.183	0.022	11.1401	0.0040	1.8353	0.0012
298	47.128	0.022	11.1272	0.0040	1.8331	0.0011
299	47.117	0.022	11.1246	0.0040	1.8327	0.0011
300	47.139	0.022	11.1298	0.0040	1.8336	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
301	47.157	0.022	11.1341	0.0040	1.8343	0.0011
302	47.119	0.022	11.1250	0.0040	1.8328	0.0011
303	47.188	0.022	11.1414	0.0040	1.8355	0.0012
304	47.119	0.022	11.1250	0.0040	1.8328	0.0011
305	47.102	0.022	11.1212	0.0040	1.8321	0.0011
306	47.137	0.022	11.1293	0.0040	1.8335	0.0011
307	47.119	0.022	11.1250	0.0040	1.8328	0.0011
308	47.137	0.022	11.1293	0.0040	1.8335	0.0011
309	47.161	0.022	11.1349	0.0040	1.8344	0.0011
310	47.130	0.022	11.1276	0.0040	1.8332	0.0011
311	47.157	0.022	11.1341	0.0040	1.8343	0.0011
312	47.128	0.022	11.1272	0.0040	1.8331	0.0011
313	47.190	0.022	11.1418	0.0040	1.8355	0.0012
314	47.117	0.022	11.1246	0.0040	1.8327	0.0011
315	47.157	0.022	11.1341	0.0040	1.8343	0.0011
316	47.115	0.022	11.1242	0.0040	1.8326	0.0011
317	47.135	0.022	11.1289	0.0040	1.8334	0.0011
318	47.157	0.022	11.1341	0.0040	1.8343	0.0011
319	47.101	0.022	11.1207	0.0040	1.8321	0.0011
320	47.139	0.022	11.1298	0.0040	1.8336	0.0011
321	47.082	0.022	11.1164	0.0040	1.8314	0.0011
322	47.193	0.022	11.1427	0.0040	1.8357	0.0012
323	47.082	0.022	11.1164	0.0040	1.8314	0.0011
324	47.164	0.022	11.1358	0.0040	1.8346	0.0012
325	47.172	0.022	11.1375	0.0040	1.8348	0.0012
326	47.150	0.022	11.1324	0.0040	1.8340	0.0011
327	47.130	0.022	11.1276	0.0040	1.8332	0.0011
328	47.104	0.022	11.1216	0.0040	1.8322	0.0011
329	47.181	0.022	11.1397	0.0040	1.8352	0.0012
330	47.144	0.022	11.1311	0.0040	1.8338	0.0011
331	47.162	0.022	11.1354	0.0040	1.8345	0.0012
332	47.075	0.022	11.1147	0.0040	1.8311	0.0011
333	47.183	0.022	11.1401	0.0040	1.8353	0.0012
334	47.102	0.022	11.1212	0.0040	1.8321	0.0011
335	47.115	0.022	11.1242	0.0040	1.8326	0.0011
336	47.104	0.022	11.1216	0.0040	1.8322	0.0011
337	47.135	0.022	11.1289	0.0040	1.8334	0.0011
338	47.135	0.022	11.1289	0.0040	1.8334	0.0011
339	47.162	0.022	11.1354	0.0040	1.8345	0.0012
340	47.155	0.022	11.1337	0.0040	1.8342	0.0011
341	47.090	0.022	11.1182	0.0040	1.8316	0.0011
342	47.161	0.022	11.1349	0.0040	1.8344	0.0011
343	47.175	0.022	11.1384	0.0040	1.8350	0.0012
344	47.077	0.022	11.1152	0.0040	1.8312	0.0011
345	47.139	0.022	11.1298	0.0040	1.8336	0.0011
346	47.179	0.022	11.1392	0.0040	1.8351	0.0012
347	47.155	0.022	11.1337	0.0040	1.8342	0.0011
348	47.028	0.022	11.1035	0.0040	1.8292	0.0011
349	47.124	0.022	11.1263	0.0040	1.8330	0.0011
350	47.142	0.022	11.1306	0.0040	1.8337	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
351	47.139	0.022	11.1298	0.0040	1.8336	0.0011
352	47.152	0.022	11.1328	0.0040	1.8341	0.0011
353	47.082	0.022	11.1164	0.0040	1.8314	0.0011
354	47.166	0.022	11.1362	0.0040	1.8346	0.0012
355	47.111	0.022	11.1233	0.0040	1.8325	0.0011
356	47.197	0.022	11.1435	0.0040	1.8358	0.0012
357	47.126	0.022	11.1268	0.0040	1.8331	0.0011
358	47.102	0.022	11.1212	0.0040	1.8321	0.0011
359	47.232	0.022	11.1517	0.0040	1.8372	0.0012
360	47.064	0.022	11.1121	0.0040	1.8307	0.0011
361	47.110	0.022	11.1229	0.0040	1.8324	0.0011
362	47.173	0.022	11.1380	0.0040	1.8349	0.0012
363	47.104	0.022	11.1216	0.0040	1.8322	0.0011
364	47.137	0.022	11.1293	0.0040	1.8335	0.0011
365	47.135	0.022	11.1289	0.0040	1.8334	0.0011
366	47.132	0.022	11.1281	0.0040	1.8333	0.0011
367	47.135	0.022	11.1289	0.0040	1.8334	0.0011
368	47.122	0.022	11.1259	0.0040	1.8329	0.0011
369	47.121	0.022	11.1255	0.0040	1.8329	0.0011
370	47.146	0.022	11.1315	0.0040	1.8338	0.0011
371	47.135	0.022	11.1289	0.0040	1.8334	0.0011
372	47.183	0.022	11.1401	0.0040	1.8353	0.0012
373	47.117	0.022	11.1246	0.0040	1.8327	0.0011
374	47.146	0.022	11.1315	0.0040	1.8338	0.0011
375	47.115	0.022	11.1242	0.0040	1.8326	0.0011
376	47.124	0.022	11.1263	0.0040	1.8330	0.0011
377	47.153	0.022	11.1332	0.0040	1.8341	0.0011
378	47.077	0.022	11.1152	0.0040	1.8312	0.0011
379	47.161	0.022	11.1349	0.0040	1.8344	0.0011
380	47.097	0.022	11.1199	0.0040	1.8319	0.0011
381	47.215	0.022	11.1478	0.0040	1.8365	0.0012
382	47.106	0.022	11.1220	0.0040	1.8323	0.0011
383	47.108	0.022	11.1225	0.0040	1.8324	0.0011
384	47.081	0.022	11.1160	0.0040	1.8313	0.0011
385	47.195	0.022	11.1431	0.0040	1.8358	0.0012
386	47.101	0.022	11.1207	0.0040	1.8321	0.0011
387	47.166	0.022	11.1362	0.0040	1.8346	0.0012
388	47.124	0.022	11.1263	0.0040	1.8330	0.0011
389	47.132	0.022	11.1281	0.0040	1.8333	0.0011
390	47.133	0.022	11.1285	0.0040	1.8333	0.0011
391	47.121	0.022	11.1255	0.0040	1.8329	0.0011
392	47.121	0.022	11.1255	0.0040	1.8329	0.0011
393	47.128	0.022	11.1272	0.0040	1.8331	0.0011
394	47.128	0.022	11.1272	0.0040	1.8331	0.0011
395	47.108	0.022	11.1225	0.0040	1.8324	0.0011
396	47.144	0.022	11.1311	0.0040	1.8338	0.0011
397	47.086	0.022	11.1173	0.0040	1.8315	0.0011
398	47.090	0.022	11.1182	0.0040	1.8316	0.0011
399	47.132	0.022	11.1281	0.0040	1.8333	0.0011
400	47.228	0.022	11.1509	0.0040	1.8370	0.0012

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
401	47.077	0.022	11.1152	0.0040	1.8312	0.0011
402	47.081	0.022	11.1160	0.0040	1.8313	0.0011
403	47.170	0.022	11.1371	0.0040	1.8348	0.0012
404	47.081	0.022	11.1160	0.0040	1.8313	0.0011
405	47.119	0.022	11.1250	0.0040	1.8328	0.0011
406	47.117	0.022	11.1246	0.0040	1.8327	0.0011
407	47.101	0.022	11.1207	0.0040	1.8321	0.0011
408	47.095	0.022	11.1195	0.0040	1.8319	0.0011
409	47.146	0.022	11.1315	0.0040	1.8338	0.0011
410	47.133	0.022	11.1285	0.0040	1.8333	0.0011
411	47.148	0.022	11.1319	0.0040	1.8339	0.0011
412	47.110	0.022	11.1229	0.0040	1.8324	0.0011
413	47.093	0.022	11.1190	0.0040	1.8318	0.0011
414	47.117	0.022	11.1246	0.0040	1.8327	0.0011
415	47.102	0.022	11.1212	0.0040	1.8321	0.0011
416	47.152	0.022	11.1328	0.0040	1.8341	0.0011
417	47.099	0.022	11.1203	0.0040	1.8320	0.0011
418	47.082	0.022	11.1164	0.0040	1.8314	0.0011
419	47.099	0.022	11.1203	0.0040	1.8320	0.0011
420	47.161	0.022	11.1349	0.0040	1.8344	0.0011
421	47.062	0.022	11.1117	0.0040	1.8306	0.0011
422	47.119	0.022	11.1250	0.0040	1.8328	0.0011
423	47.099	0.022	11.1203	0.0040	1.8320	0.0011
424	47.066	0.022	11.1126	0.0040	1.8307	0.0011
425	47.099	0.022	11.1203	0.0040	1.8320	0.0011
426	47.091	0.022	11.1186	0.0040	1.8317	0.0011
427	47.212	0.022	11.1470	0.0040	1.8364	0.0012
428	47.157	0.022	11.1341	0.0040	1.8343	0.0011
429	47.046	0.022	11.1078	0.0040	1.8299	0.0011
430	47.086	0.022	11.1173	0.0040	1.8315	0.0011
431	47.148	0.022	11.1319	0.0040	1.8339	0.0011
432	47.115	0.022	11.1242	0.0040	1.8326	0.0011
433	47.137	0.022	11.1293	0.0040	1.8335	0.0011
434	47.068	0.022	11.1130	0.0040	1.8308	0.0011
435	47.193	0.022	11.1427	0.0040	1.8357	0.0012
436	47.066	0.022	11.1126	0.0040	1.8307	0.0011
437	47.124	0.022	11.1263	0.0040	1.8330	0.0011
438	47.102	0.022	11.1212	0.0040	1.8321	0.0011
439	47.081	0.022	11.1160	0.0040	1.8313	0.0011
440	47.086	0.022	11.1173	0.0040	1.8315	0.0011
441	47.055	0.022	11.1100	0.0040	1.8303	0.0011
442	47.157	0.022	11.1341	0.0040	1.8343	0.0011
443	47.073	0.022	11.1143	0.0040	1.8310	0.0011
444	47.066	0.022	11.1126	0.0040	1.8307	0.0011
445	47.097	0.022	11.1199	0.0040	1.8319	0.0011
446	47.099	0.022	11.1203	0.0040	1.8320	0.0011
447	47.110	0.022	11.1229	0.0040	1.8324	0.0011
448	47.037	0.022	11.1057	0.0040	1.8296	0.0011
449	47.206	0.022	11.1457	0.0040	1.8362	0.0012
450	47.028	0.022	11.1035	0.0040	1.8292	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
451	47.077	0.022	11.1152	0.0040	1.8312	0.0011
452	47.170	0.022	11.1371	0.0040	1.8348	0.0012
453	47.075	0.022	11.1147	0.0040	1.8311	0.0011
454	47.053	0.022	11.1096	0.0040	1.8302	0.0011
455	47.093	0.022	11.1190	0.0040	1.8318	0.0011
456	47.024	0.022	11.1027	0.0040	1.8291	0.0011
457	47.141	0.022	11.1302	0.0040	1.8336	0.0011
458	47.077	0.022	11.1152	0.0040	1.8312	0.0011
459	47.111	0.022	11.1233	0.0040	1.8325	0.0011
460	47.073	0.022	11.1143	0.0040	1.8310	0.0011
461	47.050	0.022	11.1087	0.0040	1.8301	0.0011
462	47.153	0.022	11.1332	0.0040	1.8341	0.0011
463	47.024	0.022	11.1027	0.0040	1.8291	0.0011
464	47.110	0.022	11.1229	0.0040	1.8324	0.0011
465	47.033	0.022	11.1048	0.0040	1.8295	0.0011
466	47.029	0.022	11.1040	0.0040	1.8293	0.0011
467	47.128	0.022	11.1272	0.0040	1.8331	0.0011
468	47.026	0.022	11.1031	0.0040	1.8292	0.0011
469	47.091	0.022	11.1186	0.0040	1.8317	0.0011
470	47.086	0.022	11.1173	0.0040	1.8315	0.0011
471	47.122	0.022	11.1259	0.0040	1.8329	0.0011
472	47.051	0.022	11.1091	0.0040	1.8302	0.0011
473	47.077	0.022	11.1152	0.0040	1.8312	0.0011
474	47.135	0.022	11.1289	0.0040	1.8334	0.0011
475	47.011	0.022	11.0997	0.0039	1.8286	0.0011
476	47.057	0.022	11.1104	0.0040	1.8304	0.0011
477	47.173	0.022	11.1380	0.0040	1.8349	0.0012
478	47.035	0.022	11.1053	0.0040	1.8295	0.0011
479	46.980	0.022	11.0924	0.0039	1.8274	0.0011
480	47.106	0.022	11.1220	0.0040	1.8323	0.0011
481	47.070	0.022	11.1134	0.0040	1.8309	0.0011
482	47.104	0.022	11.1216	0.0040	1.8322	0.0011
483	47.064	0.022	11.1121	0.0040	1.8307	0.0011
484	47.060	0.022	11.1113	0.0040	1.8305	0.0011
485	47.008	0.022	11.0988	0.0039	1.8285	0.0011
486	47.088	0.022	11.1177	0.0040	1.8316	0.0011
487	47.091	0.022	11.1186	0.0040	1.8317	0.0011
488	47.081	0.022	11.1160	0.0040	1.8313	0.0011
489	47.095	0.022	11.1195	0.0040	1.8319	0.0011
490	47.026	0.022	11.1031	0.0040	1.8292	0.0011
491	47.097	0.022	11.1199	0.0040	1.8319	0.0011
492	47.017	0.022	11.1010	0.0039	1.8288	0.0011
493	47.059	0.022	11.1109	0.0040	1.8304	0.0011
494	47.050	0.022	11.1087	0.0040	1.8301	0.0011
495	47.090	0.022	11.1182	0.0040	1.8316	0.0011
496	47.046	0.022	11.1078	0.0040	1.8299	0.0011
497	47.060	0.022	11.1113	0.0040	1.8305	0.0011
498	47.035	0.022	11.1053	0.0040	1.8295	0.0011
499	47.011	0.022	11.0997	0.0039	1.8286	0.0011
500	47.090	0.022	11.1182	0.0040	1.8316	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
501	47.057	0.022	11.1104	0.0040	1.8304	0.0011
502	47.053	0.022	11.1096	0.0040	1.8302	0.0011
503	47.037	0.022	11.1057	0.0040	1.8296	0.0011
504	47.097	0.022	11.1199	0.0040	1.8319	0.0011
505	47.073	0.022	11.1143	0.0040	1.8310	0.0011
506	47.029	0.022	11.1040	0.0040	1.8293	0.0011
507	47.040	0.022	11.1066	0.0040	1.8297	0.0011
508	47.068	0.022	11.1130	0.0040	1.8308	0.0011
509	47.051	0.022	11.1091	0.0040	1.8302	0.0011
510	47.068	0.022	11.1130	0.0040	1.8308	0.0011
511	47.091	0.022	11.1186	0.0040	1.8317	0.0011
512	47.033	0.022	11.1048	0.0040	1.8295	0.0011
513	47.011	0.022	11.0997	0.0039	1.8286	0.0011
514	47.064	0.022	11.1121	0.0040	1.8307	0.0011
515	47.084	0.022	11.1169	0.0040	1.8314	0.0011
516	47.008	0.022	11.0988	0.0039	1.8285	0.0011
517	47.029	0.022	11.1040	0.0040	1.8293	0.0011
518	47.028	0.022	11.1035	0.0040	1.8292	0.0011
519	47.046	0.022	11.1078	0.0040	1.8299	0.0011
520	47.020	0.022	11.1018	0.0040	1.8290	0.0011
521	47.040	0.022	11.1066	0.0040	1.8297	0.0011
522	47.073	0.022	11.1143	0.0040	1.8310	0.0011
523	47.028	0.022	11.1035	0.0040	1.8292	0.0011
524	47.115	0.022	11.1242	0.0040	1.8326	0.0011
525	47.042	0.022	11.1070	0.0040	1.8298	0.0011
526	47.026	0.022	11.1031	0.0040	1.8292	0.0011
527	47.013	0.022	11.1001	0.0039	1.8287	0.0011
528	47.028	0.022	11.1035	0.0040	1.8292	0.0011
529	47.099	0.022	11.1203	0.0040	1.8320	0.0011
530	47.000	0.022	11.0971	0.0039	1.8282	0.0011
531	47.009	0.022	11.0992	0.0039	1.8285	0.0011
532	47.128	0.022	11.1272	0.0040	1.8331	0.0011
533	47.031	0.022	11.1044	0.0040	1.8294	0.0011
534	47.004	0.022	11.0979	0.0039	1.8283	0.0011
535	46.995	0.022	11.0958	0.0039	1.8280	0.0011
536	47.035	0.022	11.1053	0.0040	1.8295	0.0011
537	47.046	0.022	11.1078	0.0040	1.8299	0.0011
538	47.026	0.022	11.1031	0.0040	1.8292	0.0011
539	47.082	0.022	11.1164	0.0040	1.8314	0.0011
540	47.086	0.022	11.1173	0.0040	1.8315	0.0011
541	46.995	0.022	11.0958	0.0039	1.8280	0.0011
542	47.057	0.022	11.1104	0.0040	1.8304	0.0011
543	47.044	0.022	11.1074	0.0040	1.8299	0.0011
544	47.033	0.022	11.1048	0.0040	1.8295	0.0011
545	47.004	0.022	11.0979	0.0039	1.8283	0.0011
546	47.062	0.022	11.1117	0.0040	1.8306	0.0011
547	47.019	0.022	11.1014	0.0040	1.8289	0.0011
548	47.081	0.022	11.1160	0.0040	1.8313	0.0011
549	46.995	0.022	11.0958	0.0039	1.8280	0.0011
550	47.059	0.022	11.1109	0.0040	1.8304	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
551	47.026	0.022	11.1031	0.0040	1.8292	0.0011
552	47.019	0.022	11.1014	0.0040	1.8289	0.0011
553	47.028	0.022	11.1035	0.0040	1.8292	0.0011
554	47.082	0.022	11.1164	0.0040	1.8314	0.0011
555	47.042	0.022	11.1070	0.0040	1.8298	0.0011
556	47.009	0.022	11.0992	0.0039	1.8285	0.0011
557	47.039	0.022	11.1061	0.0040	1.8297	0.0011
558	47.046	0.022	11.1078	0.0040	1.8299	0.0011
559	46.960	0.022	11.0876	0.0039	1.8266	0.0011
560	47.035	0.022	11.1053	0.0040	1.8295	0.0011
561	47.024	0.022	11.1027	0.0040	1.8291	0.0011
562	47.039	0.022	11.1061	0.0040	1.8297	0.0011
563	47.026	0.022	11.1031	0.0040	1.8292	0.0011
564	47.064	0.022	11.1121	0.0040	1.8307	0.0011
565	47.022	0.022	11.1022	0.0040	1.8290	0.0011
566	47.026	0.022	11.1031	0.0040	1.8292	0.0011
567	47.031	0.022	11.1044	0.0040	1.8294	0.0011
568	47.064	0.022	11.1121	0.0040	1.8307	0.0011
569	47.013	0.022	11.1001	0.0039	1.8287	0.0011
570	47.066	0.022	11.1126	0.0040	1.8307	0.0011
571	47.017	0.022	11.1010	0.0039	1.8288	0.0011
572	47.024	0.022	11.1027	0.0040	1.8291	0.0011
573	47.013	0.022	11.1001	0.0039	1.8287	0.0011
574	47.029	0.022	11.1040	0.0040	1.8293	0.0011
575	47.000	0.022	11.0971	0.0039	1.8282	0.0011
576	47.073	0.022	11.1143	0.0040	1.8310	0.0011
577	47.037	0.022	11.1057	0.0040	1.8296	0.0011
578	46.958	0.022	11.0872	0.0039	1.8265	0.0011
579	47.101	0.022	11.1207	0.0040	1.8321	0.0011
580	46.982	0.022	11.0928	0.0039	1.8275	0.0011
581	46.986	0.022	11.0936	0.0039	1.8276	0.0011
582	47.020	0.022	11.1018	0.0040	1.8290	0.0011
583	47.024	0.022	11.1027	0.0040	1.8291	0.0011
584	47.071	0.022	11.1139	0.0040	1.8309	0.0011
585	46.993	0.022	11.0954	0.0039	1.8279	0.0011
586	47.039	0.022	11.1061	0.0040	1.8297	0.0011
587	47.009	0.022	11.0992	0.0039	1.8285	0.0011
588	46.991	0.022	11.0949	0.0039	1.8278	0.0011
589	47.093	0.022	11.1190	0.0040	1.8318	0.0011
590	47.024	0.022	11.1027	0.0040	1.8291	0.0011
591	47.024	0.022	11.1027	0.0040	1.8291	0.0011
592	47.029	0.022	11.1040	0.0040	1.8293	0.0011
593	47.006	0.022	11.0984	0.0039	1.8284	0.0011
594	47.051	0.022	11.1091	0.0040	1.8302	0.0011
595	46.984	0.022	11.0932	0.0039	1.8275	0.0011
596	47.024	0.022	11.1027	0.0040	1.8291	0.0011
597	47.022	0.022	11.1022	0.0040	1.8290	0.0011
598	47.033	0.022	11.1048	0.0040	1.8295	0.0011
599	46.999	0.022	11.0967	0.0039	1.8281	0.0011
600	47.066	0.022	11.1126	0.0040	1.8307	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
601	46.999	0.022	11.0967	0.0039	1.8281	0.0011
602	47.044	0.022	11.1074	0.0040	1.8299	0.0011
603	46.986	0.022	11.0936	0.0039	1.8276	0.0011
604	47.046	0.022	11.1078	0.0040	1.8299	0.0011
605	46.957	0.022	11.0868	0.0039	1.8265	0.0011
606	47.057	0.022	11.1104	0.0040	1.8304	0.0011
607	46.971	0.022	11.0902	0.0039	1.8270	0.0011
608	47.082	0.022	11.1164	0.0040	1.8314	0.0011
609	47.035	0.022	11.1053	0.0040	1.8295	0.0011
610	47.046	0.022	11.1078	0.0040	1.8299	0.0011
611	47.042	0.022	11.1070	0.0040	1.8298	0.0011
612	46.989	0.022	11.0945	0.0039	1.8278	0.0011
613	46.937	0.022	11.0820	0.0039	1.8257	0.0011
614	47.044	0.022	11.1074	0.0040	1.8299	0.0011
615	47.019	0.022	11.1014	0.0040	1.8289	0.0011
616	47.053	0.022	11.1096	0.0040	1.8302	0.0011
617	46.977	0.022	11.0915	0.0039	1.8273	0.0011
618	47.033	0.022	11.1048	0.0040	1.8295	0.0011
619	47.022	0.022	11.1022	0.0040	1.8290	0.0011
620	47.006	0.022	11.0984	0.0039	1.8284	0.0011
621	47.035	0.022	11.1053	0.0040	1.8295	0.0011
622	47.022	0.022	11.1022	0.0040	1.8290	0.0011
623	46.964	0.022	11.0885	0.0039	1.8268	0.0011
624	47.064	0.022	11.1121	0.0040	1.8307	0.0011
625	47.028	0.022	11.1035	0.0040	1.8292	0.0011
626	47.028	0.022	11.1035	0.0040	1.8292	0.0011
627	47.019	0.022	11.1014	0.0040	1.8289	0.0011
628	46.977	0.022	11.0915	0.0039	1.8273	0.0011
629	46.993	0.022	11.0954	0.0039	1.8279	0.0011
630	47.104	0.022	11.1216	0.0040	1.8322	0.0011
631	47.009	0.022	11.0992	0.0039	1.8285	0.0011
632	47.028	0.022	11.1035	0.0040	1.8292	0.0011
633	46.984	0.022	11.0932	0.0039	1.8275	0.0011
634	47.026	0.022	11.1031	0.0040	1.8292	0.0011
635	47.053	0.022	11.1096	0.0040	1.8302	0.0011
636	47.009	0.022	11.0992	0.0039	1.8285	0.0011
637	46.953	0.022	11.0859	0.0039	1.8263	0.0011
638	47.053	0.022	11.1096	0.0040	1.8302	0.0011
639	47.004	0.022	11.0979	0.0039	1.8283	0.0011
640	47.093	0.022	11.1190	0.0040	1.8318	0.0011
641	47.004	0.022	11.0979	0.0039	1.8283	0.0011
642	46.997	0.022	11.0962	0.0039	1.8280	0.0011
643	46.999	0.022	11.0967	0.0039	1.8281	0.0011
644	46.973	0.022	11.0906	0.0039	1.8271	0.0011
645	47.006	0.022	11.0984	0.0039	1.8284	0.0011
646	46.999	0.022	11.0967	0.0039	1.8281	0.0011
647	47.020	0.022	11.1018	0.0040	1.8290	0.0011
648	46.997	0.022	11.0962	0.0039	1.8280	0.0011
649	47.022	0.022	11.1022	0.0040	1.8290	0.0011
650	47.029	0.022	11.1040	0.0040	1.8293	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
651	47.028	0.022	11.1035	0.0040	1.8292	0.0011
652	46.997	0.022	11.0962	0.0039	1.8280	0.0011
653	47.008	0.022	11.0988	0.0039	1.8285	0.0011
654	47.031	0.022	11.1044	0.0040	1.8294	0.0011
655	46.995	0.022	11.0958	0.0039	1.8280	0.0011
656	47.033	0.022	11.1048	0.0040	1.8295	0.0011
657	46.993	0.022	11.0954	0.0039	1.8279	0.0011
658	46.993	0.022	11.0954	0.0039	1.8279	0.0011
659	47.039	0.022	11.1061	0.0040	1.8297	0.0011
660	47.029	0.022	11.1040	0.0040	1.8293	0.0011
661	47.028	0.022	11.1035	0.0040	1.8292	0.0011
662	46.997	0.022	11.0962	0.0039	1.8280	0.0011
663	47.022	0.022	11.1022	0.0040	1.8290	0.0011
664	47.053	0.022	11.1096	0.0040	1.8302	0.0011
665	47.031	0.022	11.1044	0.0040	1.8294	0.0011
666	47.008	0.022	11.0988	0.0039	1.8285	0.0011
667	47.042	0.022	11.1070	0.0040	1.8298	0.0011
668	46.955	0.022	11.0863	0.0039	1.8264	0.0011
669	47.093	0.022	11.1190	0.0040	1.8318	0.0011
670	46.980	0.022	11.0924	0.0039	1.8274	0.0011
671	47.053	0.022	11.1096	0.0040	1.8302	0.0011
672	47.019	0.022	11.1014	0.0040	1.8289	0.0011
673	47.150	0.022	11.1324	0.0040	1.8340	0.0011
674	47.055	0.022	11.1100	0.0040	1.8303	0.0011
675	47.139	0.022	11.1298	0.0040	1.8336	0.0011
676	47.086	0.022	11.1173	0.0040	1.8315	0.0011
677	47.106	0.022	11.1220	0.0040	1.8323	0.0011
678	47.124	0.022	11.1263	0.0040	1.8330	0.0011
679	47.099	0.022	11.1203	0.0040	1.8320	0.0011
680	47.177	0.022	11.1388	0.0040	1.8350	0.0012
681	47.053	0.022	11.1096	0.0040	1.8302	0.0011
682	47.153	0.022	11.1332	0.0040	1.8341	0.0011
683	47.040	0.022	11.1066	0.0040	1.8297	0.0011
684	47.101	0.022	11.1207	0.0040	1.8321	0.0011
685	47.113	0.022	11.1238	0.0040	1.8326	0.0011
686	47.110	0.022	11.1229	0.0040	1.8324	0.0011
687	47.097	0.022	11.1199	0.0040	1.8319	0.0011
688	47.088	0.022	11.1177	0.0040	1.8316	0.0011
689	47.133	0.022	11.1285	0.0040	1.8333	0.0011
690	47.124	0.022	11.1263	0.0040	1.8330	0.0011
691	47.050	0.022	11.1087	0.0040	1.8301	0.0011
692	47.104	0.022	11.1216	0.0040	1.8322	0.0011
693	47.070	0.022	11.1134	0.0040	1.8309	0.0011
694	47.166	0.022	11.1362	0.0040	1.8346	0.0012
695	47.053	0.022	11.1096	0.0040	1.8302	0.0011
696	47.060	0.022	11.1113	0.0040	1.8305	0.0011
697	47.186	0.022	11.1410	0.0040	1.8354	0.0012
698	47.040	0.022	11.1066	0.0040	1.8297	0.0011
699	47.033	0.022	11.1048	0.0040	1.8295	0.0011
700	47.111	0.022	11.1233	0.0040	1.8325	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
701	47.104	0.022	11.1216	0.0040	1.8322	0.0011
702	47.130	0.022	11.1276	0.0040	1.8332	0.0011
703	47.060	0.022	11.1113	0.0040	1.8305	0.0011
704	47.119	0.022	11.1250	0.0040	1.8328	0.0011
705	47.055	0.022	11.1100	0.0040	1.8303	0.0011
706	47.079	0.022	11.1156	0.0040	1.8312	0.0011
707	47.204	0.022	11.1453	0.0040	1.8361	0.0012
708	47.053	0.022	11.1096	0.0040	1.8302	0.0011
709	47.115	0.022	11.1242	0.0040	1.8326	0.0011
710	47.073	0.022	11.1143	0.0040	1.8310	0.0011
711	47.095	0.022	11.1195	0.0040	1.8319	0.0011
712	47.111	0.022	11.1233	0.0040	1.8325	0.0011
713	47.091	0.022	11.1186	0.0040	1.8317	0.0011
714	47.130	0.022	11.1276	0.0040	1.8332	0.0011
715	47.059	0.022	11.1109	0.0040	1.8304	0.0011
716	47.148	0.022	11.1319	0.0040	1.8339	0.0011
717	47.053	0.022	11.1096	0.0040	1.8302	0.0011
718	47.130	0.022	11.1276	0.0040	1.8332	0.0011
719	47.022	0.022	11.1022	0.0040	1.8290	0.0011
720	47.155	0.022	11.1337	0.0040	1.8342	0.0011
721	47.119	0.022	11.1250	0.0040	1.8328	0.0011
722	47.084	0.022	11.1169	0.0040	1.8314	0.0011
723	47.135	0.022	11.1289	0.0040	1.8334	0.0011
724	47.086	0.022	11.1173	0.0040	1.8315	0.0011
725	47.064	0.022	11.1121	0.0040	1.8307	0.0011
726	47.130	0.022	11.1276	0.0040	1.8332	0.0011
727	47.070	0.022	11.1134	0.0040	1.8309	0.0011
728	47.135	0.022	11.1289	0.0040	1.8334	0.0011
729	47.108	0.022	11.1225	0.0040	1.8324	0.0011
730	47.095	0.022	11.1195	0.0040	1.8319	0.0011
731	47.093	0.022	11.1190	0.0040	1.8318	0.0011
732	47.051	0.022	11.1091	0.0040	1.8302	0.0011
733	47.064	0.022	11.1121	0.0040	1.8307	0.0011
734	47.101	0.022	11.1207	0.0040	1.8321	0.0011
735	47.179	0.022	11.1392	0.0040	1.8351	0.0012
736	47.108	0.022	11.1225	0.0040	1.8324	0.0011
737	47.102	0.022	11.1212	0.0040	1.8321	0.0011
738	47.039	0.022	11.1061	0.0040	1.8297	0.0011
739	47.097	0.022	11.1199	0.0040	1.8319	0.0011
740	47.133	0.022	11.1285	0.0040	1.8333	0.0011
741	47.055	0.022	11.1100	0.0040	1.8303	0.0011
742	47.113	0.022	11.1238	0.0040	1.8326	0.0011
743	47.104	0.022	11.1216	0.0040	1.8322	0.0011
744	47.139	0.022	11.1298	0.0040	1.8336	0.0011
745	47.060	0.022	11.1113	0.0040	1.8305	0.0011
746	47.081	0.022	11.1160	0.0040	1.8313	0.0011
747	47.068	0.022	11.1130	0.0040	1.8308	0.0011
748	47.141	0.022	11.1302	0.0040	1.8336	0.0011
749	47.093	0.022	11.1190	0.0040	1.8318	0.0011
750	47.137	0.022	11.1293	0.0040	1.8335	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
751	47.073	0.022	11.1143	0.0040	1.8310	0.0011
752	47.106	0.022	11.1220	0.0040	1.8323	0.0011
753	47.064	0.022	11.1121	0.0040	1.8307	0.0011
754	47.086	0.022	11.1173	0.0040	1.8315	0.0011
755	47.099	0.022	11.1203	0.0040	1.8320	0.0011
756	47.062	0.022	11.1117	0.0040	1.8306	0.0011
757	47.099	0.022	11.1203	0.0040	1.8320	0.0011
758	47.128	0.022	11.1272	0.0040	1.8331	0.0011
759	47.093	0.022	11.1190	0.0040	1.8318	0.0011
760	47.062	0.022	11.1117	0.0040	1.8306	0.0011
761	47.186	0.022	11.1410	0.0040	1.8354	0.0012
762	47.102	0.022	11.1212	0.0040	1.8321	0.0011
763	47.037	0.022	11.1057	0.0040	1.8296	0.0011
764	47.122	0.022	11.1259	0.0040	1.8329	0.0011
765	47.128	0.022	11.1272	0.0040	1.8331	0.0011
766	47.050	0.022	11.1087	0.0040	1.8301	0.0011
767	47.148	0.022	11.1319	0.0040	1.8339	0.0011
768	46.980	0.022	11.0924	0.0039	1.8274	0.0011
769	47.133	0.022	11.1285	0.0040	1.8333	0.0011
770	47.122	0.022	11.1259	0.0040	1.8329	0.0011
771	47.090	0.022	11.1182	0.0040	1.8316	0.0011
772	47.057	0.022	11.1104	0.0040	1.8304	0.0011
773	47.122	0.022	11.1259	0.0040	1.8329	0.0011
774	47.155	0.022	11.1337	0.0040	1.8342	0.0011
775	47.075	0.022	11.1147	0.0040	1.8311	0.0011
776	47.079	0.022	11.1156	0.0040	1.8312	0.0011
777	47.111	0.022	11.1233	0.0040	1.8325	0.0011
778	47.095	0.022	11.1195	0.0040	1.8319	0.0011
779	47.077	0.022	11.1152	0.0040	1.8312	0.0011
780	47.106	0.022	11.1220	0.0040	1.8323	0.0011
781	47.130	0.022	11.1276	0.0040	1.8332	0.0011
782	47.039	0.022	11.1061	0.0040	1.8297	0.0011
783	47.097	0.022	11.1199	0.0040	1.8319	0.0011
784	47.095	0.022	11.1195	0.0040	1.8319	0.0011
785	47.099	0.022	11.1203	0.0040	1.8320	0.0011
786	47.113	0.022	11.1238	0.0040	1.8326	0.0011
787	47.039	0.022	11.1061	0.0040	1.8297	0.0011
788	47.071	0.022	11.1139	0.0040	1.8309	0.0011
789	47.099	0.022	11.1203	0.0040	1.8320	0.0011
790	47.082	0.022	11.1164	0.0040	1.8314	0.0011
791	47.108	0.022	11.1225	0.0040	1.8324	0.0011
792	47.152	0.022	11.1328	0.0040	1.8341	0.0011
793	47.015	0.022	11.1005	0.0039	1.8287	0.0011
794	47.148	0.022	11.1319	0.0040	1.8339	0.0011
795	47.028	0.022	11.1035	0.0040	1.8292	0.0011
796	47.161	0.022	11.1349	0.0040	1.8344	0.0011
797	47.035	0.022	11.1053	0.0040	1.8295	0.0011
798	47.183	0.022	11.1401	0.0040	1.8353	0.0012
799	47.091	0.022	11.1186	0.0040	1.8317	0.0011
800	47.046	0.022	11.1078	0.0040	1.8299	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
801	47.095	0.022	11.1195	0.0040	1.8319	0.0011
802	47.086	0.022	11.1173	0.0040	1.8315	0.0011
803	47.150	0.022	11.1324	0.0040	1.8340	0.0011
804	47.099	0.022	11.1203	0.0040	1.8320	0.0011
805	47.066	0.022	11.1126	0.0040	1.8307	0.0011
806	47.081	0.022	11.1160	0.0040	1.8313	0.0011
807	47.093	0.022	11.1190	0.0040	1.8318	0.0011
808	47.099	0.022	11.1203	0.0040	1.8320	0.0011
809	47.055	0.022	11.1100	0.0040	1.8303	0.0011
810	47.111	0.022	11.1233	0.0040	1.8325	0.0011
811	47.111	0.022	11.1233	0.0040	1.8325	0.0011
812	47.144	0.022	11.1311	0.0040	1.8338	0.0011
813	47.068	0.022	11.1130	0.0040	1.8308	0.0011
814	47.039	0.022	11.1061	0.0040	1.8297	0.0011
815	47.201	0.022	11.1444	0.0040	1.8360	0.0012
816	47.057	0.022	11.1104	0.0040	1.8304	0.0011
817	47.082	0.022	11.1164	0.0040	1.8314	0.0011
818	47.142	0.022	11.1306	0.0040	1.8337	0.0011
819	47.040	0.022	11.1066	0.0040	1.8297	0.0011
820	47.111	0.022	11.1233	0.0040	1.8325	0.0011
821	47.037	0.022	11.1057	0.0040	1.8296	0.0011
822	47.115	0.022	11.1242	0.0040	1.8326	0.0011
823	47.104	0.022	11.1216	0.0040	1.8322	0.0011
824	47.048	0.022	11.1083	0.0040	1.8300	0.0011
825	47.121	0.022	11.1255	0.0040	1.8329	0.0011
826	47.153	0.022	11.1332	0.0040	1.8341	0.0011
827	47.050	0.022	11.1087	0.0040	1.8301	0.0011
828	47.101	0.022	11.1207	0.0040	1.8321	0.0011
829	47.082	0.022	11.1164	0.0040	1.8314	0.0011
830	47.106	0.022	11.1220	0.0040	1.8323	0.0011
831	47.095	0.022	11.1195	0.0040	1.8319	0.0011
832	47.155	0.022	11.1337	0.0040	1.8342	0.0011
833	47.059	0.022	11.1109	0.0040	1.8304	0.0011
834	47.050	0.022	11.1087	0.0040	1.8301	0.0011
835	47.117	0.022	11.1246	0.0040	1.8327	0.0011
836	47.115	0.022	11.1242	0.0040	1.8326	0.0011
837	47.070	0.022	11.1134	0.0040	1.8309	0.0011
838	47.117	0.022	11.1246	0.0040	1.8327	0.0011
839	47.115	0.022	11.1242	0.0040	1.8326	0.0011
840	47.139	0.022	11.1298	0.0040	1.8336	0.0011
841	47.081	0.022	11.1160	0.0040	1.8313	0.0011
842	47.148	0.022	11.1319	0.0040	1.8339	0.0011
843	47.104	0.022	11.1216	0.0040	1.8322	0.0011
844	47.075	0.022	11.1147	0.0040	1.8311	0.0011
845	47.019	0.022	11.1014	0.0040	1.8289	0.0011
846	47.077	0.022	11.1152	0.0040	1.8312	0.0011
847	47.086	0.022	11.1173	0.0040	1.8315	0.0011
848	47.128	0.022	11.1272	0.0040	1.8331	0.0011
849	47.088	0.022	11.1177	0.0040	1.8316	0.0011
850	47.086	0.022	11.1173	0.0040	1.8315	0.0011

Unit #	^{238}U		^{235}U		^{239}Pu	
	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]	Mass [1] [mg]	Uncertainty [2] [mg]
851	47.077	0.022	11.1152	0.0040	1.8312	0.0011
852	47.073	0.022	11.1143	0.0040	1.8310	0.0011
853	47.144	0.022	11.1311	0.0040	1.8338	0.0011
854	47.122	0.022	11.1259	0.0040	1.8329	0.0011
855	47.073	0.022	11.1143	0.0040	1.8310	0.0011
856	47.099	0.022	11.1203	0.0040	1.8320	0.0011
857	47.050	0.022	11.1087	0.0040	1.8301	0.0011
858	47.119	0.022	11.1250	0.0040	1.8328	0.0011
859	47.008	0.022	11.0988	0.0039	1.8285	0.0011
860	47.126	0.022	11.1268	0.0040	1.8331	0.0011
861	47.086	0.022	11.1173	0.0040	1.8315	0.0011
862	47.177	0.022	11.1388	0.0040	1.8350	0.0012

[1] The certified values are considered to be traceable to the SI based on the use of traceable metals (NBL PO CRM 116-A, CETAMA MP2 and NBL PO CRM 112-A), primary methods of measurement (weighing) and calibration of measurement systems. The reference date for the mass of ^{238}U, ^{235}U and ^{239}Pu per unit is January 1, 2022.

[2] The reference material was produced in compliance with ISO/IEC 17034:2016 and certified in accordance with ISO Guide 35:2017. The uncertainty of the certified value 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 98-3:2008, Guide to the Expression of Uncertainty in Measurement (GUM:1995).

The atomic masses of radionuclides were obtained from Wang et al. (The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017). The half-lives of radionuclides were obtained from DDEP-BIPM (Table of radionuclides) and R. Wellum et al. (A new evaluation of the half-life of ^{241}Pu, J. Anal. At. Spectrom., 24, 801-807, 2009).

New Brunswick Laboratory
U.S. Department of Energy

Certificate of Analysis
CRM 112-A
Uranium (normal) Metal Assay and Isotopic Standard

Uranium Assay:	**0.99975 g U/g metal**
Uranium Assay Uncertainty:	**0.00006 g U/g metal**

	$^{234}U/^{238}U$	$^{235}U/^{238}U$
Atom Ratio:	**0.000052841**	**0.0072543**
Atom Ratio Uncertainty:	**0.000000082**	**0.0000040**

	^{234}U	^{235}U	^{238}U
Atom Percent:	**0.0052458**	**0.72017**	**99.27458**
Atom Percent Uncertainty:	**0.0000081**	**0.00039**	**0.00039**
Weight Percent:	**0.0051579**	**0.71114**	**99.28370**
Weight Percent Uncertainty:	**0.0000080**	**0.00038**	**0.00038**

Relative Atomic Weight:	**238.028918**
Relative Atomic Weight Uncertainty:	**0.000012**

Note: ^{233}U and ^{236}U were not detected. The limit of detection of uranium ratios for the technique used is 5×10^{-9}. The $^{238}U/^{235}U$ ratio and uncertainty may be calculated as 137.849 ± 0.076.

This Certified Reference Material (CRM) is a uranium concentration and isotopic solution standard intended for use in calibration of and/or quality control for uranium analysis methods. Each unit of CRM 112-A consists of metal piece of nominal mass as listed on the container.

NOTE: The CRM should be handled under proper radiologically-controlled conditions at all times.

The uncertainty assigned to the certified assay value is the 95% confidence limit for the mean. This limit includes components due to both random analytical error and allowances for all known and quantified sources of systematic uncertainties. The uranium assay was determined using a constant-current coulometric reduction of uranyl ions with electrogenerated titanous ions in dilute sulfuric acid. A correction was made for the iron and vanadium content of the material. The total estimated impurities in the CRM (223 µg/g) yield a calculated uranium assay value of 0.99978.

September 30, 2010
Argonne, Illinois

Jon Neuhoff, Director
New Brunswick Laboratory

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The uncertainties for the uranium isotopic and atomic weight values are expressed as expanded uncertainties (U) as $U = k*u_c$ where u_c is the combined standard uncertainty and k is the coverage factor (k = 2). Uncertainties were determined according to the JCGM 100:2008 *Guide to the Expression of Uncertainty in Measurement*. The coverage factor of 2 was chosen to provide an approximate 95% level of confidence. The input quantities associated with the uranium isotopic composition included uncertainties from the certified value for CRM U030-A, measurement precision, and background corrections associated with the analytical techniques.

This CRM was originally issued in 1972 by the National Bureau of Standards (NBS) as Standard Reference Material (SRM) 960. The material was produced and shipped to NBL, at the request of the NBL, by the Mallincrodt Chemical Works (MCW) factory in St. Louis, Missouri. The MCW factory used the 'direct-ingot' or 'dingot' technique which produces high purity massive uranium metals with low carbon content. The dingot was shipped to NBL in 1959 and subsequently cut and processed at National Lead of Ohio prior to certification by NBS. Details of the production of the material may be found in NBL report NBL-RM-2010-CRM 112A.

The assay measurements leading to the certification of the uranium assay were performed at the National Bureau of Standards. In 1987, the technical and administrate transfer of NBS Special Nuclear SRMs into the NBL CRM Program was completed. In 1998, the standard material was repackaged and verified for uranium assay and atomic mass at NBL. In 2010, the material was again repackaged and isotopic certification and assay verification measurements were performed at the New Brunswick Laboratory.

NBL has performed uranium isotopic certification measurements on a random sampling of metal pieces of one (1) gram. NBL does not guarantee uranium isotopic homogeneity for metal pieces smaller than one gram.

Prior to use, surface oxide must be removed to ensure accurate uranium assay values. A suggested procedure is given below.

Suggested Procedure for Achieving Accurate Weighing and Assay Values

1. Soak the uranium metal sample in 8 M nitric acid for 10-20 minutes in order to remove all visible surface oxides and impurities.

2. In order to ensure an accurate uranium metal weight, the following steps should be performed rapidly to minimize oxidation of the sample.

3. Thoroughly rinse the metal piece with distilled, deionized water.

4. Remove excess water by thoroughly rinsing the metal piece with pure acetone.

5. Allow the acetone to evaporate (30 – 60 seconds is typically sufficient).

6. Perform a weighing of sufficient accuracy for users need.

September 30, 2010
Argonne, Illinois

Jon Neuhoff, Director
New Brunswick Laboratory

(Revision of Certificate dated July 31, 2002

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

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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.

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 +32-14-571 863

European Commission - JRC

30207 BAGNOLS SUR CEZE CEDEX
Téléphone 04.66.79.69.88 - Télécopie 04.66.79.69.89

ISO 9001
BUREAU VERITAS
Certification

Packaging list for IRMM

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

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

CETAMA CRM manager

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

Annex 5 The certificate of plutonium isotope abundances of CETAMA MP2

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

CERTIFICATE of a reference measurement

IM/MeaC/07/116

11 April 2007

SUBJECT : Recertification of CEA CETAMA MP2

1. Applicant: A. Verbruggen

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

3. Measurands:
   - Isotopic composition

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

Retieseweg, B-2440 Geel, Belgium; Tel.: +32-(0)14-211 • Fax: +32-(0)14-571 978• http://www.irmm.jrc.be page1 of 2

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 uranium amount content and isotope abundances of CETAMA MP2

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

CERTIFICATE of a reference measurement

IM/MeaC/06/06-MP2
6 March 2006

1. Applicant: DEN/DRCP CETAMA
CEA/VALRHO/Marcoule - B.P. 17171
30207 BAGNOLS-SUR-CEZE cedex

2. Sample Identification:
- MP2 – uranium fraction
- chemical form: in 4 M HNO_3 solution
- IM sample registration number: IM-NUCLEAR-2006-02-00700

3. Measurands:
- Element amount content: **2.798 6(25) µmol (U)·g^{-1}**
  657.99(58) µg (U)·g^{-1}
- Isotopic composition

isotope amount ratio(s)	
$n(^{233}U)/n(^{235}U)$	N/A (spiked with ^{233}U)
$n(^{234}U)/n(^{235}U)$	0.009 005 0(38)
$n(^{236}U)/n(^{235}U)$	0.082 571(28)
$n(^{238}U)/n(^{235}U)$	N/A (set to ^{238}U=0)

amount fraction (·100)		mass fraction (·100)	
$n(^{233}U)/n(U)$	N/A	$m(^{233}U)/m(U)$	N/A
$n(^{234}U)/n(U)$	0.8 249 5(36)	$m(^{234}U)/m(U)$	0.8 212 0(35)
$n(^{235}U)/n(U)$	91.610 7(22)	$m(^{235}U)/m(U)$	91.584 4(22)
$n(^{236}U)/n(U)$	7.564 4(24)	$m(^{236}U)/m(U)$	7.594 4(24)
$n(^{238}U)/n(U)$	N/A	$m(^{238}U)/m(U)$	N/A

molar mass: 235.111 416(26) g·mol^{-1}

Retieseweg, B-2440 Geel, BelgiumTel.: +32-(0)14-571 211 • Fax: +32-(0)14-571 863 • http://www.irmm.jrc.be

4. Date of receipt of sample : NA
   Date of completion of measurement : 20 February 2006

5. Uncertainty:
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. 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 content and ratios; other values are derived from them. Reproducing the derived values may result in differences due to rounding errors.
The detailed uncertainty budget for the uranium amount content is enclosed (see Attachment).

6. Analytical measurement procedure
- Sample preparation has been accomplished by a chemical conditioning and subsequent separation on ion exchanger.
- Analytical method/technique used : Isotope Dilution by ThIMS
- Measurement of uranium Isotopic Ratios by the TRITON TIMS mass spectrometer.
- Reference number of the measurement data: S:\D04-IM\Secure Data\ARCHIVE IM Measurements data files\TRITON\TRITON DATA MP-2-01 T6216
- The atomic masses, used in the calculations, are[1]
  ^{238}Pu : 238.049 552 5(44) g·mol^{-1}
  ^{239}Pu : 239.052 155 6(44) g·mol^{-1}
  ^{240}Pu : 240.053 806 5(42) g·mol^{-1}
  ^{241}Pu : 241.056 844 4(42) g·mol^{-1}
  ^{242}Pu : 242.058 735 9(42) g·mol^{-1}
  ^{244}Pu : 244.064 197(10) g·mol^{-1}
- The half lives used in the calculations are
  ^{238}Pu : 8.77 (03) · 10^1 a[2]
  ^{239}Pu : 2.411 (03) · 10^4 a[2]
  ^{240}Pu : 6.563 (07) · 10^3 a[2]
  ^{241}Pu : 1.429 (06) · 10^1 a[3]
  ^{242}Pu : 3.735 (11) · 10^5 a[2]
  ^{244}Pu : 8.00 (09) · 10^7 a[2]

- Metrological weighings are performed by R Eykens. Mass spectrometric measurements were performed by S Richter using the TRITON TIMS mass spectrometer, using samples prepared by F. Kehoe and R. Eykens. A Verbruggen was responsible for the preparation and issuance of the certificate.

André Verbruggen
Task leader

Copies: P Taylor, IM Unit Head, R Wellum, S Richter, F Kehoe, R Eykens, Archive

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[1] G. Audi and A.H. Wapstra, The 1993 atomic mass evaluation , Nucl Phys A565 (1993) 1-65.
[2] IAEA, Decay data of the Transactinium Nuclides, Technical Reports Series No. 261, 1986
[3] P. De Bièvre, A. Verbruggen, 'A new measurement of the ^{241}Pu half-life by isotope mass spectrometry', Int. Conf. on Nuclear Data for Science and Technology, May 19-24, 1997 Trieste, Italy

Uncertainty budget for isotope amount content

Quantity	Value	Standard uncertainty	%
mass of spike (g)	0.519 500	0.000 029	1.6
amount content spike (mol/g)	$4.299\,30 \cdot 10^{-6}$	$0.000\,34 \cdot 10^{-6}$	3.2
mass content MP2 solution (g/g)	$0.917\,679 \cdot 10^{-3}$	$0.000\,238 \cdot 10^{-3}$	34.2
mass MP2 solution (g)	150.322 90	0.000 87	0.0
$n(^{234}U)/n(^{233}U)$ in blend (mol/mol)	0.001 785 173	0.000 000 304	0.3
$n(^{235}U)/n(^{233}U)$ in blend (mol/mol)	0.158 356 4	0.000 053 0	54.0
$n(^{236}U)/n(^{233}U)$ in blend (mol/mol)	0.010 307 547	0.000 006 57	6.7

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

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

CERTIFIED REFERENCE MATERIAL
IRMM – 046c

CERTIFICATE OF ANALYSIS

NITRIC ACID SOLUTION		
	Isotope amount content	
	Certified value [1] [µmol/g]	Uncertainty [2] [µmol/g]
^{242}Pu	0.35491	0.00015
^{233}U	4.4627	0.0010
	Isotope amount ratio	
	Certified value [1] [mol/mol]	Uncertainty [2] [mol/mol]
$n(^{234}U)/n(^{233}U)$	0.0001939	0.0000012
$n(^{235}U)/n(^{233}U)$	0.0000735	0.0000023
$n(^{236}U)/n(^{233}U)$	0.0000038	0.0000018
$n(^{238}U)/n(^{233}U)$	0.0021043	0.0000039
$n(^{238}Pu)/n(^{242}Pu)$	0.0053359	0.0000049
$n(^{239}Pu)/n(^{242}Pu)$	0.0022699	0.0000014
$n(^{240}Pu)/n(^{242}Pu)$	0.046084	0.000037
$n(^{241}Pu)/n(^{242}Pu)$	0.0029924	0.0000032
$n(^{244}Pu)/n(^{242}Pu)$	0.00025739	0.00000049

[1] The certified values are traceable to the International System of units (SI) via IRMM-1027m, IRMM-074/10 and IRMM-290b/A3. The reference date for the certified values is July 1, 2010.
[2] The certified uncertainty is the expanded uncertainty with a coverage factor k = 2 corresponding to a level of confidence of about 95 % estimated in accordance with ISO/IEC Guide 98-3, Guide to the Expression of Uncertainty in Measurement (GUM:1995), ISO, 2008.

There is no minimum sample intake to be taken into account.

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

Geel, October 2020

Last revision

Signed: _____ 23-10-2020

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

Derived Values		
	Isotopic mass fraction	
	Value [1] [%]	Uncertainty [2] [%]
$m(^{233}U)/m(U)\times100$	99.75836	0.00051
$m(^{234}U)/m(U)\times100$	0.01942	0.00012
$m(^{235}U)/m(U)\times100$	0.00740	0.00023
$m(^{236}U)/m(U)\times100$	0.00038	0.00019
$m(^{238}U)/m(U)\times100$	0.21443	0.00040
$m(^{238}Pu)/m(Pu)\times100$	0.49672	0.00044
$m(^{239}Pu)/m(Pu)\times100$	0.21220	0.00012
$m(^{240}Pu)/m(Pu)\times100$	4.3261	0.0033
$m(^{241}Pu)/m(Pu)\times100$	0.28208	0.00030
$m(^{242}Pu)/m(Pu)\times100$	94.6583	0.0038
$m(^{244}Pu)/m(Pu)\times100$	0.024364	0.000046
	Amount content	
	Value [1] [µmol/g]	Uncertainty [2] [µmol/g]
Pu	0.37512	0.00015
U	4.4733	0.0010
	Mass fraction	
	Value [1] [mg/g]	Uncertainty [2] [mg/g]
Pu	0.090757	0.000037
^{242}Pu	0.085909	0.000035
U	1.04251	0.00024
^{233}U	1.04000	0.00024

[1] The derived values are obtained from the certified values. The reference date for the derived values is July 1, 2010.
[2] The certified uncertainty is the expanded uncertainty with a coverage factor k = 2 corresponding to a level of confidence of about 95 % estimated in accordance with ISO/IEC Guide 98-3, Guide to the Expression of Uncertainty in Measurement (GUM:1995), ISO, 2008.
The atomic masses used in the calculation were taken from Wang et al., The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C. Vol 41, No. 3, 2017.
Half-lives of plutonium isotopes were taken from Laboratorie National Henry Becquerel, http://www.nucleide.org/DDEPwg/DDEPdata.htm and R. Wellum et al, J .Anal. At. Spectrom., 24, 801-807, 2009.

DESCRIPTION OF THE MATERIAL

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

ANALYTICAL METHODS USED FOR CERTIFICATION

The certified values were established by isotope dilution mass spectrometry (IDMS) on randomly selected units of IRMM-046c using IRMM-1027m as spike. The isotope ratio measurements were performed on a Triton TIMS (Thermo Fisher Scientific) using total evaporation method. Pu standard IRMM-290b/A3 and U standard IRMM-074/10 were used to correct for the mass fractionation effects during isotopic measurement.

SAFETY INFORMATION

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

INSTRUCTIONS FOR USE AND INTENDED USE

The material is ready for use after ampoule opening. Users are cautioned that once the ampoule is opened, the amount contents of plutonium and uranium may be affected by evaporation losses.
IRMM-046c is for use as a spike Isotopic Reference Material (IRM) to determine the plutonium and uranium amount contents by isotope dilution mass spectrometry (IDMS) in a wide range of nuclear samples.

STORAGE

The users are reminded to close the vial(s) immediately after taking the sample.
The vials should be stored at + 18 °C ± 5 °C.
However, the European Commission cannot be held responsible for changes that happen during storage of the material at the customer's premises, especially of opened samples.

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

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

Annex 8 IRMM-1027w mother solution verification

Figure 10 Verification results of the IRMM-1027w mother solution by IDMS on the a) ^{235}U, b) ^{238}U and c) ^{239}Pu amount contents. Red dashed lines show the relative expanded uncertainty of the gravimetric value with a coverage factor k = 2 with the exception of ^{235}U amount content and mass fraction values, which have a coverage factor k = 2.3 (df_{eff} = 9). Blue lines show the mean ID-TIMS values and the blue shaded area represents their expanded uncertainties with a coverage factor k = 2.

Annex 9 Verification of IRMM-1027w by JRC-Karlsruhe G.II.8

Figure 11 Uranium isotope ratio verification measurements for a) $n(^{235}\mathrm{U})/n(^{238}\mathrm{U})$ b) $n(^{234}\mathrm{U})/n(^{238}\mathrm{U})$ and c) $n(^{236}\mathrm{U})/n(^{238}\mathrm{U})$. Error bars show the expanded uncertainties (k = 2 that corresponds to a level of confidence of about 95 %). Red dashed lines show the relative expanded uncertainty of the gravimetric value with a coverage factor k = 2 with the exception of $n(^{235}\mathrm{U})/n(^{238}\mathrm{U})$ amount content and mass fraction values, which have a coverage factor k = 2.2 (df_{eff} = 15).

Figure 12 Plutonium isotope ratio verification measurements for a) $n(^{240}Pu)/n(^{239}Pu)$ b) $n(^{238}Pu)/n(^{239}Pu)$ c) $n(^{241}Pu)/n(^{239}Pu)$ and d) $n(^{242}Pu)/n(^{239}Pu)$ ratios. Error bars show the expanded uncertainties (k = 2 that corresponds to a level of confidence of about 95 %). Red dashed lines show the relative expanded uncertainty of the gravimetric value with a coverage factor k = 2

Figure 13 Verification measurements for a) total uranium mass per unit b) total plutonium mass per unit. Error bars show the expanded uncertainties (k = 2 that corresponds to a level of confidence of about 95 %). Red dashed lines show the relative expanded uncertainty of the gravimetric value with a coverage factor k = 2

Annex 10 Results of the homogeneity assessment for IRMM-1027w

Figure 14 The normalised amount content of ^{235}U from homogeneity study for the 47 replicate measurements (15 selected units - 3 replicates and 1 selected unit – 2 replicates) are shown as a function of the analytical sequence. **No significant trend** at the 95% CI was observed (p>0.05).

Figure 15 The amount content of ^{235}U from homogeneity study for the 47 replicate measurements (15 selected units - 3 replicates and 1 selected unit – 2 replicates) are shown as a function of the filling sequence. The x positions are slightly 'dodged' to make overlapping data visible. **No significant trend** at the 95% CI was observed (p>0.05).

Figure 16 The normalised amount content of ^{238}U from homogeneity study for the 47 replicate measurements (15 selected units - 3 replicates and 1 selected unit – 2 replicates) are shown as a function of the analytical sequence. **No significant trend** at the 95% CI was observed ($p<0.05$).

Figure 17 The amount content of ^{238}U from homogeneity study for the 47 replicate measurements (15 selected units - 3 replicates and 1 selected unit – 2 replicates) are shown as a function of the filling sequence. The positions are slightly 'dodged' to make overlapping data visible. **No significant trend** at the 95% CI was observed ($p>0.05$).

Figure 18 The amount content of ^{239}Pu from homogeneity study for the 57 replicate measurements (19 selected units, 3 replicates each) are shown as a function of the analytical sequence. **No significant trend** at the 95% CI was observed.

Figure 19 The amount content of ^{239}Pu from homogeneity study for the 57 replicate measurements (19 selected units, 3 replicates each) are shown as a function of the filling sequence. The positions are slightly 'dodged' to make overlapping data visible. **No significant trend** at the 95% CI was observed.

Figure 20 Tukey's boxplot representation of day-to-day differences for a) ^{235}U b) ^{238}U and c) ^{239}Pu amount contents. The boxes represent the interquartile range (IQR) between the first and third quartile, the whiskers represent either the extremes or the 'fences' (1.5*IQR). The individual daily replicate measurements are represented with the circles. Colour coding: replicate measurements of the same unit.

Figure 21 Tukey's boxplot representation of spike ampoule-to-ampoule differences for a) ^{235}U b) ^{238}U and c) ^{239}Pu amount contents. The boxes represent the interquartile range (IQR) between the first and third quartile, the whiskers represent either the extremes or the 'fences' (1.5*IQR). The individual daily replicate measurements are represented with the circles. Colour coding: replicate measurements of the same unit.

Annex 11 The weighing certificate of the aliquots of dispensed solution of IRMM-1027w per unit before drying

Joint Research Centre	**Certificate of weighing**	**Directorate G – Nuclear Safety and Security** **G.2 - Standards for Nuclear Safety, Security and Safeguards Unit**

E. 3952 **Issued date:** 09/11/2021 **Page** 1 **of** 7

Applicant: Kalman Toth **Project:** IRMM-1027w

Description: Dispensing of IRMM-1027w U/Pu nitrate solution into individual vials

Request for analysis number: n/a **ID number:** n/a

Date of receipt of request: 02/06/2021 **Weighing dates**: 15-18/06/2021

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

Observations:
The measurements were performed according to Work instruction IMS-JRC.G-C1.1-WIN-0057 "WEIGHING AND MASS METROLOGY IN JRC.G.2 (NUCLEAR SAFEGUARDS TEAM)".

The dispensing and weighing were performed according to work instruction IMS-JRC.G-C1.1-WIN-0060 Preparation of large sized dried spikes" on balance Sartorius TE124 installed in the dispensing robot box with inventory No. 2006 00290 17.

The results were corrected for the buoyancy of air and the NUCOMAT dispensing factor (E3945).

Traceability:
The certified mass values are traceable to the SI through regular calibrations of the JRC G2's principal standards. The mass standard identified as H208 (cylinder + vial certificate E3945) 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. All reported uncertainties are expanded uncertainties $U = k \bullet u_c$ where u_c is the combined standard uncertainty calculated according to the ISO/BIPM Guide to the expression of Uncertainty in Measurement. The coverage factor $k = 2$ corresponds to a coverage probability of about 95%.

Rožle Jakopič
Nuclear Chemistry Laboratory responsible

Jeroen Bauwens
Analyst

Retieseweg, B-2440 Geel, Belgium; Tel.: +32-(0)14-571 211 • https://ec.europa.eu/jrc

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
001	2.5920	042	2.5896	083	2.5905	124	2.5885
002	2.5929	043	2.5888	084	2.5912	125	2.5885
003	2.5883	044	2.5894	085	2.5891	126	2.5875
004	2.5896	045	2.5913	086	2.5928	127	2.5891
005	2.5881	046	2.5887	087	2.5881	128	2.5882
006	2.5918	047	2.5919	088	2.5890	129	2.5920
007	2.5893	048	2.5900	089	2.5887	130	2.5920
008	2.5889	049	2.5902	090	2.5880	131	2.5836
009	2.5904	050	2.5872	091	2.5894	132	2.5907
010	2.5894	051	2.5901	092	2.5912	133	2.5912
011	2.5925	052	2.5892	093	2.5895	134	2.5873
012	2.5872	053	2.5937	094	2.5878	135	2.5905
013	2.5935	054	2.5863	095	2.5897	136	2.5879
014	2.5910	055	2.5902	096	2.5890	137	2.5935
015	2.5898	056	2.5906	097	2.5892	138	2.5857
016	2.5913	057	2.5904	098	2.5879	139	2.5896
017	2.5927	058	2.5899	099	2.5867	140	2.5902
018	2.5881	059	2.5895	100	2.5898	141	2.5884
019	2.5894	060	2.5885	101	2.5885	142	2.5864
020	2.5915	061	2.5926	102	2.5932	143	2.5902
021	2.5932	062	2.5915	103	2.5871	144	2.5881
022	2.5904	063	2.5883	104	2.5909	145	2.5930
023	2.5923	064	2.5908	105	2.5843	146	2.5880
024	2.5902	065	2.5925	106	2.5892	147	2.5881
025	2.5912	066	2.5859	107	2.5913	148	2.5902
026	2.5856	067	2.5906	108	2.5909	149	2.5854
027	2.5901	068	2.5917	109	2.5871	150	2.5900
028	2.5909	069	2.5888	110	2.5884	151	2.5880
029	2.5911	070	2.5882	111	2.5906	152	2.5895
030	2.5919	071	2.5883	112	2.5870	153	2.5872
031	2.5924	072	2.5904	113	2.5903	154	2.5884
032	2.5899	073	2.5945	114	2.5907	155	2.5911
033	2.5909	074	2.5862	115	2.5877	156	2.5909
034	2.5892	075	2.5909	116	2.5917	157	2.5864
035	2.5887	076	2.5920	117	2.5895	158	2.5912
036	2.5891	077	2.5894	118	2.5888	159	2.5890
037	2.5898	078	2.5890	119	2.5909	160	2.5869
038	2.5907	079	2.5889	120	2.5878	161	2.5895
039	2.5911	080	2.5917	121	2.5906	162	2.5897
040	2.5925	081	2.5905	122	2.5872	163	2.5871
041	2.5901	082	2.5864	123	2.5930	164	2.5891

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
165	2.5888	206	2.5839	247	2.5894	288	2.5880
166	2.5878	207	2.5923	248	2.5858	289	2.5862
167	2.5913	208	2.5877	249	2.5871	290	2.5903
168	2.5875	209	2.5911	250	2.5881	291	2.5877
169	2.5883	210	2.5847	251	2.5883	292	2.5858
170	2.5903	211	2.5884	252	2.5857	293	2.5864
171	2.5859	212	2.5908	253	2.5887	294	2.5849
172	2.5901	213	2.5848	254	2.5877	295	2.5913
173	2.5859	214	2.5875	255	2.5876	296	2.5855
174	2.5930	215	2.5881	256	2.5886	297	2.5898
175	2.5880	216	2.5893	257	2.5884	298	2.5868
176	2.5886	217	2.5901	258	2.5873	299	2.5862
177	2.5844	218	2.5858	259	2.5864	300	2.5874
178	2.5882	219	2.5884	260	2.5898	301	2.5884
179	2.5909	220	2.5870	261	2.5876	302	2.5863
180	2.5866	221	2.5912	262	2.5861	303	2.5901
181	2.5898	222	2.5866	263	2.5882	304	2.5863
182	2.5889	223	2.5891	264	2.5878	305	2.5854
183	2.5852	224	2.5883	265	2.5893	306	2.5873
184	2.5877	225	2.5876	266	2.5857	307	2.5863
185	2.5909	226	2.5887	267	2.5874	308	2.5873
186	2.5872	227	2.5876	268	2.5853	309	2.5886
187	2.5885	228	2.5893	269	2.5877	310	2.5869
188	2.5859	229	2.5850	270	2.5862	311	2.5884
189	2.5881	230	2.5889	271	2.5883	312	2.5868
190	2.5905	231	2.5867	272	2.5890	313	2.5902
191	2.5864	232	2.5874	273	2.5898	314	2.5862
192	2.5895	233	2.5872	274	2.5846	315	2.5884
193	2.5929	234	2.5877	275	2.5889	316	2.5861
194	2.5903	235	2.5869	276	2.5887	317	2.5872
195	2.5865	236	2.5890	277	2.5867	318	2.5884
196	2.5899	237	2.5884	278	2.5870	319	2.5853
197	2.5913	238	2.5849	279	2.5889	320	2.5874
198	2.5899	239	2.5885	280	2.5865	321	2.5843
199	2.5889	240	2.5923	281	2.5844	322	2.5904
200	2.5859	241	2.5836	282	2.5875	323	2.5843
201	2.5883	242	2.5894	283	2.5903	324	2.5888
202	2.5895	243	2.5880	284	2.5861	325	2.5892
203	2.5866	244	2.5862	285	2.5880	326	2.5880
204	2.5876	245	2.5872	286	2.5871	327	2.5869
205	2.5902	246	2.5900	287	2.5872	328	2.5855

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
329	2.5897	370	2.5878	411	2.5879	452	2.5891
330	2.5877	371	2.5872	412	2.5858	453	2.5839
331	2.5887	372	2.5898	413	2.5849	454	2.5827
332	2.5839	373	2.5862	414	2.5862	455	2.5849
333	2.5898	374	2.5878	415	2.5854	456	2.5811
334	2.5854	375	2.5861	416	2.5881	457	2.5875
335	2.5861	376	2.5866	417	2.5852	458	2.5840
336	2.5855	377	2.5882	418	2.5843	459	2.5859
337	2.5872	378	2.5840	419	2.5852	460	2.5838
338	2.5872	379	2.5886	420	2.5886	461	2.5825
339	2.5887	380	2.5851	421	2.5832	462	2.5882
340	2.5883	381	2.5916	422	2.5863	463	2.5811
341	2.5847	382	2.5856	423	2.5852	464	2.5858
342	2.5886	383	2.5857	424	2.5834	465	2.5816
343	2.5894	384	2.5842	425	2.5852	466	2.5814
344	2.5840	385	2.5905	426	2.5848	467	2.5868
345	2.5874	386	2.5853	427	2.5914	468	2.5812
346	2.5896	387	2.5889	428	2.5884	469	2.5848
347	2.5883	388	2.5866	429	2.5823	470	2.5845
348	2.5813	389	2.5870	430	2.5845	471	2.5865
349	2.5866	390	2.5871	431	2.5879	472	2.5826
350	2.5876	391	2.5864	432	2.5861	473	2.5840
351	2.5874	392	2.5864	433	2.5873	474	2.5872
352	2.5881	393	2.5868	434	2.5835	475	2.5804
353	2.5843	394	2.5868	435	2.5904	476	2.5829
354	2.5889	395	2.5857	436	2.5834	477	2.5893
355	2.5859	396	2.5877	437	2.5866	478	2.5817
356	2.5906	397	2.5845	438	2.5854	479	2.5787
357	2.5867	398	2.5847	439	2.5842	480	2.5856
358	2.5854	399	2.5870	440	2.5845	481	2.5836
359	2.5925	400	2.5923	441	2.5828	482	2.5855
360	2.5833	401	2.5840	442	2.5884	483	2.5833
361	2.5858	402	2.5842	443	2.5838	484	2.5831
362	2.5893	403	2.5891	444	2.5834	485	2.5802
363	2.5855	404	2.5842	445	2.5851	486	2.5846
364	2.5873	405	2.5863	446	2.5852	487	2.5848
365	2.5872	406	2.5862	447	2.5858	488	2.5842
366	2.5870	407	2.5853	448	2.5818	489	2.5850
367	2.5872	408	2.5850	449	2.5911	490	2.5812
368	2.5865	409	2.5878	450	2.5813	491	2.5851
369	2.5864	410	2.5871	451	2.5840	492	2.5807

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
493	2.5830	534	2.5800	575	2.5798	616	2.5827
494	2.5825	535	2.5795	576	2.5838	617	2.5785
495	2.5847	536	2.5817	577	2.5818	618	2.5816
496	2.5823	537	2.5823	578	2.5775	619	2.5810
497	2.5831	538	2.5812	579	2.5853	620	2.5801
498	2.5817	539	2.5843	580	2.5788	621	2.5817
499	2.5804	540	2.5845	581	2.5790	622	2.5810
500	2.5847	541	2.5795	582	2.5809	623	2.5778
501	2.5829	542	2.5829	583	2.5811	624	2.5833
502	2.5827	543	2.5822	584	2.5837	625	2.5813
503	2.5818	544	2.5816	585	2.5794	626	2.5813
504	2.5851	545	2.5800	586	2.5819	627	2.5808
505	2.5838	546	2.5832	587	2.5803	628	2.5785
506	2.5814	547	2.5808	588	2.5793	629	2.5794
507	2.5820	548	2.5842	589	2.5849	630	2.5855
508	2.5835	549	2.5795	590	2.5811	631	2.5803
509	2.5826	550	2.5830	591	2.5811	632	2.5813
510	2.5835	551	2.5812	592	2.5814	633	2.5789
511	2.5848	552	2.5808	593	2.5801	634	2.5812
512	2.5816	553	2.5813	594	2.5826	635	2.5827
513	2.5804	554	2.5843	595	2.5789	636	2.5803
514	2.5833	555	2.5821	596	2.5811	637	2.5772
515	2.5844	556	2.5803	597	2.5810	638	2.5827
516	2.5802	557	2.5819	598	2.5816	639	2.5800
517	2.5814	558	2.5823	599	2.5797	640	2.5849
518	2.5813	559	2.5776	600	2.5834	641	2.5800
519	2.5823	560	2.5817	601	2.5797	642	2.5796
520	2.5809	561	2.5811	602	2.5822	643	2.5797
521	2.5820	562	2.5819	603	2.5790	644	2.5783
522	2.5838	563	2.5812	604	2.5823	645	2.5801
523	2.5813	564	2.5833	605	2.5774	646	2.5797
524	2.5861	565	2.5810	606	2.5829	647	2.5809
525	2.5821	566	2.5812	607	2.5782	648	2.5796
526	2.5812	567	2.5815	608	2.5843	649	2.5810
527	2.5805	568	2.5833	609	2.5817	650	2.5814
528	2.5813	569	2.5805	610	2.5823	651	2.5813
529	2.5852	570	2.5834	611	2.5821	652	2.5796
530	2.5798	571	2.5807	612	2.5792	653	2.5802
531	2.5803	572	2.5811	613	2.5763	654	2.5815
532	2.5868	573	2.5805	614	2.5822	655	2.5795
533	2.5815	574	2.5814	615	2.5808	656	2.5816

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
657	2.5794	698	2.5820	739	2.5851	780	2.5856
658	2.5794	699	2.5816	740	2.5871	781	2.5869
659	2.5819	700	2.5859	741	2.5828	782	2.5819
660	2.5814	701	2.5855	742	2.5860	783	2.5851
661	2.5813	702	2.5869	743	2.5855	784	2.5850
662	2.5796	703	2.5831	744	2.5874	785	2.5852
663	2.5810	704	2.5863	745	2.5831	786	2.5860
664	2.5827	705	2.5828	746	2.5842	787	2.5819
665	2.5815	706	2.5841	747	2.5835	788	2.5837
666	2.5802	707	2.5910	748	2.5875	789	2.5852
667	2.5821	708	2.5827	749	2.5849	790	2.5843
668	2.5773	709	2.5861	750	2.5873	791	2.5857
669	2.5849	710	2.5838	751	2.5838	792	2.5881
670	2.5787	711	2.5850	752	2.5856	793	2.5806
671	2.5827	712	2.5859	753	2.5833	794	2.5879
672	2.5808	713	2.5848	754	2.5845	795	2.5813
673	2.5880	714	2.5869	755	2.5852	796	2.5886
674	2.5828	715	2.5830	756	2.5832	797	2.5817
675	2.5874	716	2.5879	757	2.5852	798	2.5898
676	2.5845	717	2.5827	758	2.5868	799	2.5848
677	2.5856	718	2.5869	759	2.5849	800	2.5823
678	2.5866	719	2.5810	760	2.5832	801	2.5850
679	2.5852	720	2.5883	761	2.5900	802	2.5845
680	2.5895	721	2.5863	762	2.5854	803	2.5880
681	2.5827	722	2.5844	763	2.5818	804	2.5852
682	2.5882	723	2.5872	764	2.5865	805	2.5834
683	2.5820	724	2.5845	765	2.5868	806	2.5842
684	2.5853	725	2.5833	766	2.5825	807	2.5849
685	2.5860	726	2.5869	767	2.5879	808	2.5852
686	2.5858	727	2.5836	768	2.5787	809	2.5828
687	2.5851	728	2.5872	769	2.5871	810	2.5859
688	2.5846	729	2.5857	770	2.5865	811	2.5859
689	2.5871	730	2.5850	771	2.5847	812	2.5877
690	2.5866	731	2.5849	772	2.5829	813	2.5835
691	2.5825	732	2.5826	773	2.5865	814	2.5819
692	2.5855	733	2.5833	774	2.5883	815	2.5908
693	2.5836	734	2.5853	775	2.5839	816	2.5829
694	2.5889	735	2.5896	776	2.5841	817	2.5843
695	2.5827	736	2.5857	777	2.5859	818	2.5876
696	2.5831	737	2.5854	778	2.5850	819	2.5820
697	2.5900	738	2.5819	779	2.5840	820	2.5859

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

Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]	Vial No.	Mass [g]
821	2.5818	862	2.5895				
822	2.5861						
823	2.5855						
824	2.5824						
825	2.5864						
826	2.5882						
827	2.5825						
828	2.5853						
829	2.5843						
830	2.5856						
831	2.5850						
832	2.5883						
833	2.5830						
834	2.5825						
835	2.5862						
836	2.5861						
837	2.5836						
838	2.5862						
839	2.5861						
840	2.5874						
841	2.5842						
842	2.5879						
843	2.5855						
844	2.5839						
845	2.5808						
846	2.5840						
847	2.5845						
848	2.5868						
849	2.5846						
850	2.5845						
851	2.5840						
852	2.5838						
853	2.5877						
854	2.5865						
855	2.5838						
856	2.5852						
857	2.5825						
858	2.5863						
859	2.5802						
860	2.5867						
861	2.5845						

Annex 12 The weighing certificate for the preparation of the mother solution of IRMM-1027w

Joint Research Centre	Certificate of weighing	Directorate G – Nuclear Safety and Security G.2 - Standards for Nuclear Safety, Security and Safeguards Unit

E. 3950 **Issued date:** 16/09/2021 **Page 1 of** 2

Applicant: Kalman Toth **Project:** IRMM-1027w certification

Description: Preparation of IRMM-1027w LSD mother solution

Request for analysis number: 4871 **ID number:** 33490

Date of receipt of request: 27/Apr/2021 **Weighing dates**: 06, 10, 25, 26/May/2021, 11/June/2021

Results:

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

ID	Mass /g	Uncertainty /g
U metal (CRM 112-A)	41.15558	0.00008
U metal (CRM 116-A)	10.16332	0.00006
Pu metal (MP2)	1.64765	0.00007
Flask + stopper empty	773.51	0.04
Flask + stopper full	3048.62	0.04
crucible	5.86853	0.00006
IRMM-1027w solution	2269.23	0.04

ID	Density /kg m^{-3}	Uncertainty / kg m^{-3}
IRMM-1027w solution	1233	5

Observations:

The measurements were performed according to work instruction IMS-JRC.G-C1.1-WIN-0057 "WEIGHING AND MASS METROLOGY IN JRC.G.2 (NUCLEAR SAFEGUARDS TEAM)".
Balances used were Mettler Toledo AT 261DR and with inventory No. 1999 0037 27, Mettler Toledo XPE205 with inventory no 2014 01153 03, and PR 5002 with inventory No. 1997 00368 and XPR 5003S with inventory No. 2018 00368 64.

During the weighing the atmospheric parameters temperature, pressure and humidity were monitored, noted and used in the calculations.

Traceability:

The certified mass values are traceable to the SI through regular calibrations of the JRC G2's principal standards. The sets of working mass standards M3 and M10 were used as reference in the mass determination and Sartorius 2kg with certification no. 121493, Sartorius 1kg with certification no. 121491, Sartorius 500g with certification number 121490 and Zwiebel 0.01g with certification number Z19 40138.

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Uncertainty:

All reported uncertainties on the weighings are expanded uncertainties $U = k \bullet u_c$ where u_c is the combined standard uncertainty calculated according to the ISO/BIPM Guide to the expression of Uncertainty in Measurement. The coverage factor $k = 2$ corresponds to a coverage probability of about 95% based on the Gaussian distribution.

The uncertainty on the density determination is expressed as half-width of limits corresponding to a rectangular probability distribution and its value was determined based on experience.

Additional information

Rozle Jakopic
Nuclear Chemistry Laboratory responsible

Jeroen Bauwens/Kalman Toth
Analyst

Annex 13 Uncertainty budget for the uranium gravimetric mixture of IRMM-1027w (extract of GUM WB calculations)

Uranium gravimetric mixture of IRMM-1027w

Author: Kalman Toth

The uranium gravimetric mixture was prepared by dissolving natural uranium (NBL CRM 112-A) and enriched uranium (NBL CRM 116-A) metals in hydrochloric/nitric acid solution that also contained plutonium metal (MP2).

Input parameters: 1) masses of the metals and the nitrate solution (E3950) 2) purity of the metals (metal certificates) 3) uranium isotope amount ratios of the metals (certificate) 4) the atomic masses according Wang et al. (The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017).

U ingrowth from Pu MP2 metal is calculated from the measurement data (2006, IRMM) plus the ingrowth from 2006 to 01 Jan 2022 (IRMM-1027w reference date)

Model Equation:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$\gamma_{Umixture}=(m_{UCRM116A}*\eta_{purityCRM116A}+m_{UNBL112A}*\eta_{purityNBL112A} + m_{UMP2})/m_{solution1027w}$;

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

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

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

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

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

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

{Amount of uranium isotopes in NBL CRM 112-A}

$n_{233.a} = m_{UNBL112A} *\eta_{purityNBL112A} * f_{233Ua} / M_{Ua}$;

$n_{234.a} = m_{UNBL112A} *\eta_{purityNBL112A} * f_{234Ua} / M_{Ua}$;

$n_{235.a} = m_{UNBL112A} *\eta_{purityNBL112A} * f_{235Ua} / M_{Ua}$;

$n_{236.a} = m_{UNBL112A} *\eta_{purityNBL112A} * f_{236Ua} / M_{Ua}$;

$n_{238.a} = m_{UNBL112A} *\eta_{purityNBL112A} * f_{238Ua} / M_{Ua}$;

{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 NBL CRM 112-A}

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

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

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

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

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

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

{Molar mass of uranium in NBL CRM 112-A}

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

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

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

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

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

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

{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}

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

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

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

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

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

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

{Combined standard uncertainty for single unit verification (IDMS)}

$c_{235Umixture}verif=c_{235Umixture}+u_{hom235U}+u_{disp}$;

$c_{238Umixture}verif=c_{238Umixture}+u_{hom238U}+u_{disp2}$;

{Calculations for Unit #1}

$m_{235Uunit1}=w_{235Umixture}*m1$;

$m_{235Uunit1full}=w_{235Umixture}*m1+u_{hom}235U_{unit1}$;

$m_{238Uunit1}=w_{238Umixture}*m1$;

$m_{238Uunit1full}=w_{238Umixture}*m1+u_{hom}238U_{unit1}$;

List of Quantities:

Quantity	Unit	Definition
$c_{235Umixture}$	mol/g	^{235}U amount content in IRMM-1027w
$c_{235Umixture}verif$	mol/g	^{235}U amount content in IRMM-1027w - combined uncertainty
$c_{238Umixture}$	mol/g	^{238}U amount content in IRMM-1027w
$c_{238Umixture}verif$	mol/g	^{238}U amount content in IRMM-1027w - combined uncertainty
$c_{Umixture}$	mol/g	U amount content in IRMM-1027w
f_{233U}	mol/mol	^{233}U amount fraction in IRMM-1027w
f_{233Ua}	mol/mol	^{233}U amount fraction in NBL CRM 112-A
f_{233Ub}	mol/mol	^{233}U amount fraction in NBL CRM 116-A
f_{234U}	mol/mol	^{234}U amount fraction in IRMM-1027w
f_{234Ua}	mol/mol	^{234}U amount fraction in NBL CRM 112-A
f_{234Ub}	mol/mol	^{234}U amount fraction in NBL CRM 116-A
f_{235U}	mol/mol	^{235}U amount fraction in IRMM-1027w
f_{235Ua}	mol/mol	^{235}U amount fraction in NBL CRM 112-A
f_{235Ub}	mol/mol	^{235}U amount fraction in NBL CRM 116-A
f_{236U}	mol/mol	^{236}U amount fraction in IRMM-1027w
f_{236Ua}	mol/mol	^{236}U amount fraction in NBL CRM 112-A
f_{236Ub}	mol/mol	^{236}U amount fraction in NBL CRM 116-A

Quantity	Unit	Definition
f_{238U}	mol/mol	^{238}U amount fraction in IRMM-1027w
f_{238Ua}	mol/mol	^{238}U amount fraction in NBL CRM 112-A
f_{238Ub}	mol/mol	^{238}U amount fraction in NBL CRM 116-A
m1	g	mass dispensed into #1
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
$m_{235Uunit1}$	g	mass of ^{235}U in #1
$m_{235Uunit1full}$	g	mass of ^{235}U in #1 - full uncertainty budget
M_{236U}	g/mol	Atomic mass of ^{236}U
M_{238U}	g/mol	Atomic mass of ^{238}U
$m_{238Uunit1}$	g	mass of ^{238}U in #1
$m_{238Uunit1full}$	g	mass of ^{238}U in #1 - full uncertainty budget
$m_{solution1027w}$	g	mass of mother solution 1027w
M_U	g/mol	Molar mass of U in IRMM-1027w
M_{Ua}	g/mol	Molar mass of U in NBL CRM 112-A
M_{Ub}	g/mol	Molar mass of U in NBL CRM 116-A
$m_{UCRM116A}$	g	Mass of enriched uranium metal, NBL CRM 116-A
m_{UMP2}	g	mass of total ingrown U from Pu MP2
$m_{UNBL112A}$	g	Mass of natural uranium metal, NBL CRM 112-A
n_{233U}	mol	Amount of U-233 in the mixture
$n_{233.a}$	mol	^{233} U amount in NBL CRM 112-A
$n_{233.b}$	mol	^{233} U amount in NBL CRM 116-A
$n_{233.c}$	mol	^{233} U amount ingrowth from Pu MP2
n_{234U}	mol	Amount of U-234 in the mixture
$n_{234.a}$	mol	^{234} U amount in NBL CRM 112-A
$n_{234.b}$	mol	^{234} U amount in NBL CRM 116-A
$n_{234.c}$	mol	^{234} U amount ingrowth from Pu MP2
n_{235U}	mol	Amount of U-235 in the mixture
$n_{235.a}$	mol	^{235} U amount in NBL CRM 112-A
$n_{235.b}$	mol	^{235} U amount in NBL CRM 116-A
$n_{235.c}$	mol	^{235} U amount ingrowth from Pu MP2
n_{236U}	mol	Amount of U-236 in the mixture
$n_{236.a}$	mol	^{236} U amount in NBL CRM 112-A
$n_{236.b}$	mol	^{236} U amount in NBL CRM 116-A
$n_{236.c}$	mol	^{236} U amount ingrowth from Pu MP2
n_{238U}	mol	Amount of U-238 in the mixture
$n_{238.a}$	mol	^{238} U amount in NBL CRM 112-A

Quantity	Unit	Definition
$n_{238.b}$	mol	^{238}U amount in NBL CRM 116-A
$n_{238.c}$	mol	^{238}U amount ingrowth from Pu MP2
$R_{233U/235Ub}$	mol/mol	^{233}U/^{235}U amount ratio in NBL CRM 116-A
$R_{233U/238U}$	mol/mol	^{233}U/^{238}U amount ratio in IRMM-1027w
$R_{233U/238Ua}$	mol/mol	^{233}U/^{238}U amount ratio in NBL CRM 112-A
$R_{234U/235Ub}$	mol/mol	^{234}U/^{235}U amount ratio in NBL CRM 116-A
$R_{234U/238U}$	mol/mol	^{234}U/^{238}U amount ratio in IRMM-1027w
$R_{234U/238Ua}$	mol/mol	^{234}U/^{238}U amount ratio in NBL CRM 112-A
$R_{235U/238U}$	mol/mol	^{235}U/^{238}U amount ratio in IRMM-1027w
$R_{235U/238Ua}$	mol/mol	^{235}U/^{238}U amount ratio in NBL CRM 112-A
$R_{236U/235Ub}$	mol/mol	^{236}U/^{235}U amount ratio in NBL CRM 116-A
$R_{236U/238U}$	mol/mol	^{236}U/^{238}U amount ratio in IRMM-1027w
$R_{236U/238Ua}$	mol/mol	^{236}U/^{238}U amount ratio in NBL CRM 112-A
$R_{238U/235Ub}$	mol/mol	^{238}U/^{235}U amount ratio in NBL CRM 116-A
u_{disp}	mol/g	uncertainty associated with dispensing - ^{235}U
u_{disp2}	mol/g	uncertainty associated with dispensing - ^{238}U
$u_{hom235U}$	mol/g	uncertainty associated with homogeniety - ^{235}U
$u_{hom}235U_{unit1}$	g	standard unceratinty associated with dispensing for ^{235}U mass in #1
$u_{hom238U}$	mol/g	uncertainty associated with homogeniety - ^{238}U
$u_{hom}238U_{unit1}$	g	standard unceratinty associated with dispensing for ^{238}U mass in #1
w_{233U}	g/g	^{233}U mass fraction in IRMM-1027w
w_{233Ua}	g/g	^{233}U mass fraction in NBL CRM 112-A
w_{233Ub}	g/g	^{233}U mass fraction in CRM 116-A
w_{234U}	g/g	^{234}U mass fraction in IRMM-1027w
w_{234Ua}	g/g	^{234}U mass fraction in NBL CRM 112-A
w_{234Ub}	g/g	^{234}U mass fraction in CRM 116-A
w_{235U}	g/g	^{235}U mass fraction in IRMM-1027w
w_{235Ua}	g/g	^{235}U mass fraction in NBL CRM 112-A
w_{235Ub}	g/g	^{235}U mass fraction in CRM 116-A
w_{236U}	g/g	^{236}U mass fraction in IRMM-1027w
w_{236Ua}	g/g	^{236}U mass fraction in NBL CRM 112-A
w_{236Ub}	g/g	^{236}U mass fraction in CRM 116-A
w_{238U}	g/g	^{238}U mass fraction in IRMM-1027w
w_{238Ua}	g/g	^{238}U mass fraction in NBL CRM 112-A
w_{238Ub}	g/g	^{238}U mass fraction in CRM 116-A
$\eta_{purityCRM116A}$	g/g	Purity of enriched uranium metal, NBL CRM 116-A
$\eta_{purityNBL112A}$	g/g	Purity of natural uranium metal, NBL CRM 112-A
$\gamma_{235Umixture}$	g/g	^{235}U mass fraction in IRMM-1027w

Quantity	Unit	Definition
$\gamma_{238Umixture}$	g/g	^{238}U mass fraction in IRMM-1027w
$\gamma_{Umixture}$	g/g	U mass fraction in IRMM-1027w
ΣR_U	mol/mol	Sum of amount ratios in gravimteric mixture, IRMM-1027w
ΣR_{Ua}	mol/mol	Sum of amount ratios in NBL CRM 112-A
ΣR_{Ub}	mol/mol	Sum of amount ratios in NBL CRM 116-A

m1:
Type B normal distribution
Value: 2.5920 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

M_{233U}:
Type B normal distribution
Value: 233.0396344 g/mol
Expanded Uncertainty: 0.0000024 g/mol
Coverage Factor: 1

the atomic masses according Wang et al. (The AME 2017 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017)

M_{234U}:
Type B normal distribution
Value: 234.0409504 g/mol
Expanded Uncertainty: 0.0000012 g/mol
Coverage Factor: 1

the atomic masses according Wang et al. (The AME 2017 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017)

M_{235U}:
Type B normal distribution
Value: 235.0439282 g/mol
Expanded Uncertainty: 0.0000012 g/mol
Coverage Factor: 1

the atomic masses according Wang et al. (The AME 2017 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017)

M_{236U}:
Type B normal distribution
Value: 236.0455662 g/mol
Expanded Uncertainty: 0.0000012 g/mol
Coverage Factor: 1

the atomic masses according Wang et al. (The AME 2017 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017)

M_{238U}:
Type B normal distribution
Value: 238.0507870 g/mol
Expanded Uncertainty: 0.0000016 g/mol
Coverage Factor: 1

the atomic masses according Wang et al. (The AME 2017 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017)

$m_{solution1027w}$:
Type B normal distribution
Value: 2269.23 g
Expanded Uncertainty: 0.04 g
Coverage Factor: 2

$m_{UCRM116A}$: Type B normal distribution
Value: 10.16332 g
Expanded Uncertainty: 0.00006 g
Coverage Factor: 2

E3950

m_{UMP2}: Import
Filename: U ingrowth in MP2 on 01Jan2022.smu
Symbol: m_UTotal

$m_{UNBL112A}$: Type B normal distribution
Value: 41.15558 g
Expanded Uncertainty: 0.00008 g
Coverage Factor: 2

E3950

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

$n_{234.c}$: Import
Filename: U ingrowth in MP2 on 01Jan2022.smu
Symbol: n_{234U}Total

$n_{235.c}$: Import
Filename: U ingrowth in MP2 on 01Jan2022.smu
Symbol: n_{235U}Total

$n_{236.c}$: Import
Filename: U ingrowth in MP2 on 01Jan2022.smu
Symbol: n_{236U}Total

$n_{238.c}$: Import
Filename: U ingrowth in MP2 on 01Jan2022.smu
Symbol: n_{238U}Total

$R_{233U/235Ub}$: Type B t-distribution
Value: 0.0000003863 mol/mol
Standard Deviation of the Mean: =0.0000000086/3.3
Degrees of Freedom: 3

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

$R_{233U/238Ua}$: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 2

Certificate of isotopic coposition NBL CRM 112-A

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

CRM 116-A certificate

$R_{234U/238Ua}$: Type B normal distribution
Value: 0.000052841 mol/mol
Expanded Uncertainty: 0.000000082 mol/mol
Coverage Factor: 2

Certificate of isotopic coposition NBL CRM 112-A

$R_{235U/238Ua}$: Type B normal distribution
Value: 0.0072543 mol/mol
Expanded Uncertainty: 0.0000040 mol/mol
Coverage Factor: 2

Certificate of isotopic coposition NBL CRM 112-A

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

CRM 116-A certificate

$R_{236U/238Ua}$: Type B normal distribution
Value: 0 mol/mol
Expanded Uncertainty: 0 mol/mol
Coverage Factor: 2

Certificate of isotopic coposition NBL CRM 112-A

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

CRM 116-A certificate

u_{disp}: Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: $2.19611 \cdot 10^{-9}$ mol/g
Coverage Factor: 1

=0.0000183009*0.00012 c(235 U mixture)*u(rel dispensing)

u_{disp2}: Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: $9.1839 \cdot 10^{-9}$ mol/g
Coverage Factor: 1

=7.65324E-05*0.00012 c(238 U mixture)*u(rel dispensing)

$u_{hom235U}$: Type B t-distribution
Value: 0 mol/g
Standard Deviation of the Mean: $2.318 \cdot 10^{-9}$ mol/g
Degrees of Freedom: 11

u_{hom}235U_{unit1}: Type B normal distribution
Value: 0 g
Expanded Uncertainty: $1.34 \cdot 10^{-6}$ g
Coverage Factor: 1

$m_{235Uunit1}$*u(rel homogeniety)

0.0111496*0.00012= 1.34e-6

$u_{hom238U}$: Type B t-distribution
Value: 0 mol/g
Standard Deviation of the Mean: $1.524 \cdot 10^{-8}$ mol/g
Degrees of Freedom: 11

u_{hom}238U_{unit1}: Type B normal distribution
Value: 0 g
Expanded Uncertainty: $9.44 \cdot 10^{-6}$ g
Coverage Factor: 1

$m_{238Uunit1}$*u(rel homogeniety)

0.047223*0.00020= 9.44e-6

$\eta_{purityCRM116A}$: Type B t-distribution
Value: 0.99945 g/g
Standard Deviation of the Mean: =0.00014/2.4
Degrees of Freedom: 7

NBL CRM 116-A certificate (coverage factor 2.4)

$\eta_{purityNBL112A}$: Type B normal distribution
Value: 0.99975 g/g
Expanded Uncertainty: 0.00006 g/g
Coverage Factor: 2

EC NRM 101 certificate

Input Correlation:

	m_{UMP2}	$n_{234.c}$	$n_{235.c}$	$n_{236.c}$	$n_{238.c}$
m_{UMP2}	1	0.2072	0.9937	0.6275	0.0122
$n_{234.c}$	0.2072	1	0.1648	0.1021	0.0022
$n_{235.c}$	0.9937	0.1648	1	0.5437	0.0121
$n_{236.c}$	0.6275	0.1021	0.5437	1	0.0075
$n_{238.c}$	0.0122	0.0022	0.0121	0.0075	1

Uncertainty Budgets:

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

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
M_{233U}	233.03963440 g/mol	$2.40\cdot10^{-6}$ g/mol	normal	$-27\cdot10^{-15}$	$-65\cdot10^{-21}$ mol/g	0.0 %
M_{234U}	234.04095040 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-820\cdot10^{-12}$	$-980\cdot10^{-18}$ mol/g	0.0 %
M_{235U}	235.04392820 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-70\cdot10^{-9}$	$-84\cdot10^{-15}$ mol/g	0.0 %
M_{236U}	236.04556620 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-670\cdot10^{-12}$	$-800\cdot10^{-18}$ mol/g	0.0 %
M_{238U}	238.05078700 g/mol	$1.60\cdot10^{-6}$ g/mol	normal	$-5.9\cdot10^{-9}$	$-9.4\cdot10^{-15}$ mol/g	0.0 %
$m_{solution1027w}$	2269.2300 g	0.0200 g	normal	$-8.1\cdot10^{-9}$	$-160\cdot10^{-12}$ mol/g	2.1 %
$m_{UCRM116A}$	10.1633200 g	$30.0\cdot10^{-6}$ g	normal	$1.7\cdot10^{-6}$	$52\cdot10^{-12}$ mol/g	0.2 %
m_{UMP2}	$1.869760\cdot10^{-3}$ g	$652\cdot10^{-9}$ g		$360\cdot10^{-9}$	$230\cdot10^{-15}$ mol/g	0.0 %
$m_{UNBL112A}$	41.1555800 g	$40.0\cdot10^{-6}$ g	normal	$13\cdot10^{-9}$	$530\cdot10^{-15}$ mol/g	0.0 %
$n_{233.c}$	0.0 mol	0.0 mol	normal	0.0	0.0 mol/g	0.0 %
$n_{234.c}$	$62.435\cdot10^{-9}$ mol	$120\cdot10^{-12}$ mol		$-83\cdot10^{-6}$	$-10\cdot10^{-15}$ mol/g	0.0 %
$n_{235.c}$	$7.28901\cdot10^{-6}$ mol	$2.55\cdot10^{-9}$ mol		$360\cdot10^{-6}$	$910\cdot10^{-15}$ mol/g	0.0 %
$n_{236.c}$	$601.179\cdot10^{-9}$ mol	$340\cdot10^{-12}$ mol		$-84\cdot10^{-6}$	$-29\cdot10^{-15}$ mol/g	0.0 %
$n_{238.c}$	$15.019\cdot10^{-12}$ mol	$143\cdot10^{-15}$ mol		$-85\cdot10^{-6}$	$-12\cdot10^{-18}$ mol/g	0.0 %
$R_{233U/235Ub}$	$386.30\cdot10^{-9}$ mol/mol	$2.61\cdot10^{-9}$ mol/mol	t-distr.	$-16\cdot10^{-6}$	$-43\cdot10^{-15}$ mol/g	0.0 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85\cdot10^{-6}$ mol/mol	normal	$-16\cdot10^{-6}$	$-80\cdot10^{-12}$ mol/g	0.5 %
$R_{234U/238Ua}$	$52.8410\cdot10^{-6}$ mol/mol	$41.0\cdot10^{-9}$ mol/mol	normal	$-540\cdot10^{-9}$	$-22\cdot10^{-15}$ mol/g	0.0 %
$R_{235U/238Ua}$	$7.25430\cdot10^{-3}$ mol/mol	$2.00\cdot10^{-6}$ mol/mol	normal	$75\cdot10^{-6}$	$150\cdot10^{-12}$ mol/g	1.8 %
$R_{236U/235Ub}$	$9.47130\cdot10^{-3}$ mol/mol	$3.85\cdot10^{-6}$ mol/mol	normal	$-17\cdot10^{-6}$	$-64\cdot10^{-12}$ mol/g	0.3 %
$R_{236U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5\cdot10^{-6}$ mol/mol	normal	$-17\cdot10^{-6}$	$-340\cdot10^{-12}$ mol/g	9.4 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3\cdot10^{-6}$ g/g	t-distr.	$18\cdot10^{-6}$	$1.0\cdot10^{-9}$ mol/g	85.6 %
$\eta_{purityNBL112A}$	0.9997500 g/g	$30.0\cdot10^{-6}$ g/g	normal	$550\cdot10^{-9}$	$16\cdot10^{-12}$ mol/g	0.0 %
$c_{235Umixture}$	$18.30096\cdot10^{-6}$ mol/g	$1.12\cdot10^{-9}$ mol/g				

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

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
M_{233U}	233.03963440 g/mol	$2.40\cdot10^{-6}$ g/mol	normal	$-1.4\cdot10^{-15}$	$-3.3\cdot10^{-21}$ mol/g	0.0 %
M_{234U}	234.04095040 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-59\cdot10^{-12}$	$-70\cdot10^{-18}$ mol/g	0.0 %
M_{235U}	235.04392820 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-5.9\cdot10^{-9}$	$-7.1\cdot10^{-15}$ mol/g	0.0 %
M_{236U}	236.04556620 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-35\cdot10^{-12}$	$-42\cdot10^{-18}$ mol/g	0.0 %
M_{238U}	238.05078700 g/mol	$1.60\cdot10^{-6}$ g/mol	normal	$-320\cdot10^{-9}$	$-500\cdot10^{-15}$ mol/g	0.0 %
$m_{solution1027w}$	2269.2300 g	0.0200 g	normal	$-34\cdot10^{-9}$	$-670\cdot10^{-12}$ mol/g	7.9 %
$m_{UCRM116A}$	10.1633200 g	$30.0\cdot10^{-6}$ g	normal	$90\cdot10^{-9}$	$2.7\cdot10^{-12}$ mol/g	0.0 %
m_{UMP2}	$1.869760\cdot10^{-3}$ g	$652\cdot10^{-9}$ g		$1.5\cdot10^{-6}$	$970\cdot10^{-15}$ mol/g	0.0 %
$m_{UNBL112A}$	41.1555800 g	$40.0\cdot10^{-6}$ g	normal	$1.8\cdot10^{-6}$	$73\cdot10^{-12}$ mol/g	0.0 %
$n_{233.c}$	0.0 mol	0.0 mol	normal	0.0	0.0 mol/g	0.0 %
$n_{234.c}$	$62.435\cdot10^{-9}$ mol	$120\cdot10^{-12}$ mol		$-350\cdot10^{-6}$	$-42\cdot10^{-15}$ mol/g	0.0 %
$n_{235.c}$	$7.28901\cdot10^{-6}$ mol	$2.55\cdot10^{-9}$ mol		$-350\cdot10^{-6}$	$-890\cdot10^{-15}$ mol/g	0.0 %
$n_{236.c}$	$601.179\cdot10^{-9}$ mol	$340\cdot10^{-12}$ mol		$-350\cdot10^{-6}$	$-120\cdot10^{-15}$ mol/g	0.0 %
$n_{238.c}$	$15.019\cdot10^{-12}$ mol	$143\cdot10^{-15}$ mol		$86\cdot10^{-6}$	$12\cdot10^{-18}$ mol/g	0.0 %
$R_{233U/235Ub}$	$386.30\cdot10^{-9}$ mol/mol	$2.61\cdot10^{-9}$ mol/mol	t-distr.	$-840\cdot10^{-9}$	$-2.2\cdot10^{-15}$ mol/g	0.0 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85\cdot10^{-6}$ mol/mol	normal	$-840\cdot10^{-9}$	$-4.1\cdot10^{-12}$ mol/g	0.0 %
$R_{234U/238Ua}$	$52.8410\cdot10^{-6}$ mol/mol	$41.0\cdot10^{-9}$ mol/mol	normal	$-74\cdot10^{-6}$	$-3.0\cdot10^{-12}$ mol/g	0.0 %
$R_{235U/238Ua}$	$7.25430\cdot10^{-3}$ mol/mol	$2.00\cdot10^{-6}$ mol/mol	normal	$-74\cdot10^{-6}$	$-150\cdot10^{-12}$ mol/g	0.4 %
$R_{236U/235Ub}$	$9.47130\cdot10^{-3}$ mol/mol	$3.85\cdot10^{-6}$ mol/mol	normal	$-850\cdot10^{-9}$	$-3.3\cdot10^{-12}$ mol/g	0.0 %
$R_{236U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 mol/g	0.0 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5\cdot10^{-6}$ mol/mol	normal	$17\cdot10^{-6}$	$350\cdot10^{-12}$ mol/g	2.1 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3\cdot10^{-6}$ g/g	t-distr.	$910\cdot10^{-9}$	$53\cdot10^{-12}$ mol/g	0.0 %
$\eta_{purityNBL112A}$	0.9997500 g/g	$30.0\cdot10^{-6}$ g/g	normal	$76\cdot10^{-6}$	$2.3\cdot10^{-9}$ mol/g	89.5 %
$c_{238Umixture}$	$76.53244\cdot10^{-6}$ mol/g	$2.40\cdot10^{-9}$ mol/g				

$m_{235Uunit1}$: mass of ^{235}U in #1

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
m1	2.592000 g	$300\cdot10^{-6}$ g	normal	$4.3\cdot10^{-3}$	$1.3\cdot10^{-6}$ g	78.2 %
M_{233U}	233.03963440 g/mol	$2.40\cdot10^{-6}$ g/mol	normal	$-17\cdot10^{-12}$	$-40\cdot10^{-18}$ g	0.0 %
M_{234U}	234.04095040 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-500\cdot10^{-9}$	$-600\cdot10^{-15}$ g	0.0 %
M_{235U}	235.04392820 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$4.5\cdot10^{-6}$	$5.5\cdot10^{-12}$ g	0.0 %
M_{236U}	236.04556620 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-410\cdot10^{-9}$	$-490\cdot10^{-15}$ g	0.0 %
M_{238U}	238.05078700 g/mol	$1.60\cdot10^{-6}$ g/mol	normal	$-3.6\cdot10^{-6}$	$-5.7\cdot10^{-12}$ g	0.0 %
$m_{solution1027w}$	2269.2300 g	0.0200 g	normal	$-4.9\cdot10^{-6}$	$-98\cdot10^{-9}$ g	0.5 %
$m_{UCRM116A}$	10.1633200 g	$30.0\cdot10^{-6}$ g	normal	$1.1\cdot10^{-3}$	$32\cdot10^{-9}$ g	0.0 %
m_{UMP2}	$1.869760\cdot10^{-3}$ g	$652\cdot10^{-9}$ g		$220\cdot10^{-6}$	$140\cdot10^{-12}$ g	0.0 %
$m_{UNBL112A}$	41.1555800 g	$40.0\cdot10^{-6}$ g	normal	$8.1\cdot10^{-6}$	$320\cdot10^{-12}$ g	0.0 %
$n_{233.c}$	0.0 mol	0.0 mol	normal	0.0	0.0 g	0.0 %
$n_{234.c}$	$62.435\cdot10^{-9}$ mol	$120\cdot10^{-12}$ mol		-0.051	$-6.1\cdot10^{-12}$ g	0.0 %
$n_{235.c}$	$7.28901\cdot10^{-6}$ mol	$2.55\cdot10^{-9}$ mol		0.22	$550\cdot10^{-12}$ g	0.0 %
$n_{236.c}$	$601.179\cdot10^{-9}$ mol	$340\cdot10^{-12}$ mol		-0.051	$-17\cdot10^{-12}$ g	0.0 %
$n_{238.c}$	$15.019\cdot10^{-12}$ mol	$143\cdot10^{-15}$ mol		-0.052	$-7.4\cdot10^{-15}$ g	0.0 %
$R_{233U/235Ub}$	$386.30\cdot10^{-9}$ mol/mol	$2.61\cdot10^{-9}$ mol/mol	t-distr.	-0.010	$-26\cdot10^{-12}$ g	0.0 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 g	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85\cdot10^{-6}$ mol/mol	normal	-0.010	$-49\cdot10^{-9}$ g	0.1 %
$R_{234U/238Ua}$	$52.8410\cdot10^{-6}$ mol/mol	$41.0\cdot10^{-9}$ mol/mol	normal	$-330\cdot10^{-6}$	$-13\cdot10^{-12}$ g	0.0 %
$R_{235U/238Ua}$	$7.25430\cdot10^{-3}$ mol/mol	$2.00\cdot10^{-6}$ mol/mol	normal	0.046	$91\cdot10^{-9}$ g	0.4 %
$R_{236U/235Ub}$	$9.47130\cdot10^{-3}$ mol/mol	$3.85\cdot10^{-6}$ mol/mol	normal	-0.010	$-39\cdot10^{-9}$ g	0.0 %
$R_{236U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 g	0.0 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5\cdot10^{-6}$ mol/mol	normal	-0.010	$-210\cdot10^{-9}$ g	2.1 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3\cdot10^{-6}$ g/g	t-distr.	0.011	$630\cdot10^{-9}$ g	18.7 %
$\eta_{purityNBL112A}$	0.9997500 g/g	$30.0\cdot10^{-6}$ g/g	normal	$330\cdot10^{-6}$	$10\cdot10^{-9}$ g	0.0 %
$m_{235Uunit1}$	0.01114956 g	$1.46\cdot10^{-6}$ g				

$m_{235Uunit1full}$: mass of ^{235}U in #1 - full uncertainty budget

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
m1	2.592000 g	$300\cdot10^{-6}$ g	normal	$4.3\cdot10^{-3}$	$1.3\cdot10^{-6}$ g	42.4 %
M_{233U}	233.03963440 g/mol	$2.40\cdot10^{-6}$ g/mol	normal	$-17\cdot10^{-12}$	$-40\cdot10^{-18}$ g	0.0 %
M_{234U}	234.04095040 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-500\cdot10^{-9}$	$-600\cdot10^{-15}$ g	0.0 %
M_{235U}	235.04392820 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$4.5\cdot10^{-6}$	$5.5\cdot10^{-12}$ g	0.0 %
M_{236U}	236.04556620 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-410\cdot10^{-9}$	$-490\cdot10^{-15}$ g	0.0 %
M_{238U}	238.05078700 g/mol	$1.60\cdot10^{-6}$ g/mol	normal	$-3.6\cdot10^{-6}$	$-5.7\cdot10^{-12}$ g	0.0 %
$m_{solution1027w}$	2269.2300 g	0.0200 g	normal	$-4.9\cdot10^{-6}$	$-98\cdot10^{-9}$ g	0.2 %
$m_{UCRM116A}$	10.1633200 g	$30.0\cdot10^{-6}$ g	normal	$1.1\cdot10^{-3}$	$32\cdot10^{-9}$ g	0.0 %
m_{UMP2}	$1.869760\cdot10^{-3}$ g	$652\cdot10^{-9}$ g		$220\cdot10^{-6}$	$140\cdot10^{-12}$ g	0.0 %
$m_{UNBL112A}$	41.1555800 g	$40.0\cdot10^{-6}$ g	normal	$8.1\cdot10^{-6}$	$320\cdot10^{-12}$ g	0.0 %
$n_{233.c}$	0.0 mol	0.0 mol	normal	0.0	0.0 g	0.0 %
$n_{234.c}$	$62.435\cdot10^{-9}$ mol	$120\cdot10^{-12}$ mol		-0.051	$-6.1\cdot10^{-12}$ g	0.0 %
$n_{235.c}$	$7.28901\cdot10^{-6}$ mol	$2.55\cdot10^{-9}$ mol		0.22	$550\cdot10^{-12}$ g	0.0 %
$n_{236.c}$	$601.179\cdot10^{-9}$ mol	$340\cdot10^{-12}$ mol		-0.051	$-17\cdot10^{-12}$ g	0.0 %
$n_{238.c}$	$15.019\cdot10^{-12}$ mol	$143\cdot10^{-15}$ mol		-0.052	$-7.4\cdot10^{-15}$ g	0.0 %
$R_{233U/235Ub}$	$386.30\cdot10^{-9}$ mol/mol	$2.61\cdot10^{-9}$ mol/mol	t-distr.	-0.010	$-26\cdot10^{-12}$ g	0.0 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 g	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85\cdot10^{-6}$ mol/mol	normal	-0.010	$-49\cdot10^{-9}$ g	0.0 %
$R_{234U/238Ua}$	$52.8410\cdot10^{-6}$ mol/mol	$41.0\cdot10^{-9}$ mol/mol	normal	$-330\cdot10^{-6}$	$-13\cdot10^{-12}$ g	0.0 %
$R_{235U/238Ua}$	$7.25430\cdot10^{-3}$ mol/mol	$2.00\cdot10^{-6}$ mol/mol	normal	0.046	$91\cdot10^{-9}$ g	0.2 %
$R_{236U/235Ub}$	$9.47130\cdot10^{-3}$ mol/mol	$3.85\cdot10^{-6}$ mol/mol	normal	-0.010	$-39\cdot10^{-9}$ g	0.0 %
$R_{236U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 g	0.0 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5\cdot10^{-6}$ mol/mol	normal	-0.010	$-210\cdot10^{-9}$ g	1.1 %
$u_{hom}235U_{unit1}$	0.0 g	$1.34\cdot10^{-6}$ g	normal	1.0	$1.3\cdot10^{-6}$ g	45.7 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3\cdot10^{-6}$ g/g	t-distr.	0.011	$630\cdot10^{-9}$ g	10.1 %
$\eta_{purityNBL112A}$	0.9997500 g/g	$30.0\cdot10^{-6}$ g/g	normal	$330\cdot10^{-6}$	$10\cdot10^{-9}$ g	0.0 %
$m_{235Uunit1full}$	0.01114956 g	$1.98\cdot10^{-6}$ g				

$m_{238Uunit1}$: mass of ^{238}U in #1

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
m1	2.592000 g	$300\cdot10^{-6}$ g	normal	0.018	$5.5\cdot10^{-6}$ g	93.2 %
M_{233U}	233.03963440 g/mol	$2.40\cdot10^{-6}$ g/mol	normal	$-860\cdot10^{-15}$	$-2.1\cdot10^{-18}$ g	0.0 %
M_{234U}	234.04095040 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-36\cdot10^{-9}$	$-43\cdot10^{-15}$ g	0.0 %
M_{235U}	235.04392820 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-3.6\cdot10^{-6}$	$-4.4\cdot10^{-12}$ g	0.0 %
M_{236U}	236.04556620 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-22\cdot10^{-9}$	$-26\cdot10^{-15}$ g	0.0 %
M_{238U}	238.05078700 g/mol	$1.60\cdot10^{-6}$ g/mol	normal	$3.6\cdot10^{-6}$	$5.8\cdot10^{-12}$ g	0.0 %
$m_{solution1027w}$	2269.2300 g	0.0200 g	normal	$-21\cdot10^{-6}$	$-420\cdot10^{-9}$ g	0.5 %
$m_{UCRM116A}$	10.1633200 g	$30.0\cdot10^{-6}$ g	normal	$55\cdot10^{-6}$	$1.7\cdot10^{-9}$ g	0.0 %
m_{UMP2}	$1.869760\cdot10^{-3}$ g	$652\cdot10^{-9}$ g		$920\cdot10^{-6}$	$600\cdot10^{-12}$ g	0.0 %
$m_{UNBL112A}$	41.1555800 g	$40.0\cdot10^{-6}$ g	normal	$1.1\cdot10^{-3}$	$45\cdot10^{-9}$ g	0.0 %
$n_{233.c}$	0.0 mol	0.0 mol	normal	0.0	0.0 g	0.0 %
$n_{234.c}$	$62.435\cdot10^{-9}$ mol	$120\cdot10^{-12}$ mol		-0.22	$-26\cdot10^{-12}$ g	0.0 %
$n_{235.c}$	$7.28901\cdot10^{-6}$ mol	$2.55\cdot10^{-9}$ mol		-0.22	$-550\cdot10^{-12}$ g	0.0 %
$n_{236.c}$	$601.179\cdot10^{-9}$ mol	$340\cdot10^{-12}$ mol		-0.22	$-74\cdot10^{-12}$ g	0.0 %
$n_{238.c}$	$15.019\cdot10^{-12}$ mol	$143\cdot10^{-15}$ mol		0.053	$7.6\cdot10^{-15}$ g	0.0 %
$R_{233U/235Ub}$	$386.30\cdot10^{-9}$ mol/mol	$2.61\cdot10^{-9}$ mol/mol	t-distr.	$-520\cdot10^{-6}$	$-1.4\cdot10^{-12}$ g	0.0 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 g	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85\cdot10^{-6}$ mol/mol	normal	$-520\cdot10^{-6}$	$-2.5\cdot10^{-9}$ g	0.0 %
$R_{234U/238Ua}$	$52.8410\cdot10^{-6}$ mol/mol	$41.0\cdot10^{-9}$ mol/mol	normal	-0.046	$-1.9\cdot10^{-9}$ g	0.0 %
$R_{235U/238Ua}$	$7.25430\cdot10^{-3}$ mol/mol	$2.00\cdot10^{-6}$ mol/mol	normal	-0.046	$-91\cdot10^{-9}$ g	0.0 %
$R_{236U/235Ub}$	$9.47130\cdot10^{-3}$ mol/mol	$3.85\cdot10^{-6}$ mol/mol	normal	$-530\cdot10^{-6}$	$-2.0\cdot10^{-9}$ g	0.0 %
$R_{236U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 g	0.0 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5\cdot10^{-6}$ mol/mol	normal	0.010	$210\cdot10^{-9}$ g	0.1 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3\cdot10^{-6}$ g/g	t-distr.	$560\cdot10^{-6}$	$33\cdot10^{-9}$ g	0.0 %
$\eta_{purityNBL112A}$	0.9997500 g/g	$30.0\cdot10^{-6}$ g/g	normal	0.047	$1.4\cdot10^{-6}$ g	6.1 %
$m_{238Uunit1}$	0.04722263 g	$5.66\cdot10^{-6}$ g				

$m_{238Uunit1full}$: mass of ^{238}U in #1 - full uncertainty budget

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
m1	2.592000 g	$300\cdot10^{-6}$ g	normal	0.018	$5.5\cdot10^{-6}$ g	24.7 %
M_{233U}	233.03963440 g/mol	$2.40\cdot10^{-6}$ g/mol	normal	$-860\cdot10^{-15}$	$-2.1\cdot10^{-18}$ g	0.0 %
M_{234U}	234.04095040 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-36\cdot10^{-9}$	$-43\cdot10^{-15}$ g	0.0 %
M_{235U}	235.04392820 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-3.6\cdot10^{-6}$	$-4.4\cdot10^{-12}$ g	0.0 %
M_{236U}	236.04556620 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-22\cdot10^{-9}$	$-26\cdot10^{-15}$ g	0.0 %
M_{238U}	238.05078700 g/mol	$1.60\cdot10^{-6}$ g/mol	normal	$3.6\cdot10^{-6}$	$5.8\cdot10^{-12}$ g	0.0 %
$m_{solution1027w}$	2269.2300 g	0.0200 g	normal	$-21\cdot10^{-6}$	$-420\cdot10^{-9}$ g	0.1 %
$m_{UCRM116A}$	10.1633200 g	$30.0\cdot10^{-6}$ g	normal	$55\cdot10^{-6}$	$1.7\cdot10^{-9}$ g	0.0 %
m_{UMP2}	$1.869760\cdot10^{-3}$ g	$652\cdot10^{-9}$ g		$920\cdot10^{-6}$	$600\cdot10^{-12}$ g	0.0 %
$m_{UNBL112A}$	41.1555800 g	$40.0\cdot10^{-6}$ g	normal	$1.1\cdot10^{-3}$	$45\cdot10^{-9}$ g	0.0 %
$n_{233.c}$	0.0 mol	0.0 mol	normal	0.0	0.0 g	0.0 %
$n_{234.c}$	$62.435\cdot10^{-9}$ mol	$120\cdot10^{-12}$ mol		-0.22	$-26\cdot10^{-12}$ g	0.0 %
$n_{235.c}$	$7.28901\cdot10^{-6}$ mol	$2.55\cdot10^{-9}$ mol		-0.22	$-550\cdot10^{-12}$ g	0.0 %
$n_{236.c}$	$601.179\cdot10^{-9}$ mol	$340\cdot10^{-12}$ mol		-0.22	$-74\cdot10^{-12}$ g	0.0 %
$n_{238.c}$	$15.019\cdot10^{-12}$ mol	$143\cdot10^{-15}$ mol		0.053	$7.6\cdot10^{-15}$ g	0.0 %
$R_{233U/235Ub}$	$386.30\cdot10^{-9}$ mol/mol	$2.61\cdot10^{-9}$ mol/mol	t-distr.	$-520\cdot10^{-6}$	$-1.4\cdot10^{-12}$ g	0.0 %
$R_{233U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 g	0.0 %
$R_{234U/235Ub}$	0.01158360 mol/mol	$4.85\cdot10^{-6}$ mol/mol	normal	$-520\cdot10^{-6}$	$-2.5\cdot10^{-9}$ g	0.0 %
$R_{234U/238Ua}$	$52.8410\cdot10^{-6}$ mol/mol	$41.0\cdot10^{-9}$ mol/mol	normal	-0.046	$-1.9\cdot10^{-9}$ g	0.0 %
$R_{235U/238Ua}$	$7.25430\cdot10^{-3}$ mol/mol	$2.00\cdot10^{-6}$ mol/mol	normal	-0.046	$-91\cdot10^{-9}$ g	0.0 %
$R_{236U/235Ub}$	$9.47130\cdot10^{-3}$ mol/mol	$3.85\cdot10^{-6}$ mol/mol	normal	$-530\cdot10^{-6}$	$-2.0\cdot10^{-9}$ g	0.0 %
$R_{236U/238Ua}$	0.0 mol/mol	0.0 mol/mol	normal	0.0	0.0 g	0.0 %
$R_{238U/235Ub}$	0.0512770 mol/mol	$20.5\cdot10^{-6}$ mol/mol	normal	0.010	$210\cdot10^{-9}$ g	0.0 %
$u_{hom}238U_{unit1}$	0.0 g	$9.44\cdot10^{-6}$ g	normal	1.0	$9.4\cdot10^{-6}$ g	73.5 %
$\eta_{purityCRM116A}$	0.9994500 g/g	$58.3\cdot10^{-6}$ g/g	t-distr.	$560\cdot10^{-6}$	$33\cdot10^{-9}$ g	0.0 %
$\eta_{purityNBL112A}$	0.9997500 g/g	$30.0\cdot10^{-6}$ g/g	normal	0.047	$1.4\cdot10^{-6}$ g	1.6 %
$m_{238Uunit1full}$	0.0472226 g	$11.0\cdot10^{-6}$ g				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
$c_{235Umixture}$	$18.3010 \cdot 10^{-6}$ mol/g	$2.6 \cdot 10^{-9}$ mol/g	2.32	95% (t-table 95.45%)
$c_{235Umixture}$verif	$18.3010 \cdot 10^{-6}$ mol/g	$7.0 \cdot 10^{-9}$ mol/g	2.06	95% (t-table 95.45%)
$c_{238Umixture}$	$76.5324 \cdot 10^{-6}$ mol/g	$4.8 \cdot 10^{-9}$ mol/g	2.00	95% (t-table 95.45%)
$c_{238Umixture}$verif	$76.532 \cdot 10^{-6}$ mol/g	$38 \cdot 10^{-9}$ mol/g	2.13	95% (t-table 95.45%)
$c_{Umixture}$	$95.2114 \cdot 10^{-6}$ mol/g	$5.4 \cdot 10^{-9}$ mol/g	2.00	95% (t-table 95.45%)
f_{233U}	$72.0 \cdot 10^{-9}$ mol/mol	$1.6 \cdot 10^{-9}$ mol/mol	3.31	95% (t-table 95.45%)
f_{234U}	$2.2017 \cdot 10^{-3}$ mol/mol	$1.8 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
f_{235U}	0.192214 mol/mol	$23 \cdot 10^{-6}$ mol/mol	2.18	95% (t-table 95.45%)
f_{236U}	$1.7684 \cdot 10^{-3}$ mol/mol	$1.4 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
f_{238U}	0.803816 mol/mol	$23 \cdot 10^{-6}$ mol/mol	2.18	95% (t-table 95.45%)
$m_{235Uunit1}$	0.0111496 g	$3.0 \cdot 10^{-6}$ g	2.03	95% (t-table 95.45%)
$m_{235Uunit1full}$	0.0111496 g	$4.0 \cdot 10^{-6}$ g	2.00	95% (t-table 95.45%)
$m_{238Uunit1}$	0.047223 g	$11 \cdot 10^{-6}$ g	2.00	95% (t-table 95.45%)
$m_{238Uunit1full}$	0.047223 g	$22 \cdot 10^{-6}$ g	2.00	95% (t-table 95.45%)
M_U	237.460452 g/mol	$70 \cdot 10^{-6}$ g/mol	2.18	95% (t-table 95.45%)
$R_{233U/238U}$	$89.6 \cdot 10^{-9}$ mol/mol	$2.0 \cdot 10^{-9}$ mol/mol	3.31	95% (t-table 95.45%)
$R_{234U/238U}$	$2.7390 \cdot 10^{-3}$ mol/mol	$2.3 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
$R_{235U/238U}$	0.239127 mol/mol	$35 \cdot 10^{-6}$ mol/mol	2.18	95% (t-table 95.45%)
$R_{236U/238U}$	$2.2000 \cdot 10^{-3}$ mol/mol	$1.8 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
w_{233U}	$70.7 \cdot 10^{-9}$ g/g	$1.6 \cdot 10^{-9}$ g/g	3.31	95% (t-table 95.45%)
w_{234U}	$2.1700 \cdot 10^{-3}$ g/g	$1.8 \cdot 10^{-6}$ g/g	2.00	95% (t-table 95.45%)
w_{235U}	0.190258 g/g	$23 \cdot 10^{-6}$ g/g	2.18	95% (t-table 95.45%)
w_{236U}	$1.7579 \cdot 10^{-3}$ g/g	$1.4 \cdot 10^{-6}$ g/g	2.00	95% (t-table 95.45%)
w_{238U}	0.805814 g/g	$23 \cdot 10^{-6}$ g/g	2.18	95% (t-table 95.45%)
$\gamma_{235Umixture}$	$4.30153 \cdot 10^{-3}$ g/g	$610 \cdot 10^{-9}$ g/g	2.32	95% (t-table 95.45%)
$\gamma_{238Umixture}$	0.0182186 g/g	$1.1 \cdot 10^{-6}$ g/g	2.00	95% (t-table 95.45%)
$\gamma_{Umixture}$	0.0226089 g/g	$1.3 \cdot 10^{-6}$ g/g	2.00	95% (t-table 95.45%)

Annex 14 Uncertainty budget for the plutonium gravimetric mixture of IRMM-1027w

Plutonium gravimetric mixture of IRMM-1027w normalised to ref date 01 Jan 2022

Author: Kalman Toth

The plutonium gravimetric mixture was prepared by dissolving plutonium MP2 metal (CEA/CETAMA) in 20 mL 6M hydrochloric acid and in 2+6+8 M nitric acid. Before the dissolution the MP2 metals were electropolished. The dissolution of the metals were done directly in the big flask of the mother soltution.

Input parameters:

1) Mass of plutonium metal and the nitrate solution (E3950) 2) Purity of plutonium metal (MP2 metal certificate) 3) Plutonium isotope amount ratios (IRMM certificate, issued 11 April 2007, date of measurment completed: 7 November 2006) 4) The atomic masses according Wang et al. (The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017). 5) Purity of MP2 metal on 01 Jan 2022 was calculated from the the purity on 1 Jan 2007 (99.875 +/-0.040), which was derived from the original CETAMA certificate (99.90 +/- 0.04).

The values are normalised to 01 Jan 2022 (reference date)

No weighing was done before the dispensing thus no evaporation correction was taking into account on the stock solution (the dispensing started the same day when the weighing was done).

Date of MP2 dissolution:

MP2 unit numbers:

Model Equation:

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

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

{Isotope amount fractions in MP2, 1 Jan 2007}

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

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

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

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

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

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

{Isotope mass fractions in MP2, 1 Jan 2007}

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

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

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

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

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

{Decayed isotope amount ratios in gravimetric mixture, IRMM-1027w, reference date}

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

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

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

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

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

{Decayed and normalised isotope amount fractions in gravimetric mixture, IRMM-1027w, reference

date}

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

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

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

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

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

{Decayed molar mass of plutonium in gravimetric mixtures, IRMM-1027w, reference date}

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

{Decayed and normalised isotope mass fractions in gravimetric mixture, IRMM-1027w, reference date}

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

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

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

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

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

{Decayed amount ratios for purity calculation, reference date}

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

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

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

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

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

{Decayed isotope masses for purity calculation, reference date}

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

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

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

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

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

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

$\eta_{PuMP2refdate}=\eta_{PuMP2Jan2007}*\Sigma md_{Pu}/m_{Pu}$;

{Decay constants}

$ln_2 = ln(2)$;

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

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

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

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

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

{Plutonium mass fraction in gravimetric mixture, IRMM-1027w, reference date}

$\gamma_{Pumixture}=(m_{PuMP2}*\eta_{PuMP2refdate})/m_{solution1027w}$;

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

{Plutonium amount content in gravimetric mixture, IRMM-1027w, reference date}

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

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

{Combined standard uncertainty for single unit verification (IDMS)}

$c_{Pumixture239}verif=c_{Pumixture239} +u_{hom239Pu}+u_{disp}$;

{Calculations for #1}

$m_{239Puunit1}=\gamma_{Pumixture239}*m1$;

$m_{239Puunit1full}=\gamma_{Pumixture239}*m1+u_{hom239Pu}unit1$;

List of Quantities:

Quantity	Unit	Definition
$c_{Pumixture}$	mol/g	Pu amount content in IRMM-1027w
$c_{Pumixture239}$	mol/g	^{239}Pu amount content in IRMM-1027w
$c_{Pumixture239}verif$	mol/g	^{239}Pu amount content in IRMM-1027w with u(hom) and u(disp)
e		
f_{238Pu}	mol/mol	^{238}Pu amount fraction in MP2, 1 Jan 2007
f_{239Pu}	mol/mol	^{239}Pu amount fraction in MP2, 1 Jan 2007
f_{240Pu}	mol/mol	^{240}Pu amount fraction in MP2, 1 Jan 2007
f_{241Pu}	mol/mol	^{241}Pu amount fraction in MP2, 1 Jan 2007
f_{242Pu}	mol/mol	^{242}Pu amount fraction in MP2, 1 Jan 2007
fd_{238Pu}	mol/mol	Decayed ^{238}Pu amount fraction in MP2, from 1 Jan 2007 to ref date
fd_{239Pu}	mol/mol	Decayed ^{239}Pu amount fraction in MP2, from 1 Jan 2007 to ref date
fd_{240Pu}	mol/mol	Decayed ^{240}Pu amount fraction in MP2, from 1 Jan 2007 to ref date
fd_{241Pu}	mol/mol	Decayed ^{241}Pu amount fraction in MP2, from 1 Jan 2007 to ref date
fd_{242Pu}	mol/mol	Decayed ^{242}Pu amount fraction in MP2, from 1 Jan 2007 to ref date
$fdnorm_{238Pu}$	mol/mol	Decayed and normalised ^{238}Pu amount fraction in gravimetric mixture, IRMM-1027w, ref date
$fdnorm_{239Pu}$	mol/mol	Decayed and normalised ^{239}Pu amount fraction in gravimetric mixture, IRMM-1027w, ref date
$fdnorm_{240Pu}$	mol/mol	Decayed and normalised ^{240}Pu amount fraction in gravimetric mixture, IRMM-1027w, ref date
$fdnorm_{241Pu}$	mol/mol	Decayed and normalised ^{241}Pu amount fraction in gravimetric mixture, IRMM-1027w, ref date
$fdnorm_{242Pu}$	mol/mol	Decayed and normalised ^{242}Pu amount fraction in gravimetric mixture, IRMM-1027w, ref date
ln_2		
m1	g	mass of aliquot in 1027w #1
M_{238Pu}	g/mol	Atomic mass of ^{238}Pu

Quantity	Unit	Definition
M_{239Pu}	g/mol	Atomic mass of ^{239}Pu
$m_{239Puunit1}$	g	mass of ^{239}Pu in 1027w #1
$m_{239Puunit1full}$	g	mass of ^{239}Pu in 1027w #1 - combined uncertainty (with u(hom))
M_{240Pu}	g/mol	Atomic mass of ^{240}Pu
M_{241Pu}	g/mol	Atomic mass of ^{241}Pu
M_{242Pu}	g/mol	Atomic mass of ^{242}Pu
md_{238Pu}	g	Decayed mass of ^{238}Pu, from 1 Jan 2007 to ref date
md_{239Pu}	g	Decayed mass of ^{239}Pu, from 1 Jan 2007 to ref date
md_{240Pu}	g	Decayed mass of ^{240}Pu, from 1 Jan 2007 to ref date
md_{241Pu}	g	Decayed mass of ^{241}Pu, from 1 Jan 2007 to ref date
md_{242Pu}	g	Decayed mass of ^{242}Pu, from 1 Jan 2007 to ref date
Md_{Pu}	g/mol	Decayed molar mass of Pu in gravimetric mixture, IRMM-1027w, ref date
M_{Pu}	g/mol	molar mass of Pu in MP2, 1 Jan 2007
m_{Pu}	g	
m_{PuMP2}	g	Mass of plutonium MP2 metal
$m_{solution1027w}$	g	Mass of IRMM-1027w mother solution
$R_{238Pu/239Pu}$	mol/mol	$^{238}Pu/^{239}Pu$ amount ratio in MP2, 1 Jan 2007
$R_{240Pu/239Pu}$	mol/mol	$^{240}Pu/^{239}Pu$ amount ratio in MP2, 1 Jan 2007
$R_{241Pu/239Pu}$	mol/mol	$^{241}Pu/^{239}Pu$ amount ratio in MP2, 1 Jan 2007
$R_{242Pu/239Pu}$	mol/mol	$^{242}Pu/^{239}Pu$ amount ratio in MP2, 1 Jan 2007
$Rd_{238Pu/239Pu}$	mol/mol	decayed $^{238}Pu/^{239}Pu$ amount ratio in IRMM-1027v, ref date
$Rd_{240Pu/239Pu}$	mol/mol	decayed $^{240}Pu/^{239}Pu$ amount ratio in IRMM-1027v, ref date
$Rd_{241Pu/239Pu}$	mol/mol	decayed $^{241}Pu/^{239}Pu$ amount ratio in IRMM-1027v, ref date
$Rd_{242Pu/239Pu}$	mol/mol	decayed $^{242}Pu/^{239}Pu$ amount ratio in IRMM-1027v, ref date
u_{disp}	mol/g	standard unceratinty associated with dispensing for ^{239}Pu amount content
$u_{hom239Pu}$	mol/g	standard unceratinty associated with homogeneity for ^{239}Pu amount content
$u_{hom239Pu}unit1$	g	standard unceratinty associated with dispensing for ^{239}Pu mass in #1
w_{238Pu}	g/g	^{238}Pu mass fraction in MP2, 1 Jan 2007
w_{239Pu}	g/g	^{239}Pu mass fraction in MP2, 1 Jan 2007
w_{240Pu}	g/g	^{240}Pu mass fraction in MP2, 1 Jan 2007
w_{241Pu}	g/g	^{241}Pu mass fraction in MP2, 1 Jan 2007
w_{242Pu}	g/g	^{242}Pu mass fraction in MP2, 1 Jan 2007
$wdnorm_{238Pu}$	g/g	Decayed and normalised ^{238}Pu mass fraction in gravimetric mixture, IRMM-1027w, ref date
$wdnorm_{239Pu}$	g/g	Decayed and normalised ^{239}Pu mass fraction in gravimetric mixture, IRMM-1027w, ref date
$wdnorm_{240Pu}$	g/g	Decayed and normalised ^{240}Pu mass fraction in gravimetric mixture, IRMM-1027w, ref date

Quantity	Unit	Definition
$wdnorm_{241Pu}$	g/g	Decayed and normalised ^{241}Pu mass fraction in gravimetric mixture, IRMM-1027w, ref date
$wdnorm_{242Pu}$	g/g	Decayed and normalised ^{242}Pu mass fraction in gravimetric mixture, IRMM-1027w, ref date
Δt	a	time difference between certification date MP2 (1 Jan 2007) and the ref date 01 Jan 2022
$\eta_{PuMP2Jan2007}$	g/g	Purity of MP2 metal, 1 Jan 2007
$\eta_{PuMP2refdate}$	g/g	
$\gamma_{Pumixture}$	g/g	Pu mass fraction in IRMM-1027w
$\gamma_{Pumixture239}$	g/g	^{239}Pu mass fraction in IRMM-1027w
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
Σmd_{Pu}	g	Sum of decayed Pu masses
ΣRd_{Pu}	mol/mol	Sum of decayed amount ratios in gravimetric mixture, IRMM-1027w, ref date
ΣR_{Pu}	mol/mol	Sum of amount ratios in MP2, 1 Jan 2007
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

e: Constant
Value: 2.71828182845904523536

m1: Type B normal distribution
Value: 2.5920 g
Expanded Uncertainty: 0.0006 g
Coverage Factor: 2

E3952

M_{238Pu}: Type B normal distribution
Value: 238.0495583 g/mol
Expanded Uncertainty: 0.0000012 g/mol
Coverage Factor: 1

The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017

M_{239Pu}: Type B normal distribution
Value: 239.0521617 g/mol
Expanded Uncertainty: 0.0000012 g/mol
Coverage Factor: 1

The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017

M_{240Pu}: Type B normal distribution
Value: 240.0538118 g/mol
Expanded Uncertainty: 0.0000012 g/mol
Coverage Factor: 1

The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017

M_{241Pu}: Type B normal distribution
Value: 241.0568497 g/mol
Expanded Uncertainty: 0.0000012 g/mol
Coverage Factor: 1

The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017

M_{242Pu}: Type B normal distribution
Value: 242.0587410 g/mol
Expanded Uncertainty: 0.0000013 g/mol
Coverage Factor: 1

The AME 2016 atomic mass evaluation (II). Tables, Graphs and References, Chinese Physics C, Vol. 41, No. 3, 2017

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

m_{PuMP2}: Type B normal distribution
Value: 1.64765 g
Expanded Uncertainty: 0.00007 g
Coverage Factor: 2

E3935

$m_{solution1027w}$: Type B rectangular distribution
Value: 2269.23 g
Halfwidth of Limits: 0.04 g

E3950

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

IRMM MP2 certificate 2007

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

IRMM MP2 certificate 2007

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

IRMM MP2 certificate 2007

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

IRMM MP2 certificate 2007

u_{disp}: Type B normal distribution
Value: 0 mol/g
Expanded Uncertainty: $3.55728 \cdot 10^{-10}$ mol/g
Coverage Factor: 1

=0.0000029644*0.00012 c(235 U mixture)*u(rel dispensing)

$u_{hom239Pu}$: Type B t-distribution
Value: 0 mol/g
Standard Deviation of the Mean: $6.149311 \cdot 10^{-10}$ mol/g
Degrees of Freedom: 14

$u_{hom239Pu}$unit1: Type B normal distribution
Value: 0 g
Expanded Uncertainty: $3.94 \cdot 10^{-7}$ g
Coverage Factor: 1

$m_{239Puunit1}$*u(rel homogeniety)
0.001876*0.00021= 3.94e-7

Δt: Constant
Value: 15.00068 a

01/01/2007, 01/01/2022, delta t= 5479 days / 365.25 = 15.00068 a

$\eta_{PuMP2Jan2007}$: Import
Filename: ..\..\..\IRMM-1027v\processing\Process control measurements\1027v Mother solution verification Pu IA\Decay MP2 from 12-03-2001 to 01-01-2007.smu
Symbol: $\eta_{PuMP2Jan2007}$

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

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

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

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

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

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

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

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

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

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

Input Correlation:

The abundance set for Pu is assumed as uncorrelated.

Uncertainty Budgets:

$c_{Pumixture239}$: ^{239}Pu amount content in IRMM-1027w

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
e	2.718281828459					
M_{238Pu}	238.04955830 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-370\cdot10^{-15}$	$-450\cdot10^{-21}$ mol/g	0.0 %
M_{239Pu}	239.05216170 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-12\cdot10^{-9}$	$-15\cdot10^{-15}$ mol/g	0.0 %
M_{240Pu}	240.05381180 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-270\cdot10^{-12}$	$-330\cdot10^{-18}$ mol/g	0.0 %
M_{241Pu}	241.05684970 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-2.9\cdot10^{-12}$	$-3.5\cdot10^{-18}$ mol/g	0.0 %
M_{242Pu}	242.05874100 g/mol	$1.30\cdot10^{-6}$ g/mol	normal	$-920\cdot10^{-15}$	$-1.2\cdot10^{-18}$ mol/g	0.0 %
m_{Pu}	1.0 g	0.0 g	normal	0.0	0.0 mol/g	0.0 %
m_{PuMP2}	1.6476500 g	$35.0\cdot10^{-6}$ g	normal	$1.8\cdot10^{-6}$	$63\cdot10^{-12}$ mol/g	1.1 %
$m_{solution1027w}$	2269.2300 g	0.0231 g	rectangular	$-1.3\cdot10^{-9}$	$-30\cdot10^{-12}$ mol/g	0.3 %
$R_{238Pu/239Pu}$	$30.830\cdot10^{-6}$ mol/mol	$145\cdot10^{-9}$ mol/mol	normal	$-2.9\cdot10^{-6}$	$-420\cdot10^{-15}$ mol/g	0.0 %
$R_{240Pu/239Pu}$	0.02243240 mol/mol	$2.55\cdot10^{-6}$ mol/mol	normal	$-2.9\cdot10^{-6}$	$-7.4\cdot10^{-12}$ mol/g	0.0 %
$R_{241Pu/239Pu}$	$237.80\cdot10^{-6}$ mol/mol	$1.55\cdot10^{-6}$ mol/mol	normal	$-2.9\cdot10^{-6}$	$-4.5\cdot10^{-12}$ mol/g	0.0 %
$R_{242Pu/239Pu}$	$75.700\cdot10^{-6}$ mol/mol	$390\cdot10^{-9}$ mol/mol	normal	$-2.9\cdot10^{-6}$	$-1.1\cdot10^{-12}$ mol/g	0.0 %
Δt	15.00068 a					
$\eta_{PuMP2Jan2007}$	0.998746 g/g	$200\cdot10^{-6}$ g/g		$3.0\cdot10^{-6}$	$590\cdot10^{-12}$ mol/g	98.6 %
τ_{238}	87.7400 a	0.0300 a	normal	0.0	0.0 mol/g	0.0 %
τ_{239}	24100.0 a	11.0 a	normal	$53\cdot10^{-15}$	$580\cdot10^{-15}$ mol/g	0.0 %
τ_{240}	6561.00 a	7.00 a	normal	0.0	$-52\cdot10^{-27}$ mol/g	0.0 %
τ_{241}	14.3250 a	0.0120 a	normal	0.0	$52\cdot10^{-27}$ mol/g	0.0 %
τ_{242}	$373.00\cdot10^{3}$ a	3000 a	normal	0.0	$100\cdot10^{-27}$ mol/g	0.0 %
$c_{Pumixture239}$	$2.964419\cdot10^{-6}$ mol/g	$598\cdot10^{-12}$ mol/g				

$m_{239Puunit1}$: mass of ^{239}Pu in 1027w #1

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
e	2.718281828459					
m1	2.592000 g	$300\cdot10^{-6}$ g	normal	$710\cdot10^{-6}$	$210\cdot10^{-9}$ g	24.8 %
M_{238Pu}	238.04955830 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-230\cdot10^{-12}$	$-280\cdot10^{-18}$ g	0.0 %
M_{239Pu}	239.05216170 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$170\cdot10^{-9}$	$210\cdot10^{-15}$ g	0.0 %
M_{240Pu}	240.05381180 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-170\cdot10^{-9}$	$-200\cdot10^{-15}$ g	0.0 %
M_{241Pu}	241.05684970 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-1.8\cdot10^{-9}$	$-2.1\cdot10^{-15}$ g	0.0 %
M_{242Pu}	242.05874100 g/mol	$1.30\cdot10^{-6}$ g/mol	normal	$-570\cdot10^{-12}$	$-740\cdot10^{-18}$ g	0.0 %
m_{Pu}	1.0 g	0.0 g	normal	0.0	0.0 g	0.0 %
m_{PuMP2}	1.6476500 g	$35.0\cdot10^{-6}$ g	normal	$1.1\cdot10^{-3}$	$39\cdot10^{-9}$ g	0.8 %
$m_{solution1027w}$	2269.2300 g	0.0231 g	rectangular	$-810\cdot10^{-9}$	$-19\cdot10^{-9}$ g	0.2 %
$R_{238Pu/239Pu}$	$30.830\cdot10^{-6}$ mol/mol	$145\cdot10^{-9}$ mol/mol	normal	$-1.8\cdot10^{-3}$	$-260\cdot10^{-12}$ g	0.0 %
$R_{240Pu/239Pu}$	0.02243240 mol/mol	$2.55\cdot10^{-6}$ mol/mol	normal	$-1.8\cdot10^{-3}$	$-4.6\cdot10^{-9}$ g	0.0 %
$R_{241Pu/239Pu}$	$237.80\cdot10^{-6}$ mol/mol	$1.55\cdot10^{-6}$ mol/mol	normal	$-1.8\cdot10^{-3}$	$-2.8\cdot10^{-9}$ g	0.0 %
$R_{242Pu/239Pu}$	$75.700\cdot10^{-6}$ mol/mol	$390\cdot10^{-9}$ mol/mol	normal	$-1.8\cdot10^{-3}$	$-710\cdot10^{-12}$ g	0.0 %
Δt	15.00068 a					
$\eta_{PuMP2Jan2007}$	0.998746 g/g	$200\cdot10^{-6}$ g/g		$1.8\cdot10^{-3}$	$370\cdot10^{-9}$ g	74.2 %
τ_{238}	87.7400 a	0.0300 a	normal	0.0	0.0 g	0.0 %
τ_{239}	24100.0 a	11.0 a	normal	$33\cdot10^{-12}$	$360\cdot10^{-12}$ g	0.0 %
τ_{240}	6561.00 a	7.00 a	normal	0.0	$-26\cdot10^{-24}$ g	0.0 %
τ_{241}	14.3250 a	0.0120 a	normal	0.0	$26\cdot10^{-24}$ g	0.0 %
τ_{242}	$373.00\cdot10^{3}$ a	3000 a	normal	0.0	$26\cdot10^{-24}$ g	0.0 %
$m_{239Puunit1}$	$1.836823\cdot10^{-3}$ g	$427\cdot10^{-9}$ g				

$m_{239Puunit1full}$: mass of ^{239}Pu in 1027w #1 - combined uncertainty (with u(hom))

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
e	2.718281828459					
m1	2.592000 g	$300\cdot10^{-6}$ g	normal	$710\cdot10^{-6}$	$210\cdot10^{-9}$ g	13.4 %
M_{238Pu}	238.04955830 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-230\cdot10^{-12}$	$-280\cdot10^{-18}$ g	0.0 %
M_{239Pu}	239.05216170 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$170\cdot10^{-9}$	$210\cdot10^{-15}$ g	0.0 %
M_{240Pu}	240.05381180 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-170\cdot10^{-9}$	$-200\cdot10^{-15}$ g	0.0 %
M_{241Pu}	241.05684970 g/mol	$1.20\cdot10^{-6}$ g/mol	normal	$-1.8\cdot10^{-9}$	$-2.1\cdot10^{-15}$ g	0.0 %
M_{242Pu}	242.05874100 g/mol	$1.30\cdot10^{-6}$ g/mol	normal	$-570\cdot10^{-12}$	$-740\cdot10^{-18}$ g	0.0 %
m_{Pu}	1.0 g	0.0 g	normal	0.0	0.0 g	0.0 %
m_{PuMP2}	1.6476500 g	$35.0\cdot10^{-6}$ g	normal	$1.1\cdot10^{-3}$	$39\cdot10^{-9}$ g	0.5 %
$m_{solution1027w}$	2269.2300 g	0.0231 g	rectangular	$-810\cdot10^{-9}$	$-19\cdot10^{-9}$ g	0.1 %
$R_{238Pu/239Pu}$	$30.830\cdot10^{-6}$ mol/mol	$145\cdot10^{-9}$ mol/mol	normal	$-1.8\cdot10^{-3}$	$-260\cdot10^{-12}$ g	0.0 %
$R_{240Pu/239Pu}$	0.02243240 mol/mol	$2.55\cdot10^{-6}$ mol/mol	normal	$-1.8\cdot10^{-3}$	$-4.6\cdot10^{-9}$ g	0.0 %
$R_{241Pu/239Pu}$	$237.80\cdot10^{-6}$ mol/mol	$1.55\cdot10^{-6}$ mol/mol	normal	$-1.8\cdot10^{-3}$	$-2.8\cdot10^{-9}$ g	0.0 %
$R_{242Pu/239Pu}$	$75.700\cdot10^{-6}$ mol/mol	$390\cdot10^{-9}$ mol/mol	normal	$-1.8\cdot10^{-3}$	$-710\cdot10^{-12}$ g	0.0 %
$u_{hom239Pu}$unit1	0.0 g	$394\cdot10^{-9}$ g	normal	1.0	$390\cdot10^{-9}$ g	46.0 %
Δt	15.00068 a					
$\eta_{PuMP2Jan2007}$	0.998746 g/g	$200\cdot10^{-6}$ g/g		$1.8\cdot10^{-3}$	$370\cdot10^{-9}$ g	40.1 %
τ_{238}	87.7400 a	0.0300 a	normal	0.0	0.0 g	0.0 %
τ_{239}	24100.0 a	11.0 a	normal	$33\cdot10^{-12}$	$360\cdot10^{-12}$ g	0.0 %
τ_{240}	6561.00 a	7.00 a	normal	0.0	$-26\cdot10^{-24}$ g	0.0 %
τ_{241}	14.3250 a	0.0120 a	normal	0.0	$26\cdot10^{-24}$ g	0.0 %
τ_{242}	$373.00\cdot10^{3}$ a	3000 a	normal	0.0	$26\cdot10^{-24}$ g	0.0 %
$m_{239Puunit1full}$	$1.836823\cdot10^{-3}$ g	$581\cdot10^{-9}$ g				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
$c_{Pumixture}$	$3.0315 \cdot 10^{-6}$ mol/g	$1.2 \cdot 10^{-9}$ mol/g	2.00	95% (t-table 95.45%)
$c_{Pumixture239}$	$2.9644 \cdot 10^{-6}$ mol/g	$1.2 \cdot 10^{-9}$ mol/g	2.00	95% (t-table 95.45%)
$c_{Pumixture239}$verif	$2.9644 \cdot 10^{-6}$ mol/g	$1.9 \cdot 10^{-9}$ mol/g	2.04	95% (t-table 95.45%)
$fdnorm_{238Pu}$	$26.79 \cdot 10^{-6}$ mol/mol	$250 \cdot 10^{-9}$ mol/mol	2.00	95% (t-table 95.45%)
$fdnorm_{239Pu}$	0.9778758 mol/mol	$5.1 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
$fdnorm_{240Pu}$	0.0219108 mol/mol	$4.9 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
$fdnorm_{241Pu}$	$112.6 \cdot 10^{-6}$ mol/mol	$1.5 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
$fdnorm_{242Pu}$	$74.06 \cdot 10^{-6}$ mol/mol	$760 \cdot 10^{-9}$ mol/mol	2.00	95% (t-table 95.45%)
$m_{239Puunit1}$	$1.83682 \cdot 10^{-3}$ g	$850 \cdot 10^{-9}$ g	2.00	95% (t-table 95.45%)
$m_{239Puunit1full}$	$1.8368 \cdot 10^{-3}$ g	$1.2 \cdot 10^{-6}$ g	2.00	95% (t-table 95.45%)
Md_{Pu}	239.0745301 g/mol	$6.6 \cdot 10^{-6}$ g/mol	2.00	95% (t-table 95.45%)
$Rd_{238Pu/239Pu}$	$27.40 \cdot 10^{-6}$ mol/mol	$260 \cdot 10^{-9}$ mol/mol	2.00	95% (t-table 95.45%)
$Rd_{240Pu/239Pu}$	0.0224065 mol/mol	$5.1 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
$Rd_{241Pu/239Pu}$	$115.1 \cdot 10^{-6}$ mol/mol	$1.5 \cdot 10^{-6}$ mol/mol	2.00	95% (t-table 95.45%)
$Rd_{242Pu/239Pu}$	$75.73 \cdot 10^{-6}$ mol/mol	$780 \cdot 10^{-9}$ mol/mol	2.00	95% (t-table 95.45%)
$wdnorm_{238Pu}$	$26.68 \cdot 10^{-6}$ g/g	$250 \cdot 10^{-9}$ g/g	2.00	95% (t-table 95.45%)
$wdnorm_{239Pu}$	0.9777843 g/g	$5.2 \cdot 10^{-6}$ g/g	2.00	95% (t-table 95.45%)
$wdnorm_{240Pu}$	0.0220006 g/g	$4.9 \cdot 10^{-6}$ g/g	2.00	95% (t-table 95.45%)
$wdnorm_{241Pu}$	$113.5 \cdot 10^{-6}$ g/g	$1.5 \cdot 10^{-6}$ g/g	2.00	95% (t-table 95.45%)
$wdnorm_{242Pu}$	$74.98 \cdot 10^{-6}$ g/g	$770 \cdot 10^{-9}$ g/g	2.00	95% (t-table 95.45%)
$\eta_{PuMP2refdate}$	0.99817 g/g	$400 \cdot 10^{-6}$ g/g	2.00	95% (t-table 95.45%)
$\gamma_{Pumixture}$	$724.75 \cdot 10^{-6}$ g/g	$290 \cdot 10^{-9}$ g/g	2.00	95% (t-table 95.45%)
$\gamma_{Pumixture239}$	$708.65 \cdot 10^{-6}$ g/g	$290 \cdot 10^{-9}$ g/g	2.00	95% (t-table 95.45%)

Annex 15 The weighing certificate of the blend mixtures for the confirmation measurements of ^{235}U, ^{238}U and ^{239}Pu amount content by ID-TIMS using IRMM-046c.

Joint Research Centre	Certificate of weighing	Directorate G – Nuclear Safety and Security G.2 - Standards for Nuclear Safety, Security and Safeguards Unit

E. 3953 rev 1 **Issued date:** ~~01/12/2021~~ 27/01/2022 **Page 1 of 3**

Applicant: K. Toth **Project:** IRMM-1027w

Description: Single unit verification of IRMM-1027w and IA

Request for analysis number: 4960 **ID number:** 34057

Date of receipt of request: 03/06/2021 **Weighing dates:** 14-17 Sep 2021

Results:

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

ID	IRMM-046c mass /g	IRMM-046c uncertainty /g	Coverage factor	Effective degrees of freedom
1027w-22/046c-25	1.82397	0.00008	2.03	81
1027w-57/046c-25	1.95381	0.00009	2.11	25
1027w-247/046c-25/083-1864	2.04917	0.00011	2.32	9
1027w-406/046c-25	1.95863	0.00013	2.52	6
QC21/046c-25/083-1884	2.00270	0.00011	2.52	6
1027w-202/046c-87	1.99928	0.00009	2.11	25
1027w-292/046c-87	2.32350	0.00008	2.11	25
1027w-443/046c-87	2.01985	0.00009	2.25	11
1027w-497/046c-87	2.14837	0.00009	2.25	11
QC24/046c-87	2.15623	0.00007	2.00	1300
1027w-126/046c-46	1.94476	0.00012	2.52	6
1027w-689/046c-46	2.01445	0.00007	2.00	160
1027w-767/046c-46	2.01263	0.00011	2.52	6
1027w-772/046c-46/083-1884	2.17773	0.00012	2.43	7
QC23/046c-46	1.99335	0.00009	2.18	15
1027w-340/046c-38	1.99944	0.00007	2.00	1700
1027w-564/046c-38	2.02933	0.00007	2.00	1200
1027w-605/046c-38/083-1864	2.00560	0.00008	2.06	40
1027w-842/046c-38	2.00593	0.00008	2.07	39
QC22/046c-38	2.00414	0.00007	2.00	1300

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ID	IRMM-083 /g	U95% / g	Coverage factor	Effective degrees of freedom
1027w-247/046c-25/083-1864	0.42182	0.00007	2.00	820
1027w-605/04c-38/083-1864	0.49126	0.00007	2.00	1300
1027w-772/046c-46/083-1884	0.59631	0.00008	2.13	21
QC21/046c-25/083-1884	0.29997	0.00010	2.28	10

ID	~~NBL-126~~ CRM-116A mass /g	~~NBL-126~~ CRM-116A uncertainty /g	Coverage factor	Effective degrees of freedom
QC21/046c-25/083-1884	1.00221	0.00009	2.07	36
QC22/046c-38	1.01585	0.00007	2.37	8
QC23/046c-46	1.00589	0.00009	2.52	6
QC24/046c-87	1.00809	0.00009	2.52	6

ID	~~CRM-116A~~ NBL-126 mass /g	~~CRM-116A~~ NBL-126 uncertainty /g	Coverage factor	Effective degrees of freedom
QC21/046c-25/083-1884	0.50461	0.00008	2.28	10
QC22/046c-38	0.67059	0.00010	2.00	150
QC23/046c-46	0.50239	0.00013	2.13	23
QC24/046c-87	0.50546	0.00011	2.17	16

Observations:

The measurements were performed according to work instruction IMS-JRC.G-C1.1-WIN-0057 "WEIGHING AND MASS METROLOGY IN JRC.G.2 (NUCLEAR SAFEGUARDS TEAM)".
The balance used was Mettler Toledo AT 261DR with inventory No. 1999 00337 27.

During the calibration process the atmospheric parameters of temperature, pressure and relative humidity were monitored, noted and used in the calculations.

Traceability:

The certified mass values are traceable to the SI through regular calibrations of the JRC G2's principal standards. The set of working mass standards M3 was used as reference in the mass determination.

Uncertainty:

All reported uncertainties are expanded uncertainties $U = k \bullet u_c$ where u_c is the combined standard uncertainty calculated according to the ISO/BIPM Guide to the expression of Uncertainty in

Measurement. The coverage factor is the 't-factor' based on the effective degrees of freedom and corresponds to a coverage probability of about 95%.

Additional information:

The density values for spikes and QC solutions used in the calculations for this certificate were as follows:

IRMM-046c - **1166 (5)** kg·m^{-3}. – see E3846
IRMM-083 – **1065 (5)** kg·m^{-3}. – see E3942
U CRM 116-A - **1259 (5)** kg·m^{-3}. – see E3901
Pu NBL-126 - **1225 (5)** kg·m^{-3}. – see E3895

Digitally signed by:
KALMAN TOTH (EUROPEAN COMMISSION)
Reason: I am the author of this document.
Date: 2022-02-03 11:20:36 UTC

Rožle Jakopič	Kálmán Tóth /Carmel Hennessy
Nuclear Chemistry Laboratory responsible	Analyst

Joint Research Centre	Certificate of weighing	Directorate G – Nuclear Safety and Security G.2 - Standards for Nuclear Safety, Security and Safeguards Unit

E. 3958 **Issued date:** 15/03/2022

Applicant: K. Toth **Project:** IRMM-1027w

Description: Single unit verification of IRMM-1027w part 2

Request for analysis number: 5048 **ID number:**

Date of receipt of request: 07/01/2022 **Weighing dates**: 20 Jan 2022

Results:

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

ID	Description	IRMM-046c mass /g	IRMM-046c uncertainty /g	Coverage factor	Effective degrees of freedom
34651	1027w-807/046c-44	2.28267	0.00013	2.52	6
34652	1027w-87/046c-44	2.39473	0.00013	2.52	6
34653	1027w-447/046c-44	2.00820	0.00010	2.18	15
34654	QC28/046c-44	1.85568	0.00009	2.13	21
34655	IAEA SAL 300003/046c-44	2.07216	0.00009	2.13	20

ID	Description	NBL-126 mass /g	NBL-126 uncertainty /g	Coverage factor	Effective degrees of freedom
34654	QC28/046c-44	0.50186	0.00007	2.00	400

Observations:

The measurements were performed according to work instruction IMS-JRC.G-C1.1-WIN-0057 "WEIGHING AND MASS METROLOGY IN JRC.G.2 (NUCLEAR SAFEGUARDS TEAM)".
The balance used was Mettler Toledo AT 261DR with inventory No. 1999 00337 27.

During the calibration process the atmospheric parameters of temperature, pressure and relative humidity were monitored, noted and used in the calculations.

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Traceability:

The certified mass values are traceable to the SI through regular calibrations of the JRC G2's principal standards. The set of working mass standards M3 was used as reference in the mass determination.

Uncertainty:

All reported uncertainties are expanded uncertainties $U = k \bullet u_c$ where u_c is the combined standard uncertainty calculated according to the ISO/BIPM Guide to the expression of Uncertainty in Measurement. The coverage factor is the 't-factor' based on the effective degrees of freedom and corresponds to a coverage probability of about 95%.

Additional information:

The density values for spikes and QC solutions used in the calculations for this certificate were as follows:

IRMM-046c - **1166 (5)** $kg \cdot m^{-3}$. – see E3846

Pu NBL-126 - **1225 (5)** $kg \cdot m^{-3}$. – see E3895

Rožle Jakopič

Nuclear Chemistry Laboratory responsible

Kálmán Tóth /Carmel Hennessy

Analyst

Annex 16 The internal test reports (#4871, #4964, #5032 and #5048) for the selected units of IRMM-1027w.

EUROPEAN COMMISSION

DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Directorate G – Nuclear Safety and Security
Unit JRC G.2 Standards for Nuclear Safety, Security and Safeguards

Mass spectrometry measurement report 4871

Customer	
Company	Internal
Requestor/contact	Kalman Toth

Sample Information	
Sample type(s)	U and Pu for IRMM-1027w
Date of receipt of sample(s)	About two days before measurements
Customer's sample(s) identification	33490 (This request was entered into the database before using numbers for individual samples)
Condition of sample(s)	Plutonium and uranium nitrate solutions. Radioactive material. Pu/U separation followed by Pu and U chemical purifications prior to mass spectrometry measurements by ID-TIMS (following IMS-JRC.G-C1.1-WIN-0062 V1.0), using the TE method (following IMS-JRC.G-C1.1-WIN-0059 v3.0).

Measurement Results

Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IA, P210824 Date: 25-26-08-2021 290-G3-QC				
	$n(^{238}Pu)/n(^{239}Pu)$	0.000588 (75)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.002195 (13)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.002623 (16)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	10.017 (10)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	0.000067 (19)	mol / mol	TIMS/TE
1027w-IA1	$n(^{238}Pu)/n(^{239}Pu)$	0.00003402 (28)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224074 (77)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001178 (38)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000743 (23)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000003	mol / mol	TIMS/TE
1027w-IA2	$n(^{238}Pu)/n(^{239}Pu)$	0.00003350 (56)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224083 (81)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001182 (22)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000766 (33)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000003	mol / mol	TIMS/TE
1027w-IA3	$n(^{238}Pu)/n(^{239}Pu)$	0.00003414 (65)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224099 (84)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001200 (10)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000754 (26)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000003	mol / mol	TIMS/TE
1027w-IA4	$n(^{238}Pu)/n(^{239}Pu)$	0.0000364 (13)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224079 (83)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001180 (15)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000729 (70)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000003	mol / mol	TIMS/TE

Registration No. 681-TEST
ISO/IEC 17025 for competence of testing laboratories

Template: IMS-JRC.G-C1.1-TMP-0068 v1.0 Mass spectrometry measurement report.dotx
File name: 1027w Internal Mass spectrometry measurement report RFA 4871.docx
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Page 1 of 3

Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IDMS, P210826				
Date: 27-28-08-2021				
QC20 NBL126-046c	$n(^{242}Pu)/n(^{239}Pu)$	0.20924 (22)	mol / mol	TIMS/TE
1027w-046c-1	$n(^{242}Pu)/n(^{239}Pu)$	0.094046 (98)	mol / mol	TIMS/TE
1027w-046c-2	$n(^{242}Pu)/n(^{239}Pu)$	0.09077 (10)	mol / mol	TIMS/TE
1027w-046c-3	$n(^{242}Pu)/n(^{239}Pu)$	0.091862 (98)	mol / mol	TIMS/TE
1027w-046c-4	$n(^{242}Pu)/n(^{239}Pu)$	0.092988 (95)	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
U-IA, T210802				
Date: 03-04/08/2021				
074-2 QC	$n(^{233}U)/n(^{238}U)$	0.30809 (14)	mol / mol	TIMS/TE
	$n(^{234}U)/n(^{238}U)$	0.0001341 (35)	mol / mol	TIMS/TE
	$n(^{235}U)/n(^{238}U)$	1.00033 (27)	mol / mol	TIMS/TE
	$n(^{236}U)/n(^{238}U)$	0.0000415 (87)	mol / mol	TIMS/TE
1027w-U1IA	$n(^{233}U)/n(^{238}U)$	<0.000003	mol / mol	TIMS/TE
	$n(^{234}U)/n(^{238}U)$	0.0027408 (11)	mol / mol	TIMS/TE
	$n(^{235}U)/n(^{238}U)$	0.239180 (73)	mol / mol	TIMS/TE
	$n(^{236}U)/n(^{238}U)$	0.0021996 (48)	mol / mol	TIMS/TE
1027w-U2IA	$n(^{233}U)/n(^{238}U)$	<0.000003	mol / mol	TIMS/TE
	$n(^{234}U)/n(^{238}U)$	0.0027442 (27)	mol / mol	TIMS/TE
	$n(^{235}U)/n(^{238}U)$	0.239231 (93)	mol / mol	TIMS/TE
	$n(^{236}U)/n(^{238}U)$	0.0022033 (55)	mol / mol	TIMS/TE
1027w-U3IA	$n(^{233}U)/n(^{238}U)$	<0.000003	mol / mol	TIMS/TE
	$n(^{234}U)/n(^{238}U)$	0.0027416 (13)	mol / mol	TIMS/TE
	$n(^{235}U)/n(^{238}U)$	0.23926 (11)	mol / mol	TIMS/TE
	$n(^{236}U)/n(^{238}U)$	0.0022038 (18)	mol / mol	TIMS/TE
1027w-U4IA	$n(^{233}U)/n(^{238}U)$	<0.000003	mol / mol	TIMS/TE
	$n(^{234}U)/n(^{238}U)$	0.0027419 (19)	mol / mol	TIMS/TE
	$n(^{235}U)/n(^{238}U)$	0.239220 (94)	mol / mol	TIMS/TE
	$n(^{236}U)/n(^{238}U)$	0.00220516 (68)	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
U-IDMS, T210817				
Date: 18-19/08/2021				
116A-046c-QC20	$n(^{233}U)/n(^{238}U)$	14.5519 (97)	mol / mol	TIMS/TE
	$n(^{233}U)/n(^{235}U)$	0.76937 (20)	mol / mol	TIMS/TE
1027w-046c-U1	$n(^{233}U)/n(^{238}U)$	0.045763 (35)	mol / mol	TIMS/TE
	$n(^{233}U)/n(^{235}U)$	0.191352 (59)	mol / mol	TIMS/TE
1027w-046c-U2	$n(^{233}U)/n(^{238}U)$	0.044156 (29)	mol / mol	TIMS/TE
	$n(^{233}U)/n(^{235}U)$	0.184637 (47)	mol / mol	TIMS/TE
1027w-046c-U3	$n(^{233}U)/n(^{238}U)$	0.044712 (50)	mol / mol	TIMS/TE
	$n(^{233}U)/n(^{235}U)$	0.186940 (92)	mol / mol	TIMS/TE
1027w-046c-U4	$n(^{233}U)/n(^{238}U)$	0.045262 (44)	mol / mol	TIMS/TE
	$n(^{233}U)/n(^{235}U)$	0.189218 (81)	mol / mol	TIMS/TE

Notes:		
	1	*Uncertainties are given as expanded (k=2) uncertainties according to the ISO Guide to the Expression of Uncertainty (GUM), corresponding to an approximate 95% confidence interval)*
	2	*Measurement method: "Total Evaporation" (TE) "Modified Total Evaporation" (MTE)*
	3	*For the full dataset including raw data, k-factor and QC samples, the reader is advised to consult the files referred to below.*

Backup Files and Raw Data

All results of mass spectrometric measurements for this request are stored in
U:\Nuclear Safeguards\Nuclear\PUTON DATA - SHARED\IRMM LSD 1027w
Filenames: (More files may be added)
P210824 (4871) Pu IA 1027w mother.xlsm
P210826 (4871) Pu IDMS 1027w mother 046c.xls
And
U:\Nuclear Safeguards\Nuclear\TRITON DATA – SHARED\ IRMM LSD 1027w
Filenames: (More files may be added)
T210802 (4871) U IA 1027w mother.xlsm
T210817 (4871) U IDMS 1027w mother with 046c.xlsm

Date	Signature Analyst	Name + Signature Laboratory Responsible
9/2/2022		S. Richter

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DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Directorate G – Nuclear Safety and Security
Unit JRC G.2 Standards for Nuclear Safety, Security and Safeguards

Mass spectrometry measurement report 4964

Customer	
Company	Internal
Requestor/contact	Kalman Toth

Sample Information	
Sample type(s)	U and Pu for IRMM-1027w
Date of receipt of sample(s)	About two days before measurements
Customer's sample(s) identification	34073, 34478, 34479, 34480, 34481, 34482, 34483, 34484
Condition of sample(s)	Plutonium and uranium nitrate solutions. Radioactive material. Pu/U separation followed by Pu and U chemical purifications prior to mass spectrometry measurements by ID-TIMS (following IMS-JRC.G-C1.1-WIN-0062 V1.0), using the TE and MTE methods (following IMS-JRC.G-C1.1-WIN-0059 v3.0).

Measurement Results

Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IA, P220125 Pu IA 1027w Date: 26/01/2022				
34073 no 56	$n(^{238}Pu)/n(^{239}Pu)$	0.00003249(29)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224101(83)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001152(19)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000761(33)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000002	mol / mol	TIMS/TE
34478 no 225	$n(^{238}Pu)/n(^{239}Pu)$	0.0000339(10)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224066(80)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001174(16)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000767(20)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000002	mol / mol	TIMS/TE
34479 no 483	$n(^{238}Pu)/n(^{239}Pu)$	0.0000336(12)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224075(83)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.00011621(45)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000737(40)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000002	mol / mol	TIMS/TE
34480 no 732	$n(^{238}Pu)/n(^{239}Pu)$	0.0000339(42)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224101(85)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001177(17)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000775(26)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000002	mol / mol	TIMS/TE

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Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IA, P210824 (4964) Pu IA 1027w mother				
Date: 24/08/2021				
34481 moso no 1	$n(^{238}Pu)/n(^{239}Pu)$	0.00003402(28)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224074(77)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001178(38)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000743(23)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000002	mol / mol	TIMS/TE
34482 moso no 2	$n(^{238}Pu)/n(^{239}Pu)$	0.00003350(56)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224083(81)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001182(22)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000766(33)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000002	mol / mol	TIMS/TE
34483 moso no 3	$n(^{238}Pu)/n(^{239}Pu)$	0.00003414(65)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224099(84)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001200(10)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000754(26)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000002	mol / mol	TIMS/TE
34484 moso no 4	$n(^{238}Pu)/n(^{239}Pu)$	0.0000364(13)	mol / mol	TIMS/TE
	$n(^{240}Pu)/n(^{239}Pu)$	0.0224079(83)	mol / mol	TIMS/TE
	$n(^{241}Pu)/n(^{239}Pu)$	0.0001180(15)	mol / mol	TIMS/TE
	$n(^{242}Pu)/n(^{239}Pu)$	0.0000729(70)	mol / mol	TIMS/TE
	$n(^{244}Pu)/n(^{239}Pu)$	<0.000002	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
U-IA, T220207 (4964) IRMM-1027w - vials - U IA by MTE - Rev 04				
Date: 07/02/2022				
34073 no 56	$n(^{234}U)/n(^{238}U)$	0.0027392(10)	mol / mol	TIMS/MTE
	$n(^{235}U)/n(^{238}U)$	0.239131(66)	mol / mol	TIMS/MTE
	$n(^{236}U)/n(^{238}U)$	0.00220002(42)	mol / mol	TIMS/MTE
34478 no 225	$n(^{234}U)/n(^{238}U)$	0.0027395(10)	mol / mol	TIMS/MTE
	$n(^{235}U)/n(^{238}U)$	0.239154(66)	mol / mol	TIMS/MTE
	$n(^{236}U)/n(^{238}U)$	0.00220011(41)	mol / mol	TIMS/MTE
34479 no 483	$n(^{234}U)/n(^{238}U)$	0.0027405(11)	mol / mol	TIMS/MTE
	$n(^{235}U)/n(^{238}U)$	0.239205(72)	mol / mol	TIMS/MTE
	$n(^{236}U)/n(^{238}U)$	0.00220051(45)	mol / mol	TIMS/MTE
34480 no 732	$n(^{234}U)/n(^{238}U)$	0.0027398(11)	mol / mol	TIMS/MTE
	$n(^{235}U)/n(^{238}U)$	0.239168(73)	mol / mol	TIMS/MTE
	$n(^{236}U)/n(^{238}U)$	0.00220019(48)	mol / mol	TIMS/MTE
U-IA, T220207 (4964) IRMM-1027w - vials - U IA by MTE - QC and AVERAGE - Rev 04				
Average* of all individual measurements for 34073, 34478, 34479, 34480				
Average*	$n(^{234}U)/n(^{238}U)$	0.0027398(11)	mol / mol	TIMS/MTE
Average*	$n(^{235}U)/n(^{238}U)$	0.239171(69)	mol / mol	TIMS/MTE
Average*	$n(^{236}U)/n(^{238}U)$	0.00220024(43)	mol / mol	TIMS/MTE

Sample ID	Analyte	Result[1]	Unit	Method[2]
U-IA, T220202 (4964) IRMM-1027w - mother sol - U IA by MTE - Rev 04				
Date: 02/02/2022				
34481 moso no 1	$n(^{234}U)/n(^{238}U)$	0.0027405(10)	mol / mol	TIMS/MTE
	$n(^{235}U)/n(^{238}U)$	0.239182(65)	mol / mol	TIMS/MTE
	$n(^{236}U)/n(^{238}U)$	0.00220091(44)	mol / mol	TIMS/MTE
34482 moso no 2	$n(^{234}U)/n(^{238}U)$	0.0027405(10)	mol / mol	TIMS/MTE
	$n(^{235}U)/n(^{238}U)$	0.239200(68)	mol / mol	TIMS/MTE
	$n(^{236}U)/n(^{238}U)$	0.00220077(43)	mol / mol	TIMS/MTE
34483 moso no 3	$n(^{234}U)/n(^{238}U)$	0.0027405(11)	mol / mol	TIMS/MTE
	$n(^{235}U)/n(^{238}U)$	0.239212(72)	mol / mol	TIMS/MTE
	$n(^{236}U)/n(^{238}U)$	0.00220081(46)	mol / mol	TIMS/MTE
34484 moso no 4	$n(^{234}U)/n(^{238}U)$	0.0027399(11)	mol / mol	TIMS/MTE
	$n(^{235}U)/n(^{238}U)$	0.239177(66)	mol / mol	TIMS/MTE
	$n(^{236}U)/n(^{238}U)$	0.00220050(47)	mol / mol	TIMS/MTE
U-IA, T220202 IRMM-1027w - mother sol - U IA by MTE - QC and AVERAGE - Rev 04				
Average* of all individual measurements for 34481, 34482, 34483, 34484, moso no 1,2,3,4				
Average*	$n(^{234}U)/n(^{238}U)$	0.0027403(10)	mol / mol	TIMS/MTE
Average*	$n(^{235}U)/n(^{238}U)$	0.239193(67)	mol / mol	TIMS/MTE
Average*	$n(^{236}U)/n(^{238}U)$	0.00220071(42)	mol / mol	TIMS/MTE

Notes:		
	1	*Uncertainties are given as expanded (k=2) uncertainties according to the ISO Guide to the Expression of Uncertainty (GUM), corresponding to an approximate 95% confidence interval)*
	2	*Measurement method: " Total Evaporation" (TE), "Modified Total Evaporation" (MTE)*
	3	*For the full dataset including raw data, k-factor and QC samples, the reader is advised to consult the files referred to below.*

Backup Files and Raw Data

All results of mass spectrometric measurements for this request are stored in
U:\Nuclear Safeguards\Nuclear\PUTON DATA - SHARED\IRMM LSD 1027w
Filenames: (More files may be added)
P210824 (4964) Pu IA 1027w mother.xlsm
P220125 (4964) Pu IA 1027w

And
U:\Nuclear Safeguards\Nuclear\TRITON DATA – SHARED\ IRMM LSD 1027w
Filenames: (More files may be added)
T220202 (4964) IRMM-1027w - mother sol - U IA by MTE - Rev 04.xlsm
T220202 (4964) IRMM-1027w - mother sol - U IA by MTE - QC and AVERAGE - Rev 04.xlsm
T220207 (4964) IRMM-1027w - vials - U IA by MTE - Rev 04.xlsm
T220207 (4964) IRMM-1027w - vials - U IA by MTE - QC and AVERAGE - Rev 04.xlsm

21/2/2022
27/2/2022

Date	Signature Analyst	Name + Signature Laboratory Responsible

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

Mass spectrometry measurement report 5032

Customer	
Company	Internal
Requestor/contact	Kalman Toth

Sample Information	
Sample type(s)	IDMS of U and Pu for IRMM-1027w vials <vial no> + 046c below
Date of receipt of sample(s)	About two days before measurements
Customer's sample(s) identification	34485 – 34504
Condition of sample(s)	Plutonium and uranium nitrate solutions. Radioactive material. Pu/U separation followed by Pu and U chemical purifications prior to mass spectrometry measurements by ID-TIMS (following IMS-JRC.G-C1.1-WIN-0062 V1.0), using the TE method (following IMS-JRC.G-C1.1-WIN-0059 v3.0).

Measurement Results

Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IDMS, P211026				
Date: 27-28/10/2021				
34489 QC21	$n(^{242}Pu)/n(^{239}Pu)$	0.19796(21)	mol / mol	TIMS/TE
34485 no 689+46c	$n(^{242}Pu)/n(^{239}Pu)$	0.093336 (96)	mol / mol	TIMS/TE
34486 no 22+46c	$n(^{242}Pu)/n(^{239}Pu)$	0.084388 (87)	mol / mol	TIMS/TE
34487 no 202+46c	$n(^{242}Pu)/n(^{239}Pu)$	0.09264 (10)	mol / mol	TIMS/TE
34488 no 340+46c	$n(^{242}Pu)/n(^{239}Pu)$	0.092649 (98)	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IDMS, P211027				
Date: 29-30/10/2021				
34494 QC22	$n(^{242}Pu)/n(^{239}Pu)$	0.14935 (15)	mol / mol	TIMS/TE
34490 no 292+46c	$n(^{242}Pu)/n(^{239}Pu)$	0.10781 (11)	mol / mol	TIMS/TE
34491 no 406+46c	$n(^{242}Pu)/n(^{239}Pu)$	0.090810 (94)	mol / mol	TIMS/TE
34492 no 126+46c	$n(^{242}Pu)/n(^{239}Pu)$	0.090142 (94)	mol / mol	TIMS/TE
34493 no 605+46c	$n(^{242}Pu)/n(^{239}Pu)$	0.093371 (98)	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IDMS, P220111				
Date:12-13/01/2022				
34499 QC23	$n(^{242}Pu)/n(^{239}Pu)$	0.19816 (21)	mol / mol	TIMS/TE
34495 no 247	$n(^{242}Pu)/n(^{239}Pu)$	0.094822 (99)	mol / mol	TIMS/TE
34496 no 772	$n(^{242}Pu)/n(^{239}Pu)$	0.10107 (10)	mol / mol	TIMS/TE
34497 no 443	$n(^{242}Pu)/n(^{239}Pu)$	0.093759 (99)	mol / mol	TIMS/TE
34498 no 564	$n(^{242}Pu)/n(^{239}Pu)$	0.094219 (99)	mol / mol	TIMS/TE

Registration No. 681-TEST
ISO/IEC 17025 for competence of testing laboratories

Template: IMS-JRC.G-C1.1-TMP-0068 v1.0 Mass spectrometry measurement report.dotx
File name: 1027w Internal Mass spectrometry measurement report RFA 5032.docx
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Potential sample leftovers may be destroyed after this period.

Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IDMS, P211022				
Date:25-26/10/2021				
34504 QC24	$n(^{242}Pu)/n(^{239}Pu)$	0.21312 (22)	mol / mol	TIMS/TE
34500 no 57	$n(^{242}Pu)/n(^{239}Pu)$	0.090403 (93)	mol / mol	TIMS/TE
34501 no 842	$n(^{242}Pu)/n(^{239}Pu)$	0.092983 (96)	mol / mol	TIMS/TE
34502 no 497	$n(^{242}Pu)/n(^{239}Pu)$	0.09976 (10	mol / mol	TIMS/TE
34503 no 767	$n(^{242}Pu)/n(^{239}Pu)$	0.093255 (96)	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
U-IDMS, T211020				
T211210*)				
Date: 22-23/10/2021				
15/12/2021*)				
34489 QC21	$n(^{233}U)/n(^{238}U)$	13.107 (11)	mol / mol	TIMS/TE
34489 QC21	$n(^{233}U)/n(^{235}U)$	0.69591 (22)	mol / mol	TIMS/TE
34485 no 689+46c	$n(^{233}U)/n(^{238}U)$	0.045455 (35)	mol / mol	TIMS/TE
34485 no 689+46c	$n(^{233}U)/n(^{235}U)$	0.189988 (57)	mol / mol	TIMS/TE
34486 no 22+46c	$n(^{233}U)/n(^{238}U)$	0.041119 (40)	mol / mol	TIMS/TE
34486 no 22+46c	$n(^{233}U)/n(^{235}U)$	0.171828 (72)	mol / mol	TIMS/TE
34487 no 202+46c	$n(^{233}U)/n(^{238}U)$	0.045106 (34)	mol / mol	TIMS/TE
34487 no 202+46c	$n(^{233}U)/n(^{235}U)$	0.188519 (56)	mol / mol	TIMS/TE
34488 no 340+46c	*)$n(^{233}U)/n(^{238}U)$	0.045198 (38)	mol / mol	TIMS/TE
34488 no 340+46c	*)$n(^{233}U)/n(^{235}U)$	0.188780 (85)	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
U-IDMS, T211025				
Date: 26-27/10/2021				
34494 QC22	$n(^{233}U)/n(^{238}U)$	13.027 (22)	mol / mol	TIMS/TE
34494 QC22	$n(^{233}U)/n(^{235}U)$	0.68755 (41)	mol / mol	TIMS/TE
34490 no 292+46c	$n(^{233}U)/n(^{238}U)$	0.052477 (34)	mol / mol	TIMS/TE
34490 no 292+46c	$n(^{233}U)/n(^{235}U)$	0.219388 (58)	mol / mol	TIMS/TE
34491 no 406+46c	$n(^{233}U)/n(^{238}U)$	0.044200 (34)	mol / mol	TIMS/TE
34491 no 406+46c	$n(^{233}U)/n(^{235}U)$	0.184777 (65)	mol / mol	TIMS/TE
34492 no 126+46c	$n(^{233}U)/n(^{238}U)$	0.043882 (31)	mol / mol	TIMS/TE
34492 no 126+46c	$n(^{233}U)/n(^{235}U)$	0.183436 (50)	mol / mol	TIMS/TE
34493 no 605+46c	$n(^{233}U)/n(^{238}U)$	0.045436 (29)	mol / mol	TIMS/TE
34493 no 605+46c	$n(^{233}U)/n(^{235}U)$	0.189966 (51)	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
U-IDMS, T220104				
Date: 05/01/2021				
34499 QC23	$n(^{233}U)/n(^{238}U)$	13.1018 (71)	mol / mol	TIMS/TE
34499 QC23	$n(^{233}U)/n(^{235}U)$	0.69035 (15)	mol / mol	TIMS/TE
34495 no 247	$n(^{233}U)/n(^{238}U)$	0.046166 (31)	mol / mol	TIMS/TE
34495 no 247	$n(^{233}U)/n(^{235}U)$	0.193018 (51)	mol / mol	TIMS/TE
34496 no 772	$n(^{233}U)/n(^{238}U)$	0.049205 (34)	mol / mol	TIMS/TE
34496 no 772	$n(^{233}U)/n(^{235}U)$	0.205725 (55)	mol / mol	TIMS/TE
34497 no 443	$n(^{233}U)/n(^{238}U)$	0.045631 (34)	mol / mol	TIMS/TE
34497 no 443	$n(^{233}U)/n(^{235}U)$	0.190810 (58)	mol / mol	TIMS/TE
34498 no 564	$n(^{233}U)/n(^{238}U)$	0.045895 (30)	mol / mol	TIMS/TE
34498 no 564	$n(^{233}U)/n(^{235}U)$	0.191813 (49)	mol / mol	TIMS/TE

Sample ID	Analyte	Result[1]	Unit	Method[2]
U-IDMS, T211019				
Date: 20-21/10/2021				
34504 QC24	$n(^{233}U)/n(^{238}U)$	14.105 (20)	mol / mol	TIMS/TE
34504 QC24	$n(^{233}U)/n(^{235}U)$	0.74547 (39)	mol / mol	TIMS/TE
34500 no 57	$n(^{233}U)/n(^{238}U)$	0.044028 (56)	mol / mol	TIMS/TE
34500 no 57	$n(^{233}U)/n(^{235}U)$	0.184007 (93)	mol / mol	TIMS/TE
34501 no 842	$n(^{233}U)/n(^{238}U)$	0.045276 (57)	mol / mol	TIMS/TE
34501 no 842	$n(^{233}U)/n(^{235}U)$	0.189247 (94)	mol / mol	TIMS/TE
34502 no 497	$n(^{233}U)/n(^{238}U)$	0.048575 (58)	mol / mol	TIMS/TE
34502 no 497	$n(^{233}U)/n(^{235}U)$	0.203044 (98)	mol / mol	TIMS/TE
34503 no 767	$n(^{233}U)/n(^{238}U)$	0.045403 (53)	mol / mol	TIMS/TE
34503 no 767	$n(^{233}U)/n(^{235}U)$	0.189776 (89)	mol / mol	TIMS/TE

Notes:		
	1	*Uncertainties are given as expanded (k=2) uncertainties according to the ISO Guide to the Expression of Uncertainty (GUM), corresponding to an approximate 95% confidence interval)*
	2	*Measurement method: " Total Evaporation" (TE)*
	3	*For the full dataset including raw data, k-factor and QC samples, the reader is advised to consult the files referred to below.*

Backup Files and Raw Data
All results of mass spectrometric measurements for this request are stored in U:\Nuclear Safeguards\Nuclear\PUTON DATA - SHARED\ LSD 1027w Filenames: (More files may be added) P211026 (5032) Pu IDMS 1027w set A.xlsm P211027 (5032) Pu IDMS 1027w set B.xlsm P220111 (5032) Pu IDMS 1027w set C.xlsm P211022 (5032) Pu IDMS 1027w set D.xlsm And U:\Nuclear Safeguards\Nuclear\TRITON DATA - SHARED\LSD 1027w Filenames: (More files may be added) T211020 (5032) U IDMS 1027w set A with 046c.xlsm T211025 (5032) U IDMS 1027w set B with 046c.xlsm T220104 (5032) U IDMS 1027w set C with 046c.xlsm T211019 (5032) U IDMS 1027w set D with 046c.xlsm T211210 (5032) U IDMS 1027w set A - U340 - QC21.xlsm

Date	Signature Analyst	Name + Signature Laboratory Responsible
9/2/2022		S. Richter

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Mass spectrometry measurement report 5048

Customer	
Company	Internal
Requestor/contact	Kalman Toth

Sample Information	
Sample type(s)	IDMS of U and Pu for IRMM-1027w QC<no> + 046c below
Date of receipt of sample(s)	About two days before measurements
Customer's sample(s) identification	34651 - 34655
Condition of sample(s)	Plutonium and uranium nitrate solutions. Radioactive material. Pu/U separation followed by Pu and U chemical purifications prior to mass spectrometry measurements by ID-TIMS (following IMS-JRC.G-C1.1-WIN-0062 V2.0), using the TE method (following IMS-JRC.G-C1.1-WIN-0059 v3.0).

Measurement Results

Sample ID	Analyte	Result[1]	Unit	Method[2]
Pu-IDMS, P220218 (5048) Pu IDMS 1027w set E Date: 18/02/2022				
34651 1027w #807	$n(^{242}Pu)/n(^{239}Pu)$	0.10585(14)	mol / mol	TIMS/TE
34652 1027w #87	$n(^{242}Pu)/n(^{239}Pu)$	0.11096(12)	mol / mol	TIMS/TE
34653 1027w #447	$n(^{242}Pu)/n(^{239}Pu)$	0.09310(10)	mol / mol	TIMS/TE
34654 QC28	$n(^{242}Pu)/n(^{239}Pu)$	0.18479(21)	mol / mol	TIMS/TE
34655 LSD 30	$n(^{242}Pu)/n(^{239}Pu)$	0.10217(11)	mol / mol	TIMS/TE

Notes:		
	1	*Uncertainties are given as expanded (k=2) uncertainties according to the ISO Guide to the Expression of Uncertainty (GUM), corresponding to an approximate 95% confidence interval)*
	2	*Measurement method: " Total Evaporation" (TE)*
	3	*For the full dataset including raw data, k-factor and QC samples, the reader is advised to consult the files referred to below.*

Backup Files and Raw Data

All results of mass spectrometric measurements for this request are stored in
U:\Nuclear Safeguards\Nuclear\PUTON DATA - SHARED\ LSD 1027w
Filenames: (More files may be added)
P220218 (5048) Pu IDMS 1027w set E.xlsm

Date	Signature Analyst	Name + Signature Laboratory Responsible
28/2/2022	C Hemery	Stephan Richter

Registration No. 681-TEST
ISO/IEC 17025 for competence of testing laboratories

Template: IMS-JRC.G-C1.1-TMP-0068 v1.0 Mass spectrometry measurement report.dotx
File name: 1027w Internal Mass spectrometry measurement report RFA 5048.docx
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Potential sample leftovers may be destroyed after this period.

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