THE JOINT RESEARCH CENTRE'S EXPERTISE IN NUCLEAR SAFEGUARDS SAMPLE ANALYSIS

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Abstract. The Joint Research Centre (JRC) in Karlsruhe, in partnership with the Directorate General for Energy (DG ENER), plays a critical role in ensuring the accurate analysis of nuclear materials, as mandated by the EURATOM Treaty. The Analytical Service at JRC Karlsruhe is dedicated to maintaining the highest standards of quality, accuracy, and traceability in its analytical measurements, with a focus on uranium and plutonium content and isotopic composition. Our laboratory is accredited according to ISO/IEC 17025 and has a proven track record of successful participation in numerous Inter-Laboratory Comparisons (ILCs), demonstrating our expertise and commitment to excellence in nuclear material analysis. We employ a range of analytical methods, including active and passive radiometric techniques and mass spectrometry, to ensure the lowest possible uncertainty in our results. Our laboratory has consistently achieved top performance in various ILCs, showcasing our ability to deliver high-quality results and our dedication to maintaining the highest standards of accuracy and reliability. This is a testament to our rigorous quality control processes and our commitment to staying at the forefront of nuclear material analysis. This paper provides insights into the factors that we believe have contributed to our top performance, including our rigorous quality control processes, our commitment to staff training and development, and our investment in state-of-the-art instrumentation. By sharing our experiences and best practices, we aim to contribute to the advancement of nuclear material accounting and control, safeguards verification, and non-proliferation efforts.

1. Introduction

The Joint Research Centre (JRC) in Karlsruhe, Germany, plays an essential role in ensuring accurate analysis of nuclear materials collaborating primarily with the Directorate-General Energy (ENER) which fulfils the safeguards obligations stipulated by the Article 77 of EURATOM treaty [1]. The JRC cooperates with ENER and other international organisations providing high-quality analytical measurements for nuclear safeguards. The Analytical Service of the JRC is accredited to ISO/IEC 17025 [2] and has a proven track record of successful participation in Inter-laboratory Comparisons (ILCs), demonstrating its expertise and commitment to excellence in nuclear material analysis. This paper highlights the factors that contribute to the Analytical Service top performance aiming to advance safeguards verification and non-proliferation efforts.

2. Key Drivers of Quality

The Analytical Service's commitment to quality is driven by five main factors:

(1) the Quality System and the ISO/IEC 17025 accreditation,
(2) the IAEA International Target Values (ITV) [3],
(3) the variety of analytical methods and techniques employed,
(4) the qualification under the IAEA Network of Analytical Laboratories and
(5) other inter-institutional collaborations.

2.1 Quality System and Requirements

The Analytical Service is an ISO/IEC 17025 accredited laboratory with 12 main methods under the scope. The quality system comprises numerous requirements to ensure the laboratory consistently maintains

high standards and effectively addresses customer needs. Among the critical requirements are traceability to the international system, robust quality assurance and control, validation of methods, comprehensive management of documents and data, and continuous monitoring of staff training and competencies, all of which contribute to the excellence of the laboratory.

The JRC Karlsruhe participates in relevant ILCs for nuclear laboratories to demonstrate its expertise and commitment to quality in nuclear material analysis.

Furthermore, the Analytical Service implements multiple layers of quality control (QC) to ensure the reliability and accuracy of its analytical measurements. This includes monitoring instrument performance using Certified Reference Materials (CRMs), monitoring the sample preparation process using a QC sample, and processing samples in replicates for some techniques like Thermal Ionization Mass Spectrometry (TIMS), Isotope Dilution Mass Spectrometry (ID-TIMS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The Analytical Service also applies cross method checks as QC, such as the ID-TIMS used to check the performance of the COMPUCEA (COMbined Procedure for Uranium Concentration and Enrichment Assay) [4] and the Hybrid K-edge (HKED) [5].

For the main techniques, the QC is implemented in a Laboratory Information Management System (LIMS). This in-house developed tool helps also to manage documents and data and it contributes to the overall effectiveness of the quality system.

2.2 Measurement Uncertainties and IAEA International Target Values (ITV)

The Analytical Service is committed to achieve measurement uncertainties in line with the ITV. These values are established by the IAEA and the safeguards community and they provide a benchmark for the laboratory's performance [3]. The adoption of ITV ensures the production of accurate and reliable results, which are instrumental in drawing safeguards conclusions. Furthermore, these values act as references for enhancing and developing analytical methods and techniques.

Table 1. Results of z-ITV [6] of the Analytical Service in the ILC IAEA 2022 NMRoRo.

Test item	Method	z-ITV [6]
UO_x Powder U- Assay	COMPUCEA	-0.61
UO_x Powder $^{235}U/^{238}U$	COMPUCEA	0.38
UO_x Powder U-ASSAY	HKED	-0.18
Dried nitrate (U-Pu) Pu-Assay	ID-TIMS	0.73
Dried nitrate (U-Pu) U- Assay	ID-TIMS	~ 0
UO_x Powder U- Assay	ID-TIMS	~ 0
Dried nitrate (U-Pu) $^{238}Pu/^{239}Pu$	TIMS	~ 0
Dried nitrate (U-Pu) $^{240}Pu/^{239}Pu$	TIMS	0.13
Dried nitrate (U-Pu) $^{241}Pu/^{239}Pu$	TIMS	-0.55
Dried nitrate (U-Pu) $^{242}Pu/^{239}Pu$	TIMS	0.11
UO_x Powder $^{235}U/^{238}U$	TIMS	~ 0

In certain ILCs related to nuclear safeguards, such as the IAEA Nuclear Material Round Robin (NMRoRo) [6] and the Safeguards Measurement Evaluation (SME) program of the US Department of Energy, the analytical performance of the participants is evaluated by comparing to the reference values and to the ITV when applicable. Table 1 presents the results of the Analytical Service of z-scores based on ITVs [6] for some methods and different type of samples. A score (absolute value) of <2 is indicative of satisfactory performance. A score between 2 and 3 is considered questionable, while scores >3 correspond to discordant results.

Furthermore, the JRC Karlsruhe actively contributes to the IAEA ITV network by participating in various working groups and sharing the expertise of its professionals.

2.3 Variety of Analytical Techniques and Methods

The Analytical Service employs a range of analytical methods, including destructive and non-destructive analyses (see Figure 1). The analysis method to be applied for specific sample is carefully selected to meet its unique requirements, ensuring appropriate results and optimal use of resources.

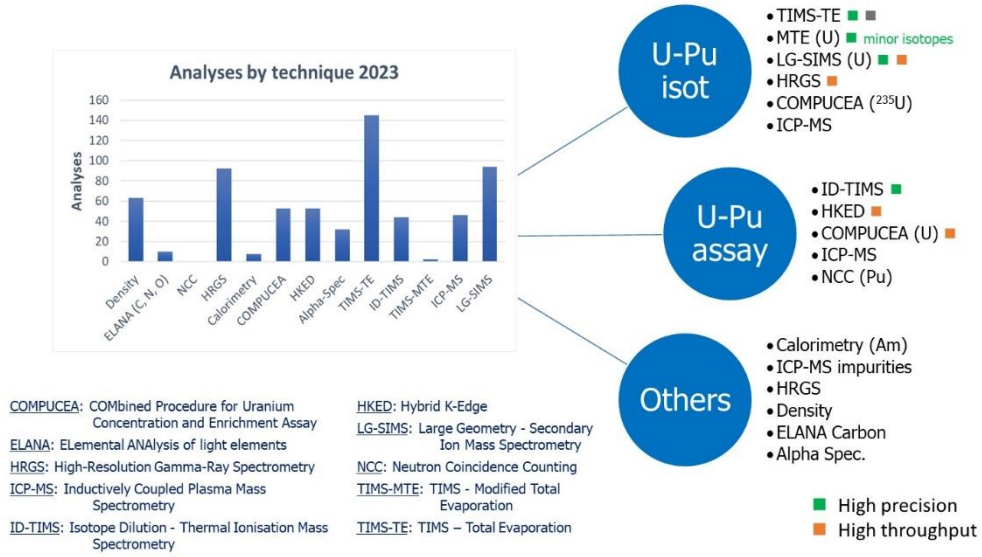

Fig. 1. Variety of methods used for analysis of samples by the Analytical Service of the JRC-Karlsruhe.

By combining the right methods, we can obtain more comprehensive results. Using the various methods to cross-check results leads to an increased level of confidence in the results of the measurements. Furthermore, the large variety of techniques facilitates the validation of new methods by comparing their results with those of already validated methods. The laboratory engages in research and development (R&D) to advance the characterisation of nuclear materials. Over the years, the JRC Karlsruhe has developed several innovative techniques, such as HKED and COMPUCEA, which have become important milestones for the safeguards community's efforts to improve nuclear material accounting and control.

2.4 Collaborations

Collaborations are essential for the Analytical Service of the JRC. The Directorate of Energy and its Euratom Safeguards unit are their primary partners. The JRC Karlsruhe is also part of the IAEA Network of Analytical Laboratories for material characterisation and environmental sample analysis, which allows for support expanding the IAEA capacity.

By working together with the various partners, including also the Commission for the Establishment of Analysis Methods (CETAMA) of the French Alternative Energies and Atomic Energy Commission (CEA) and other international safeguards organisations, the Analytical Service engages with the safeguards community to share knowledge, address challenges, find synergies and enhance the analytical capabilities of safeguards analysis. This collaborative approach plays a vital role in the success of the Analytical Service, ensuring that the field of safeguards analysis continues to advance and maintains a high standard of accuracy and efficiency.

2.5 Performance

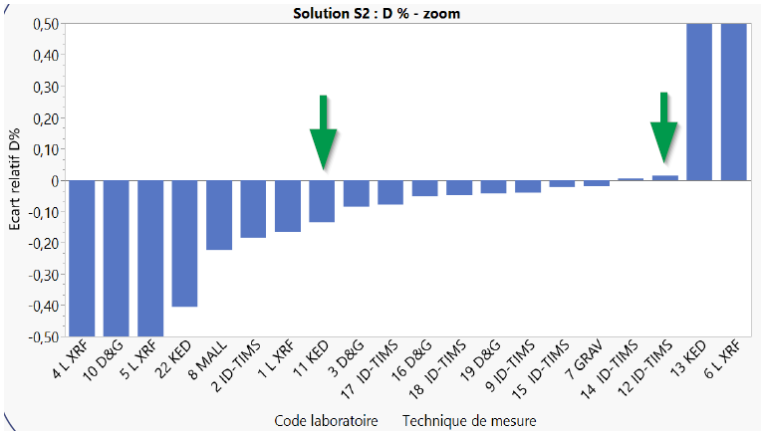

Fig. 2. CEA/CETAMA EQRAIN 2023 U content results by H_KED and ID-TIMS.
Source: NT des/ISEC/DMRC/CETAMA DL-2024-08 [7]

The Analytical Service demonstrates its commitment to excellence by consistently achieving top performance in ILCs (see Figures 2-4). The exercises, such as EQRAIN from CETAMA, the NMRoRo and ESPA organised by the IAEA and the SME from the New Brunswick Laboratory (NBL) program office, are essential for evaluating the laboratory's performance and quality assurance. By participating in ILCs, the Analytical Service not only receives valuable feedback for improvement, but also demonstrates its dedication to staying at the forefront of nuclear material analysis. This consistent excellence is a direct result of the laboratory's rigorous quality control processes and dedication. The ability of the JRC Karlsruhe to maintain the highest standards of accuracy and reliability is a testament to the expertise of its team, further solidifying its position as a trusted partner in the safeguards community.

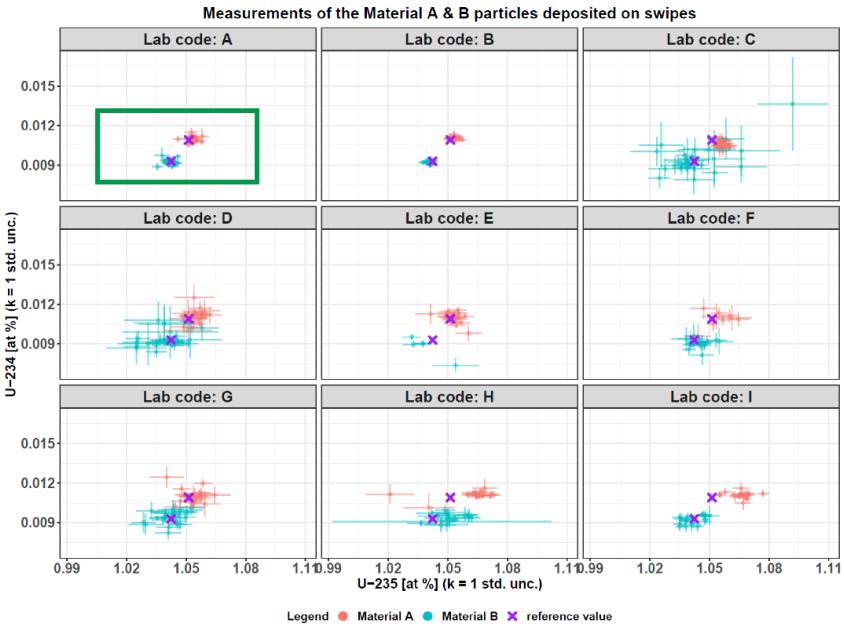

Fig. 3. IAEA ESPA results by LG-SIMS.
Source: IAEA SG-RP-20101 [8]

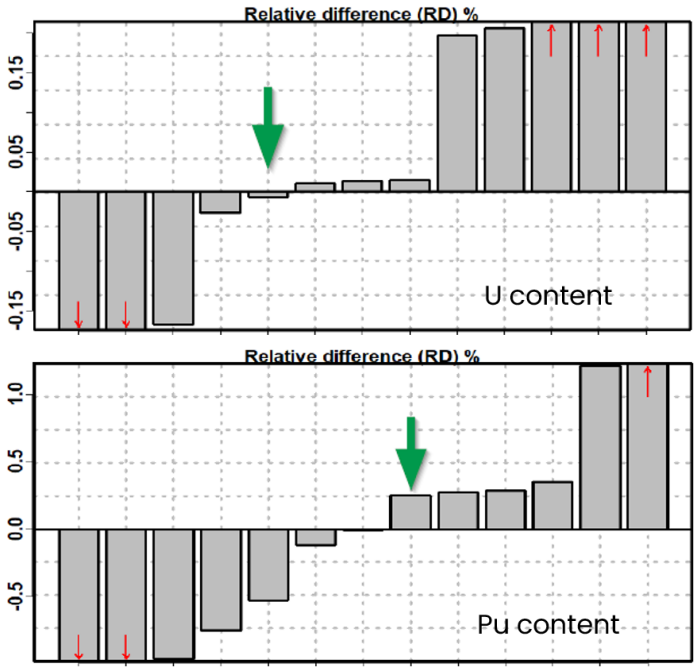

Fig. 4. IAEA NMRoRo 2022 results by ID-TIMS for uranium and plutonium content assay. Source: IAEA SG-RP-20267 [6]

3. Conclusion

The JRC's Analytical Service is committed to delivering quality and timely results for nuclear safeguards verification supporting organisations of the European Union and beyond. By prioritizing quality and maintaining state-of-the-art methods and procedures under its quality system, the JRC Karlsruhe is able to be one of the top performers in the field and a highly reliable partner for the safeguards authorities.

The internationally recognized ISO/IEC 17025 accreditation provides credibility, efficiency, and recognition in the global market by establishing a framework for continuous improvement, adherence to requirements and consistent measurement results.

References

[1] Consolidated version of the treaty establishing the European Atomic Energy Community, Official Journal of the European Union, 2012/C 327/01, (2012).
[2] International Organization for Standardization. ISO/IEC 17025:2017, https://www.iso.org/standard/66912.html, (2018).
[3] International Atomic Energy Agency, IAEA-STR-368, https://nucleus.iaea.org/sites/connect/ITVpublic/Pages/default.aspx, (2022).
[4] N. Erdmann, ESARDA Bull. **43**. 30-39, (2009).
[5] H. Ottmar, H. Eberle, Kernforschungszentrum Karlsruhe report Kfk 4590, (1991).
[6] IAEA, SG-RP-20267, Report Evaluation of the IAEA 2022 NMRoRo exercise, 2023
[7] NT des/ISEC/DMRC/CETAMA DL-2024-08 EQRAIN U 17 interlaboratory comparison
[8] IAEA, SG-RP-20101, Report Evaluation of the 2021 IAEA ESPA blind interlaboratory comparison exercise, 2023