

Joint Research Centre's Support to Nuclear Compliance Assurance

Sevini, F.¹, Aregbe, Y.², Sequeira, V.¹, Simola, K.³, Matuzas, V.³, Zuleger, E.⁴, Buda, R.⁴, Versino, C.¹, Renda, G.¹, Abbas, K.¹, Favalli, A.¹, Nonneman, S.¹, Tanarro Colodron, J.⁵, Peinador Veira, M.⁵

¹JRC.G Ispra, ²JRC.G Geel, ³JRC.G Petten, ⁴JRC.G Karlsruhe, ⁵JRC.02

Abstract

The Treaty establishing the European Atomic Energy Community (EURATOM Treaty) constitutes EURATOM's primary law. Since its establishment, several binding secondary legislations (directives, regulations and decisions) were adopted in the fields of nuclear safeguards, nuclear safety and radiation protection. The European Commission is responsible for the enforcement of Chapter VII of the EURATOM Treaty, and the related regulation on the application of EURATOM safeguards and any safeguarding obligations under an agreement with a third state or an international organisation.

The European Commission Joint Research Centre (JRC) has its roots in Article 8 of the Euratom Treaty and seeks to strengthen its role at the service of the European Union vision and to work in enhanced partnerships inside and outside the European Commission. Through the recent revitalisation of its Strategy 2030, the JRC also reaffirms the role of nuclear activities in its mandate. From 2023 onwards, the work programme of the JRC will be organised in portfolios as the main building blocks in a cross-disciplinary approach. The portfolio of activities "Support to Nuclear Compliance Assurance" of the JRC's 2023-2024 Work Programme supports the implementation of the EURATOM legal framework, with particular focus on the Nuclear Safeguards and Non-proliferation regimes. It includes also the support to the harmonised implementation of the EU dual-use trade control legislation, aiming at preventing the illicit export of sensitive technologies, stemming from the political agreements within the international export control regimes and the legal requirements of the nuclear Non Proliferation Treaty.

The portfolio's activities include: R&D on nuclear safeguards techniques; developing tools for inspectors; operating the on-site laboratory; providing central analytical support and in field assistance; environmental monitoring; provision of reference materials; data analysis, organising proficiency testing; reviewing related to Member States' implementation of EURATOM directives; supporting dual-use trade control implementation by data and technical analyses; capacity building; nuclear safeguards education and training.

Introduction

In the spirit of trust, collaboration and transparency, JRC signals its increased openness to engaging with partners to put science at the service of the European Union vision. Through the recent revitalisation of the Strategy 2030, the JRC also reaffirms the role of nuclear activities in its mandate¹. The work programme of the JRC has been organised in portfolios as the main building blocks of a cross-disciplinary approach. The successful cooperation of JRC, EURATOM safeguards, the IAEA and distinguished international experts for the release of the International Target Values (ITV) revision and Network site² and the ESARDA “reconciliation paper”³ inspired in 2022 the creation of the Nuclear Compliance Assurance (NCA) portfolio, reaching out to stakeholders and joining forces within the JRC. The NCA portfolio encompasses three lines of work instrumental to the fulfilment of the obligations deriving from the EURATOM treaty, the Nuclear Non-Proliferation Treaty and the EU dual-use Regulations.

EURATOM nuclear safeguards are a Commission competence (DG ENER), obligatory to all MS with nuclear materials, under the EURATOM Treaty Chapter VII. Their main purpose is to assure that nuclear materials are only used for their declared (civil) use and are not diverted for non-peaceful applications.

Internationally, the mandate for nuclear safeguards is with the International Atomic Energy Agency under the nuclear Non-Proliferation Treaty, to which all EU Member States adhere. The IAEA also seeks to have assurance of absence of clandestine activities w.r.t nuclear weapon production. The EC support programme to the IAEA provides technology and expertise for the effective implementation of safeguards verification measures.

The following eight projects develop the support to the implementation of EURATOM nuclear safeguards, as well as the support to IAEA’s international safeguards, strategic trade control and non-proliferation:

- *Safeguards MeasurementS (SAMS)*
- *Metrological Tools For Nuclear Safeguards (METRO)*
- *Non Destructive Assay Techniques For Safeguards (NDA4SFG)*
- *Containment And Surveillance Of Nuclear Materials (CSNM)*
- *Safeguards Training And Capacity Building (STCB)*
- *Methodologies And Knowledge Management For Nuclear Non Proliferation And Safeguards (MEDAKNOW)*
- *Data Analytics For Nuclear Safeguards And Non-Proliferation Applications (NUCLICS)*
- *Strategic Dual-Use Trade Control For Non-Proliferation And Global Issues*

The key requirements of the EURATOM treaty address also the protection of EU citizens from radiations. The EURATOM legislative framework includes three key legislative acts related to nuclear safety, safe management and shipment of spent fuel and radioactive waste;. These legal requirements and associated implementation support are addressed by the two following projects:

- *Safety, HumAn Resources and Policy support for nuclear ENergy (SHARPEN)*
- *Business Continuity For Radiological Emergencies*

The portfolio includes also a project addressing *Knowledge Management And Dissemination* dedicated to increase the reach and impact of the knowledge assets developed by the portfolio and to carry out foresight exercises reinforcing the anticipatory capacity of the experts involved in the portfolio so they can anticipate future risks and opportunities for assuring nuclear compliance.

The R&D scope of the portfolio's projects is functional to support the complex set of implementation measures and verification techniques summarised in Fig. 1. Details of the single projects are provided in the following paragraphs.

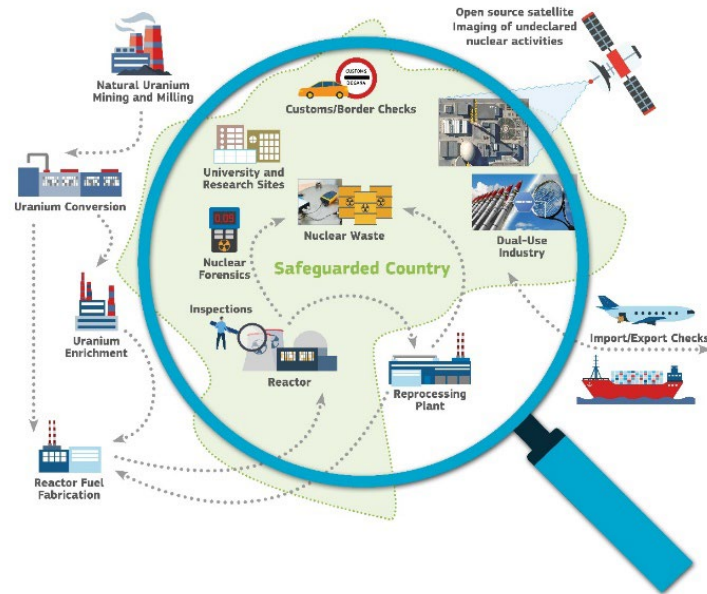


Fig. 1 – Nuclear fuel cycle and associated safeguards implementation, verification activities, safety, waste and strategic trade control measures

Safeguards Measurements (SAMS)

The SAMS project focuses on the techniques and methods implemented to provide the operational support to safeguards authorities, foremost EURATOM and the International Atomic Energy Agency (IAEA), in nuclear and fissile material analysis. Noteworthy are:

- the running of the on-site laboratory (LSS) in the reprocessing plant in Orano La Hague,
- the in-field measurement campaigns in the European nuclear fuel fabrication plants, and
- the analytical support in JRC-Karlsruhe.

A wide range of analytical methods is deployed with capacities stretching from:

- the detection of clandestine nuclear activities by finding individual particles with the large geometry secondary ionisation mass spectrometry (LG-SIMS)
- the determination of the uranium and plutonium mass fraction in small samples with isotope dilution thermal ionisation mass spectrometry (IDMS)
- the measurement of high concentration spent fuel dissolver liquid in the hot cells in the LSS using the Karlsruhe developed Hybrid K-edge densitometry/XRF (HKED) method.

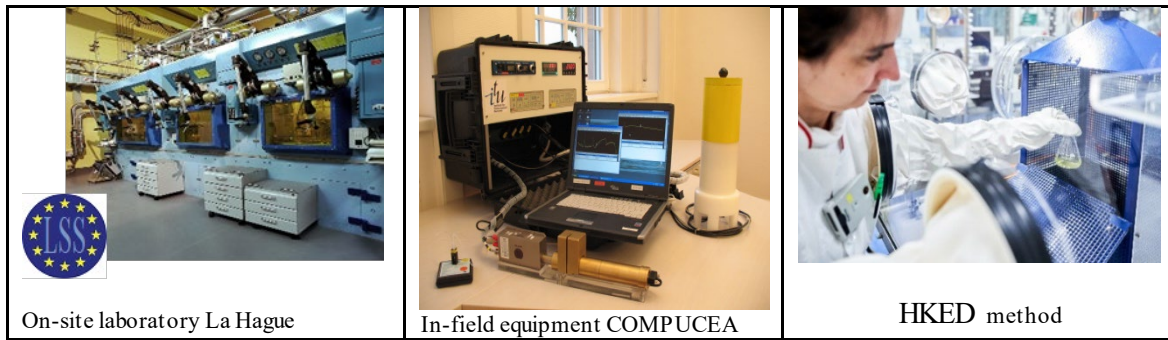


Fig. 2 - Operational Support to Safeguards Authorities

To ensure the future fitness of these methods, R&D and refurbishments are essential and, thus, a significant part of the project. The goals are to develop, improve and maintain analytical techniques and methodologies to ensure efficient and effective nuclear safeguards employing state-of-the-art equipment.

The experiences and knowledge acquired and the developments are also beneficial for other projects in the JRC, such as nuclear forensics and decommissioning.

Metrological Tools For Nuclear Safeguards (METRO)

EURATOM safeguards include verification of the nuclear material accountancy of nuclear facility operators. Article 8 of the EURATOM Treaty mandates the JRC to ensure that a uniform nuclear terminology and a standard system of measurements are established. This includes the development and provision of certified nuclear reference materials and reference measurements, the coordination of inter-laboratory comparisons and the provision of international document standards in the field of expertise. By providing these measurement quality control tools, the JRC is directly contributing to the effectiveness of nuclear safeguards systems, supporting the authorities in meeting the challenge to achieve their required high level of detection probability. Verification and accountancy measurements of nuclear materials will remain crucial for the foreseeable future.

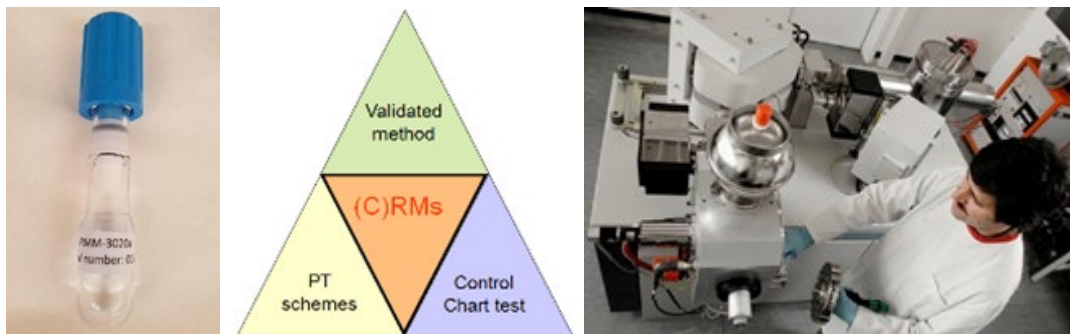


Fig. 3 - Uranium isotope reference material for calibration of instruments, validation of methods and for quality control purposes

Methodologies And Knowledge Management For Nuclear Non-Proliferation And Safeguards (MEDAKNOW)

Nuclear Technologies are constantly evolving, and so are their potential deployment contexts. Future nuclear energy systems will exhibit evolutionary and revolutionary design features and implementations aimed at improving their safety, economics, sustainability and nuclear proliferation resistance and security. The new avenues that this evolution open have the potential to see the deployment of nuclear energy systems in substantially different contexts than the ones

that were typically interested by the exploitation of nuclear power. Some examples are the non-electrical applications of nuclear energy, the development of closed nuclear fuel cycles insisting on thorium and plutonium, the deployment of Small Modular Reactors and Microreactors with different than usual siting options (very remote areas, highly densely populated areas, industrial complexes, floating, transportable). Independently of their intended use, all nuclear energy systems deployed in non-nuclear-weapons-states will have to comply with the non-proliferation regime provisions and their related implementation. The MEDAKNOW project aims at investigating what are the impacts of current and future nuclear energy systems on the effective and efficient compliance with the existing nuclear non-proliferation regimes via the creation of proliferation resistance and nuclear safeguards evaluation methodologies, adopting a holistic, systems thinking approach. By doing so, it investigates both the ways in which a nuclear energy system design might be improved to achieve a higher nuclear proliferation resistance and the ways in which the nuclear safeguards approaches and techniques may evolve for coping with new systems designs and nuclear energy deployment contexts. Aspects as proliferation resistance by design, safeguards by design, Safety, Security and Safeguards (3S) interactions, State Level Approaches analyses and evaluations are researched both in-house and within the major related international initiatives. The project actively supports the IAEA on the improvement the effectiveness and efficiency of State-level Safeguards Approaches and on the use of open source analysis to inform and support the non-proliferation regime for the verification of the correctness and completeness of safeguards declarations. Given its mandate under the EURATOM Treaty and the broad non-proliferation and nuclear safeguard competences available, the JRC is in a unique position to provide effective support in this context.

Strategic Dual-Use Trade Control For Non-Proliferation And Global Issues (STRIKE)

Building on activities started in 2010, the STRIKE project supports the EU strategic trade control policy definition and implementation by analytical, technical, monitoring and capacity building activities.

Strategic trade controls developed as response to proliferation events and geopolitical tensions since the Cold War, followed by the entry into force of various international treaties and agreements aiming at curbing or preventing weapons proliferation. This has been tackled by the progressive definition of a strategic trade control framework based on international legally binding instruments, like the Non-Proliferation Treaty (NPT) and the Chemical Weapons Convention (CWC), as well as guidelines defined by the international export control regimes, like the Nuclear Suppliers Group (NSG), which are included in the EU strategic trade control regulation together with their control lists. Although not directly related to nuclear safeguards' implementation, nuclear export controls stem from the Non Proliferation Treaty's art. III.2's export control requirements, as well as the CSA Model Additional Protocol's reporting obligations (art. 2.a.IX and Annex II, based on the NSG Trigger List)⁴. For these reasons, the JRC founded and still contributes to the ESARDA Export Control Working Group.

The latest revision of the EU Regulation 2021/821 entered into force in September 2021 introducing new challenges for its harmonized implementation in EU-27 member states. Strategic trade control increasingly addresses also emerging technologies showing a growing relevance to non-proliferation and EU strategic autonomy. Important geo-economic aspects of the EU strategic trade control framework are also sanction measures against countries violating international laws and treaties, as well as cooperation with third countries open to trade control partnership with the EU.

Data Analytics For Nuclear Safeguards And Non-Proliferation Applications (NUCLICS)

In times of 'big data', the growing availability of data is not matched by a corresponding ability to make sense of data, support sense-making, inform decisions and policies in a timely fashion.

NUCLICS provides expertise and makes use of state-of-the-art data analytics methodologies and off-the-shelves tools for business intelligence focusing on data sources in the domains of nuclear safeguards and non-proliferation. The goal is to support the work of nuclear inspectors, analysts and policy officers by making available data sets, processing techniques, and complete analytical products that will reflect new expressed needs and respond to new questions. For example, ENER is planning to build a new centralized safeguards data repository at headquarters. It is expected that such repository will open new possibilities to perform statistical analysis on acquired measurement data with novel cross-sections of data (e.g. for outlier's detection, process control) in order to support effectively inspectors' decisions and monitor the performance of safeguards equipment. As a second example, the IAEA Department of Safeguards is making use of open source data on international trade for non-proliferation assessments since several years with JRC support. NUCCLICS will continue to support the IAEA by identifying emerging trade data sources and in the competent use of visualisation techniques already in use in the context of IAEA analytical tasks. As a third example, in relation to the EC policies for export controls of strategic items, the project will continue to support TRADE trade analyses in support to the design, implementation and monitoring of Regulations that apply to the EU and influence outreach programmes for Third Countries. Further, the project will maintain flagship trade related analytical products, such as the Strategic Trade Atlas, developed for the World Customs Organization and adopted by the UNSCR 1540 Group of Experts.

Safeguards Training And Capacity Building (STCB)

The project aims at coordinating the different training courses on nuclear safeguards and security, which are delivered in Ispra, Karlsruhe and Geel. Beside the provision of training courses on NDA techniques, tank calibration, containment and surveillance techniques, laser verification techniques, complementary access for nuclear safeguards to various organizations, in particular to DG ENER, IAEA and JAEA, this project aims at also building capacities on new techniques, approaches and methodologies for safeguards through dedicated R&D that would be undertaken. Moreover, the coordination of these training activities and capacity building are of utmost relevance to avoid fragmentation and duplication of efforts among the different JRC Sites. This coordination aims also at harmonization and standardization within JRC through the different provided training courses. This concerns the content of the course, the duration, the preparation, the evaluation, the resources, etc. Trainings can be delivered both by JRC and could be supported by external experts (pool of experts, subcontracting) depending of the context, in-house expertise and legal mandate (e.g. EURATOM inspectors only JRC). STCB project includes the yearly organization of the international course on nuclear safeguards and non-proliferation (ESARDA Course). STCB also includes coordination or support to DGs or EC services such as FPI to implement EU policy priorities by providing technical/scientific expertise such as for the implementation EU CBRN Centres of Excellence initiative.

Non-Destructive Assay (NDA) Techniques For Safeguards (NDA4SFG)

The NDA work performed in this project is directly linked to the support of EURATOM inspectors of DG ENER; it extends also to supporting IAEA inspectors verifying that the International Non-proliferation Treaty is correctly implemented and respected in the EU. The science and technology developed and used in this project is mainly related to particle detection and related analytical methods and finds its applications also in the security and waste management domains. Therefore, the project includes all three groups of activities, namely nuclear safeguards, security, and waste management. Extensive use will be made of modelling techniques for the design of detector systems, data reduction, as well as development and testing of novel methods. New measurement methods will be developed in cooperation with international partners. The NDA activities span all

aspects of the nuclear fuel cycle, from verification of fresh nuclear fuel to the spent nuclear fuel. Signatures of special nuclear materials are based on particles (e.g., neutrons of different energy), X-rays and gamma-rays, decay heat, muons, and their combinations. As far as performance evaluation and standardization are concerned, the ITRAP laboratory in the NDA group will be extensively used, opening its doors to external work and allowing commercial equipment vendors to test their equipment from the point of view of its performance and in cooperation with the national laboratories similar to ITRAP.

Containment And Surveillance Of Nuclear Materials (CSNM)

The CSNM project supports DG ENER and IAEA with R&D on innovative containment and surveillance technologies for nuclear materials, which are becoming increasingly important for an efficient and effective implementation of nuclear safeguards. It aims to advance the use of remote monitoring systems and reduce the need for on-site inspector presence for routine tasks. The project also contributes to shaping the safeguards approaches for new types of nuclear facilities, e.g. underground repositories or particularly sensitive facilities like gas centrifuge enrichment or spent fuel reprocessing facilities. The technologies developed under the project are also applicable in related fields, such as nuclear decommissioning and security.



Fig. 4 – Advanced Safeguards Measurement, Monitoring and Modelling Laboratory (AS3ML)

Safety, HumAn Resources and Policy support for nuclear ENergy (SHARPEN)

Nuclear energy is part of the energy mix of almost half of EU Member States. The Energy Union Strategy stresses that Member States need to apply the highest standards of safety, security, waste management and non-proliferation as well as to diversify nuclear fuel supplies. Energy mix strategy envisages that, by 2050, more than 80% of electricity will be from renewable sources, which - together with a nuclear power share of approximately 15% - will be the backbone of a European low carbon power system. Safety, Human Resources and Policy Support for Nuclear Energy are considered in the current context, which integrates the pandemic experience, the evolving geopolitical developments, energy crisis and the Member States and regulatory interests in following technology and organisational developments of the nuclear systems. Nuclear reactor

safety and safe management of radioactive waste remain of utmost importance for the European Atomic Energy Community. The EURATOM legislative framework includes three related key legislative acts, namely the Nuclear Safety Directive (Directive 2009/71/EURATOM, as amended by Directive 2014/87/EURATOM), the Directive on the responsible and safe management of spent fuel and radioactive waste (Directive 2011/70/EURATOM), and the Directive on the supervision and control of shipments of radioactive waste and spent fuel (Directive 2006/117/EURATOM). DG ENER is the responsible entity for overseeing the implementation of these Directives by the Member States, including their transposition into national law and evaluation of Member States' periodic reporting on their implementation, including supports the Human Resources relevant Policies. In order to effectively discharge its responsibilities in this role, DG ENER requires the support of nuclear reactor safety and radioactive waste management expertise.

Knowledge Management And Dissemination (KNOWMADIS)

This project supports the technical assistance to European Commission obligations under EURATOM and to EU flagship initiatives through information gathering and distillation, sense making, framing and anticipation. In particular, by signalling emerging trends implying relevant risks and opportunities that may require policy action at European level and therefore to be considered as part of the work programme of the Joint Research Centre.

The main strategic knowledge management actions to be carried out within the scope of the project are: optimising research and dissemination tools, connecting knowledge with communication through workshops, and mapping existing collaboration and envisaged strategic partnerships.

Beyond them, the project has a particular focus on foresight with actions dedicated to:

- Bridge the gap between the EURATOM and non-EURATOM activities of the Joint Research Centre exploring synergies and supporting new initiatives of collaboration. Bring frequently together a EURATOM focused Horizon Scanning network to make sense out of the ongoing trends and identified signals of change.
- Keep updated an observatory of nuclear emerging technologies.
- Organise webinars with invited experts to tackle relevant EURATOM related trending topics.
- Prepare Science for Policy Briefs informing European Commission policymakers about potential future risks and opportunities.

Business Continuity For Radiological Emergencies (BC4RadEmerg)

After the Chernobyl disaster in 1986, the need was formulated to join forces at the EU level to exchange radiological data between the Member States and interested partners. This is important during a crisis, but absolute data values should be compared with normal values related to the local natural background. During an emergency, crisis communication is essential for coordinated crisis response and efficient management. Radiological disasters are impacting large areas and even other counties from where the need is felt to make use of advice at the European level. In 1987 this discussion between Member States and the European Commission culminated in a Council Decision 87/600 (ECURIE Arrangements) and the Recommendation 2000/473/ EURATOM. Member States are obliged to provide local radiological data to the Commission and the Commission will provide advice. In case of an emergency, the Member States are obliged to inform the European Commission instantaneously and the latter will start up a crisis team that will interact with all Member States in relation to the emergency. The EURDEP information system is the tool that allows the Member States to submit local radiological datasets every 30 minutes, during normal times, and during emergencies. The system processes the data and makes them available to the Member States for downloading. The ECURIE information system is the European Union's

platform for early notification and exchange of information in case of a radiological emergency. Both systems are business critical and need to be very reliable under normal and emergency conditions.

Conclusions

The European Commission adopted a Complementary Climate Delegated Act to accelerate decarbonisation, including specific nuclear energy activities in the list of economic activities covered by the EU taxonomy. The European and international nuclear safeguards authorities must contribute to meeting the new challenges of satisfying increasing energy demands, tackling climate change, as well as re-invigorate nuclear arms control and non-proliferation, contributing to peace and prosperity.

The projects constituting the NCA portfolio evolve from decades of successful research activities, developed in support to the policy stakeholders (ENER, IAEA, as well as Commission's TRADE and FPI) and in support to Member States. They have been subject to continuous assessments. The experts panel of the ex-post evaluation of the JRC's activities under Horizon 2020 and the EURATOM Research and Training programme strongly recommended that the "*JRC should maintain a strong research programme for nuclear safeguards and non-proliferation*". Further the panel stated that "*the role of the JRC in supporting and developing nuclear safeguards and non-proliferation is essential for any current and future nuclear fuel cycle facility, in Europe and globally. For these goals, the JRC should ensure the availability of both human resources and the infrastructure for the experimental work and modelling activities*"⁵.

The 20% EURATOM budget cut spread over 2021-2027 in line with the new JRC Strategy for its nuclear activities' implementation plan is the biggest challenge for this new portfolio and its deliverables. The success of this portfolio is therefore closely linked to the strategic efforts of preserving the skills and competences in nuclear safeguards R&D, which can only be achieved through close cooperation with stakeholders benefitting from the ESARDA platform. One goal of joining forces in the new JRC Nuclear Compliance Assurance portfolio is to foster ESARDA's relevance for the coming years⁶.

Acknowledgements

The authors would like to thank Razvan Buda, Karin Casteleyn, Elena Stringa, Xavier Arnes Novau, Christos Charatsis, Andrea De Luca, Stephan Richter and many others for their contributions.

¹ Revitalising the JRC Strategy, Publications Office of the European Union, 2023 2030; doi:10.2760/726726

² International Target Values (ITV) Network site;
<https://nucleus.iaea.org/sites/connect/ITVpublic/SitePages/Home.aspx>, last accessed April 2023

Milestones in Safeguards for the year 2022 in technologies, methodologies and tools;
<https://www.iaea.org/interactive/timeline/110566/5743><https://www.iaea.org/interactive/timeline/110566/5743>,
last accessed April 2023

³ O Alique, Y. Aregbe,...C. Norman,.. et al. Statistical error model-based and GUM-based analysis of measurement uncertainties in nuclear safeguards – a reconciliation, ESARDA BULLETIN, No. 64, Issue 1, June 2022

⁴ Filippo Sevini, Enzo Caponetti, Christos Charatsis, Xavier Arnes-Novau, *Supporting the Additional Protocol declarations on nuclear research and technology by the JRC TIM DU platform*, ESARDA BULLETIN, No 62, June 2021
<https://publications.jrc.ec.europa.eu/repository/handle/JRC125416>

⁵ Ex post evaluation of the JRC activities under Horizon 2020 and Euratom (2014-2020), Luxembourg: Publications Office of the European Union, 2022; doi:10.2760/25731

⁶ ESARDA World Café Report 2019; https://esarda.jrc.ec.europa.eu/publications/world-cafe-report-2019_en, last accessed April 2023