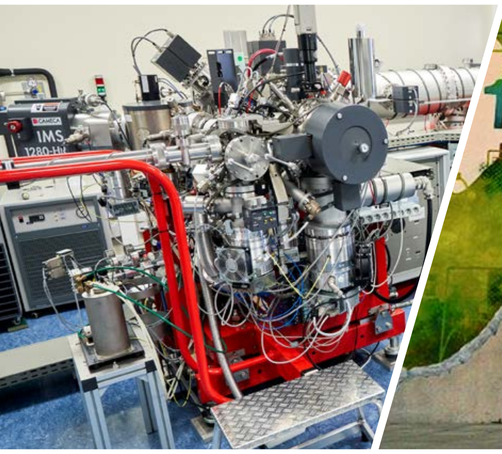
European Commission

THE JOINT RESEARCH CENTRE SUPPORTING NUCLEAR SAFEGUARDS

BUILDING ON 60+ YEARS OF EXPERIENCE



Joint Research Centre

A visit to the on-site safeguards laboratory operated by the JRC at the reprocessing plant in La Hague, France.

FOREWORD

Nuclear safeguards are a fundamental component of global nuclear non-proliferation. Euratom safeguards are control activities designed to ensure that civil nuclear materials are not diverted from their intended peaceful use in the EU. In close collaboration with the Directorate General for Energy, the JRC supports the European Commission in fulfilling the obligations set out by the Euratom Treaty in the areas of nuclear safeguards, research, education, training, and radiation protection.

The JRC has been contributing to the implementation of the Euratom safeguards programme by providing technical analyses, tools, technologies, and expertise in many technical areas related to the effective implementation of safeguards. Additionally, it supports the European Commission's compliance with the safeguards obligations assumed under international agreements. For over 40 years, the European Commission has been providing scientific and technical support on safeguards to the International Atomic Energy Agency (IAEA) through its Support Programme utilising its nuclear infrastructures and expertise for the global interest. Our scientists are well integrated into the international scientific community, publishing in high-ranking peer-reviewed scientific journals, contributing regularly to international safeguards conferences, and collaborating with researchers in the European Safeguards Research & Development Association and worldwide.

The new JRC Strategy for its Nuclear Activities emphasizes safeguards as one of its key research priorities. Safeguards systems must keep up with digital technology developments and remain fit for purpose. New foresight tools will be increasingly used to present a science-based vision of emerging issues in safeguards. Research and innovation play a crucial role in the field of nuclear safeguards. The JRC is mandated to provide the scientific know-how to ensure effective safeguards of current and emerging nuclear facilities. As a pioneer in developing and applying safeguards instrumentation and technologies worldwide, the JRC continues to invest in maintaining the necessary skills, competencies, and state-of-the-art infrastructures. The JRC contributes to developing safeguards-by-design concepts for, e.g., small modular reactors as well as solutions for safeguarding decommissioning activities.

As a policy support directorate, we are intensifying our efforts to develop tools for efficient knowledge management and incorporate this element as part of our evidence-based science and research activities to address the challenge of an ageing workforce in the nuclear (safeguards) field. The JRC will continue to respond to the European Union's key challenges in terms of digitalisation, decarbonisation, prosperity, and peace while considering budget constraints within the Euratom Research and Training Programme. This publication highlights the main concepts, technologies, equipment, and tools used in safeguards verification activities conducted to support Euratom safeguards and the IAEA's non-proliferation regime.

Bernard Magenhann
Deputy Director-General of the Joint Research Centre

A visit to the Ispra Nuclear Safeguards, Security and Standardisation Laboratory.

FOREWORD

In 2023, the JRC proudly celebrates 60 years of support for nuclear safeguards with our European and international partners.

Nuclear safeguards research and development have been integral to the core activities of the JRC since its inception. Our mission includes implementing the JRC Euratom Research and Training Programme and the JRC Strategy for its Nuclear Activities. We support the European Commission's work in safeguards with various activities, including technical services, training, and the development of efficient safeguards and proliferation resistance systems. Our contribution is central to the European Commission's Support Programme to the International Atomic Energy Agency. Furthermore, the JRC holds the secretariat of the European Safeguards R&D Association (ESARDA).

The JRC's assets are its skilled staff, demonstrated record of R&D support in nuclear safety, security and safeguards, and its unique facilities. Within these facilities, we provide a wide range of analytical measurements crucial for verifying compliance with nuclear safeguards agreements and detecting clandestine nuclear activities. We develop and apply accurate methods and standards for non-destructive, destructive, and trace analysis, including particle analyses. These measurements are subject to a rigorous quality system supported by metrological quality control tools and standardised test methods. The JRC offers nuclear reference materials to safeguards authorities, EU Member States and partner countries.

Euratom has assigned the JRC with the design, implementation, and operation of the on-site laboratories at the reprocessing plants in La Hague, France, and Sellafield, UK. The laboratory in La Hague continues to deliver analytical results to Euratom inspectors directly on-site, allowing timely verification of spent fuel reprocessing without the need for nuclear material transport. Safeguards heavily relies on the containment and surveillance of nuclear materials. The JRC supports inspector verification with seals, 3D surveillance, and laser systems for spent fuel storage facilities and the world's first final repository.

In 2013, we established a dedicated training centre (EUSECTRA) to address the continuous training needs of nuclear security and safeguards, preserving and strengthening their knowledge and improving field inspections.
The JRC develops new tools and techniques for trade. The recently published Strategic Trade Atlas can be readily used for training purposes and to prepare coordinated customs operations related to nuclear activities.

Our many achievements testify to our multi-faceted expertise, which contributes to the safety of the European citizen. With sustained support, we can continue to meet the challenges of global nuclear safeguards. I hope that this brochure will give the reader a taste of our activities and ambitions.

Ulla Engelmann
Director of JRC Directorate G (Nuclear Safety and Security)

EU Science Hub
https://joint-research-centre.ec.europa.eu

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01 INTRODUCTION

WHY SAFEGUARDS R&D AND SUPPORT?

The European Atomic Energy Community (Euratom Treaty), established in 1957, serves as the foundation for the European Union's involvement in nuclear safety and security. It regulates civilian nuclear activities, implements safeguards to monitor the use of nuclear materials, controls the supply of fissile materials within EU member states, and funds international research on nuclear fission and fusion (chapter 7). Furthermore, the EU Commission Regulation (Euratom) No 302/2005 establishes the legal framework for implementing nuclear safeguards within the EU.

Nuclear safeguards are measures taken to ensure compliance with international obligations (Treaty on the Non-Proliferation of Nuclear Weapons) that prohibit the use of nuclear materials for nuclear weapons. The European Commission conducts nuclear inspections throughout the European Union. Safeguarding the entire nuclear fuel cycle within the EU, from uranium conversion to fuel production, power reactors, spent fuel reprocessing, and final disposal, is a complex task.

The Joint Research Centre (JRC) supports the European Commission in implementing the Euratom Treaty. The JRC's nuclear activities for 2020-2025 are defined by the Research and Training Programme of the European Atomic Energy Community, established in the Council Regulation (Euratom) 2021/765. While primarily focusing on nuclear safeguards and non-proliferation (EC responsibilities), the JRC also leverages technical synergies with aspects of nuclear security such as combating illicit trafficking and nuclear forensics (national responsibilities). This results in the following areas of focus:

- development of improved methodologies, detection/verification methods, and technologies to support community safeguards and strengthen international safeguards
- development and application of enhanced methods and technologies to prevent, detect, and respond to nuclear and radiological incidents, including qualification of detection technology and development of nuclear forensics methods and techniques to combat illicit trafficking in synergy with the global CBRN (Chemical, Biological, Radiological, and Nuclear) framework
- support for the implementation of the Treaty on the Non-Proliferation of Nuclear Weapons and European Union strategies through analysis studies and monitoring of the technical evolution of export control regimes to assist relevant Commission and other services.

In 2022, the JRC adopted a Strategy for its Nuclear Activities to make the nuclear activities more effective and to optimise resources for research and policy support in nuclear safety, security and safeguards. The strategy sets out new priorities on improved accuracy of analytical methods to support nuclear safeguards inspections, enhanced use of portable technologies in sensitive nuclear fuel cycle facilities, continued development and production of Certified Reference Materials (CRM) and more digitalisation of advanced technologies in nuclear safeguards.

OUR MISSION

The JRC's mission is to provide independent, evidence-based knowledge and science, supporting EU policies to positively impact society based on the approaches of anticipation, integration and impact. The JRC provides scientific, technical and operational support to the European Commission Directorate General for Energy (DG ENER) responsible for nuclear safeguards inspections in the EU. The JRC supports DG ENER in the fields of nuclear-material measurements, measurement methods and standards, containment and surveillance, process monitoring, and development of in-field tools for Euratom inspectors.

The JRC possesses and maintains unique nuclear facilities to cover development, experimental and analytical needs in nuclear safety, safeguards and security.
A wide spectrum of training courses on safeguards techniques and on the development of reference materials is delivered to nuclear inspectors and other international partners at the JRC sites in Karlsruhe, Ispra and Geel.

The JRC operates the Euratom safeguards analytical on-site laboratory at the Orano reprocessing plant in La Hague (France), whose throughput represents a substantial share of the world's reprocessed spent nuclear fuel. JRC experts carry out around 600 spent fuel analyses annually, thus allowing Euratom inspectors to check the fissile material chain and inventory of the nuclear facilities.

EUROPEAN COMMISSION SUPPORT PROGRAMME TO THE IAEA (EC SP)

The European Commission provides scientific and technical support to the International Atomic Agency (IAEA) through a series of activities such as nuclear material measurement, process monitoring, containment and surveillance and advanced safeguards approaches. Most of them are clustered under the European Commission Cooperative Support Programme (EC SP) established in 1981. The EC SP was involved in altogether 147 tasks with currently 36 active tasks. The JRC operates the EC SP in close cooperation with the EC Directorate General for Energy. Approximately 30% of the EC SP tasks are executed jointly or in close collaboration with other Members States Support Programmes.

The program covers the following areas of research and development activity:

- Measurement techniques for destructive and non-destructive analysis
- Containment, surveillance and sealing/identification techniques;
- Development of reference materials and reference particles tailored to the Euratom and the IAEA safeguards needs
- Information technologies for non-proliferation studies – e.g., open source data collection, trade analysis
- Process monitoring techniques
- Concepts, approaches and methodologies
- Training programmes for nuclear inspectors.

Moreover, the support to the IAEA includes nuclear material and environmental sample analyses in the frame of the IAEA Network of Analytical Laboratories (NWAL).

Nuclear strategy objectives on safeguards

Nuclear energy systems need to comply with nuclear safety, security and non-proliferation provisions. This applies to the responsible use of current nuclear technology, to decommissioning of nuclear facilities and to novel advanced reactors currently under development. There is the unique opportunity to ensure compliance to these regimes through a proper design, integrating from the start the mandatory features. The JRC is actively contributing to the major international initiatives working on Proliferation Resistance and Safeguards by Design: the Generation IV International Forum (GIF) - Proliferation Resistance and Physical Protection.

The strategy lays out a set of key foresight elements for safeguards accountancy verification to be foreseen for new and innovative reactor and nuclear applications systems as well as for the enhancing the digitalisation of nuclear sector.

LABORATORIES AND FACILITIES FOR NUCLEAR SAFEGUARDS

Ispra (Italy)

- Nuclear Safeguards, Security and Standardisation Laboratory
- Design Information Verification Laboratory
- European Nuclear Security Training Centre (EUSECTRA)

Karlsruhe (Germany)

- Large Geometry-Secondary Ion Mass Spectrometry
- (LG-SIMS)
- Nuclear and Trace Analysis Facility
- Nuclear Forensics Laboratories
- European Nuclear Security Training Centre (EUSECTRA)

Geel (Belgium)

- Nuclear Reference Material and Measurement Facility
- La Hague (France):
- On-site laboratory at the Orano, reprocessing plant

La Hague (France)

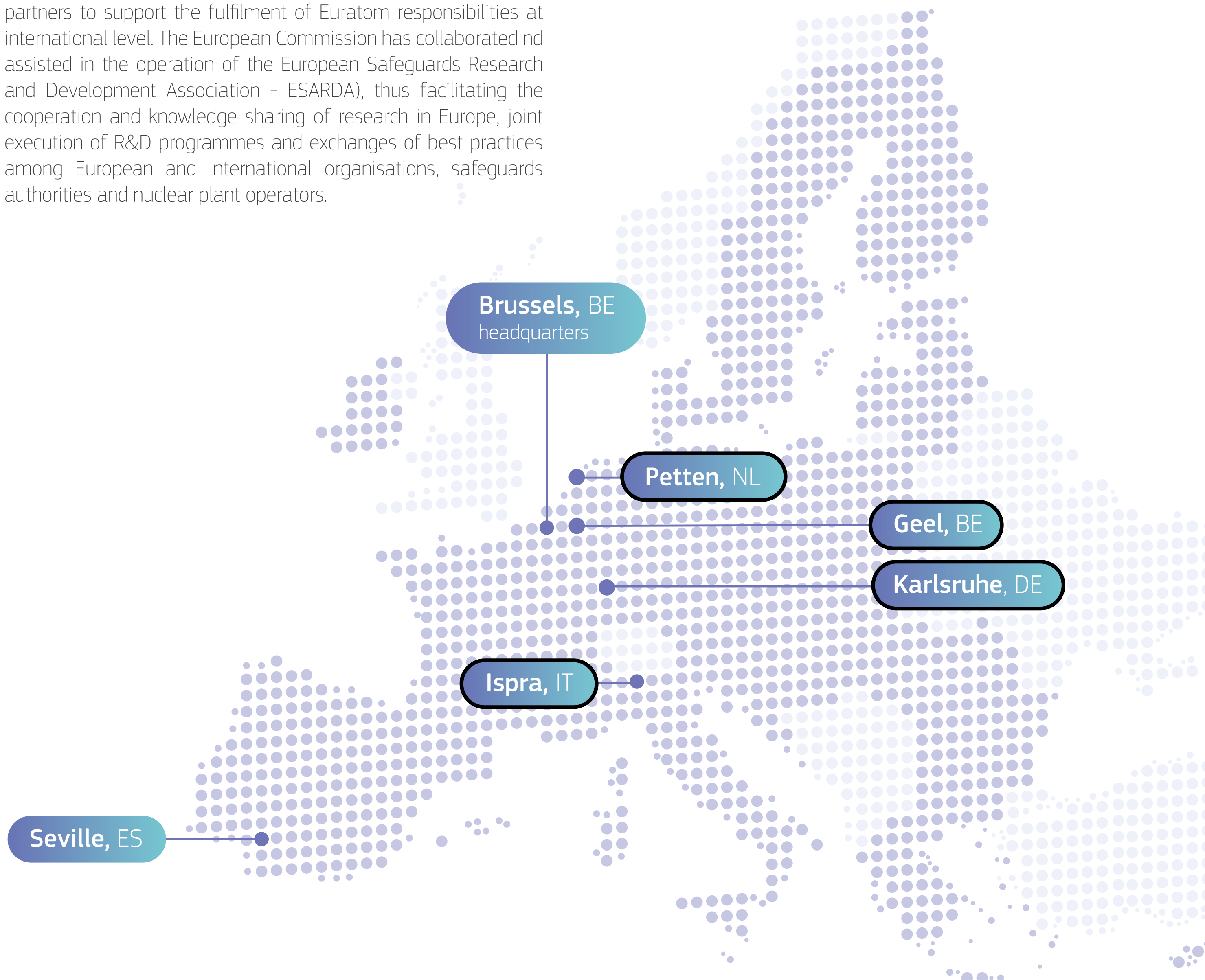
- On-site laboratory at the Orano, reprocessing plant

EUROPEAN AND INTERNATIONAL COOPERATION

The JRC has established a strong cooperation with international partners to support the fulfilment of Euratom responsibilities at international level. The European Commission has collaborated nd assisted in the operation of the European Safeguards Research and Development Association - ESARDA), thus facilitating the cooperation and knowledge sharing of research in Europe, joint execution of R&D programmes and exchanges of best practices among European and international organisations, safeguards authorities and nuclear plant operators.

Furthermore, several R&D cooperation agreements have been established between Euratom and national authorities with responsibilities on safeguards (Argentina, Australia, Canada, Japan, South Africa, United Kingdom, United States) or regional associations (Brazilian–Argentine Agency for Accounting and Control of Nuclear Materials, Asia-Pacific Safeguards Network). In specific cases, our safeguards expertise and R&D results are part of European Union outreach activities worldwide.

Beyond traditional safeguards capacity building, African Commission On Nuclear Energy (AFCONE) has been working closely with JRC within the framework of ESARDA. Through cooperation under the Instrument for Nuclear Safety Cooperation (INSC), the JRC contributes to the improvement of nuclear safety levels and efficient and effective nuclear safeguards in non-EU countries.



The JRC sites – the ones hosting nuclear safeguards facilities are marked with a black border around the name.

TESTIMONIALS FROM SOME OF OUR PARTNERS

UNITED STATES

The U.S. Department of Energy/National Nuclear Security Administration continues to highly value our collaboration with the European Commission's Joint Research Centre (JRC) on IAEA safeguards. Together, we have completed over 60 technical projects--pioneering state-of-the-art technical solutions to address growing challenges in IAEA safeguards implementation globally. The depth of our ongoing cooperation is a testament to the strength of our shared commitment to addressing future challenges and the vitality of this important and lasting partnership.

Corey Hinderstein, *Deputy Administrator for Defense Nuclear Non-Proliferation, National Nuclear Security Administration (NNSA), US Department of Energy*

UKRAINE

The cooperation between the Joint Research Center and the Institute for Nuclear Research of the National Academy of Sciences of Ukraine is framed by TACIS projects. This was achieved by providing us with advanced equipment and the participation of nuclear safeguards training courses and by conducting joint research of the seized material by our staff. We appreciate their timely support and highly specialized scientific expertise and tools to help upgrade our verification capabilities.

Volodymyr Tryshyn, *Deputy Director of the Institute for Nuclear Research of the National Academy of Sciences of Ukraine*

ABACC

The areas of interest with the European Commission's Joint Research Centre incompasse a broad spectrum, among them the performance of technical projects in containment and surveillance, characterization and supply of nuclear material standards, exchange of experience on safeguards operations (including the analysis of safeguards regional systems role), safeguards criteria and approaches, unattended systems for verification of nuclear material, and the exchange of experience on common use of equipment with the IAEA, nuclear material accountancy and inspectors training.

Marco Marzo, *Secretary of Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC)*

ESARDA

The JRC conducts research and development activities that are highly relevant to the ESARDA community. JRC contributes to ESARDA's efforts in training and capacity building of professionals in the field of nuclear safeguards and non-proliferation. ESARDA's management, secretariat and research publications are mostly signed by highly skilled experts of the JRC. Their knowledge and research findings help advance the state-of-the-art in nuclear safeguards technology and practices all over the world. The JRC holds a pivotal role in strengthening the capabilities of the safeguards community and has played a leading role in developing novel safeguards technologies that meet the needs of new type of nuclear facilities.

Mari Lahti, *President of European Safeguards Research and Development Association (ESARDA)*

EURATOM (DG ENER)

The Directorate "Euratom Safeguards" at the Directorate General for Energy is implementing the safeguards obligations of the European Commission under the Euratom Treaty. The Joint Research Centre of the Commission has been an integrated part of this work right from the beginning. Today, its forward-looking approach and the scientific competence of its staff are indispensable components of Euratom Safeguards. Among the numerous success stories of the close collaboration we find the provision of analytical services, the operation of the on-site-laboratory in La Hague, the preparation of high-quality Certified Reference Materials, the provision of trainings to Euratom Safeguards inspectors, and the development, calibration and deployment of measurement techniques, as well as containment and surveillance tools. I am sure many others will be added in the future, addressing the European Commission's objective to maintain the highest possible level of nuclear safety, security and safeguards in the EU.

Stephan Lechner, *Director of Euratom Safeguards, European Commission, Directorate General for Energy (DG ENER)*

IAEA

The Joint Research Centre (JRC) is a vital partner for the IAEA's Department of Safeguards. Through the European Commission Support Programme (EC SP), the JRC has improved the tools and techniques that the IAEA relies upon for safeguards implementation across the world. Particularly invaluable contributions from the recent past have included advanced training courses for inspectors and efforts to enhance the sensitivity, reliability and timeliness of the analysis of samples taken in the field through development and optimization of spike and certified reference materials, verification technologies like the Combined Procedure for Uranium Concentration and Enrichment Assay (COMPUCEA). JRC experts have played essential roles for over 40 years in advancing the state of the art in the technical domains of relevance to safeguards.

Massimo Aparo, *Head of the Department of Safeguards, International Atomic Energy Agency (IAEA)*

AFCONE

AFCONE has been collaborating with the JRC for a number of years, and the most significant strides in the recent operationalization of AFCONE are linked to our partnership. AFCONE and The Radiation and Nuclear Safety Authority of Finland (STUK) launched a safeguards capacity building programme for African States that was facilitated by the JRC. This collaboration between JRC and AFCONE led to the first ever safeguards capacity building programme managed and organised by an African organisation.

Enobot Agboraw, *Executive Secretary, African Commission on Nuclear Energy (AFCONE)*

JAPAN

I'd like to congratulate the 60th anniversary of nuclear activities in Karlsruhe. Japan Atomic Energy Agency and the Joint Research Centre haven working together for more 30 years on joint research and development projects and capacity building activities in the field of nuclear non-proliferation and nuclear security. As a cooperation partner in this field, we wish the Joint Research Centre continued development and success in the future.

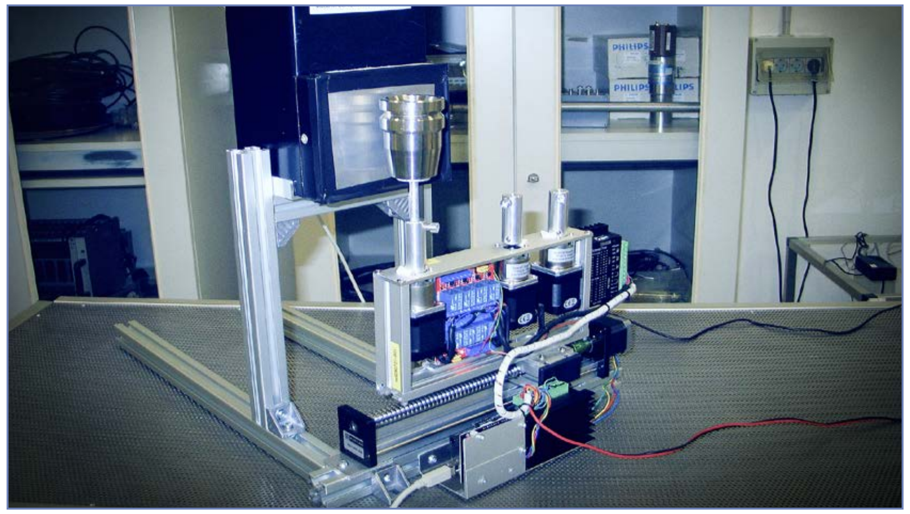
Masato Hori Ph.D., *Director, Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN), Japan Atomic Energy Agency (JAEA)*

LABORATORIES AND FACILITIES FOR NUCLEAR SAFEGUARDS

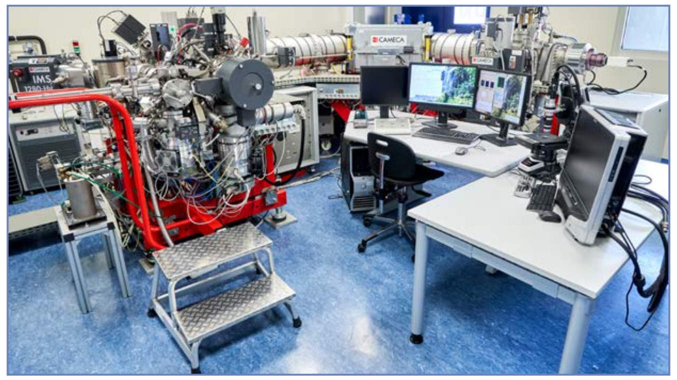
Overview

The JRC operates several laboratories with unique facilities, dedicated to nuclear safeguards and related research, which help providing independent scientific and technical expertise in the field of nuclear safeguards. They play an important role in supporting the European Union's commitment to nuclear non-proliferation and safeguards. Their focus is to develop and provide advanced analytical techniques, tools, and standards for verifying the peaceful use of nuclear materials and detecting potential nuclear weapons-related activities.

01 NUCLEAR SAFEGUARDS, SECURITY AND STANDARDISATION LABORATORY



02 LARGE GEOMETRY-SECONDARY ION MASS SPECTROMETRY (LG-SIMS)

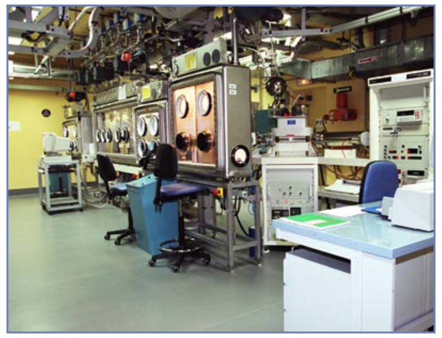


03 NUCLEAR REFERENCE MATERIAL AND MEASUREMENT FACILITY

04 ADVANCED SAFEGUARDS LABORATORY (AS3ML)

05 NUCLEAR AND TRACE ANALYSIS FACILITY

06 ON-SITE LABORATORY AT THE ORANO, REPROCESSING PLANT



07 NUCLEAR FORENSICS LABORATORIES

08 EUROPEAN NUCLEAR SECURITY TRAINING CENTRE (EUSECTRA).

Future Objectives

- Ensuring sustainability and continuity of knowledge is essential for maintaining and enhancing the capabilities of nuclear safeguards laboratories
- Continue providing support to EU member states in fulfilling their obligations under international nuclear treaties
- Conducting research to stay ahead of emerging nuclear technologies and threats
- Training and capacity building to improve international expertise in safeguards.

KEYWORDS

- EURATOM Treaty
- EU Regulations
- Non-Proliferation
- Laboratory
- Nuclear Material Analysis
- Certified Reference Materials
- Non-Destructive Analysis
- International Target Values
- Nuclear Material Accountancy
- On-site Laboratory
- Containment and Surveillance
- Seals
- Lasers

MAIN PARTNERS:
DG ENER, IAEA, EEAS

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- Industry
- Research
- Academia

The global scope of non-proliferation

02 CONCEPTS AND APPROACHES FOR SAFEGUARDS AND NON-PROLIFERATION

The first clear goal of nuclear safeguards is to prevent the spread of nuclear weapons. The role of nuclear inspectorates is to verify the declarations made by operators or states regarding nuclear materials used for civilian purposes. The JRC collaborates with Euratom and IAEA inspectorates to support their verification activities through the development and improvement of metrological tools and analytical services, the testing of systems for the containment and surveillance of nuclear materials, and the research and design of novel non-destructive assay techniques.

To gain a broader view of proliferation risk in space and time, the JRC goes beyond verification techniques. In a global dimension, the trade of dual-use and sensitive technologies poses a known proliferation risk. The JRC provides technical assistance to the EC services in updating and implementing strategic trade controls and monitoring exports.

Looking into the future, anticipation is crucial. Scientific and technical experts agree that to achieve a sound and rapid deployment, novel nuclear reactors and nuclear facilities must follow a safeguard-by-design approach and demonstrate their proliferation resistance. The JRC takes part in major international fora, actively shaping the future safeguards and non-proliferation framework.

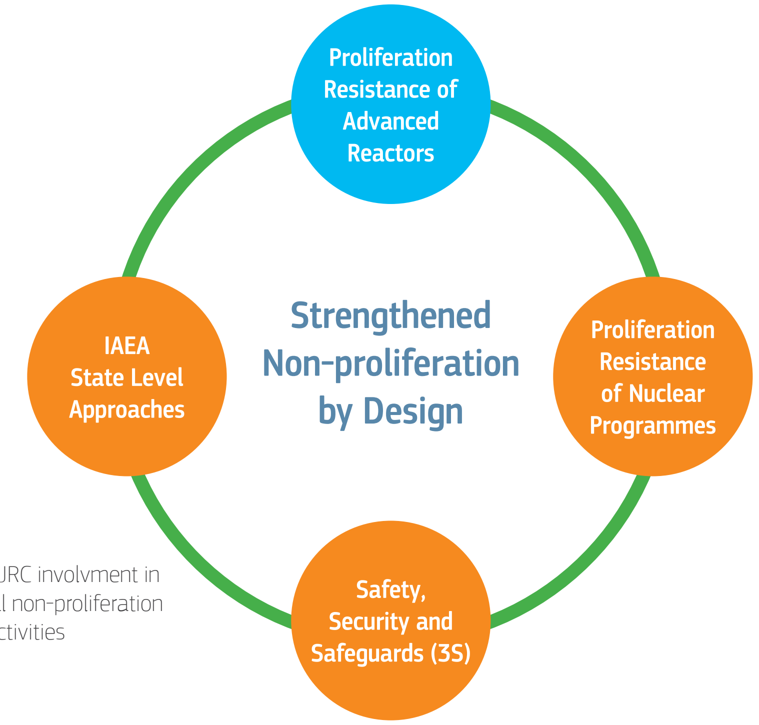
Like in many other sectors, data and data-driven technologies will play an increasingly significant role in nuclear safeguards. JRC research aims to leverage these technologies to not only enhance the effectiveness and efficiency of safeguards technologies but also to extract new knowledge from the data collected during verifications.

PROLIFERATION RESISTANCE AND SAFEGUARDS-BY-DESIGN

Overview

Nuclear energy systems need to comply with nuclear safety, security and non-proliferation provisions. Novel advanced reactors currently under development have the unique opportunity to ensure compliance to these regimes through a proper design, integrating from the start the mandatory features.

The JRC is actively contributing to the major international initiatives working on Proliferation Resistance and Safeguards by Design: the Generation IV International Forum (GIF) - Proliferation Resistance and Physical Protection (PR&PP) Working Group and the initiatives led by the International Atomic Energy Agency.



Generation IV International Forum (GIF)
International Atomic Energy Agency (IAEA)

Fig. 1: The JRC involvment in international non-proliferation by design activities

Fig. 2: Cover of a GEN IV white paper.

01 PROLIFERATION RESISTANCE - GIF

The JRC contributed to the analysis of six Generation IV (GEN IV) advanced reactor technologies (link to 6 GIF white papers), providing reactors' designers with insights on the implication of design choices for the proliferation resistance of the reactor.

02 PROLIFERATION RESISTANCE – IAEA

The JRC collaborates with the IAEA for the update of the proliferation resistance manual of the International Project on Innovative Nuclear reactors (INPRO), whose aim is to assess the sustainability of novel nuclear fuel cycles. Proliferation resistance is an essential aspect for sustainability.

03 INTERFACES BETWEEN SAFETY, SECURITY AND SAFEGUARDS.

Within IAEA activities on the interfaces and synergies between Safety, Security and Safeguards(3S) on the applicability of safety standards to non-water-cooled reactors and SMRs, the JRC contributes to the 3S interaction.

04 3S BY DESIGN

3S by design for novel advanced reactors and small modular reactors (SMRs). The JRC is participating to IAEA activities with contributions on 3S interfaces and challenges for Novel Advanced Reactors and Small Modular Reactors

Base load electricity generation, load following electrical generation within a range of 50% to 100% power district heating and process heat up to 287^{o}C.

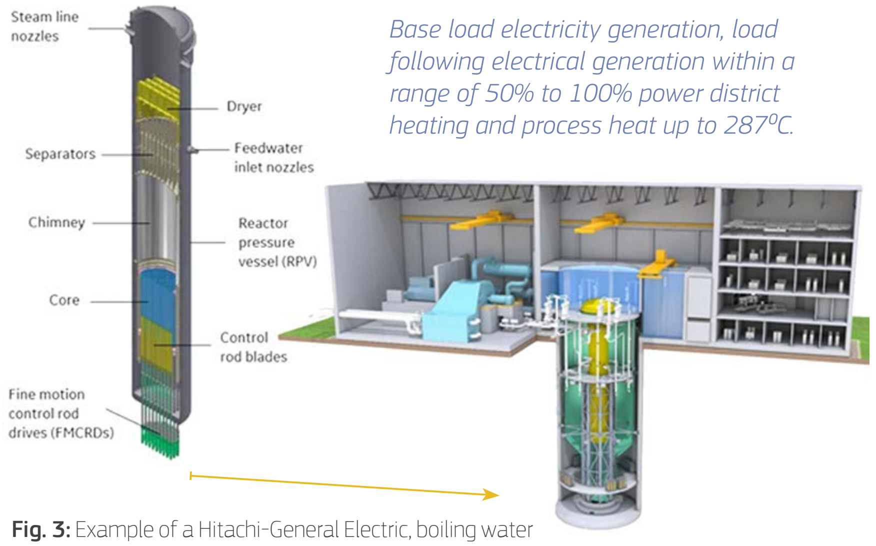


Fig. 3: Example of a Hitachi-General Electric, boiling water reactorX-300, boiling water reactor, land based SMR.

Off-load reactor, high temperature steam: industrial process heat, H2 production, high efficiency electricity generation, including cogeneration.

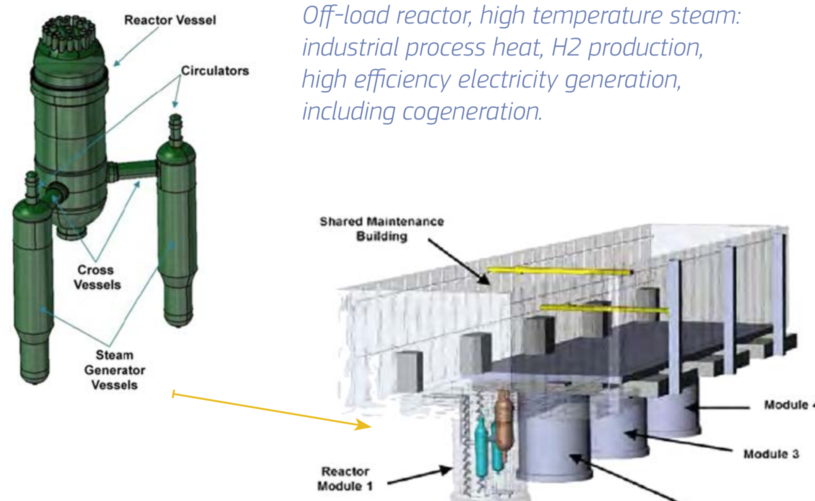


Fig. 4: Example of a Framatome Inc SC-HTGR, Prismatic blocks SMR.

Future Objectives

- Investigate on 3S interfaces and Proliferation Resistance on GEN-IV and novel advanced reactors, in particular SMRs, focusing on implications of siting options
- Progress on 3S by Design for Small Modular Reactors
- Contribute to IAEA INPRO Proliferation Resistance Manual and provide assistance on selected applications
- Contribute to IAEA Guidelines on 3S aspects affecting nuclear Safety for IAEA Design Safety Review missions
- Support IIAEA R&D on State Level Safeguards Approaches

KEYWORDS

Generation IV International Forum (GIF)

GIF Proliferation Resistance & Physical Protection Working Group (PRPPWG)

GIF White Papers PRPPWG

IAEA INPRO

INPRO Proliferation Resistance manual

3S by Design

MAIN PARTNERS:
DG ENER, IAEA

OTHER INTERESTED DG'S:
DG GROW, DG TRADE

MAIN STAKEHOLDERS:
- Designers of Novel Advanced Reactors and Small Modular Reactors
- Nuclear Industry
- Nuclear Associations
- Safeguards Inspectorates

DATA ANALYTICS FOR SAFEGUARDS AND NON-PROLIFERATION

Overview

In times of 'big data', the growing availability of data is not matched by a corresponding ability to make sense of data. The JRC is providing to Euratom safeguards and to the IAEA expertise and state-of-the art data analytics to support the need of inspectors, analysts and policy makers to make sense of data. The JRC makes available data sets, processing techniques, and complete analytical products

01 DATA ANALYTICS TOOLS FOR EURATOM SAFEGUARDS

Euratom safeguards inspectors perform conformity checks on accountancy and physical verification of nuclear material. On-site inspection makes use of independent measurement systems.

The JRC is supporting Euratom through the development of analytical tools combining robust statistics and time series analysis to detect anomalies in the on-site measurements (e.g. structural breaks or outliers). This analysis is a different analytical angle compared to classical inspector tasks and it is expected to help improving the assessment results.

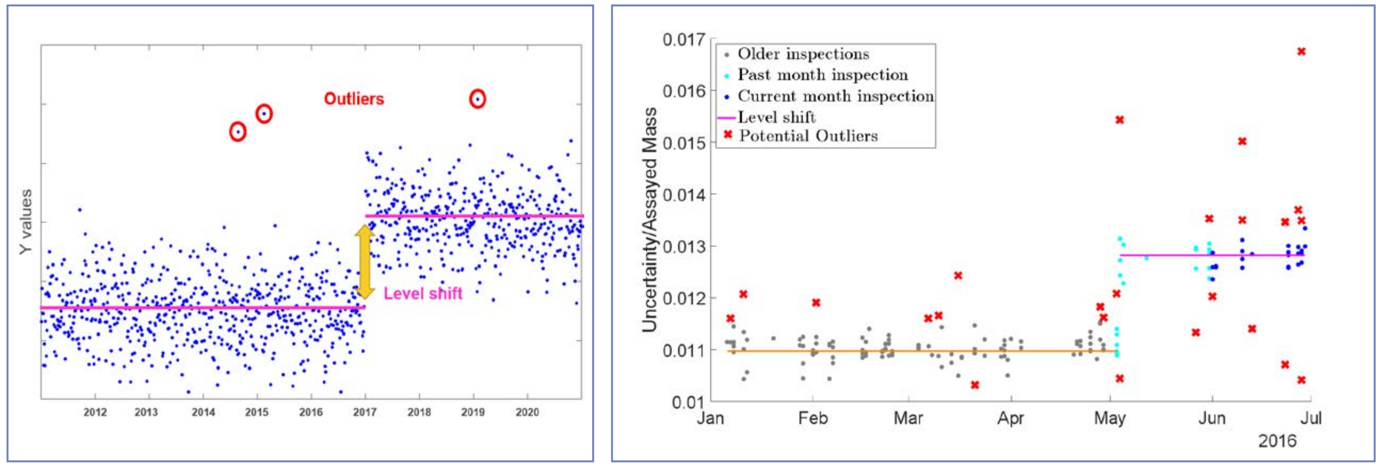


Fig. 1: Left: Detection of level shift and outliers. Right: Application of the detection method for plutonium oxide cans.

02 SUPPORT TO IAEA STATE EVALUATION

The JRC is supporting IAEA trade analysts since several years. Co-designed trade data sources and analytical tools are important inputs to the IAEA's State Evaluation Groups. For example, in 2022 the JRC developed a resource on the world trade of phosphates, because the extraction of uranium from phosphates is of concern to the IAEA against a background of past uses in undeclared activities

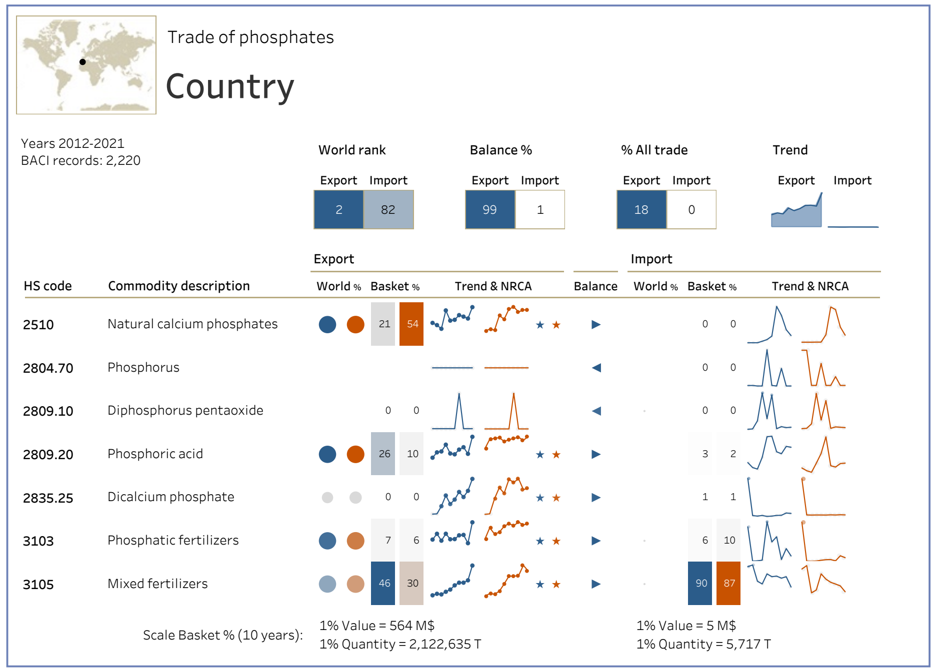


Fig. 2: Country based view of the tade of phosphate products.

05 DATA ANALYTICS FOR EC STRATEGIC EXPORT CONTROL

The JRC collects and analyses data on the implementation the EU Regulation for export control and contributes with it to the annual EC report to Council and Parliament. Dual-use and strategic trade controls are implemented by EU national authorities: the data collected and analysed by the JRC allow the EC and Member States to review the implementation of controls in an 'EU-level playing field'.

The JRC expertise in monitoring trade controls is also applied in the context of the monitoring of sanctions, where it is important for the Commission to estimate the effects of prohibitions before they are adopted and to assess the effects after adoption.

03 THE NUCLEAR TRADE ATLAS

The Nuclear Trade Atlas is a digital tool to help analyse trade flows related to nuclear activities. It is developed by the JRC in collaboration with US Department of Energy and it is based on data from the United Nations Statistical Division. An evaluation of the nuclear relevance for each of a series of items shows which countries are trading a given item (commodity-based view) or which items are exchanged by a given country (country-based view).

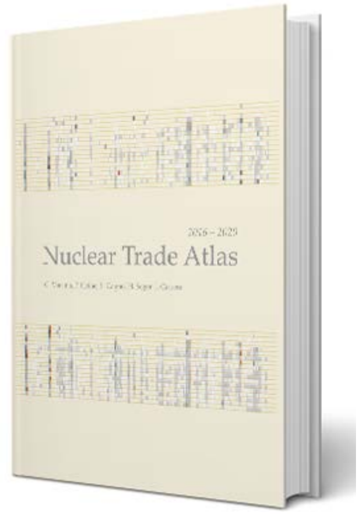


Fig. 3: The Nuclear Trade Atlas book.

04 JRC SUPPORT TO THE WORLD CUSTOMS ORGANISATION

JRC support to the World Customs Organisation in their program for Strategic Trade Compliance Enforcement worldwide. For the WCO the JRC developed the Strategic Trade Atlas used for training and to prepare coordinated customs operations. The impact of this work is large due to the global scope of work of the WCO.

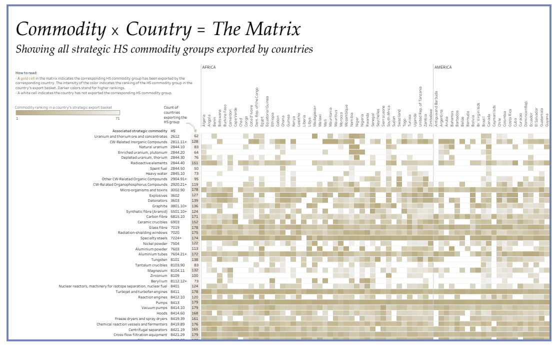


Fig. 4: The Nuclear Trade Atlas book (internal page).

Future Objectives

- Euratom Safeguards long-term strategy foresees an assessment of risk based on the results of past verification activities and the evaluation of confidence factors capturing limits and uncertainties encountered during the process. The JRC plans to enhance its data analytics capacity by scaling analytical tools and data infrastructure involving also the Data Mining Unit.
- In strategic trade analysis, the JRC will support DG TRADE implementation of new provisions on export license data transparency and the World Customs Organisation with trade data analytics and capacity building on the use of Nuclear Trade Atlas and the Strategic Trade Atlas for customs operation exercises.

KEYWORDS

Data Analytics

Nuclear Trade Atlas

Strategic Trade Atlas

EC Strategic Trade Control - Dual use regulation

MAIN PARTNERS:
DG ENER, DG TRADE, IAEA, US DEPARTMENT OF ENERGY

OTHER INTERESTED DG'S:
DG INTPA

MAIN STAKEHOLDERS:
- Safeguards inspectors
- Safeguards Analysts
- Trade policy makers
- Customs

STRATEGIC TRADE CONTROL

Overview

Strategic, or dual-use, items have both civil and military applications. Since the 80's, undeclared weapon proliferation programmes are largely based on the illicit procurement of a wide range of dual-use equipment, materials, software and technologies. A known example of nuclear "dual-use" proliferation was the AQK Pakistani network, which succeeded to by-pass the "nuclear safeguarded facility-based export controls" set-up by the Nuclear Suppliers Group after the India nuclear test of 1974.

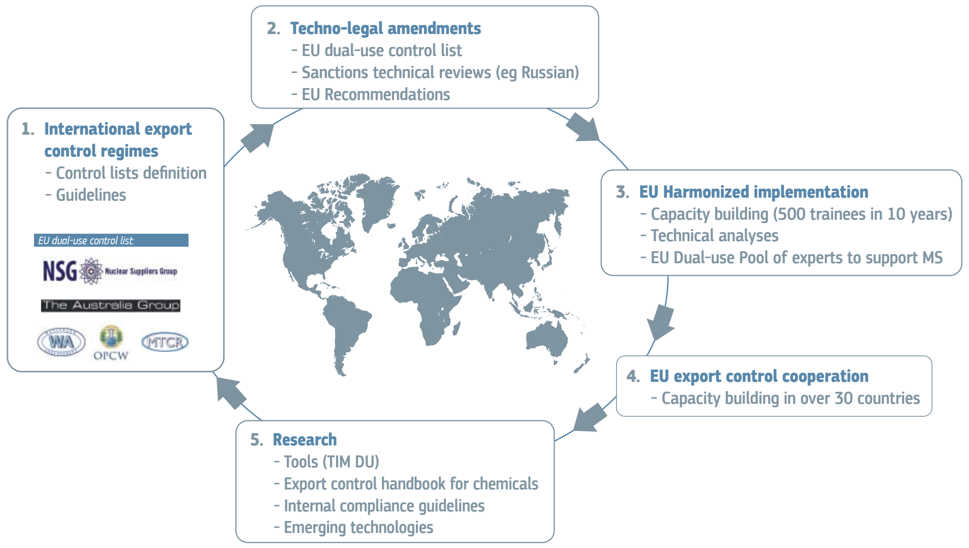


Fig. 1: Strategic Trade Control's policy support cycle.

01 PRE-NORMATIVE SUPPORT

The **European Union dual-use control list** (Annex I to the Dual-Use Regulation 2021/821.) integrates the International export control regimes control lists and items of the Chemical Weapons Convention.

The JRC supports the EU in **Nuclear Suppliers Group** (nuclear goods and technology) and **Australia Group** (bio- and chemical goods and technology) related aspects by analyses of proposals and contribution to meetings.

Fig. 2: Examples of dual-use items.

02 SUPPORT TO TECHNICAL REVIEWS AND AMENDMENTS

Contribution to the amendment of Annex I's **EU dual-use control list** under the Delegated Act to the Commission (DGTRADE);

Contribution to **sanction** control lists amendments(e.g Russia, Iran).

Fig. 3: Capacity building seminar.

03 SUPPORT TO HARMONISED CONTROL IMPLEMENTATION

Operation of the **EU Dual-use pool of experts** to the benefit of and in collaboration with EU authorities, to provide non-binding advice to technical questions concerning goods rating.

Capacity building
Technical seminars are regularly provided to EU licensing officers, also in cooperation with the US Dept. of Energy and EU national authorities.

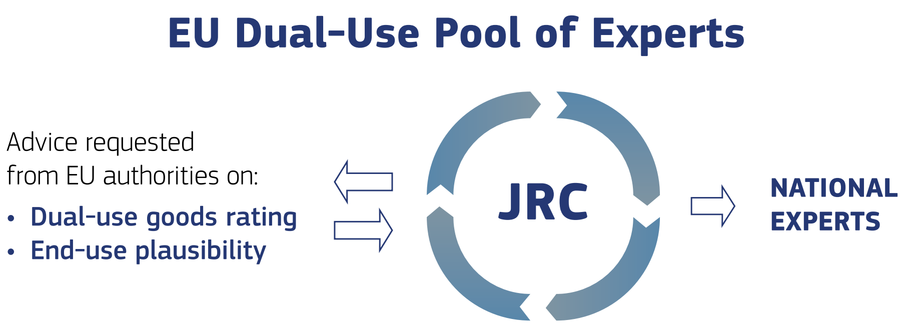


Fig. 4: EU Dual-use Pool of Experts support cycle.

04 EU EXPORT CONTROL COOPERATION

The JRC provides support to the Service for Foreign Policy Instruments for the definition and **evaluation of the EU Partner to Partner export control programme in more than 30 partner countries.**

05 RESEARCH

Research aims at developing tools and guides facilitating the policy support activities. The TIM Dual Use platform allows searching for dual-use related publications, patents and EU funded projects, fostering internal compliance and outreach activities. The Export control handbook for chemicals maps the EU regulations concerning thousands of sensitive chemicals and has been downloaded more than 4000 times since its first publication in 2019.

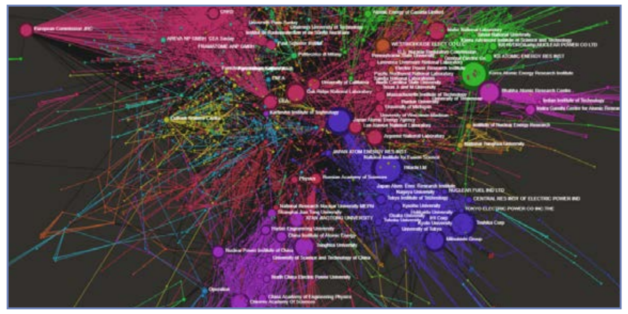


Fig. 5: Screengrab of nuclear related publications.

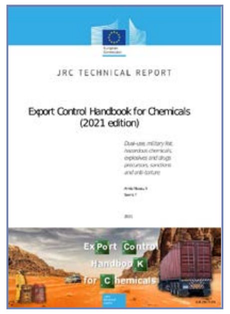


Fig. 6: Export control handbook for chemicals.

TIM DUAL USE
https://knowledge4policy.ec.europa.eu/text-mining/tim-dual-use_en

Access TIM Dual Use dashboards for technologies related to the EU dual-use control list's categories:

Cat.0 Nuclear Material, Facilities and Equipment
Cat.1 Special Materials and Related Equipment
Cat.2 Material Processing
Cat.3 Electronics
Cat.4 Computers
Cat.5 Telecommunications and Information Security
Cat.6 Sensors and Lasers
Cat.7 Navigation and Avionics
Cat.8 Marine
Cat.9 Aerospace and propulsion

Access TIM Dual Use dashboards for Emerging technologies:
Additive Manufacturing, Artificial Intelligence, Biotechnology, Blockchain, Cyber-Surveillance, Nanotechnology, Quantum Technology, Smart Materials.

Future Objectives

Countering the illicit procurement of sensitive goods, technologies and software is an essential element of the fight against the illegal proliferation of weapons of mass destruction, conventional weapons and their means of delivery, including e.g. unmanned air vehicles. Strategic trade controls and the complementary Foreign Direct Investments Screening also are also essential measures to foster EU's strategic autonomy. As long as the EU will implement these policies, the JRC will be called to contribute and even develop further its portfolio of activities, if the necessary resources will be provided to enable the maintenance of a multi-disciplinary critical mass of competences.

KEYWORDS

Nuclear
Safeguards
Dual-use
Non-Proliferation
Foreign policy
Sanctions technical reviews
EU regulations
Export control handbook
Nuclear material
Chemical weapons convention
Dual-use pool of experts
EU licensing officers
Export control handbook

MAIN PARTNERS:
TRADE, FPI

OTHER INTERESTED DG'S:
TAXUD, ENER, FISMA, RTD

MAIN STAKEHOLDERS:
- Export Licencing authorities of EU Member States
- Customs authorities of EU Member States
- TRADE, FPI

Samples ready to be introduced for measurement into the Hybrid K-edge system.

03 TECHNOLOGY, EQUIPMENT AND TOOLS FOR SAFEGUARDS VERIFICATION

Nuclear safeguards ensure that nuclear material is used only for peaceful purposes. Euratom Safeguards entrusts the Joint Research Centre (JRC) to support its efforts in verifying nuclear facility operators' nuclear material accountancy declarations and providing operational support to avoid any misuse of nuclear material. Under the Euratom Treaty, Euratom Safeguards is also collaborating with the International Atomic Energy Agency (IAEA) in a "partnership approach" equally supported by the JRC, thus contributing to the worldwide objective of nuclear non-proliferation.

The JRC is the leading science and knowledge service of the European Commission and, therefore, is in the best position to develop state-of-the-art technology, equipment and tools needed for containment/surveillance and for the destructive and non-destructive analysis of nuclear material under safeguards. In addition, the JRC has a mandate in the Euratom Treaty to ensure that uniform nuclear terminology and a standard system of measurements are established.

The JRC does its Safeguards Research and Development (R&D) in co-creation with leading partners and stakeholders in the discipline-oriented ESARDA Working Groups to maintain and continuously further improve technologies, methodologies and techniques for nuclear compliance assurance and to create an agile approach in response to future safeguards challenges.

Verifying the dissolution of uranium sample.

3.1 ANALYTICAL AND REFERENCE TECHNIQUES

Measuring bulk and particle nuclear materials is a crucial part of nuclear safeguards. These measurements involve a variety of analytical methods and are conducted in nuclear laboratories on-site, off-site, or in the field depending on the sample's nature. A rigorous quality system, supported by metrological quality control tools, ensures the accuracy of these measurements. They play a vital role in the effectiveness of nuclear safeguards systems, helping authorities meet the challenge of achieving a high level of detection probability. In the worst-case scenario, they may need to stand in court.

NUCLEAR REFERENCE MATERIALS

Overview

The European Commission`s Joint Research Centre (JRC) has the mandate in the Euratom Treaty of ensuring a standard system of measurements.

This includes the provision of various actinide isotopic certified reference materials (CRMs) for nuclear safeguards, security and safety (3S) to policy partners, research institutes, academia and industry in compliance with ISO 17034:2016 and accredited by the Belgian Accreditation Body (BELAC)

Prioritisation in this competence domain is done in line with the JRC's mandate in co-creation with Euratom Safeguards and stakeholders at an international level via consultations, dedicated support programmes (EC-SP to the IAEA), technical meetings and working groups, such as in ESARDA.

The JRC CRMs are applied worldwide for instrument calibration, validation of analytical methods and for quality control in nuclear energy and non-energy applications.: https://crm.jrc.ec.europa.eu/

01 RM CERTIFIED FOR ISOTOPE AMOUNT RATIOS

Uranium hexafluoride (UF_6):
- IRMM-019-027 series

Uranium solutions:
- IRMM-183-187 (set of 5 units)
- IRMM-3100a
- IRMM-3020-3090 (set of 5 units)
- IRMM-2019-2030 (set of 12 units)
- IRMM-073 series (set of 15 units)
- IRMM-074 series (set of 10 units)
- IRMM-075 series (set of 6 units)
- EC-NRM-199

Plutonium solutions:
- IRMM-290 series (set of 7 units)
- IRMM-290a series (set of 7 units)
- IRMM-290b series (set of 7 units)

Fig. 1: IRMM-3020a uranium solution.

02 RM certified for production date ("age dating")

Uranium dried nitrate:
- IRMM-1000a and IRMM-1000b

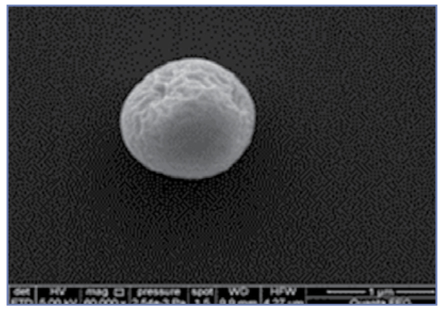


Fig. 2: Scanning electron microscope (SEM) image of a single IRMM-2331P particle (taken at Forschungszentrum Jülich).

Fig. 3: IRMM-1027 Large-Sized Dried (LSD) Spike U/Pu CRM.

03 RM CERTIFIED FOR ELEMENT MASS FRACTION

Uranium dioxide (pellets):
- EC-NRM-106 (natural U)
- EC-NRM-110 (depleted U)

Uranium ore:
- EC-NRM-113
- EC-NRM-114 (natural U)

04 RM CERTIFIED FOR PRODUCTION ^{60}CO MASSIC ACTIVITY

Stainless steel disk:
- EURM-800 and EURM-801

05 RM FOR REACTOR NEUTRON FISSION DOSIMETRY

Oxide microspheres certified for (isotope) mass fraction:
- IRMM-501 ($^{238}UO_2$)
- IRMM-502 ($^{237}NpO_2$)

06 URANIUM PARTICLE REFERENCE MATERIALS

Triuranium octoxide (U_3O_8) particle:
- IRMM-2329P (Isotope amount ratio and Uranium amount per particle)
- IRMM-2331P (Isotope amount ratio)

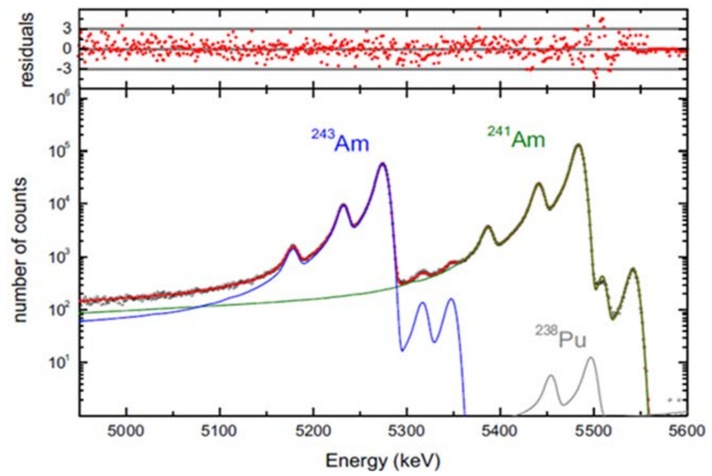


Fig. 4: Measured (dots) and fitted (lines) alpha spectrum of the ^{243,241}Am material.

07 RM CERTIFIED FOR ISOTOPE AMOUNT CONTENT AND ISOTOPE AMOUNT RATIOS (ISOTOPE DILUTION MASS SPECTROMETRY (IDMS)

Uranium solutions:
- IRMM-054 (enriched in ^{235}U)
- IRMM-3636a and IRMM-3636b ("double spike" certified for ^{233}U, ^{236}U amount content, ^{233}U/^{236}U ratio close to 1)
- IRMM-3660a and IRMM-3660b (enriched in ^{236}U)

Fig. 5: A unit of IRMM-0243

Plutonium solutions:
- IRMM-049e
- IRMM-083 (enriched in ^{240}Pu)

Mixed Uranium /Plutonium dried nitrate:
- IRMM-1027 series LSD

Americium solution:
- IRMM-0243 (called STAM by CETAMA) (enriched in ^{243}Am)

Uranium particles U_3O_8:
- IRMM-2329P and IRMM-2331P (isotope amount ratios only)

08 SUMMARY

- The JRC has the mandate of ensuring a standard measurements system.
- We provide certified nuclear reference materials for 3s.
- The JRC CRMs are applied worldwide in nuclear energy and non-energy applications.

Future Objectives and Challenges

Provision of certified nuclear reference materials (CRMs) in compliance with ISO 17034 and accredited by the Belgium Accreditation Body (BELAC) to support the authorities in achieving their required high level of detection probability in nuclear safeguards and security.

Future CRM projects:
- IRMM-040b (^{233}U) and IRMM-046d (^{242}Pu/^{233}U).
- IRMM-1027 series U/Pu Large-Sized Dried spike.
- IRMM-1038a U Large-Sized Dried spike.
- Preserving skills and competences in the field of nuclear CRM production.

KEYWORDS

- Certified Reference Materials catalogue
- LSD spike CRMs
- Am CRM and half-life
- Plutonium handbook
- Nuclear Non-Proliferation; Arms Control Verification
- Uranium material standards
- Particle CRMs
- ISO 17034:2016
- EURM

MAIN PARTNERS:
DG ENER, IAEA, EEAS

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- Industry
- Research
- Academia

METROLOGICAL TOOLS FOR SAFEGUARDS & SECURITY

Overview

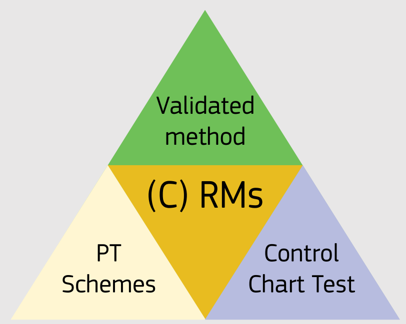
The European Commission`s Joint Research Centre (JRC) competence domain of metrological tools for nuclear safeguards, security and safety (3S) is the contemporary response to the 1957 Euratom Treaty mandate to specialise in Nuclear Measurements for Isotope Analysis.

Metrology is defined as the science of measurement and its application, encompassing amongst others the accuracy, traceability, reliability and comparability of measurement results, linking them to reference standards and conformity assessment tools.

Confidence in the analytical results provided by laboratories carrying out measurements for independent safeguards verification, is on the basis of international political decisions in view of the peaceful use of nuclear energy in any geopolitical context. Independent accurate measurement results are equally required for special and environmental sample analysis.

Quality assurance (QA) and quality control (QC) comprise different aspects:

- Method validation via Certified Reference Materials (CRM) and instrument calibration.
- Traceability and Comparability of measurement results.
- Uncertainty of measurement results (Guide to the expression of uncertainty in measurement).
- External performance evaluation.
- Document/data control and deployment of a quality system.



01 CONFIDENCE IN RESULTS

Accountancy and control of nuclear material require analytical measurements that "shall either conform to the latest international standards or be equivalent in quality to such standards" IAEA INFCIRC/153. This equally applies to verifying the absence of undeclared nuclear materials and activities under the Additional Protocol (AP) INFCIRC/540 (Corr.). Nuclear safeguards conclusions are based to a large extent on comparison of obtained measurement results with the declarations of the operator. More recently, safeguards has become increasingly investigative and deals with consistency of measurable material properties with declared processes.

In nuclear forensics, characteristic parameters (also referred to as "signatures") are used for re-establishing the history of nuclear material found out of regulatory control. QA and QC in destructive sample analysis in nuclear safeguards and security are the means to comply with the requirements to provide accurate and reliable measurement results.

02 CONFORMITY ASSESSMENT

Laboratories performing measurements in nuclear safeguards and nuclear security have to demonstrate their competence and increasingly their proficiency in compliance with ISO/IEC 17025 on an international level and to their respective accreditation bodies through internal and external quality control measures.

The JRC is accredited by the Belgian Accreditation Body (BELAC) according to ISO/IEC 17043:2010 Conformity assessment — General requirements for proficiency testing.

- In the JRC's Regular European Inter-laboratory Measurement Evaluation Programme (REIMEP), samples matching materials analysed routinely in the nuclear fuel cycle are sent to participating laboratories for measurements with undisclosed reference values.
- The JRC's Nuclear Signatures Inter-laboratory Measurement Evaluation Programme (NUSIMEP) is an example of an external quality control programme in the field of environmental sample analysis, involving element and isotopic analysis of trace amounts of nuclear material in the environment.

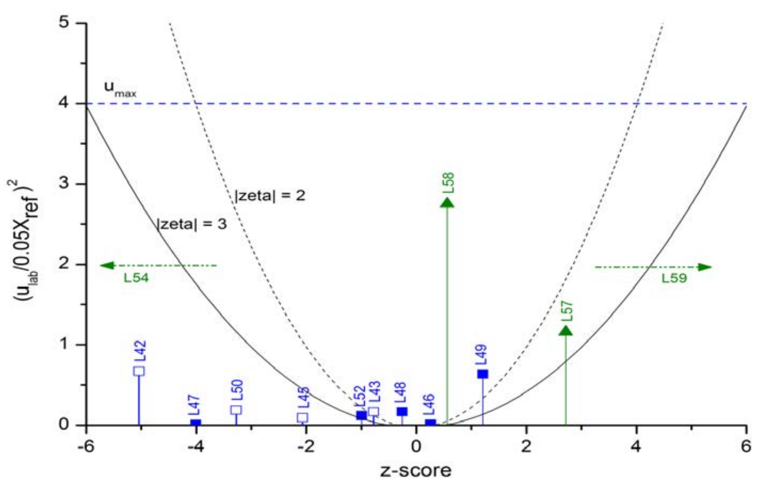


Fig. 1: 'Naji plot' of REIMEP-22: (U Age Dating - Determination of the production date of a uranium certified test sample) all participants' performance. The Nuclear Forensics International Technical Working Group (ITWG) laboratories are identified by open symbols., Venchiarutti et al. DOI 10.1515/ract-2015-2437

03 URANIUM PARTICLE REFERENCE MATERIALS FOR ENVIRONMENTAL SWIPE SAMPLE ANALYSIS

Environmental swipe samples collected at nuclear facilities during inspections are used by (inter)national safeguards authorities to verify the absence of undeclared nuclear material and/or activities in nuclear facilities under safeguards. Nuclear security authorities also use environmental samples for evidence collection in cases of border interdictions of nuclear material, and seizures or discoveries of nuclear material in the public domain. Uranium particle analysis is a powerful tool to this end:

- The JRC, the Forschungszentrum Jülich (FZJ), Germany, and the International Atomic Energy Agency (IAEA) joined forces to release the first uranium oxide microparticle reference materials for nuclear safeguards and security, IRMM-2329P and IRMM-2331P.

Fig. 2: Scanning Electron Microscope (SEM) image of IRMM-2331P particle Diameter 1.3 µm.

04 INTERNATIONAL TARGET VALUES (ITV) NETWORK

ITV represent estimates of achievable uncertainties under routine measurement conditions. They are used as a reference by nuclear plant operators, State and regional authorities, safeguards inspectors, safeguards laboratories and other safeguards practitioners. The proper application of metrological quality control and conformity assessment tools is indispensable to the achievement of measurement accuracy in compliance with the ITV.

05 SUMMARY

- Accurate data and knowledge allow effective detection to avoid malicious uses of nuclear materials, safguarding society.
- The JRC is accredited for ISO17025, ISO17034 and ISO17043.
- The JRC provides the references and standards on which we can build on in a rapidly changing world!

Future Objectives and Challenges

- Quality control and quality assurance remain indispensable for providing reliable, high quality measurement results to safeguards authorities.
- An essential part of a quality system is to assure that analytical staff is well trained, that infrastructure and equipment is operational and that an appropriate project management system with data and document control is implemented.
- Guaranteeing tailor-made quality control tools for future nuclear fuel cycles.
- Assessment of measurement capabilities of Network of Analytical Laboratories in nuclear safeguards & security.
- ITV review in a continuous way by an extended ITV Expert Network.

KEYWORDS

- Certified Reference Materials catalogue
- International Target Values
- Reconciliation paper
- GUM - JCGM 100:2008
- ISO/IEC 17043:2010
- ISO/IEC 17025
- LG-SIMS
- Interlaboratory comparisons
- Particle CRMs
- ITWG
- Plutonium handbook
- Nuclear Non-Proliferation; Arms Control Verification

MAIN PARTNERS:
DG ENER, IAEA, EEAS

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- Industry
- Research
- Academia

STANDARDISATION IN NUCLEAR MASS SPECTROMETRY

Overview

Standardisation is the process of implementing and developing technical standards helping to maximize compatibility, interoperability, safety, repeatability, or quality.

The peaceful use of nuclear energy has to take place with the highest standards of nuclear safety, security and non-proliferation. Safeguarding at the front-end of the nuclear fuel cycle is a major priority for Euratom and IAEA safeguards. From a non-proliferation standpoint, uranium enrichment is a sensitive technology which needs to be subject to tight European and international control.

The JRC's contribution to international standards is a perfect example of how developed expertise (knowledge production) is disseminated (knowledge transfer), leading to the implementation of new standards applicable in nuclear material analysis, accountancy and nuclear safeguards.

Standards for test methods in nuclear mass spectrometry are also widely used in the fields of geochemistry and cosmochemistry, reaching out to non-energy nuclear applications

This JRC activity also strengthens the JRC's relation with industry (EUR 28753 EN).

01 STANDARDISED TEST METHODS

The role of standards is high on the policy agenda of the European Commission.

Standardised test methods are important to compare results achieved in laboratories worldwide. The JRC collaborates with international bodies and organisations to harmonise scientific techniques and standardise analytical processes.

ASTM International (American Society for Testing and Materials) is one of the global providers of voluntary consensus standards, including standards in the area of nuclear measurements.

Fig. 1: Thermal Ionization Mass Spectrometer at JRC-Geel.

02 STANDARD TEST METHODS FOR THERMAL IONSIATION MASS SPECTROMETRY (TIMS) AUTHORED AND CO-AUTHORED BY THE JRC

ASTM C1832-21:
The JRC-developed the Standard Test Method for Determination of Uranium Isotopic Composition by Modified Total Evaporation (MTE) Method Using Thermal Ionization Mass Spectrometer.
This is a method for routine TIMS measurements of uranium isotope ratios with improved precision and accuracy for major ($^{235}U/^{238}U$) and minor isotope ratios ($^{234}U/^{238}U$ and $^{236}U/^{238}U$)

Fig. 2: UF6 gas source mass spectrometer called "URANUS" at the JRC-Geel.

ASTM C1871-18:
Standard Test Method for Determination of Uranium Isotopic Composition by the Double Spike Method Using a Thermal Ionization Mass Spectrometer. The double spike method has been used for studies of uranium fractionation effects in isotope geochemistry and cosmochemistry, for uranium source attribution in nuclear forensics and for investigation of conversion or sampling processes in nuclear industry and nuclear safeguards..

ASTM C1672-17:
Standard Test Method for Determination of Uranium or Plutonium Isotopic Compo- sition or Concentration by the Total Evapo- ration Method Using a Thermal Ionization Mass Spectrometer.
The total evaporation method allows for a wide range of sample loading with no significant change in precision or accuracy. The method is also suitable for trace-level loadings with some loss of precision and accuracy.

Fig. 3: "Cristallini" sampling method for UF6 by adsorption and hydrolysis of UF6 gas in alumina pellets.

03 URANIUM HEXAFLUORIDE (UF_6) GAS SOURCE MASS SPECTROMETRY

Facility operators and safeguards inspectors routinely take UF_6 samples from processing lines, isotopic enrichment cascades or storage cylinders to determine their U isotopic composition, and most importantly the $n(^{235}U)/n(^{238}U)$ isotope ratio, needed to calculate the amount of fissile ^{235}U in the sample. Conventional sampling practices collect samples of UF_6, usually in quantities greater than one gram and air transport operators are unwilling to transport such samples.

ASTM C1880-19: Standard Practice for Sampling Gaseous Uranium Hexafluoride using Alumina Pellets.
"Cristallini" sampling method for UF_6 by adsorption and hydrolysis of UF_6 gas in alumina pellets inside a fluorothene P-10 tube, using the sorbent properties of aluminum oxide (Al_2O_3) for cheaper and safer nuclear transport.

ASTM C1913-21: Standard Practice for Sampling Gaseous Uranium Hexafluoride Using Zeolite in Single-Use Destructive Assay Sampler. SUDA samples are expected to be transported as "excepted small quantities" package because the conversion to a less hazardous, more stable chemical species avoids the chemical hazards of UF_6.

Fig. 4: Single-Use Destructive Assay (SUDA) sampler for Uranium Hexafluoride (UF6) gas.

04 SUMMARY

- Mass Spectrometry identifies the isotopic composition of nuclear materials.
- The peaceful use of nuclear energy needs the highest standards of 3S.
- Standard Test Methods are subject to regular review and development.
- Non-standardised procedures may lead to unreliable scenarios.

Future Objectives and Challenges

- The JRC will continue to work on standardisation in order to include all relevant test methods to enhance the worldwide use of standardised methods for nuclear mass spectrometry measurement.
- The JRC will transfer the knowledge of implementing standardised test methods in safeguards laboratories.
- The JRC will continue promoting standardisation and a harmonised measurement system for the benefit of nuclear safeguards & security, the nuclear industry but also research institutions beyond the nuclear field.

KEYWORDS

- Certified Reference Materials catalogue
- ASTM International Standards in Europe
- Uranium material standards
- Uranium hexafluoride
- ISO/IEC 17025

MAIN PARTNERS:
DG ENER, IAEA, EEAS

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- Industry
- Research
- Academia

INNOVATION IN NUCLEAR CRMS FOR FISSILE MATERIAL CONTROL

Overview

Euratom Safeguards entrusts the JRC with the development of analytical and quality control methods, and with sample analysis.

To this end, the JRC was among the pioneers in the field of development, production and certification of Large sized dried (LSD) spikes, which are certified reference materials (CRMs) used for measuring the U and Pu isotope amount content in mainly spent nuclear fuel solutions by isotope dilution thermal ionization mass spectrometry (ID-TIMS).

They play a very important role in safeguarding nuclear reprocessing plants. A recent achievement in the further development of certified reference materials (CRMs) was the successful implementation of INS-CRM exploratory research project for extending the shelf-life of LSD spikes.

This transdisciplinary research effort enabled to interact beyond the nuclear sciences with the fields of polymer physics, chemistry and material science focusing on sustainability.

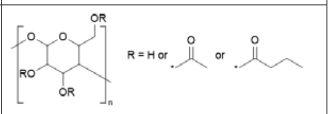
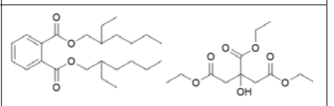
Material Type	Molecular structure
Polymer(s)	
Plasticizers	

Fig. 1: Molecular structure of CAB, DOP and TEC.

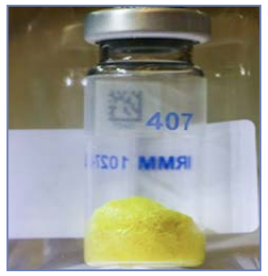


Fig. 2: IRMM-1027 Large-Sized Dried (LSD) Spike CRM in CMC.

01 EMBEDDING MATRICES TO EXTEND THE SHELF LIFE OF REFERENCE MATERIALS

Shelf life plays a crucial role in the safe transport, usability and storage of any actinide material. Therefore, a stabilizing matrix is applied that embeds the actinides of dried spike CRMs and fixes them at the bottom of the vial. This matrix must guarantee sufficient shelf life, while dissolving easily in nitric acid solution and not interfering during actinide separation techniques or ID-TIMS measurements.

It is not straightforward to find suitable matrices that meet all these requirements at the same time. Embedding matrices with excellent resistance to radiolysis, oxidation and hydrolysis are likely to offer limited usability of the spike CRM.

02 CELLULOSE ACETATE BUTYRATE (CAB) WITH DIOCTYL PHTHALATE (DOP)

Since 2002, a solvent cast polymer embedding film of cellulose-acetate butyrate **(CAB)** has been used as embedding matrix for the IRMM-1027 LSD spikes having the following characteristics:

- Good adherence to the glass.
- Easy to prepare and dispense.
- Readily dissolves in hot HNO3.
- Drawback: Tendency towards crack formation and flaking after a few years.

The addition of 20-30% Dioctyl phthalate **(DOP)** and triethyl citrate (TEC) plasticizer were tested on U/Pu samples for their mechanical resilience and ageing mechanisms with the result that DOP outperformed TEC in terms of elasticity and toughness. **DOP** boosts the initial mechanical properties of the cellulose based embedding films and reduces the internal stress at the polymer-embedded material interface:

- No tendency towards crack formation and flaking after a few years

03 CARBOXYMETHYL CELLULOSE (CMC)

Carboxymethyl cellulose **(CMC)** is used as a viscosity modifier or thickener, and to stabilize emulsions in various products, both food and non-food, including ice cream, cakes, tooth paste, fabric, detergents and in advanced battery applications.

Embedding IRMM-1027 LSD spikes with **CMC** foam shows:

- Good adherence to the glass
- Feasible to prepare and dispense
- Readily dissolves in hot HNO3
- No tendency towards flaking

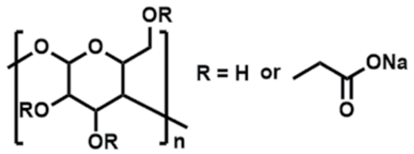


Fig. 3: Molecular structure of CMC

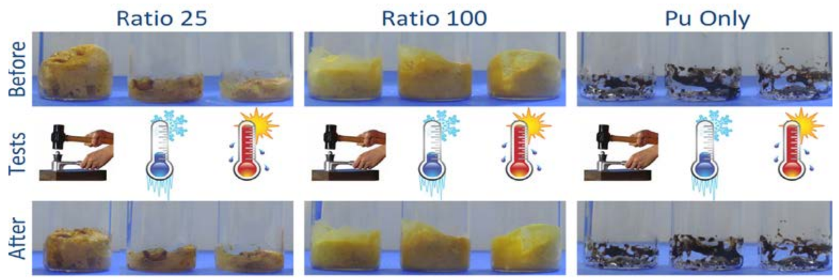


Fig. 4: LSD spikes of various U/Pu ratio exposed to transport simulation and elevated and low temperatures. The integrity of the spikes is well preserved.

04 CAB RECONDITIONING – H_3PO_4

Flaked spike CRMs treated with H_3PO_4 can be transformed into a homogeneous amorphous material and used for measurements

- Reconstructs homogeneity and integrity.
- Easy to prepare.
- Dissolves quickly in hot HNO_3.
- Stability > 6 months.

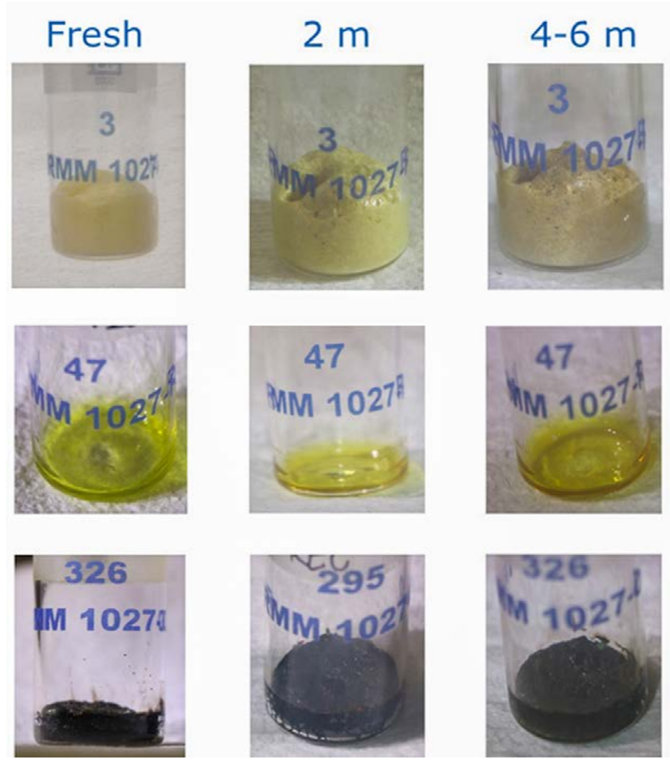


Fig. 5: From top to bottom: CMC, CAB/DOP and H_3PO_4 reconditioned U/Pu spikes after six months ageing.

05 SUMMARY

- The JRC develops analytical and quality control methods for Euratom safeguards reaching out beyond nuclear sciences.
- Stabilising matrixes improve actinide materials' shelf life, which is important for usability.

Achievements and Future Objectives – CAB/DOP and CMC

- A shelf life of at least 5 years can be achieved for dried actinide CMRs if CAB/DOP or CMC is used as embedding matrix.
- The validity of the certificate can be further extended via post certification monitoring, using isotope dilution thermal ionization mass spectrometry.
- Flaking dried actinide CRMs can be reconditioned with phosphoric acid.
- Recently, a European patent application was filed on an entire portfolio of organic embedding matrices that will further optimise the characteristics of LSD spikes and other actinide CRMs to meet contemporary demands of policy partners and stakeholders.

KEYWORDS

Certified Reference Materials catalogue

LSD spike CRMs

Cellulose acetate butyrate

Plutonium handbook

Mass spectrometry

MAIN PARTNERS:
DG ENER, IAEA, EEAS

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:

- Safeguards authorities
- Member States
- Industry
- Research
- Academia

HIGH ACCURACY ANALYTICAL MEASUREMENTS FOR SAFEGUARDS

Overview

Independent measurements of nuclear material are the backbone of safeguards verification. To this end, Euratom or IAEA inspectors may take samples at well-defined positions in nuclear facilities. These samples represent a small fraction of the much larger material inventory of the facility. Therefore they must be representative and must be characterized with the highest accuracy achievable. The overall analytical uncertainties must meet the requirements set by the International Atomic Energy Agency in the International Target Values (ITV) (STR-368 (R1.1). The JRC provides for the timely and accurate analysis of such samples using state of the art techniques as well as for the further perfection of analytical methodologies.

01 EURATOM SAFEGUARDS VERIFICATIONS CONCEPTS

SAMPLING:
Samples are taken at European facilities by Euratom inspectors at key points in the process following well established sampling schemes.

SAMPLE TRANSFER:
The samples are transferred to the JRC-Karlsruhe analysts for analytical investigations. Depending on their origin, the samples follow three pre-established analysis flows.

Orano Reprocessing plant, La Hague (FRA)	Laboratoire Sur Site (LSS) – laboratory owned by DG-ENER and operated by the JRC-Karlsruhe – costly and complicated transport of samples are avoided while providing timely accurate results
Fuel elements factories at Västerás (SWE) and Juzbado (ESP)	COMPUCEA – in-field measurements performed by the JRC-Karlsruhe operators delivering timely results during Physical Inventory Verifications campaigns of IAEA&Euratom inspectors
European and international facilities	The Analytical Service (AS) provides under the framework of the Euratom Treaty a large number of analytical techniques accredited according to ISO/IEC 17025 for Euratom, IAEA and other international safeguards organisations

Table. 1: Analysis route for safeguards samples depending on their origin

02 METHODS AND MEASURMENTS

The activities of the LSS and of the COMPUCEA are detailed in separate posters. The core activity of the AS is the measurement of samples for verification of declared activities, nuclear forensic, transport and scientific projects. The Large Geometry Secondary Ionisation Mass Spectrometry is used for the verification of undeclared activities and is detailed on page 40.

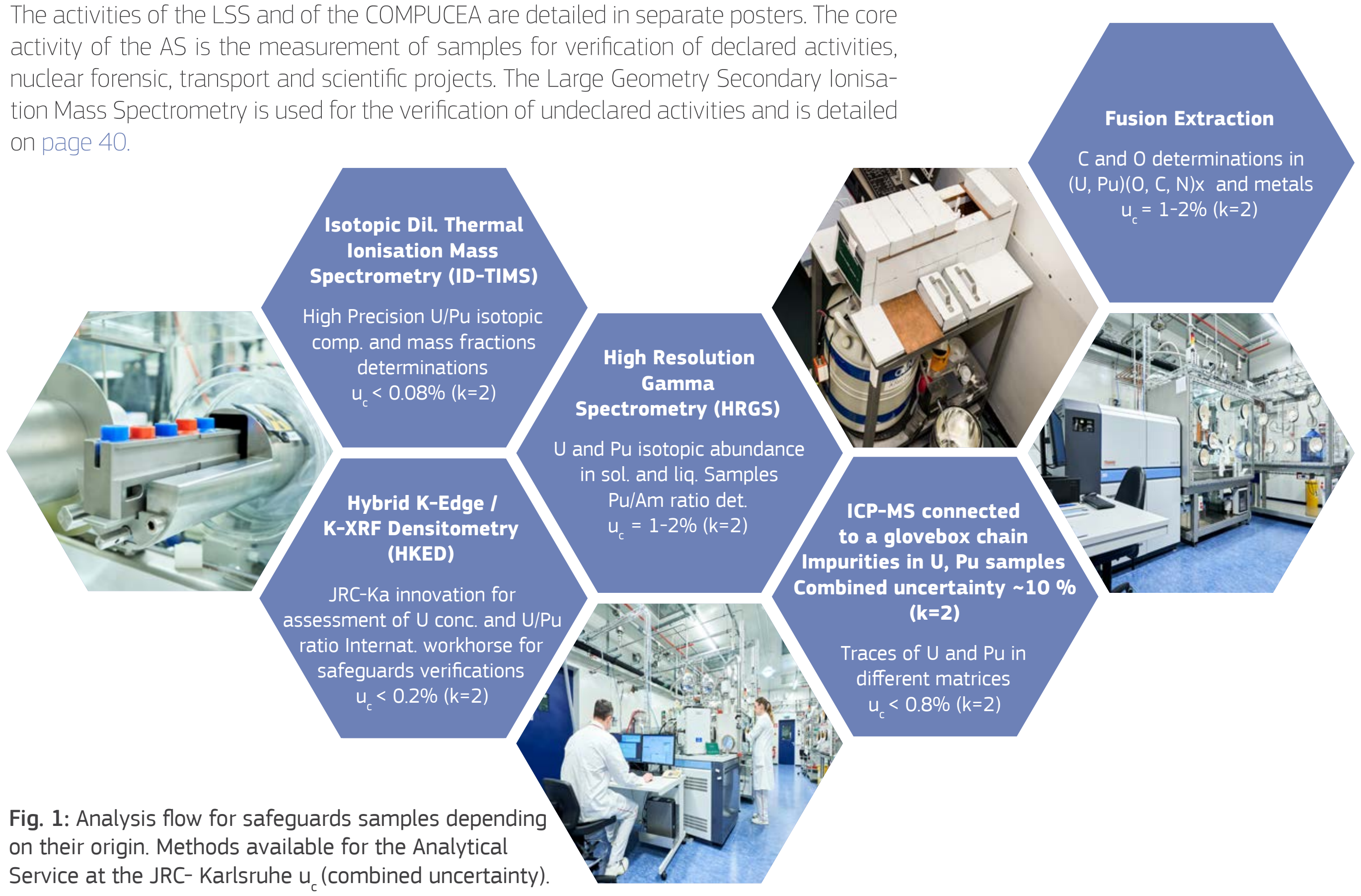


Fig. 1: Analysis flow for safeguards samples depending on their origin. Methods available for the Analytical Service at the JRC- Karlsruhe u_c (combined uncertainty).

03 QUALITY ASSURANCE

The analytical results must be traceable to certified reference materials. The collaboration with the JRC-Geel and other international reference materials providers is of critical importance. The methods are optimised for highest accuracy achievable as required by the International Target Vlaues (ITVs*).

The performance of the AS is constantly monitored by participating to Inter-Laboratory Comparison exercises (ILCs). At the same time the AS is part of the Network of Analytical Laboratories (NWAL) of the IAEA.

The results of the AS have always been evaluated between the top 5% performers, making the AS one of the most reliable partner for the safeguards authorities.

* STR – 368 (Revision 1.1)

04 RESEARCH AND DESIGN

Scientists of the JRC have developed the utilised analytical methods, procedures and quality control measures to deliver high quality results to Euratom safeguards in a timely manner. The instrumentation is kept at the cutting-edge level and continuous research and innovation is invested to improve the equipment and the analytical methods applied.

05 OUTCOME

The JRC-Karlsruhe has been providing analytical results needed by the Euratom safeguards for more than 23 years. Around 20.000 samples were analysed for the partner organisation DG-ENER and other organisations. The milestones in technical developments originating from the Karlsruhe site are equally important. The valuable expertise of the Analytical Service has a global outreach through collaboration agreements with international safeguards organisations like the ones listed here below:
IAEA,CEA, US-DOE, KINAC, ABACC, JAEA

Achievements and Future Objectives

- Ensure continuity of analytical support for safeguards authorities at European and international level.
- R&D to keep the state of the art of methods and instrumentation.

KEYWORDS

- Analytical Service
- Uranium and Plutoium Analyses
- Euratom
- ITV's
- NWAL

MAIN PARTNERS:
DG ENER, IAEA, US-DOE, CEA-FRA, JAEA, ABACC

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- IAEA

HKED – THE SAFEGUARDS WORKHORSE

Overview

Hybrid K-edge / K-XRF densitometry (HKED) is a key analytical technique for nuclear safeguards of nuclear reprocessing and of nuclear fuel production.

HKED uses X-rays to determine the U and Pu concentration in liquids with typical combined uncertainties of 0.2% and 0.7%, respectively.

The JRC operates the HKED systems used for Euratom safeguards. The JRC's research and development on HKED aims to reduce calibration work, improve robustness, and solve hardware and software issues.

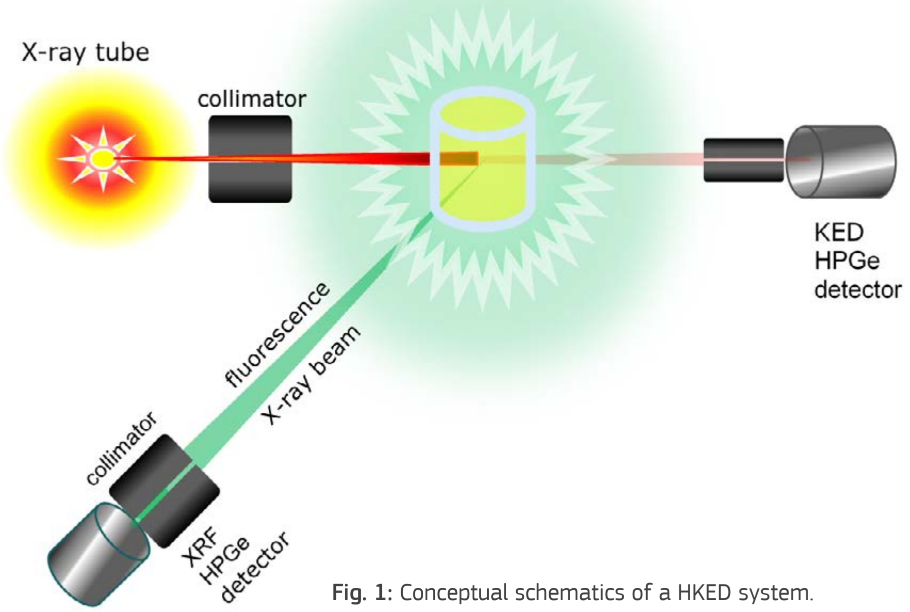


Fig. 1: Conceptual schematics of a HKED system.

01 INTRODUCTION

Hybrid K-edge / K-XRF densitometry (HKED) can simultaneously determine the uranium (U) and plutonium (Pu) concentration in actinide solutions of any radiation level. Today it is difficult to imagine safeguarding nuclear reprocessing plants without HKED. HKED is also used for measuring the U and Pu content of pellets and powders from nuclear fuel production plants.

HKED is faster, simpler and cheaper than other analytical methods which provide the same or just slightly better combined measurement uncertainty than HKED. That is why it is the main analytical technique used for safeguarding reprocessing pants and fuel production – the safeguards workhorse.

The first HKED system of the present kind, using an X-ray tube as radiation source, was set up in the 1980s in Karlsruhe, Germany. Since then, a total of about 20 systems have been installed and worked reliably worldwide. The basic design and performance have not changed significantly. However, several challenges and possibilities for improvements have been identified.

02 THE HKED TECHNIQUE

HKED is a combination of two techniques: X-ray transmission around the K-edge energies (KED) and X-ray fluorescence (XRF) measurement. The liquid sample is placed in an X-ray beam and two gamma spectrometers are used to measure the transmitted and the fluorescent X-ray radiation (Fig 1). Solid samples (pellets, powders) need to be dissolved before analysis. The KED measurement is used for determining the concentration of the major element (usually U), while XRF is for the concentration of the minor element (usually Pu).

Fig. 2: HKED is safeguarding more plutonium than all other analytical techniques altogether.

HKED is the workhorse of the Euratom on-site safeguards laboratory.

03 CHALLENGES

The JRC, together with its international partners, works on addressing challenges of the HKED technique, arising from recent technological and societal changes.

- Ensuring sustainability of hardware and software: A new hardware-software interface was designed and implemented by the JRC. The JRC advocates common access to source codes and avoiding that a single commercial entity has control.
- Improving analytical performance: New algorithms are being developed at the JRC to improve HKED performance and robustness and to reduce calibration efforts.
- Keeping continuity of knowledge: The JRC co-organises HKED workshops, disseminates publications and data, provides trainings.

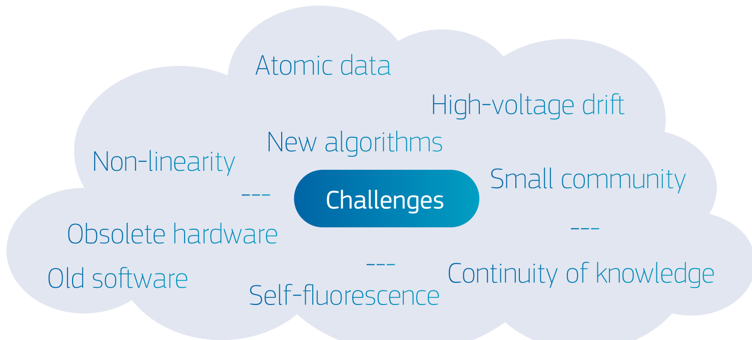


Fig. 3: HKED challenge cloud

04 CONCLUSION

The HKED technique is a proven tool for nuclear material accountancy verifications. Today, nuclear safeguards of reprocessing plants is unthinkable without HKED. The JRC operates the HKED systems for ERURATOM safeguards and works on advancing the technique beyond its state-of-the-art, to respond to technological and societal changes.

Future Objectives

- Ensuring sustainability of hardware and software
- Improving analytical performance
- Keeping continuity of knowledge

KEYWORDS

Euratom Treaty
EU regulations
Non-Proliferation
Safeguards
Nuclear Fuel
Uranium
Plutonium
Nuclear Reprocessing
On-site lab
Physical Inventory Verifications

MAIN PARTNERS:
DG ENER, IAEA

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- IAEA

COMPUCEA - THE METHOD FOR INSPECTIONS AT FUEL FABRICATION PLANTS

Overview

The Combined Procedure for Uranium Concentration and Enrichment Assay (COMPUCEA) is a high-accuracy technique used for measuring the uranium element concentration and ^{235}U-enrichment.

The analyses are performed with mobile equipment, in fuel fabrication plants during Physical Inventory Verification (PIV) activities of the international nuclear safeguards authorities (Euratom, IAEA).

The samples are selected by the safeguards inspectors and measured by COMPUCEA analysts directly in field during the PIV.

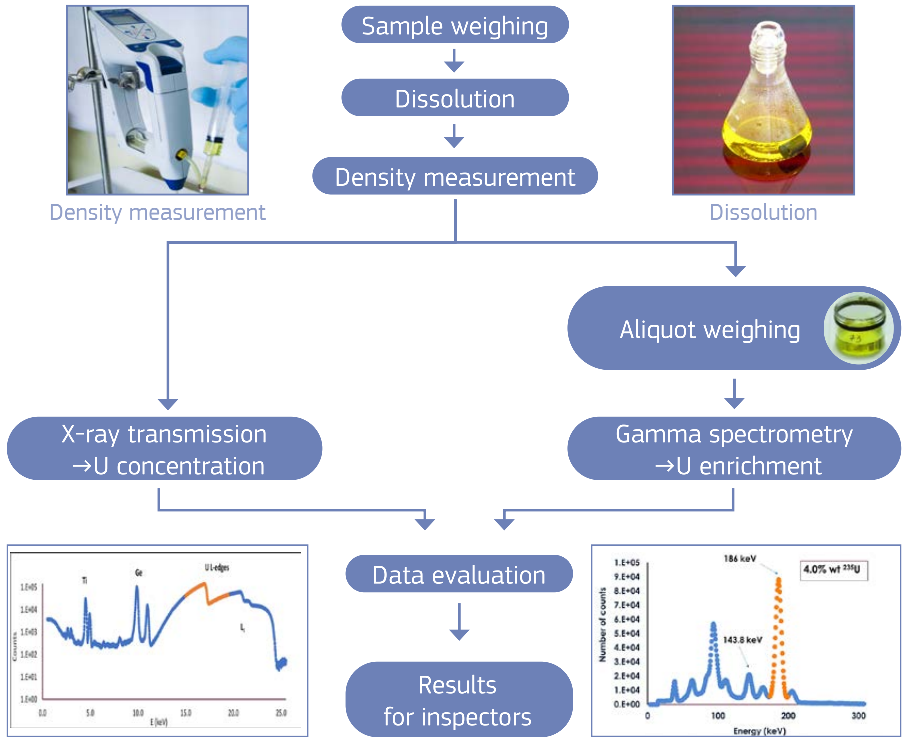
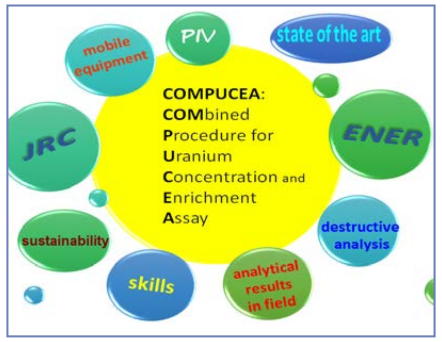


Fig. 1: COMPUCEA analysis scheme.

01 INTRODUCTION

The method, developed in the JRC-Karlsruhe, stemmed from the need to have a portable instrument able to measure both uranium content and uranium enrichment in field. With COMPUCEA the analytical results are immediately available to the safeguards inspectors in field. This allows a timely conclusion of the PIV and any observed discrepancies can be investigated immediately. With this approach, there is no need to send the samples to the safeguards laboratories.



02 THE METHOD

COMPUCEA is based on radiation measurements. However, the complete analysis procedure is a combination of chemistry and radiation spectrometry. The analytical steps include quantitative sample dissolution, solution density measurement, quantitative aliquoting etc., before the radiation measurements.

The solid samples are first dissolved, as COMPUCEA can measure samples only in liquid form. U concentration is measured by X-ray transmission measurement at the L-absorption edge of uranium (LED). For ^{235}U enrichment, absolute gamma measurement of the 186 keV peak of ^{235}U in well-defined geometry by $LaBr_3$(Ce) detector is used (ENR). The instruments are calibrated with certified reference material and daily quality control measurements are done.

03 THE INSTRUMENT

COMPUCEA is owned by DG-ENER and operated by the JRC analysts. Since its development, the technique continued to be used successfully in European fuel fabrication plants to support Euratom and IAEA inspections during PIVs. In 2011 the International Atomic Energy Agency (IAEA) adopted the use of COMPUCEA for international safeguards in non-European countries. It is being successfully used since.

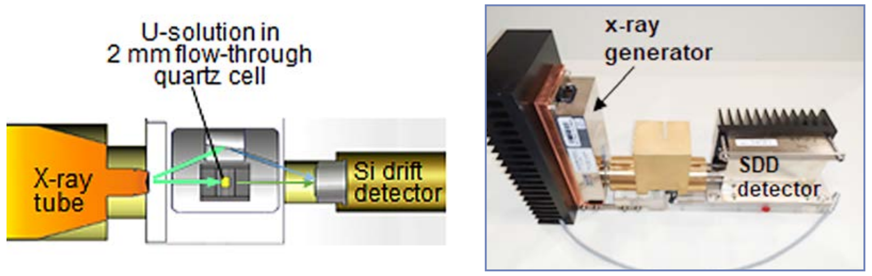


Fig. 2: Device for U concentration measurement

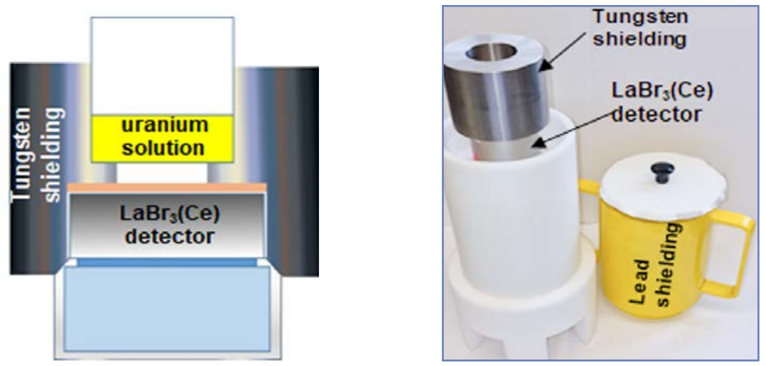


Fig. 3: Device for ^{235}U enrichment measurement.

04 RECENT DEVELOPMENTS

In 2017 the scope of COMPUCEA has been extended with the validation of the technique for the analysis of uranium hexafluoride samples (UF_6). The purpose of the extension was to support the IAEA in the verification of uranium conversion and enrichment facilities worldwide. The procedure adds a critical new step in the sample preparation to transfer the uranium from UF_6 to a nitric-acid solution, from where the well-established and validated COMPUCEA procedure can be followed.

Several versions of COMPUCEA were developed to meet the evolving needs and changing requirements. The current version has been finalized in 2023.

05 CONCLUSION

COMPUCEA analysts do high-accuracy in-field analytical measurements for nuclear safeguards accountancy verification with mobile analytical equipment. To the best of our knowledge, this cannot be done with any other safeguards measurement technique currently in use.

Future Objectives

- Ensuring sustainability, with state of the art equipment
- Preserving skills and competences
- Addressing evolving needs.

KEYWORDS

Euratom Treaty
EU regulations
Physical Inventory Verifications
Infield analysis
Transportable
Uranium elemental analysis
Uranium enrichment

MAIN PARTNERS:
DG ENER, IAEA

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- IAEA

OPERATING THE EURATOM LSS

Overview

The Euratom LSS is an on-site laboratory the European Commission operates within the French civil spent fuel reprocessing facility of Orano La Hague. Analysts from the JRC-Karlsruhe perform independent analyses of fissile material for nuclear safeguards. They provide the Euratom inspectors (DG ENER) with near-real-time analytical results and verification of the nuclear material accountancy. This work is critical to maintaining the integrity of the nuclear industry and protecting the public from potential hazards.

Fig. 1: Hot cells for highly radioactive dissolved spent fuel samples.

01 RAISON D'ÊTRE

Safeguarding bulk nuclear material facilities, and in particular spent fuel reprocessing plants, pose challenges, due to the nature and quantity of the special fissionable material (^{235}U and plutonium) present. Nuclear material is handled in loose form and changes in chemical and physical form occur, allowing for the material to be combined or split. Verifying the inventories is more intensive and samples are typically collected for analysis.

The increase in reprocessing capacity in the 90s in La Hague lead to the installation of the on-site laboratory to perform these independent analyses. The major advantages were timeliness, higher efficiency and cost effectiveness, waste reduction, reduced transport needs, assuring sample authentication. Furthermore, re-verifications could be done with minimal delay.

Larger facility throughputs contribute to larger absolute uncertainties in the material balance evaluation. It is thus of paramount importance to apply methods that deliver fit-for-purpose precision and accuracy combined with short analysis times and low resource consumption.

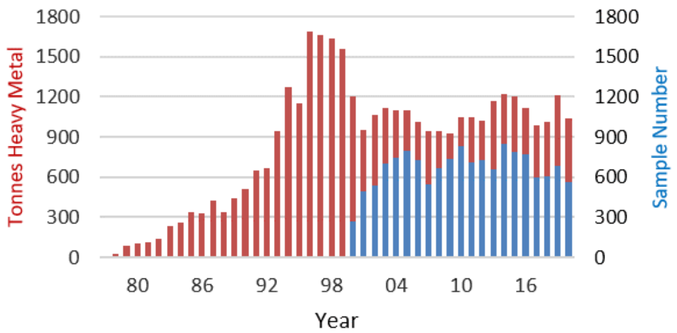


Fig. 2: Used fuel treated in La Hague (1977 – 2020 in THM, source Orano) and samples received in the LSS (2000 – 2020).

02 ANALYTICAL METHODS

The in Karlsruhe developed radiometric analytical method – HKED, a combination of K-edge Densitometry (KED) and X-ray Fluorescence (XRF), allows determining the uranium and plutonium concentrations above 0.5 g/l in liquid samples within a few days and with uncertainties better than 1% and well within the International Target Values.

To avoid having to dissolve powder samples, gamma spectrometry is used for the assay of plutonium isotopic composition.

The method is sensitive to matrix characteristics, such as the acidity, and needs appropriate calibration. The LSS has opted to prepare, from excess samples, reference solutions certified using the second available primary analytical method isotope dilution (ID) coupled with thermal ionization mass spectrometry (TIMS). The spike used (IRMM 1027 series) guarantees traceability to the international standard. ID-TIMS is the method used to resolve discrepancies between the operator's declarations and the LSS results. Measurement uncertainties in the order of 0.1% are possible with this method. It is furthermore used to determine U enrichment.

High precision density measurements complete the analysis performed.

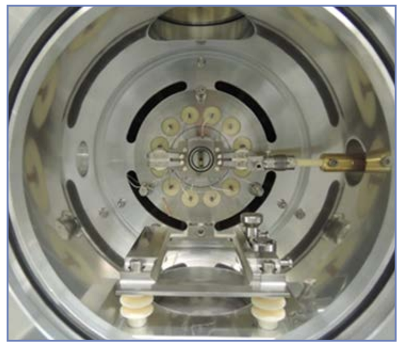


Fig. 3: Ion source head mass spectrometer.

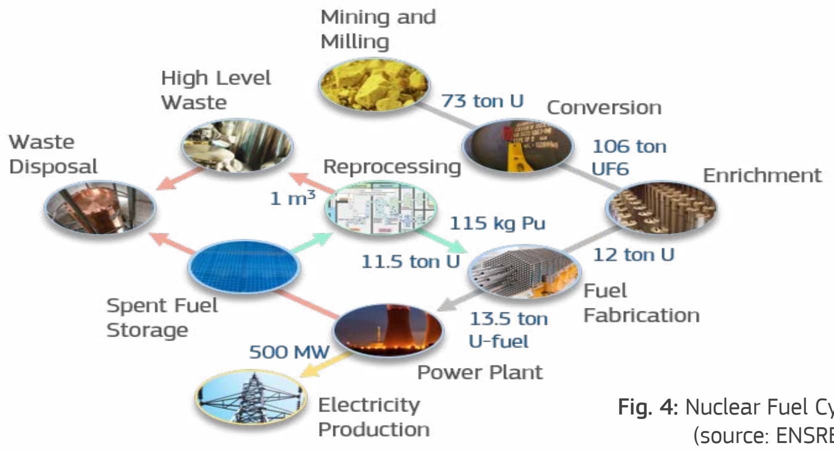


Fig. 4: Nuclear Fuel Cycle (source: ENSREG).

03 PRACTICAL IMPLEMENTATION

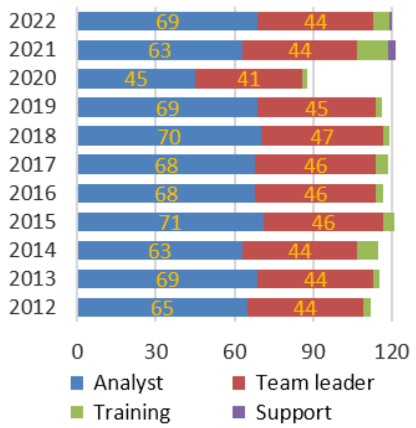


Fig. 5: Mission weeks.

Two to three JRC analysts travel weekly to the LSS to perform a multitude of tasks related to the analyses of the samples. These include measurements, quality control, chemical preparations, data management, maintenance and repair, and innovations. Under the constrains of working with highly radioactive materials in a small team this requires a trained workforce with unique skill sets.

The LSS is operated by the JRC on average 45 weeks during the year (team leader weeks in the figure). Even during the Covid-19 pandemic, the lab was closed only for a few extra weeks.

Around 15000 samples have been analysed over the two decades of operating the LSS. This amounts to performing well over 50000 measurements under stringent quality assurance.

04 FIT FOR THE FUTURE

Investments have been or are being made to replace and upgrade the existing instrumentation with newer state-of-the-art equipment. Examples are the upgrade of the MAT262 mass spectrometer and the replacement of all NIM modules with Mirion Lynx digital signal analysers.

Off the shelf solutions are seldom available so the JRC invests resources for their development and nuclearisation. Examples are the development of a semi-automatic separation unit and an external density measuring cell.

Future Objectives

The Euratom on-site laboratory in the nuclear reprocessing facility in La Hague (F) is an essential part of effective safeguards assuring that nuclear material remains in peaceful use. Continued efforts to increase efficiency and maintain the high quality of the performed analyses are primordial. Refurbishments and renovations of the infrastructure, instrumentation and procedures, taking into account changing boundary conditions and resources, will guarantee longer-term nuclear safeguards.

KEYWORDS

- Nuclear Material Accountancy
- Spent Fuel Reprocessing
- Euratom Treaty
- Nuclear Fissile Material
- On-site Laboratory
- Special Nuclear Material
- Uranium
- Plutonium

LSS on-site Laboratory

MAIN PARTNERS:
DG ENER

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- Industry

STRENGTHENED NUCLEAR SAFEGUARDS – Measurement of uranium particles in environmental samples

Overview

Nuclear safeguards inspectors collect samples containing dust particles at nuclear facilities and other locations, using a process known as environmental sampling. Such samples, in the form of cotton swipes, contain uranium particles that can reveal information about the current and past activities at a nuclear facility and verify whether a state is abiding by its legal commitment not to divert nuclear material from peaceful activities or engage in undeclared nuclear activities. The JRC-Karlsruhe started environmental sample analysis in 90's and was one of the first laboratories in the IAEA's network of laboratories for particle analysis.

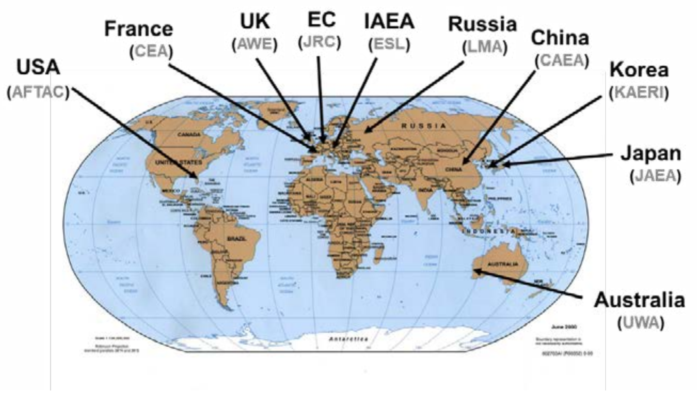


Fig. 1: IAEA's Network of Analytical Laboratories (NWAL) for particle analysis.

Fig. 2: Sampling kit.

Fig. 3: Swipe sample.

01 INTRODUCTION

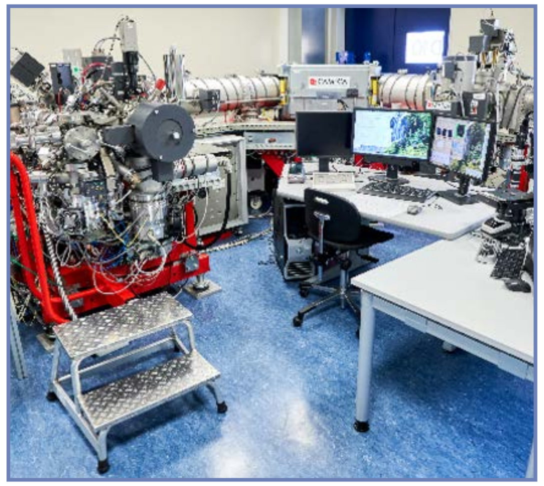
Environmental sampling for safeguards is based on the principle that every process, no matter how leak tight, emits small amounts of material to the environment. This was demonstrated successfully after the Gulf War, during the IAEA's programme "93+2", when environmental samples were collected from the vicinity of Iraq's destroyed nuclear facilities.

Environmental sampling is performed using cotton swipes (10cm x 10 cm). The amount of radioactivity in the uranium particles is undetectable, thus they can be easily transferred to laboratories for analysis.

02 INTRODUCTION

LG-SIMS laboratory, which is a state of the art technique for uranium particle analysis, was established at the JRC-Karlsruhe in a joint effort with DG-ENER in 2013.

LG-SIMS allows, in a first step, to localise the uranium particles in a matrix of millions of dust particles and determine their approximate ^{235}U enrichment. In the second step, precise microbeam measurements are performed to all uranium isotopes simultaneously to obtain the isotopic composition of micrometer sized particles. All this can be performed within 24 hours.



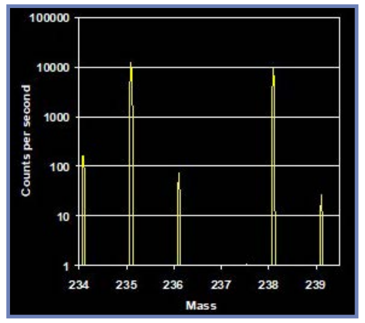


Fig. 4: (Left) Cameca IMS 1280HR LG-SIMS sample.

Fig. 5: (Above) Mass spectrum of non-natural uranium.

03 SAMPLE PREPARATION

First, the swipe is screened by Monochromatic Micro-focusing X-Ray fluorescence (MMXRF) to identify the uranium rich areas on the swipe. After that, the dust is transferred to a graphite planchet using a vacuum impactor technique. The work is performed in a clean room using disposal glove-bags and other single-use tools to avoid cross-contamination.

Fig. 6: Graphite planchet with particles.

04 MEASUREMENT UNCERTAINTIES AND QUALITY CONTROL

LG-SIMS laboratory at the JRC-Karlsruhe has ISO17025 accreditation, which calls for strict working protocols and therefore ensures accurate and precise results. The performance of the laboratory is monitored frequently by proficiency tests.

Typically achieved uncertainties are below 0.1% for the ^{235}U enrichment and below 1% for the minor isotopes, ^{234}U and ^{236}U. Due to the excellent precision and the possibility to detect inhomogeneities in samples, LG-SIMS is applied also for nuclear forensic analysis.

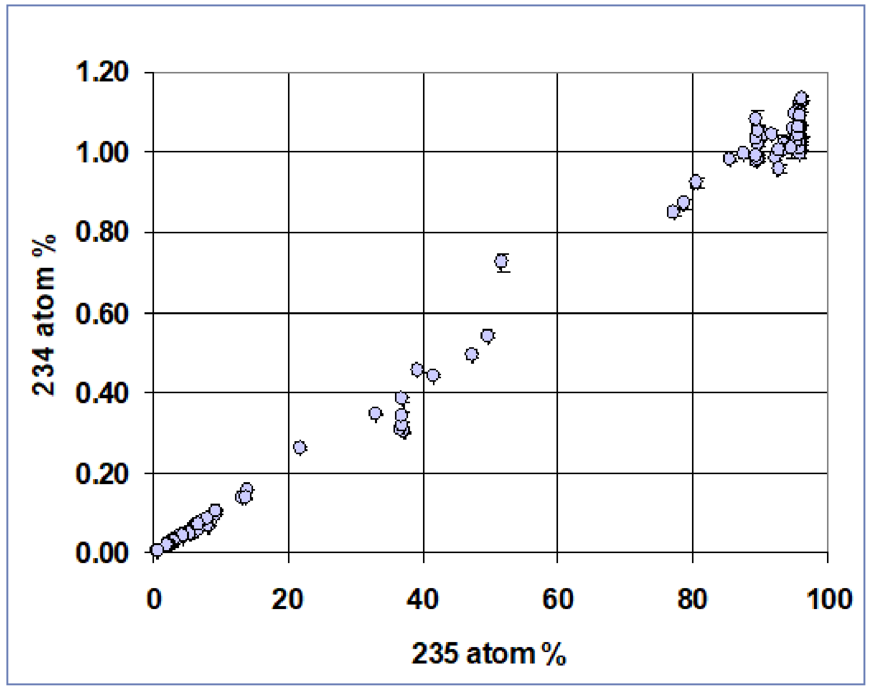


Fig. 7: ^{235}U enrichment vs. ^{234}U abundance in a nuclear forensics sample.

Future Objectives

- Maintain the output of the LG-SIMS laboratory at the maximum, i.e. about 100 sample analysis per year
- Maintain the high quality of results and fast turnaround time
- Fine-tune the process where applicable

KEYWORDS

Uranium
Environmental sampling
Particle analysis
Secondary Ion Mass Spectrometry
Nuclear material
Nuclear forensics
ISO17025

MAIN PARTNERS:
DG ENER, IAEA

OTHER INTERESTED DG'S:
DG HOME

MAIN STAKEHOLDERS:
- International safeguards authorities
- National safeguards authorities
- EU Member States


Laser based systems for the surveillance of nuclear storage facilities

3.2 SYSTEMS FOR THE CONTAINMENT AND SURVEILLANCE OF NUCLEAR MATERIALS

The objective of the project is to equip nuclear inspectors with the most advanced tools and techniques to verify that nuclear materials and facilities are used for peaceful applications, in compliance with the European and international safeguards legislation. The team brings together scientific and technological competences, such as laser science, robotics, digital imaging, machine learning and virtual reality to design, develop and test the most effective equipment for nuclear inspectors.

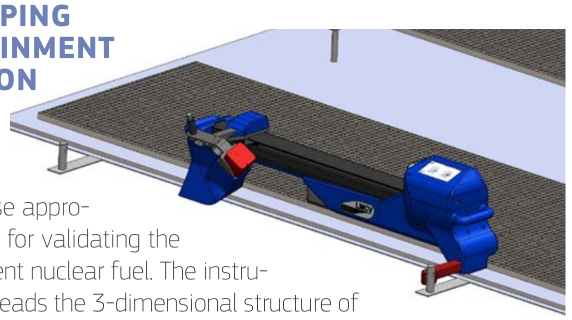
OPTICAL SOLUTIONS FOR NUCLEAR SAFEGUARDS

Overview

Nuclear Safeguards instruments have always used light as source to gather information. Recently, the use of more sophisticated systems have emerged thanks to the vast amount of industrial solutions available like commercially available laser scanners, miniaturized cameras, computer processing boards and displays.

The JRC has for a significant amount of years supported the Nuclear Safeguards industry with innovative solutions for complex problems. We interact with DG-ENER and IAEA finding solutions and assist with on-site installation support for different challenges. The four selected examples on this page shows various optical technologies with which the JRC is supporting the Nuclear Safeguards Industry.

01 LASER MAPPING FOR CONTAINMENT VERIFICATION



The **Laser Mapping for Containment Verification (LMCV)** system is an easy to use approved safeguards instrument used for validating the authenticity of containers for spent nuclear fuel. The instrument, operated by an inspector, reads the 3-dimensional structure of the lid closure welds using a laser and dedicated camera (fig 1). The authenticity is concluded by providing a 3-dimensional surface analysis against a reference data-set (fig 2). This concludes that the weld and surrounding metallic structure has not been opened or altered. This instrument provides a fast and effective way to assist the inspectors to validate the complete stock of containers in an installation during a Physical Inventory Verification. The instrument is currently in operation by both IAEA and ENER.

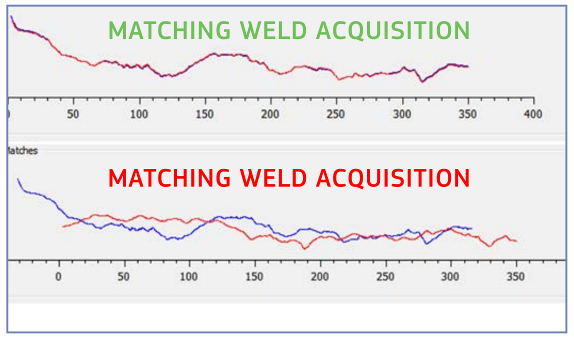


Fig. 1: (Top) Mechanical drawing of an LMCV instrument placed on top of spent fuel for a use-case in Europe.

Fig. 2: (Left) Analysis result of the fingerprint of a weld against correct and different welds.

02 EMBEDDED UNIVERSAL SEAL READER

There are several seals that can be used by Inspectors to immobilise an equipment or to prevent an object to be altered. A large number of both passive and active seals are applied every day. In order to validate the active seals in the field an inspector needs to bring a computer. For passive seals, another device with a camera would be needed. The JRC has since a few years developed a new portable device that can be hand-carried and perform reading operations for most common passive and active seals. This generic device is called the **Embedded Universal Seal-reader (EUSR).**

By using modern commercially available components, a small hand-carried reading platform is now available which has an exchangeable seal-reading mount. The intrinsic main module is enough to read the active seals (fig 3) and for each passive seal, currently available and future, a dedicated reading module (fig 4) can be applied which makes it possible to validate the correctness of the seals in in the field. This universal reader is easy to use and requires minimum training.

Fig. 3: (Top left) EUSR connected to the EOSS Active Seal (Top right) and AUAS Active Seal.

Fig. 4: (Bottom right) EUSR equipped with a Camera module to validate a passive seal.

03 SURFACE AUTHENTICATION

To support future Nuclear Safeguards challenges, the JRC has developed the prototype of a surface authentication system based on **Coherent Scanning Interferometry (CSI).**

Its initial application objective would be the authentication of spent fuel encapsulation canisters before and after transport operations, which are outside the immediate control of Nuclear Safeguards.

The working principle is based on the localized interference of white light. Interference occurs only, when parts of the surface topography move in focus during the measurement scan and allows to reconstruct the height information of the surface with high depth accuracy.

The technique resolves the shallow topography of engraving traces in the canister identifier tag as fingerprint used to uniquely validate the correct surface for authentication, as can be seen in the figure below. The current challenge is to translate this technique into a portable, fully automated authentication system for the field.

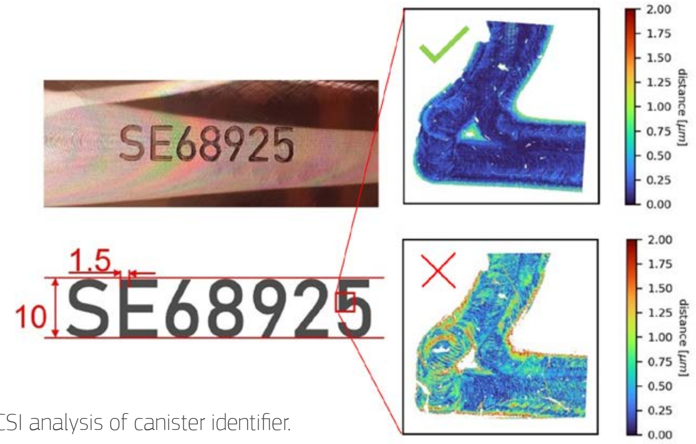


Fig. 5: CSI analysis of canister identifier.

04 NEW NUCLEAR SAFEGUARDS CAMERA CONCEPT

The JRC is working on a new concept for a Nuclear Safeguards camera using commercially available components aiming for a extendable and configurable system including a camera with advanced image processing. Additional resources such as enhanced processing power, laser scanners and gamma detectors can be added.

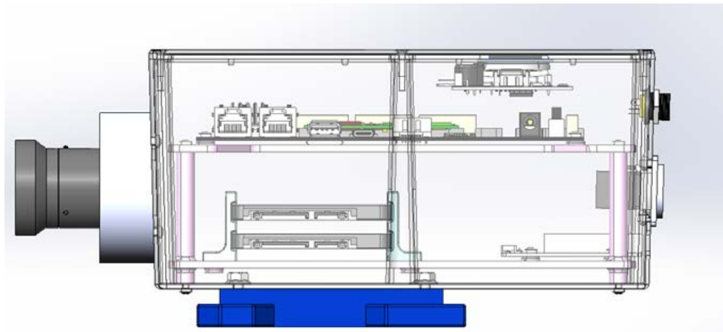


Fig. 6: Schematic drawing of the new Nuclear Camera concept from the JRC.

Future Objectives

Future developments includes extending Embedded Universal Sealreader with more passive seals and gamma detector module and to further develop the new camera concept .

KEYWORDS

Nuclear safeguards

Information management

Containment

Surveillance

Surface forensics

Light interaction

Photonics

Verification methodologies

MAIN PARTNERS:
DG ENER, IAEA

MAIN STAKEHOLDERS:
- DG ENER
- IAEA
- National Safeguards Authorities
- Nuclear Operators

3D MAPPING FOR NUCLEAR SAFEGUARDS VERIFICATION

Overview

For many years, the JRC has been developing 3D scanning techniques for nuclear safeguards verification.

Safeguards inspectors from DG ENER and IAEA use the tools in several facilities for the verification of the Basic Technical Characteristics (BTC) and Design Information Verification (DIV). The inspection activities include the verification of declared changes using static scanners, as well as verifying the absence of undeclared changes using mobile scanning.

The JRC provides technical support, both in preparation and during the on-site activities, including training the inspectors in the use of the 3D technologies.

01 3D LASER SCANNING

3D laser sensors allow building accurate 3D reconstructions of entire facilities and performing safeguards verifications over time (Fig. 1).

Depending on the use-case, two types of sensors are used: (1) static laser scanners, which provide high-resolution models with millimetre accuracy at the expense of long acquisition times (in the order of minutes per scan) and (2) mobile laser scanners, that provide real-time scans at the expense of lower resolution and accuracy (in the order of centimetres).

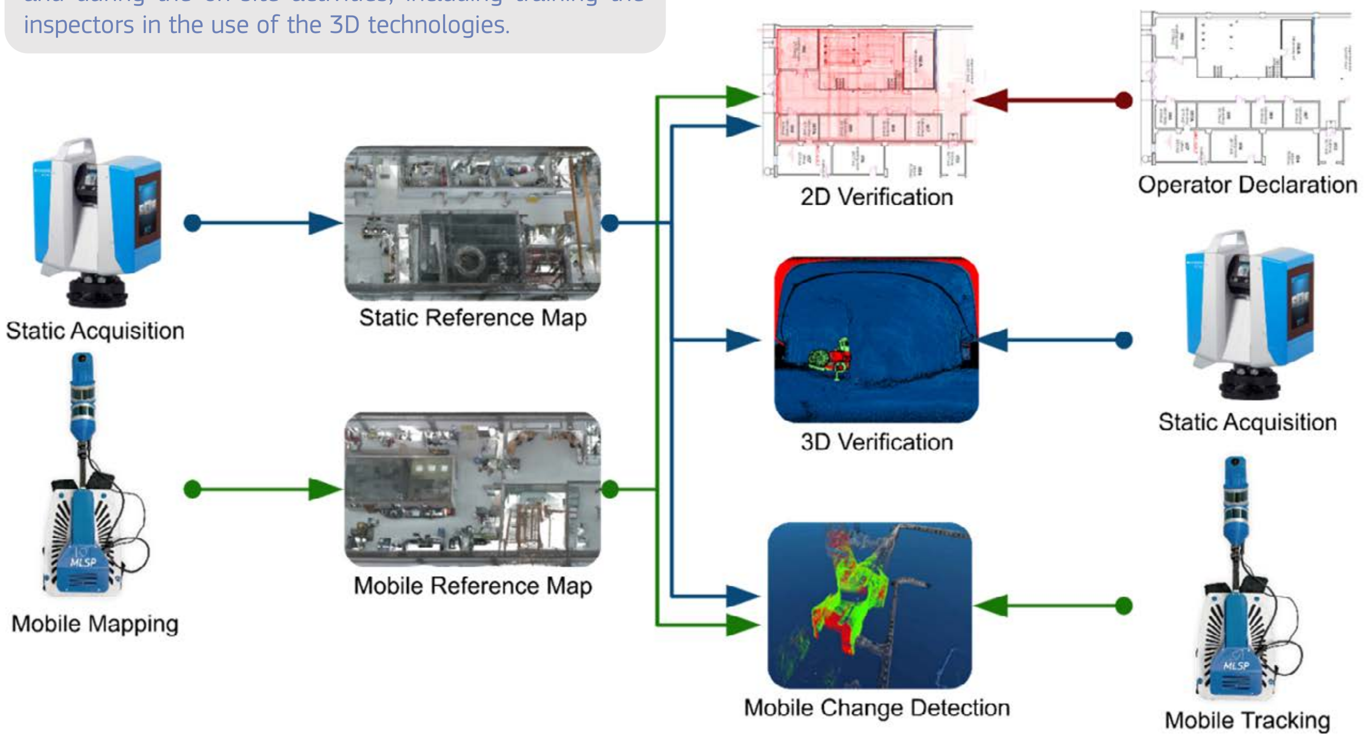


Fig. 1: Overview of the 3D verification pipeline. Laser sensors (left) allow building accurate 3D reconstructions of full facilities (centre-left) which are used as reference models. These models can be used to verify operator-provided design information of the facility (top-right), to perform accurate 3D analysis of changes over time (centre-right) or to perform real-time change detection (bottom-right).

02 THE MOBILE LASER SCANNING PLATFORM (MLSP)

The Mobile Laser Scanning Platform (MLSP) is a portable system developed by G.II.7 to support nuclear inspectors in safeguards applications (Fig. 2).

It is based on 3D SLAM (Simultaneous Localization and Mapping) technology: the laser scanner acquires several 3D scans per second and builds a 3D map as the sensor moves through the environment.

One of the key benefits of the system is that it does not rely on global positioning sensors, so it can work in GPS-denied environments (i.e. indoor or underground environments). The JRC has patented the MLSP and concluded a license agreement with an Italian SME, covering commercialization in non-nuclear applications.

Fig. 2: User carrying the MLSP backpack.

03 THE PROCESSING SOFTWARE: STEAM DESKTOP

STeAM Desktop is the in-house developed software for processing the 3D data acquired with the laser scanners. It has two main purposes:

Sensor integration and scan alignment: It imports scans from different sources (e.g., static laser scanners, the MLSP or 3rd party models) and combines/aligns them, resulting in a single, globally consistent 3D model.

Data analysis: STeAM Desktop provides a wide range of analysis tools that were developed to the specific needs of the nuclear safeguards inspector. Amongst others, it allows to compare 2D CAD drawings wrt 3D scanned models, 3D scans wrt other 3D scans or improving the live change analysis performed by the MLSP.

04 FEATURED APPLICATIONS

The technology has multiple applications, both in the nuclear and non-nuclear other fields. Some example use cases are:

Design Information Verification (DIV) @ Onkalo spent nuclear fuel repository: The technology was demonstrated by the JRC in 2007 in the Finish geological repository. Deployment by ENER and IAEA started in 2014 when a first reference 3D model was created. The inspectors update on a yearly basis the model with scans of new tunnels. To verify declared changes in the previously scanned areas the inspectorates use the mobile mapping system.

Physical Inventory Verification (PIV) @ Pierrelatte, France: Nuclear safeguards inspectors use the JRC's 3D technology for the yearly verification of the declared inventory of nuclear material at the facility in Pierrelatte, France.

3D Information Management System (3DIMS): A 3D database supporting the JRC's decommissioning activities was developed to geo-locate and track all the items in the facility under decommission (Fig. 3 – left). It is based on a full 3D model of the ESSOR reactor and the INE area at the JRC-Ispra.

Gamma radiation mapping: MLSP has the ability to act as an accurate GPS that works both outdoors and also indoors. It combines the measurements of a portable gamma detector with accurate live positioning. The results (Fig.3 – right) are accurate radiation maps of nuclear facilities that can be computed in real-time.

Non-nuclear applications: Through the collaboration with other the JRC units and the license agreement of the technology, the potential of our systems has been demonstrated in other domains, including infrastructure mapping in the JRC, construction monitoring, mapping of underground mines and cultural heritage.

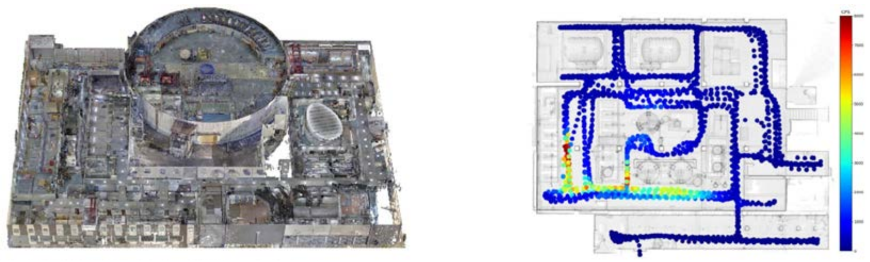


Fig. 3: (Left) 3D model of the ESSOR reactor for the decommissioning database, 3DIMS. (right) Gamma radiation mapping with the MLSP.

Future Objectives

Future developments include the integration of new nuclear-relevant sensors into mobile mapping and the application of the developed SLAM algorithms to robotic platforms.

KEYWORDS

- Nuclear Safeguards
- Containment and Surveillance
- 3D Mapping
- Digital Transformation
- Design Information
- Physical Inventory Verification

MAIN PARTNERS:
DG ENER, IAEA

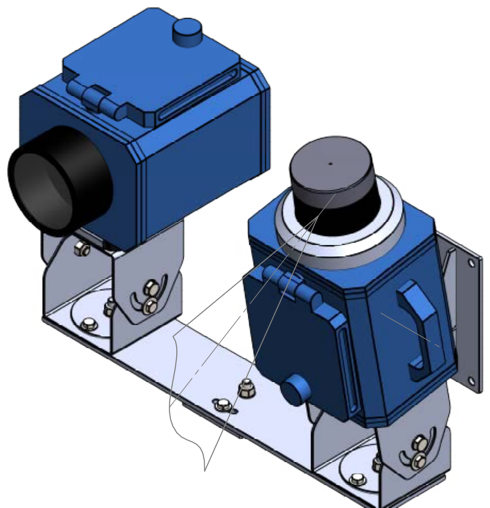
OTHER INTERESTED DG'S:
DG RTD

MAIN STAKEHOLDERS:
- DG ENER
- IAEA
- National Safeguards Authorities
- Nuclear Operators

3D SURVEILLANCE FOR NUCLEAR SAFEGUARDS VERIFICATION

Overview

Nuclear safeguards inspectors routinely apply video surveillance in hundreds of facilities in order to maintain continuity of knowledge between on-site inspections. The video footage needs to be reviewed manually and creates significant workload for the inspectorates. In order to increase the efficiency and effectiveness of the surveillance workflow, the JRC developed a 3D surveillance system, which complements traditional video cameras.



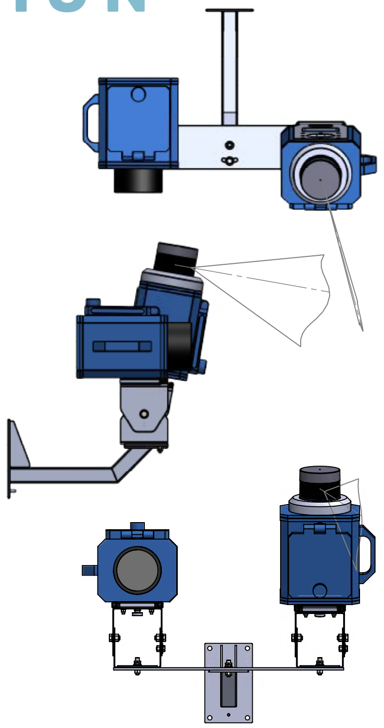


Fig. 1: A standard surveillance video camera (left) mounted in combination with a LCCT laser head (right).

01 LASER CURTAIN FOR CONTAINMENT AND TRACKING (LCCT)

LCCT is an active, continuous 3D surveillance system based on real-time laser scanners (Fig. 1), which allows event-based monitoring of nuclear facilities. It can remotely and securely transmit event data and has the potential to significantly reduce safeguards inspection effort.

On a local server running at the facility, all laser data is fused into a single 3D data set and analysed in real-time to monitor and track safeguards-relevant activities. Since the analysis works in a 3D space, event detection can be restricted to pre-defined areas of interest. Furthermore, the measurements are based on active laser light, which allows for a more robust event detection compared to the optical video surveillance.

The area of interest is divided into multiple monitoring zones. Any activity in the monitored zones triggers an event and the sequence of events can be used to verify declared activities. When an event is detected, the LCCT records the metadata (event type, time stamp and zone ID) and saves the corresponding laser data to a file (Fig. 2).

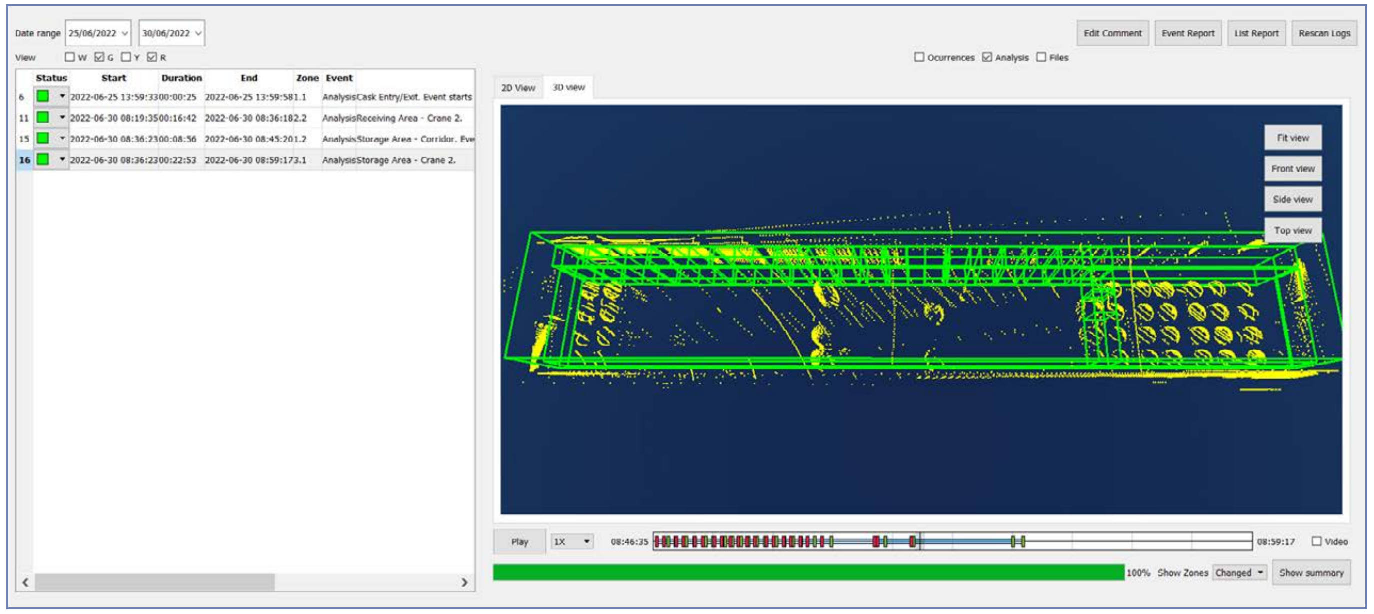


Fig. 2: Snapshot of the LCCT review tool. The table on the left lists all detected events, the view on the right shows the corresponding 3D data.

02 FEATURED INSTALLATIONS

LCCT has been deployed at various nuclear facilities since 2015:
La Hague, France: At the fuel reprocessing facility in La Hague France, Euratom is using LCCT to monitor movements of nuclear material in the spent fuel pond.

Atucha, Argentina: IAEA is using LCCT to monitor the transfer of spent fuel from the cooling pond to the dry storage at the nuclear power plant (NPP).

Spent Fuel Storage Facilities: A field trial is running in Gundremmingen, Germany, to evaluate LCCT for monitoring interim spent fuel storage facilities (SFSF). After the shutdown of the last NPP in Germany in 2023, all spent fuel will be transferred to on-site dry storages where the material will remain for several decades. LCCT can significantly increase the efficiency and effectiveness in safeguarding these quasi-static facilities. Deployment of LCCT in similar SFSFs in Belgium and Slovakia is scheduled for 2023.

Onkalo, Finland: The world-wide first final repository for spent nuclear fuel will soon go operational in Finland. LCCT is a core component of the safeguards equipment that will provide near-real time monitoring to the nuclear safeguards inspectors at Euratom and IAEA.

Fig. 3: Spent fuel storage facility at Gundremmeningen, Germany, used for field testing LCCT.

Future Objectives

Current R&D work integrates machine learning techniques to improve LCCT's detection and classification capabilities. This will allow to further automatize data analysis and distinguish safeguards relevant and non-relevant objects or activities (Fig. 4).

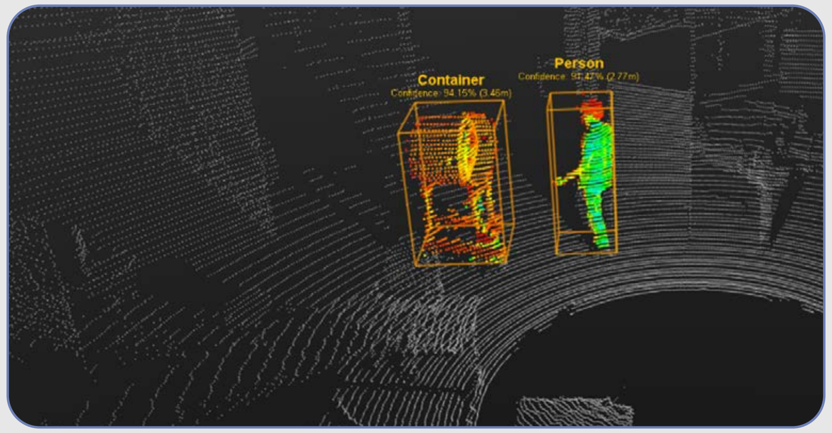


Fig. 4: Example of two safeguards-relevant objects detected in 3D scan data using a machine learning algorithm.

KEYWORDS

Nuclear Safeguards
Containment and Surveillance
3D Surveillance
Digital Transformation
Design Information Verification
Physical Inventory Verification

MAIN PARTNERS:
DG ENER, IAEA

OTHER INTERESTED DG'S:
DG RTD

MAIN STAKEHOLDERS:
- DG ENER
- IAEA
- National Safeguards Authorities
- Nuclear Operators

SEALS AND SEALING SYSTEMS

Overview

As part of containment in Nuclear Safeguards, seals play an important role since the beginning. Seals are essential in static or semi-static inventories to reduce the effort needed on verification activities. Seals, or Tamper Indicating Devices, are also essential in detecting unauthorized access to specific areas or equipment. The JRC has a long standing and acknowledged experience in containment systems and seals. JRC systems are used by Euratom inspectors in Europe and by IAEA inspectors across the globe. The research for new sealing systems that improve efficiency and effectiveness is well supported not only by inspectors but also by regulatory bodies and facility operators.

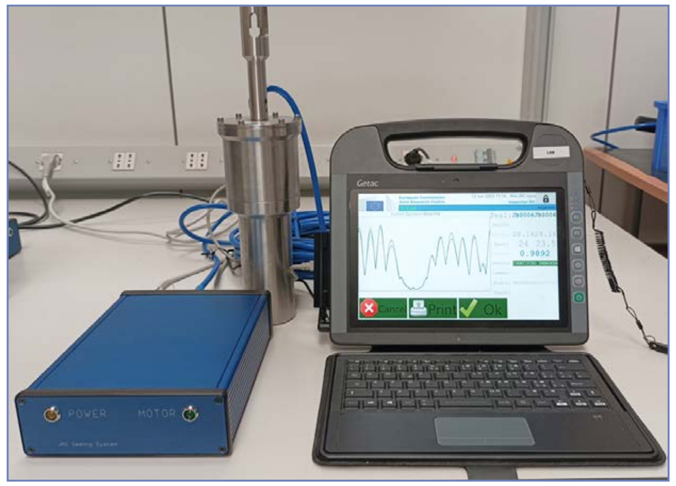


Fig. 1: The JRC Underwater Sealing System.

01 ORIGINS

UNDER WATER SEALING:
The JRC sealing activities in nuclear safeguards started at reprocessing facilities in France and UK, but really took off when a replacement of an existing sealing system for CANDU spent fuels was needed. The first ultrasonic seals and the complete acquisition and analysis system was then developed. The robustness of the system and its reliability made it suitable to be deployed in different facilities, starting from Romania to Canada, Pakistan and other countries.

Fig. 2: The CANDU ultrasonic seals.

02 ULTRASONIC SEALING SYSTEMS

The JRC ultrasonic sealing system is composed of three main parts.

- **The seal:** a special bolt which contains a distinctive fingerprint obtained by the fusion of a set of discs, which make each seal unique and not clonable.
- **The reading head:** a rugged instrument that can work underwater and under radiation which is precisely machined to align the ultrasonic probe to the inner unique pattern of the seal.
- **The acquisition system:** the electronic part that acquires the ultrasonic signal and converts it to digital data that is analyzed by the software to identify the seals and verify that they have not been broken. An important tool to assist the inspectors in their activities.

The system can be adapted to different locking systems.

On a specific request from inspectors, the JRC developed also a version of ultrasonic seals that can be used on dry storage casks. The seal, named Ultrasonic Optical Sealing Bolt, combines a traditional ultrasonic seal with a pass-through feature for optical fibers. This solution ensures that when the seal is removed, the optical fiber is cut. With this feature, a cask can be sealed also with other wire seals (passive or active) providing a great flexibility to inspectors and increasing the effectiveness of the wire seal. Such seals have been applied in Lithuania on a large number of casks, providing significant benefits in term of time spent on inspections, safety of personnel and reduced dose rate for inspectors.

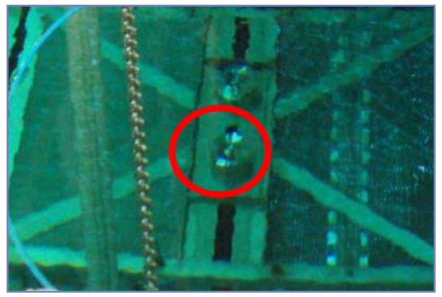


Fig. 3: A seal insalled in a spent fuel pond.

Fig. 4: Ultrasonic Optical Sealing Bolt (UOSB).

03 RESEARCH

In support of nuclear inspectors (Euratom and IAEA) the JRC did research on electronic and passive seals and is actively developing new sealing systems. Ongoing developments include the Operator Applied and Removed Seal (OARS) that consists in a remotely supervised system to reduce the need of on-site inspectors, particularly for frequent transport casks loading and unloading.

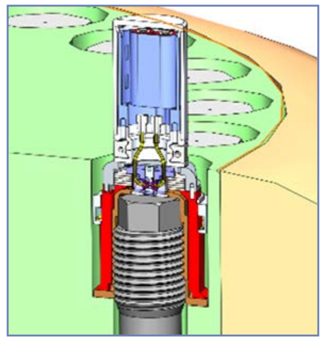


Fig. 5: (Above and below) OARS.

Another advanced development is the Reusable Random Pattern Passive seal (R2P2) which once completed will be the first reusable passive seal in safeguards. On top of the immediate cost advantage, it will also be easy to use and verifiable in field, using a universal seal reader, developed by the JRC. Such reader is able to verify most of existing safeguard seals and is an open platform ready to integrate future seals or other sensors.

Fig. 6: Reusable Passive Seal

04 TRAINING

The JRC provides training to inspectors on the use of its systems on location and on site. Training courses focus on hands on and practical activities to provide inspectors with the knowledge and expertise needed for their job.

Fig. 7: Testing facility.

Fig. 8: Training facility.

05 TEST AND VULNERABILITY ASSESSMENT

The JRC performs tests on its equipment (environmental tests, electrical, endurance) and delivers Vulnerability Assessment on third party equipment on request.

Future Objectives

Ongoing research in seals and containment systems is continuously striving to offer new and innovative solutions that not only enhance security but also improve efficiency in our increasingly interconnected world. In this digital age, where data availability and automation hold significant importance, innovative approaches are being explored, including the utilisation of advanced materials and the rapidly emerging field of additive manufacturing. These advancements present exciting opportunities for further advancements in this field. a look into the future of nuclear within the JRC.

KEYWORDS

Nuclear
Safeguards
Seals
Non-Proliferation
Nuclear Material
Spent fuel
Interim repository
Containment
Nuclear material
Euratom Treaty

MAIN PARTNERS:
DG ENER, IAEA

OTHER INTERESTED DG'S:
DG TAXUD

MAIN STAKEHOLDERS:
- Nuclear Inspectorates,
- Facility operators,
- Nuclear Safeguards Regulatory Bodies

VIDEOZOOM FOR SURVEILLANCE REVIEWS

Overview

Research on methods and tools for inspectors reviewing video surveillance streams.

VideoZoom uses image summaries and a zooming interface to enable the inspector's ability to detect safeguards-relevant events, whether typical or presenting anomalies.Inspectors see image details or context information on-demand.

Fig. 1: Installation of surveilence camera.

01 SURVEILLANCE

Nuclear safeguards verify that a State's nuclear material is not diverted in order to build weapons or explosive devices.

Camera surveillance in nuclear facilities helps to attain safeguards at a low cost since it does not require the continuous presence of inspectors in the facilities. Nor does it interfere with day to day plant operations.

02 IMAGE REVIEWS

Surveillance streams contain thousands of images. Inspectors review them in order to find the safeguards-relevant events.

The term 'safeguards-relevant' covers both operations expected during normal plant operation and possibly any irregular activities. Statistically less than 0.01% of the images in a stream are safeguards-relevant. Hence the need for tools to help focusing the inspectors' attention directly to the relevant parts of the image stream.

03 SCENE CHANGES

The current approach to image reviews makes use of scene change detection (SCD) within areas of interest (AOIs). AOIs are locations where safeguards-relevant events are expected to take place given the process under review.

Filtering the image stream by AOIs reduces the SCD events to be reviewed. This can be effective for regular processes, but not for the irregular ones (if any) as these may take place outside expected AOIs.

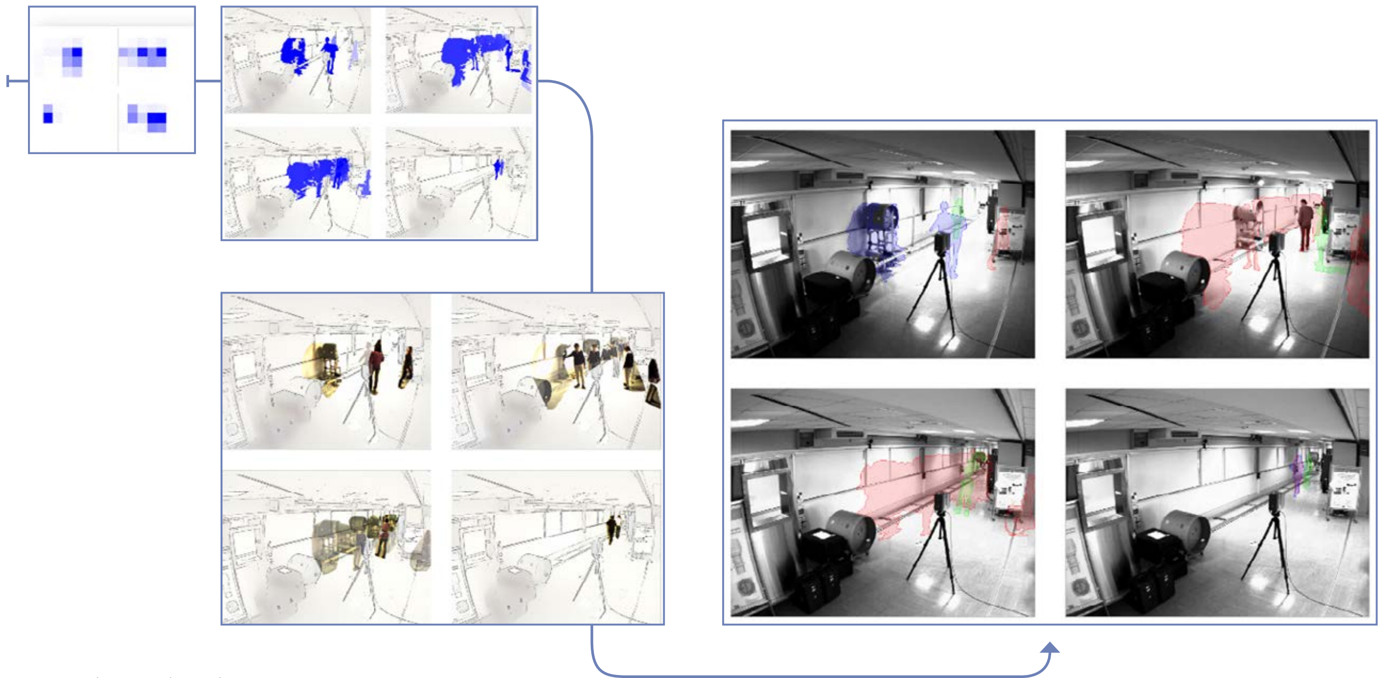


Fig. 2: The storyboard.

04 VIDEO SUMMARISATION

The JRC designed the VideoZoom prototype for image reviews removing the 'AOI assumption of relevance'. VideoZoom detects scene changes on the whole image plane.

Because changes are too numerous to be seen one-by-one at a photographic level, they are summarised and rendered at different levels of abstraction.

The image architecture is made of four layers of summaries, each one revealing more information about the image changes. The last layer of a summary is a video play of the images as taken by the camera.

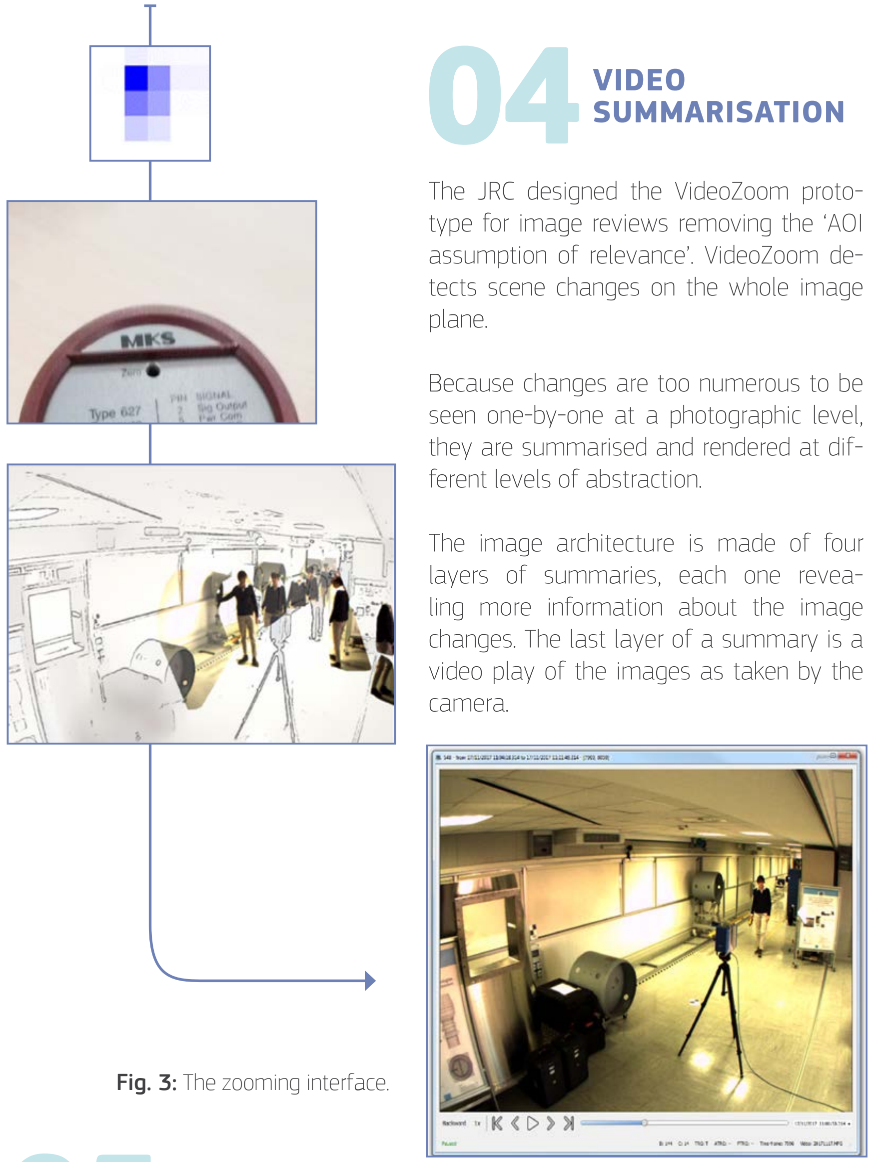


Fig. 3: The zooming interface.

05 STORYBOARD

During the image review the sequence of summaries is presented on screen like a storyboard. Summaries are ordered by time on a grid layout read left-right, top-down.

06 ZOOMING INTERFACE

On the storyboard a zooming interface allows the reviewer to navigate the summary layers and decide which are to be viewed with full photographic detail and, conversely, which can be skipped because of clear no safeguards-relevance.

In this way reviewers can make best use of their time by investigating what really requires their attention.

Future Objectives

VideoZoom is being integrated into the official image review tool in use at ENER and IAEA by safeguards inspectors. On the research side the JRC will extend VideoZoom by real-time Machine Learning to further assist the nuclear inspector in the detection of safeguards–relevant events within videosurveillance streams.

KEYWORDS

Video surveillance
Image review
Change detection
Safeguards-relevant events
Regular events
Anomalies
Video summarisation
Inspectors

MAIN PARTNERS:
ENER, IAEA

MAIN STAKEHOLDERS:
- Safeguards Authorities
- Nuclear Inspectors

Non-destructive assay equipment.

3.3 NON-DESTRUCTIVE MEASUREMENTS

Non-destructive assay or non-destructive analysis (NDA) is typically applied to determination techniques for plutonium and uranium (and other actinides) in items where the integrity is not altered or damaged. This is in contrast to destructive analysis (DA), which is a process of taking samples from the item in question and analysing the elements in these samples either by chemical means or by radiometric methods.

In nuclear safeguards, the items can be nuclear fuel pellets, fresh or spent fuel rods, cylinders with gaseous nuclear material, waste barrels, dry casks for long-term storage, and many others. NDA techniques measure either the radiation emitted by the isotopes during their decay or the radiation that is induced by another radioactive source. Most uranium and plutonium isotopes emit radiation that is specific for the isotope, and that can be used to assess the presence of the element and to quantify the amount of it inside, for example, a sealed container. The significant advantage of NDA techniques is timeliness. After items have been packaged, it is not economical to open the containers again for sampling. NDA measurements are the only reliable technique for heterogeneous items.

Nuclear inspectors in the field rely on both NDA and DA doing reliable and rapid non-destructive analysis while at the same time carefully selecting samples for assay off-site. In several situations, however, NDA tools are sufficient for verifying safeguards compliance, saving time and money.

IMAGING TECHNOLOGIES AND ADVANCED ALGORITHMS

Overview

In the recent years, the improvement of the performances of digital systems, together with the success of data-driven algorithms, has enormously improved the potential of imaging technologies. Accordingly, their application as a powerful asset in the context of international nuclear safeguards is increasing. The JRC and the scientific community are working to adapt and develop novel imaging techniques in safeguards, tackling the peculiar experimental and algorithmic challenges that these applications entail. A multidisciplinary approach is indeed required, merging numerical modelling, data science and experimental physics.

Fig. 1: High-energy X-ray tomography in Area 40.

01 EXAMPLE 1: PASSIVE GAMMA EMISSION TOMOGRAPHY

The Passive Gamma Emission Tomography (PGET) device allows inspectors to image directly the spatial distribution of active materials in spent fuel assemblies, aiming at detecting potential nuclear material diversion.

The analysis of PGET measurements and the evaluation of its applicability rely on the availability of comprehensive datasets. However, experimental data are expensive and limited: that is why Monte Carlo simulations are used to complement them. However, the computational cost is high (several days for simulating a single acquisition). We developed a physics-informed limited-data framework, able to produce high-fidelity PGET simulated data at a fraction of the computational cost, paying a sparing error penalty.

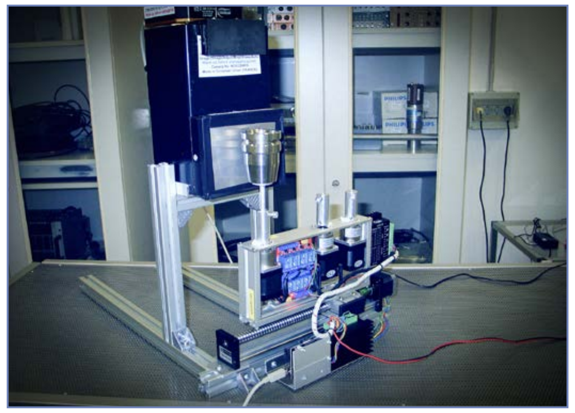


Fig. 2: Multi-probe tomography camera holding a seal.

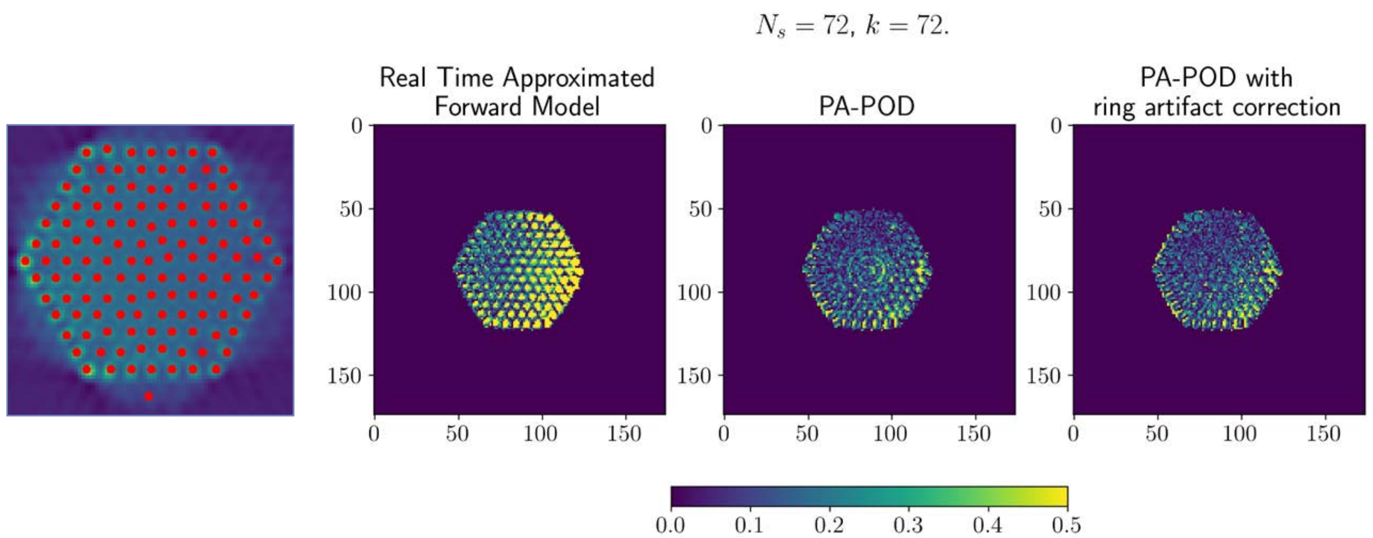


Fig. 3: Physics-Aware Proper-Orthogonal-Decomposition method in action: these relative error maps show how this approach allows to reconstruct a full measurement starting from a limited subset of data. The ultimate goal is to detect potential anomalies at a pin-wise level. (here to cutoff Ns=72 k=72 from the image: that is beyond the purpose of the figure in this context and hard to explain).

02 EXAMPLE 2: MULTI-PROBE DYNAMIC AND STATIC IMAGING

As an evolution of active interrogation of materials, multi-probe imaging is revealing as a powerful technique to characterize nuclear materials even in dynamic conditions. Indeed, due to the different radiation-matter interaction properties, different probes are able to highlight different materials' features. We are exploring the combination of X-ray and neutron tomography to characterize the spatial distribution of light elements, especially when they are embedded in heavy closed metallic environments.

Here, the experimental work meets the conceptualisation and implementation of cutting-edge algorithms to tackle image processing, data merging and scarce data reconstruction, arising many spin-off applications beyond safeguards. Indeed, these approaches find ground in many civil and industrial applications: one example is the in-situ and in-operando investigation of materials for energy supply, being the electrochemical properties often connected to the distribution and movement of light elements, such as hydrogen and lithium.

Fig. 4: Test sample with different materials.

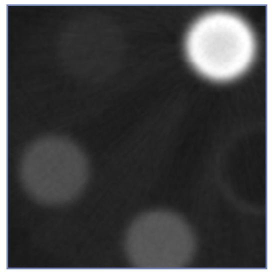


Fig. 5: Thermal neutron tomography.

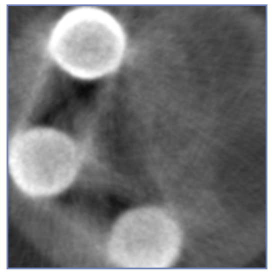


Fig. 6: X-ray tomography.

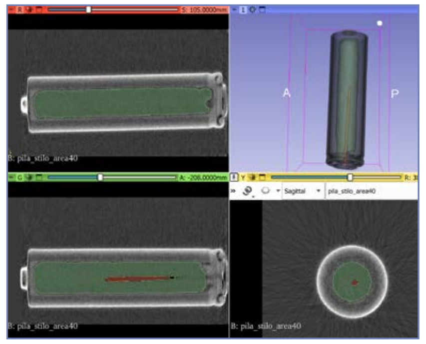


Fig. 7: X-ray tomography and segmentation of a common battery.

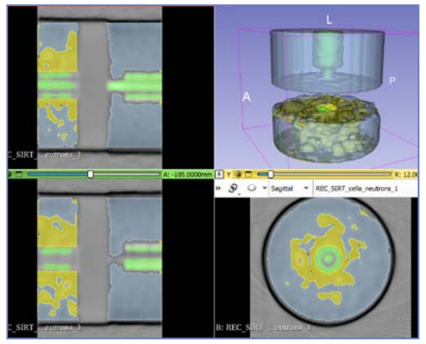


Fig. 8: Neutron tomography of a cycled zinc-spheroids-bed battery cell; materials segmentation detail.

Future Objectives

Among the ongoing activities, we are studying the feasibility of muon tomography for the reverification of dry casks for long-term storage of nuclear materials. Here, a non-destructive method is mandatory, and the high-energy cosmic muons represent a suitable probe to penetrate the thick and strongly absorbing materials casks are made of, leveraging the deeply penetrating properties of these particles. However, the atmospheric muon flux is such that a single muon passes through an area the size of a human hand per second: again, low-statistics and scarce data reconstruction algorithms will play a crucial role.

KEYWORDS

Imaging

Advanced Algorithms

Non Destructive Assay Techniques

3D Reconstruction

Tomography

Safeguards and Non-Proliferation

Partial Defect

Industrial Application of Nuclear Techniques

MAIN PARTNERS:
DG ENER

MAIN STAKEHOLDERS:
- Safeguards inspectors (Euratom, IAEA)
- Industry using Non destructive assay - Battery industry –
- University and research organisations

NON DESTRUCTIVE ASSAY EXPERIMENTAL AND VIRTUAL TECHNIQUES

Overview

Development and validation of new NDA techniques is constantly needed to face present and future challenges for complying with international obligations in nuclear safeguards and non-proliferation.

The JRC is supporting safeguards inspectorates (EURATOM/IAEA) not only for development/validation of Instruments and methods for nuclear material verifications but also in training.

01 THE D-D AND D-T NEUTRON GENERATORS

The JRC operates a D-D Neutron Generator (GENIE16) for the production of continuous or pulsed 2.5 MeV neutrons that allow the investigation of innovative active NDA techniques for nuclear safeguards applications. One example being the Compact Nuclear Resonance Transmission and delayed gamma spectrometry.

A D-T Neutron Generator for high neutron energy (14 MeV) for various NDA application such as Differential Die-Away Analysis; Neutron Activation Analysis, Active Prompt Gamma-ray analysis (analysis and nuclear data gathering); Analysis (experimentation and nuclear data gathering). The experimental set-up also allows the validation of Monte Carlo models.

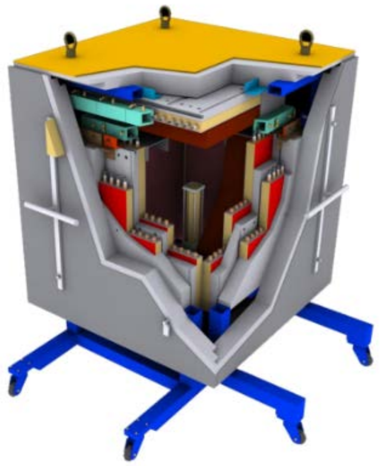


Fig. 1: The D-D neutron generator in operation in PERLA lab (above) and (right) a 3D rendering of the Pulsed Neutron Interrogation Test Assembly (PUNITA), a tool for development.

02 DELAYED GAMMA SPECTROMETRY (DGS)

DGS is an NDA technique, which consists of the analysis of short-lived fission products (FPs) in the high energy range (> 3 MeV) of gamma-ray spectra of a nuclear material sample irradiated with neutrons. The technique was first investigated in PUNITA Lab with a D-T neutron generator then further explored in PERLA lab using sealed 252Cf neutron sources and D-D neutron generator. DGS is suited for nuclear safeguards inspections specially for the high activity samples of irradiated nuclear fuel such as for uranium enrichments and plutonium isotopic compositions in MOX samples.

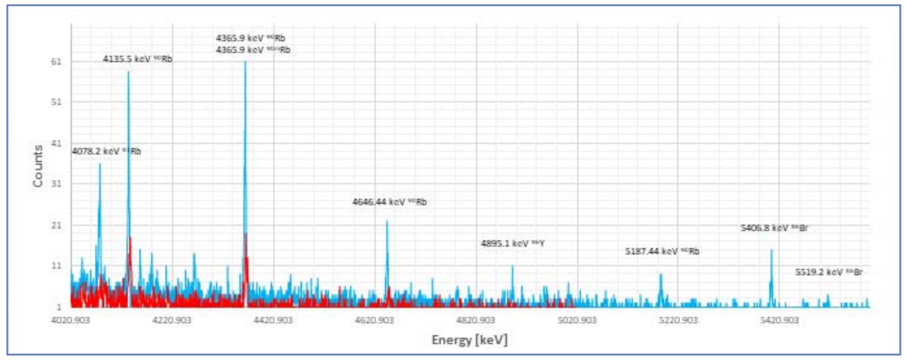


Fig. 2: Example of a DGS gamma-ray spectra of an irradiated and unirradiated uranium sample.

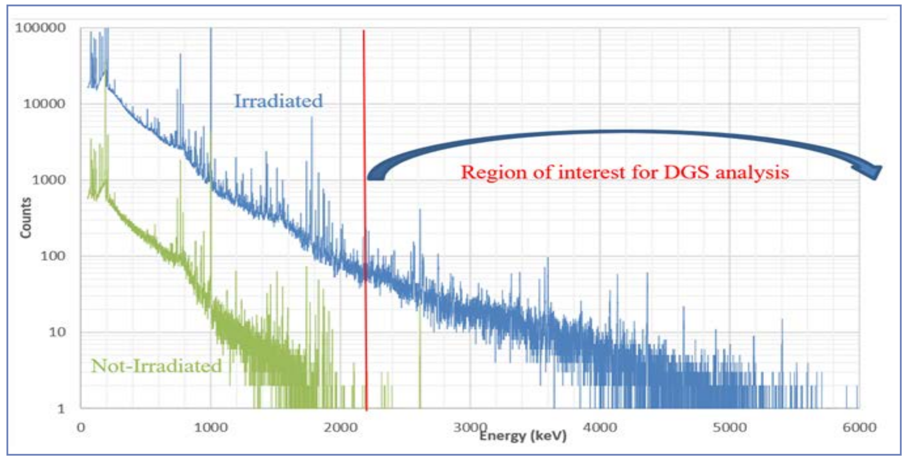


Fig. 3: Example of short lived fission products identified in the high energy gamma range of a DGS gamma-ray spectrum of a low enriched uranium sample.

03 NOVEL DETECTORS, ELECTRONICS AND ANALYSIS METHODS

New electronics and detectors have been developed to replace obsolescent equipment or to use as an alternative to He-3 as neutron detector to overcome the He-3 supply shortage. Novel time digitiser electronics allows to operate at higher count rates, to reduce counting dead-time, increasing the performance of existing and new systems and may be combined with more advanced data interpretation models.

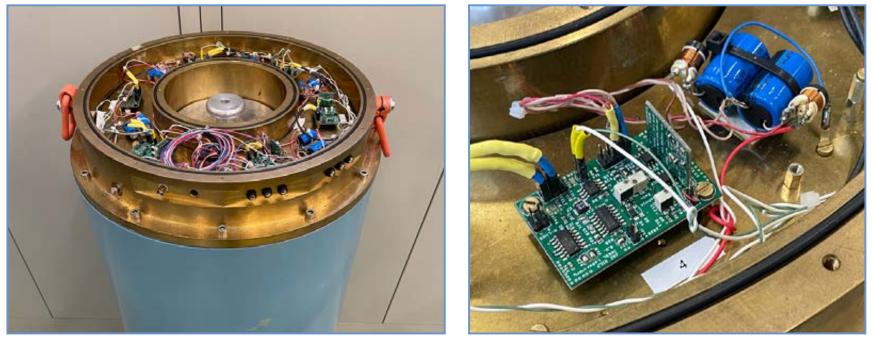


Fig. 4: The JRC BBNCC – Boron Based Neutron Correlation Counter with novel pre-amplifier/amplifier circuits.

04 VIRTUAL ENVIRONMENT FOR THE TRAINING OF INSPECTORS

VR is a simulated 3D environment that allows trainees to explore and interact with virtual surroundings such as virtual nuclear materials, instruments or equipment. VR is experiencing a notable expansion in many fields. VR is currently used in many applications for entertainment, but it is being increasingly used also for industrial applications such as product development. In this way VR technology is being explored for nuclear safeguards and security training.

Fig. 5: A virtual view of the Perla laboratory.

Future Objectives

Equipment currently used for nuclear safeguards inspections in the field is aging and will need refurbishment or replacement in the future. The new instruments and electronics that have been developed combined with the acquired know-how will provide a solid basis to tackle the above challenge. List mode acquisition may improve the accuracy and precision of the measurements give an opportunity to allow the quality control of the measurements.

Research in measurement techniques like DGS may result in the development of new tools for the safeguards of spent fuel.

KEYWORDS

Safeguards and Non-Proliferation
Advanced Digital Techniques
Non Destructive Assay Techniques
Neutron Generators
List Mode Acquisition
Novel Electronics
Training
Mixed Reality
Augmented and Virtual Reality

MAIN PARTNERS:
DG ENER

MAIN STAKEHOLDERS:
- Safeguards inspectors (Euratom, IAEA)
- Industry using Non destructive assay
- University and research organisations

GAMMA SPECTROMETRY OF URANIUM AND PLUTONIUM

Overview

The JRC continuously evaluates and improves gamma spectrometry for determining isotopic composition of uranium and plutonium. This helps safeguards inspectors in the filed and analysts in safeguards labs to optimise the use of gamma-spectrometers and improve the non-destructive isotopic analyses of uranium and plutonium.

01 INTRODUCTION

Gamma spectrometry is the main method used by nuclear safeguards inspectors for fast in-field verification of uranium and plutonium. It is a non-destructive method, which enables swift determinations of the uranium enrichment and of plutonium isotopic composition in field. Examples of the JRC contributions to the improvement of this method include isotopic analysis of shielded nuclear material, evaluating influence of bismuth on uranium measurements, validation of spectrum analysis for European mixed-oxide (MOX), medium-resolution gamma spectrometry (MRGS) and a large free spectrum database.

02 ISOTOPIC ANALYSIS OF SHIELDED MATERIAL

The JRC-Karlsruhe tested the FRAM software's ability to accurately determine the isotopic composition of shielded uranium and plutonium. Over 17 000 spectra of certified reference materials were analyzed using different FRAM parameter sets. The performance of FRAM was evaluated based on shielding thickness, measurement time, isotopic composition, and spectrum quality. For uranium analysis, a new FRAM parameter set was developed, providing more accurate results than the default sets. For plutonium the default parameter sets were found to be optimal. As nuclear material is frequently stored in shielded containers, these results are relevant for the daily work of nuclear safeguards inspectors in the field.

03 BISMUTH AND ISOTOPIC ANALYSIS OF URANIUM

The X-ray fluorescence (XRF) peaks of bismuth impact the determination of ^{235}U enrichment by gamma spectrometry. Fig. 1. shows the overlapping peaks. These XRF peaks are present in most spectra recorded by germanium detectors built after 2003, due to bismuth in the new detectors, and in spectra of reprocessed uranium and of some cladded uranium fuel, due to bismuth in these materials. The JRC-Karlsruhe found that bismuth in the detector causes a bias of about 3% in the measured ^{235}U enrichment. If bismuth cannot be avoided, bias correction or increased reported uncertainty should be considered. Detector manufacturers were informed and already provided bismuth-free detectors for safeguards.

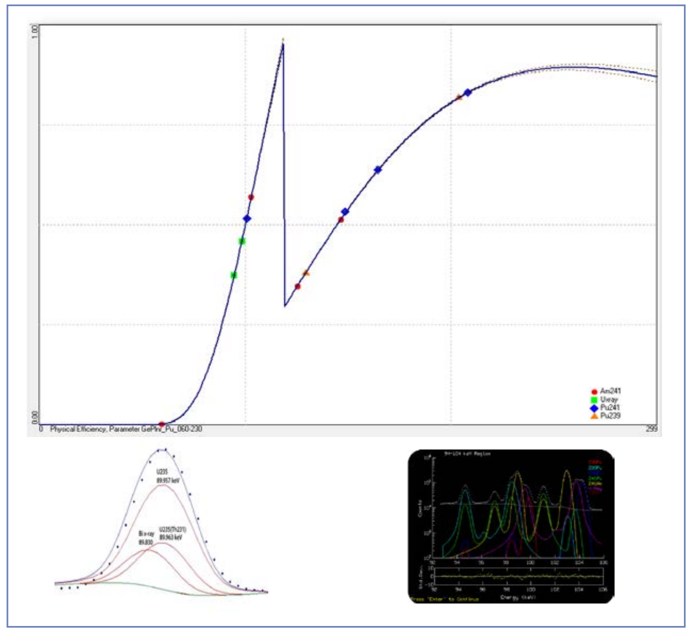


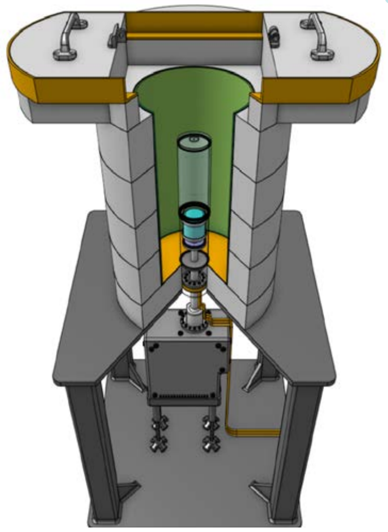
Fig. 1: Gamma spectrum analysis.

04 MEDIUM-RESOLUTION GAMMA SPECTROMETRY

MRGS is increasingly used for in-field nuclear safeguards measurements due to its portability and ease of maintenance. However, there is still room for improvement in related spectra analysis software. The JRC-Karlsruhe collected high-quality medium-resolution spectra of certified uranium and plutonium reference materials using CdZnTe and $LaBr_3$ detectors, in collaboration with the IAEA. These spectra are crucial for developing and validating spectrum analysis algorithms.

Fig. 2: Setup for recording spectra of a Pu sample by a CdZnTe detector.

05 ISOTOPIC ANALYSIS OF EUROPEAN MOX FUEL



All routinely used software for plutonium isotopic analysis has been developed outside Europe, and has been validated for non-European plutonium. However, the plutonium in European MOX fuel, with its high burn-up level, is unique. Therefore, the JRC and its international partners work on testing and fine-tuning the software for European plutonium. This is a key element for trustworthy nuclear safeguards in Europe.

Fig. 3: Schematic view of a high-resolution gamma spectrometer at the JRC-Karlsruhe.

06 OPEN DATA FOR OPEN SCIENCE

The JRC-Karlsruhe recorded around 20 000 spectra of certified reference materials for research topics on gamma spectrometry, using high-resolution and medium-resolution gamma spectrometers. All spectra are freely available through the JRC Data Catalogue: https://data.jrc.ec.europa.eu/collection/id-00266

To extend the free spectrum database, the JRC-Karlsruhe will use validated open-source modelling and simulation tools to generate artificial spectra, representing a wide range of material compositions and experimental setups.

07 CONCLUSION

The JRC is continuously improving gamma spectrometry for determining the isotopic composition of uranium and plutonium, helping safeguards inspectors and analysts optimise the use of gamma spectrometers. The JRC-Karlsruhe has tested and improved the isotopic analysis of shielded nuclear material, collected high-quality gamma spectra of certified uranium and plutonium reference materials, and evaluated the influence of bismuth on uranium measurements. The JRC-Karlsruhe also works on validating spectrum analysis algorithms for European MOX and creating a large free spectrum database.

Future Objectives

- Filling the gaps in open data for algorithm development and validation
- Developing and improving software analysis algorithms
- Keeping continuity of knowledge

KEYWORDS

Euratom Treaty

EU regulations

Plutonium

Uranium

Physical Inventory Verifications

Gamma spectrometry

Isotopic composition

Open data

Spectrum database

European MOX fuel

MAIN PARTNERS:
DG ENER, IAEA

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- IAEA

Euratom and IAEA Safeguards Inspectors.

04 KNOWLEDGE DISSEMINATION EDUCATION & TRAINING IN NUCLEAR SAFEGUARDS

The European Year of skills 2023 has boosted participation and talent through lifelong learning to have a workforce with the skills in demand for transitioning to a low-carbon economy. The Council of the European Union stressed, in 2008, the importance of the availability of skills and competences in the nuclear field in the framework of education and training. A decade later, the JRC presented a Nuclear Job Taxonomy based on the methodology from the OECD-NEA. In 2019, ESARDA put forward a Roadmap to its future strategic direction to embrace the Young Generation by fostering educational and knowledge management activities. The ESARDA academic course on Nuclear Safe- guards and Non-Proliferation is recognised by the European Nuclear Higher Education Network (ENEN) aiming at students and young professionals from nuclear engineering and analytical sciences but also from other fields, such as law, international relations, political sciences, behavioural sciences and statistics. The Specialising Master programme in Nuclear Safeguards was, for the first time, implemented at the Politecnico di Milano under coordination by ENEN and funding by the EC in 2022.

STRENGTHENING SAFEGUARDS THROUGH TRAINING AND CAPACITY BUILDING

Overview

Nuclear safeguards is an absolute priority for the EU. The Joint Research Centre provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society. At a technical level, the JRC plays an important role in the field of nuclear research, training and education to strengthen nuclear safeguards. The JRC works closely with Euratom safeguards , whose mission is to ensure that nuclear material within the EU is not diverted from its intended peaceful use according to the Euratom treaty. Technologies, methodologies and trainings are developed according to the Euratom Safeguards inspectorate's needs. At an international level, the JRC cooperates with the IAEA mainly through The European Commission Support Programme (EC-SP) to the International Atomic Energy Agency in the field of research and development in Nuclear Safeguards.

01 THE JRC SAFEGUARDS TRAINING PORTFOLIO

The portfolio of training courses offered by EUSECTRA at the JRC is based on identified needs of Euratom and the IAEA. The JRC with its strong expertise in Research & Development (R&D) over decades offers in close interaction and concertation with safeguards inspectors the following training courses:

- Additional Protocol Exercise (APEX)
- International course on Nuclear Safeguards and Non-Proliferation
- Safeguards tank calibration course
- 3D Laser-based Design Information Verification
- Passive Neutron Assay
- Active neutron interrogation Active Well Coincidence Counter (AWCC)
- ESARDA Course Nuclear Safeguards and Non-Proliferation
- Estimation of uncertainties and the use of reference materials (EURM).
- Mass/Volume Methodology and Tank calibration course
- Laser Curtain for Containment and Tracking (LCCT)
- Laser Mapping for Containment Verification (LMCV)
- The JRC ultrasonic sealing systems
- Uranium enrichment and plutonium isotopic composition verification

02 NON DESTRUCTIVE ASSAY (NDA) TRAININGS

NDA nuclear safeguards training take place in a specifically dedicated separate laboratory of the European Nuclear Security Training Centre- EUSECTRA at the JRC-Karlsruhe and the JRC-Ispra, where exclusively encapsulated radioactive material is handled. Hands-on NDA training provides Euratom and IAEA inspectors a unique opportunity to become familiar with detection and verification of nuclear materials in real conditions. These trainings focus on active and passive neutron counting techniques as well as on gamma-ray measurements.

Fig. 1: NDA training held in the EUSECTRA lab at the JRC-Karlsruhe.

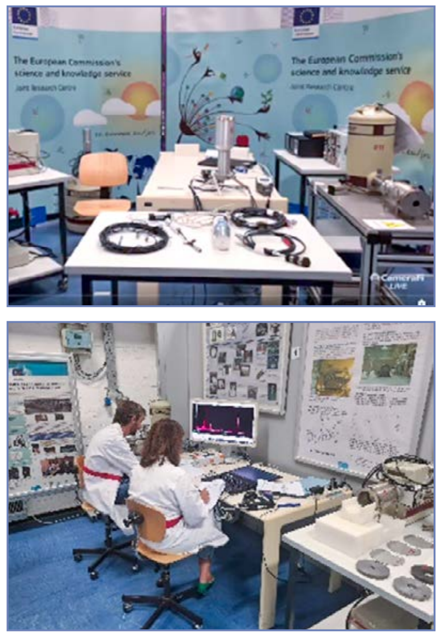


Fig. 2: Gamma-ray spectrometry training in the EUSECTRA lab at the JRC-Ispra.

03 LASER TECHNIQUES FOR CONTAINMENT AND SURVEILLANCE (C/S) TRAINING

Lasers have various applications in safeguards, particularly for C/S. Laser technology allows inspectors to perform scans for integrity verification purpose as well as 3D-surveillance. A set of these trainings are delivered at the JRC-Ispra for both IAEA and Euratom inspectors.

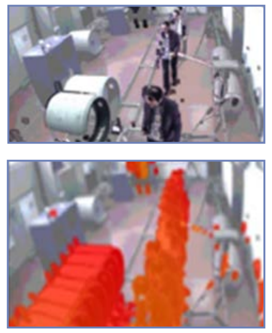


Fig. 3: 3D-lab at the JRC-Ispra.

04 TRAININGS IN SEALS

Seals play an important role in the implementation of safeguards. The JRC offers in Ispra trainings for IAEA and Euratom inspectors on the utilization of seals in their verifications duties. These trainings cover the use of ultrasonic seals for underwater and dry storage of nuclear materials. Some of these seals are developed at JRC-Ispra.

05 INTERNATIONAL COURSE ON NUCLEAR SAFEGUARDS AND NON-PROLIFERATION (ESARDA COURSE)

This annual one-week course organised at the JRC-Ispra is open to students but also to young professionals from the nuclear and related fields. It aims at complementing nuclear engineering, environmental or political studies by including nuclear safeguards and non-proliferation. The course addresses aspects of the efforts it takes to create a global nuclear non-proliferation system and its operation in practice. The course includes lectures, group exercises and lab visits and covers most aspects of Safeguards and its implementation.

06 ADDITIONAL PROTOCOL EXERCISE : APEX

APEX started in 2012 at JRC-Ispra and is currently organised annually at JRC-Karlsruhe. This exercise offers a unique opportunity for both IAEA and Euratom inspectors to prepare and conduct a complementary access inspection in a complex R&D environment. Such exercise is a key element to train inspectors to assure the absence of undeclared nuclear material or activities at nuclear sites and installations.

Fig. 4: Trainees in a R&D environment during APEX training at JRC - Karlsruhe.

Future Objectives

The JRC will continue to develop trainings to meet the requirement of inspectors in order to give them appropriate knowledge to ensure peaceful use of nuclear materials. On top of in-presence training, further development of on-line training to support continuity of knowledge is foreseen.

KEYWORDS

Nuclear
Safeguards
Seals
Non-Proliferation
Euratom
ADDITIONAL PROTOCOL
Lasers
Nuclear Material
Training
NDA
ESARDA
ESARDA Syllabus
EUSECTRA
JRC Science and Knowlege activities
EURM training

MAIN PARTNERS:
DG ENER, IAEA, DG HOME

OTHER INTERESTED DG'S:
DG INTPA, DG FPI, DG EMPL

MAIN STAKEHOLDERS:
- Member States

EUROPEAN SAFEGUARDS R&D ASSOCIATION - ESARDA

Overview

ESARDA is an association of European organisations formed to advance and harmonise research and development in the area of nuclear safeguards.

Created in 1969, ESARDA is a network of organisations including national regulatory authorities (carrying out the controls), nuclear facilities operators (those being controlled), research centres and universities (carrying out the safeguards-related R&D), aiming to bring together the international nuclear safeguards community. Currently ESARDA forms a network of organisations and partnerships inside and outside the EU for co-ordination of research, exchange of information and joint execution of R&D programmes through various activities such as:

- Annual Meetings and Symposia
- Working Groups
- ESARDA Publications
- ESARDA academic course on Nuclear Safeguards and Non-Proliferation

In 2019 ESARDA issued the 50th anniversary symposium report on the ESARDA Reflection Group 2019, which defined a roadmap of actions to engage all its parties, members, partners and the public in fostering ESARDA's relevance for the next decade.

01 ESARDA'S HISTORY AT A GLANCE

ESARDA was established in 1969 as a joint venture between the European Atomic Energy Community (Euratom) and the Karlsruhe Nuclear Research Centre (KfK, Germany) "to harmonise the R&D activities in the area of international safeguards and ensure a mutual exchange of information and technical assistance". Hence, the JRC was involved from the very beginning and has taken a prominent role throughout that period. ESARDA is a forum forum for the exchange of information and ideas between nuclear facility operators, safeguards authorities and persons engaged in R&D. More than five decades later, ESARDA still remains THE platform for bringing partners and stakeholders together, significantly contributing to raise professional safeguards standards. ESARDA's main objective is to assist the European and International safeguards community with the advancement of safeguards, enhancing the efficiency of systems and measures, as well as investigating how new techniques and approaches can be developed and implemented.

ESARDA's different phases in the evolution and examples on achievements throughout decades in the cooperative development of safeguards are published in the 50 years Anniversary Booklet.

02 THE JRC'S ROLE IN ESARDA

The JRC as a founding member of ESARDA has been playing an essential role in the operation and orientation of ESARDA. The JRC provides for the secretariat of the association and issues the ESARDA Bulletin. Moreover, the ESARDA academic course on Nuclear Safeguards and Non-Proliferation is hosted at the JRC-Ispra site and co-organised by the JRC's Nuclear Safety and Security directorate. JRC experts serve at various levels (Steering Committee, Executive Board, Working Groups, Editorial Committee) providing guidance and contributing to the advancement of safeguards technologies and methodologies.

03 ESARDA GOVERNANCE AND STRUCTURE

ESARDA is an association established by an Agreement, which has legal force according to the Belgian law.

As of 2023, ESARDA counts 36 Parties, 15 Associated members, and six collaboration agreements.

The European Commission represents the European Atomic Energy Community (Euratom). The JRC holds the ESARDA secretariat.

ESARDA's asset consists in the parties, associated and individual members, collaborators as well as representatives from collaboratiing organisations such as IAEA, ABACC, AFCONE, APSN, ENEN. In 2023 INMM and ESARDA held their second Joint Annual Meeting on *Atoms for Peace* – Evolution of Technologies for the Future. The success of ESARDA strongly depends on the commitment of each organisation and the voluntarily engagement of each member actively involved in nuclear safeguards R&D.

04 ESARDA PUBLICATIONS AND COURSES

The ESARDA Bulletin is the indexed academic peer-reviewed journal featuring scientific and technical articles related to safeguards and verification. The ESARDA Connector is the Newsletter dedicated to disseminating activities within the association. The ESARDA academic course on Nuclear Safeguards and Non-Proliferation is co-organised by the JRC and the ESARDA Training and Knowledge Management working group (WG). The modules for the first ENEN Specialising Master Programme in NUCLEAR SAFEGUARDS were developed in collaboration with different ESARDA WGs.

05 ESARDA WORKING GROUPS

ESARDA has established standing Working Groups dealing with various technical subjects. The Working Groups (WG) are the key bodies of ESARDA!

Discipline – oriented WGs:

- Techniques and Standards for Destructive Analysis
- Techniques and Standards for Non-Destructive Analysis
- Containment and Surveillance

International WG:

- Gamma Spectrometry Techniques for U/Pu Isotopics

Horizontal – oriented WGs:

- Export Control
- Final Disposal
- Implementation of Safeguards
- Material Balance Evaluation
- Training and Knowledge Management
- Verification Technologies and Methodologies

06 ESARDA'S RELEVANCE FOR THE NEXT DECADE

The ESARDA Reflection Group 2019 (RG2019) established a roadmap for the ESARDA short and medium-term future priorities based on the new landscape in Europe and internationally. During the ESARDA 50th anniversary symposium an interactive session, was held to harness the collective intelligence rooting the RG2019 roadmap actions transparently for active ownership and implementation at organisational and individual level.

ESARDA holds annual meetings, symposia and organises dedicated and joint events with its partners and stakeholders to build on co-creation and synergies for keeping ESARDA abreast of developing technologies in a changing world.

Future Objectives

- ESARDA priorities are driven by the requirements of EC safeguards policy, its evolution, and resource constraints in implementing safeguards
- ESARDA remains the R&D network for the design, development, test and validation of innovative safeguards approaches with specific technical objectives
- ESARDA aims to enhance the visibility of nuclear safeguards and reach out to young generations and new partners
- ESARDA must consider the changing (geo)-political agenda and public initiatives even if sometimes beyond ESARDA's 'mandate' for nuclear safeguards R&D development and outreach to maintain its relevance and influence over the next decade and beyond

KEYWORDS

ESARDA | ESARDA Flyer | ESARDA Anniversary Booklet | ESARDA Connector | ESARDA Bulletin | ESARDA Syllabus | ESARDA Reflection Group 2017-2019 Report | ESARDA World Café Report 2019

MAIN PARTNERS:
DG ENER, IAEA, EEAS

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:

- Safeguards authorities
- Member States
- Industry
- Research
- Academia

Explore the possibilities of our future.

05 FORESIGHT

The JRC must respond to the changing scientific and political landscape, building on a solid partnership with Euratom safeguards. Foresight will become increasingly a tool to evaluate and assess future JRC strategies for R&D in safeguards. Increasing emphasis is given to outreach and exchange with experts and initiatives beyond nuclear safeguards and beyond the nuclear field as such. Similar analytical methods, techniques, instrumentation and metrological quality tools needed in safeguards are equally applicable or applied in nuclear forensics, nuclear decommissioning and waste management, the development of small modular nuclear reactors and advanced reactor systems, in nuclear medical applications, in export control, in geochemistry, and even in food industry. Particularly, methods and approaches in data and text analytics, together with outreach to AI and machine learning, are of significant interest.

The biggest challenge, though, remains to address the ageing workforce in the nuclear safeguards field and to engage the next generation by communicating JRC's assets and the vast potential for synergies of safeguards R&D and the European Green Deal.

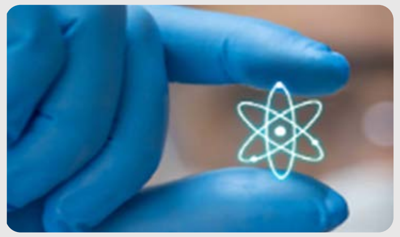
FUTURE AND FORESIGHT IN NUCLEAR SAFEGUARDS

Overview

The JRC's Strategy for Nuclear Activities identified key actions necessary for future adjustments in response to the changing scientific and political landscape in the EU and at a global level.

The JRC and Euratom Safeguards (DG ENER) will work even closer together, implementing nuclear safeguards in Europe in line with Euratom Treaty chapter 7 as two arms of one body. The JRC will further ensure an active and strategic partnership with EU Member States, international organisations and third countries addressing the future priorities and challenges in nuclear safeguards, security and safety (3S).

Foresight tools will be increasingly used to present a science-based vision of emerging issues in safeguards. Focus will equally be given to develop tools for efficient knowledge management and to incorporate this element as part of the research activities to respond to the challenge of an ageing workforce in the nuclear (safeguards) field.



01 EURATOM SAFEGUARDS (DG ENER) AND THE JRC – A STRONG AND LONGSTANDING PARTNERSHIP FOR THE FUTURE

DG ENER analyses the information declared by all users of nuclear materials within the EU and performs on-site inspections to verify their correctness, completeness and coherence. The JRC provides the necessary evidence-based science, research and knowledge tools to DG ENER needed for this implementation of the Euratom Treaty chapter 7 within a close JRC – DG ENER partnership.

Current and future ENER - the JRC nuclear safeguards priorities:

- Continued operation of the Euratom Safeguards On-site Laboratory in La Hague, France
- Support in technical development
- New surveillance technologies
- Business intelligence, data analysis and integration

Emerging safeguards challenges to be addressed by DG ENER and the JRC:

- Decommissioning of individual nuclear installations
- Deep geological repositories
- Small holders of nuclear material
- Closeness of Euratom Safeguards operations to their political mandate

02 THE IAEA DRIVERS 2057: EXPLORE THE POSSIBLE

The International Atomic Energy developed with external experts, including experts from the JRC, the IAEA Drivers 2057 card deck. All participants in the Symposium on International Safeguards in 2022 (#IAEASG2022) were invited to a journey on exploring the past and imagining a range of issues that are shaping the future operating environment for safeguards:

- Society
- Emerging Technologies
- Climate and nuclear energy
- Economy
- Geopolitics, Security and Governance

By using this IAEA Drivers 2057 card deck, the safeguards community can rehearse different versions of the future and design more adaptive strategies for dealing with the rapidly changing context in which it operates.

03 FORESIGHT & HORIZON SCANNING

The JRC has engaged in Horizon Scanning and literally took up the IAEA's card deck. The JRC is hosting a Euratom focused Drivers 2057 foresight workshop in November 2023. With policy partners, stakeholders, industry, experts and Member States representatives on the future impact of its research and knowledge tools. Nuclear safeguards, security and safety (3S) Euratom Drivers might be:

- Classical safeguards concepts at risk
- Nuclear energy in support to the European Green Deal to accelerate decarbonisation
- Information overload and new information capabilities, thrustworthiness, evidence
- Peace, prosperity, fairness

Fig. 1: Euratom and IAEA Safeguards Inspectors.

04 REACHING OUT TO THE NEXT GENERATION

In times of Euratom Research and Training Programme budget reduction but increasing demands from Member States the shrinking work force in the nuclear field in Europe. has become a crucial point of concern for the future.

There are opportunities of nuclear deployment in a variety of sectors, encouraging young skills and leadership is therefore a must for the future of nucleolar safeguards.

The JRC committed in its Strategy for Nuclear Activities to maintaining critical capabilities and acquiring new skills in line with future JRC priorities. The JRC is proactively supporting European and international efforts to attract young professionals students and pupils to choose a career path in nuclear safeguards, eg. the 'Back to School and University' EC staff engagement programme and the ENEN Specialising Master Programme in NUCLEAR SAFEGUARDS.

Fig. 2: Euratom and IAEA Safeguards Inspectors.

05 JRC'S ASSETS IN FACING THE FUTURE

The JRC based on its mandate in the Euratom Treaty has a long standing record of successful research and policy support in the 3S. It remains in a pole position to keep R&D abreast of possible new and or advanced concepts of nuclear facilities which might require adapted or new safeguards approaches, e.g. small modular reactors (SMR), final repositories, accelerator driven thorium systems. The JRC still has competent technical and scientific staff to develop future verification measurement and surveillance techniques and contribute to advances in implementation of safeguards.

Future Objectives

The JRC priorities in science, research and knowledge support:

- strengthening the safeguards approaches at the back-end of the nuclear fuel cycle, final repositories and on decommissioning
- supporting safeguards for new and innovative reactor and nuclear applications systems
- facilitating synergies and collaboration between partners and stakeholders in nuclear safeguards

The JRC will need to maintain critical capabilities and laboratory infrastructure in nuclear safeguards while simultaneously acquire new skills with an ageing workforce. Foresight, horizon scanning and anticipatory governance will become an intrinsic tool in order to identify significant emerging issues, as well as in the assessment of future strategies in nuclear safeguards.

KEYWORDS

- The JRC Strategy for its Nuclear Activities
- Horizon Scanning for 3S
- Symposium on International Safeguards 2022
- ESARDA Reflection Group 2017-2019 Report
- ESARDA World Café Report 2019
- ESPAS
- Energy explained
- Fairness

MAIN PARTNERS:
DG ENER, IAEA, EEAS

OTHER INTERESTED DG'S:
DG HOME, DG RTD

MAIN STAKEHOLDERS:

- Member States
- Industry
- Research
- Acedemia

BEYOND SAFEGUARDS

Overview

In the JRC's re-vitalised strategy 2030 the role of and mandate of the JRC's nuclear activities is reaffirmed. Nuclear Safeguards is part of the JRC's scientific and policy support to the European Commission Priorities

- A stronger Europe in the World
- A European Green Deal
- An economy that works for people

To respond to these priorities the JRC builds on its core strengths research and scientific excellence in its nuclear and non-nuclear disciplines.

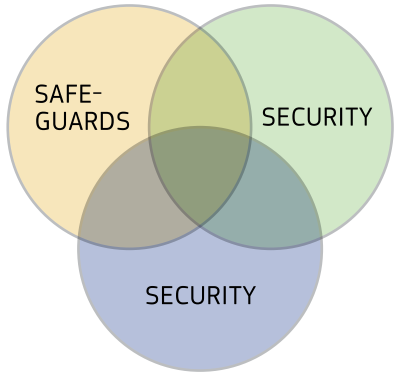
As outlined in the JRC work programme 2023-2024 the new portfolio approach brings together scientific disciplines from across the JRC to address a common theme or issue spanning different priorities to better integrate the JRC's work across scientific and policy domains.

Emphasis is given to synergies between nuclear and non-nuclear fields with relevant safeguards impact

01 "3S" - SAFEGUARDS, SECURITY & SAFETY

Support in nuclear compliance assurance with the Euratom Treaty and all respective legislations in safeguards, security, safety, waste management and strategic trade control. Is one main priority of the JRC. Although the legislative framework is clearly different, measurement methods, techniques, instrumentation, quality tools, training and concepts developed and needed in safeguards as presented in the previous chapters of this brochure are often equally applicable and important in nuclear security and nuclear safety areas. A non-exhaustive list is given below:

- 3S for the extension of the lifetime of the current nuclear reactor fleet and for new and innovative reactor concepts
- Nuclear forensics and illicit trafficking identifying nuclear signatures
- Nuclear waste management and research on transmutation of spent nuclear fuel
- Nuclear materials research
- Export control, regulating the export of goods, software and technology.
- Nuclear data used by Euratom partners - OECD Nuclear Energy Agency (NEA)
- Nuclear (medical) applications of radionuclides
- Environmental Radioactivity Monitoring
- Digital systems for 3S



02 GLOBAL WARMING

Global warming due to the release of greenhouse gases was first predicted in the late 19th century. Scientists warned about it from the 60s onwards and based their scenarios over decades on ever accurate simulations, computer models, satellite observations and measurements. Today global warming has become a threat to human wellbeing and biodiversity (United Nations Framework Convention on Climate Change). Some EU countries have never engaged in nuclear energy, some others are currently fading out fossil and nuclear energy simultaneously but for about 14 European countries nuclear plays a role in mitigating the adverse effects of global warming. This implies the application of nuclear safeguards (by design) in the EU for the following fields within the JRC workprogramme:

- Safe and secure nuclear technology in support of the transition towards climate neutrality
- Baseload low-carbon electricity
- Clean hydrogen production
- Decarbonized, smart and safe mobility
- Transition to a green economy
  - JRC technical assessment of nuclear energy with respect to the criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')
  - Net Zero Industry Act

The Second International Conference on Climate Change and the role of Nuclear Power 2023: Atoms4NetZero is held in October 2023 with the purpose to provide a forum for Member States, representatives of relevant low carbon energy sectors, international organisations, and other stakeholders to exchange information on the role of nuclear power in the energy transitions towards net zero emissions.

03 SYNERGIES NUCLEAR AND NON-NUCLEAR DISCIPLINES

Nuclear safeguards affects various scientific, technical, political, sensorial and emotional spheres. These are intrinsic to the perception of risks as well as to the cooperation for peace and prosperity. Recently due to the geopolitical context more public awareness for synergies in EU's solidarity with Ukraine has been raised, e.g the European Instrument for International Nuclear Safety Cooperation (INSC).

Methods and approaches in data and text analytics together with outreach to robotics, AI and machine learning are of major interest for safeguards to lower the inspection burden for the safeguards authorities as well as for the operator. Cybersecurity is a concern when dealing with remote transfer of sensitive data. Exchanges and advances in simulations and imaging techniques are of mutual benefit.

Sandardization and metrological nuclear quality control tools such as certified reference materials (CRMs) are equally important in safeguards as in civil security, boarder control, public health, food sciences, geochemistry, earth sciences and for industrial applications.

Foresight on trends and emerging technologies, such as blokchain, 3D printing or using nuclear technology against plastic pollution is increasing those synergies.

04 COMMUNICATION AND 'SOFT SKILLS'

The JRC is currently implementing its new communication strategy including the communication of its nuclear (safeguards) activities to stakeholders and the public, similar to ESARDA when reflecting on its future relevance.

In the nuclear field any communication plan has to be flexible depending on the addressed audiences (children, general public, scientific experts, Member States), but cannot be too simplistic to avoid misunderstandings.

The relevance of safeguards to the European Green Deal independent of the individual choice of a countries' energy mix can open the dialogue with policy makers.
Soft skills, such as social and behavioral competences, motivation, and team spirit are facilitators when bringing people from the nuclear and non-nuclear field together.

Future Objectives and Challenges

The new JRC portfolio approach is an enabler to enhance the synergies between nuclear and non-nuclear disciplines especially in the field of nuclear safeguards, a requirement in the Euratom Treaty.

The JRC will position its safeguards activities and their cross-fertilization with other scientific disciplines as part of its evidence based impartial policy support.

The JRC will engage on the benefits of its stakeholders and the public on the benefit of its nuclear safeguards activities beyond the nuclear field.

KEYWORDS

- JRC re-vitalized strategy 2030
- JRC Strategy for its Nuclear Activities
- Horizon Scanning for 3S
- JRC technical assessment
- ESARDA World Café Report 2019
- UNFCC
- Energy explained
- Public Health
- 3S in Ukraine
- Emerging Technologies
- Safeguards and Nuclear Power
- Futurium
- EURM Training

MAIN PARTNERS:
DG ENER, IAEA, EEAS, DG INTPA

OTHER INTERESTED DG'S:
DG HOME, DG RTD, DG ECHO, DG CLIMA, REA

MAIN STAKEHOLDERS:
- Safeguards authorities
- Member States
- Industry
- Research
- Academia

LIST OF ACRONYMS

ABACC Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials

APSN Asia-Pacific Nuclear Safeguards Network

CEA Commissariat à l'Energie Atomique (France)

DG ENER Directorate-General for Energy

DG FPI Directorate-General for Foreign Policy Instruments

DG INTPA Directorate-General for International Cooperation and Development

DG HOME Directorate-General Migration and Home Affairs

DG RTD Directorate-General for Research and Development

DG TAXUD Directorate-General for Taxation

DG TRADE Directorate-General for Trade

EC European Commission

EEAS European External Action Service

ESARDA European Safeguards Research and Development Association

ENEN European Nuclear Education Network

ENSREG European Nuclear Safety Regulators Group

EU European Union

EURATOM European Atomic Energy Community

IAEA International Atomic Energy Agency

INMM Institute of Nuclear Materials Management

JAEA Japan Atomic Energy Agency

JRC Joint Research Centre

NWAL Network of Analytical Laboratories

OECD Organisation for Economic Co-operation and Development

US DoE United States Department of Energy

US NNSA United States National Nuclear Security Administration

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