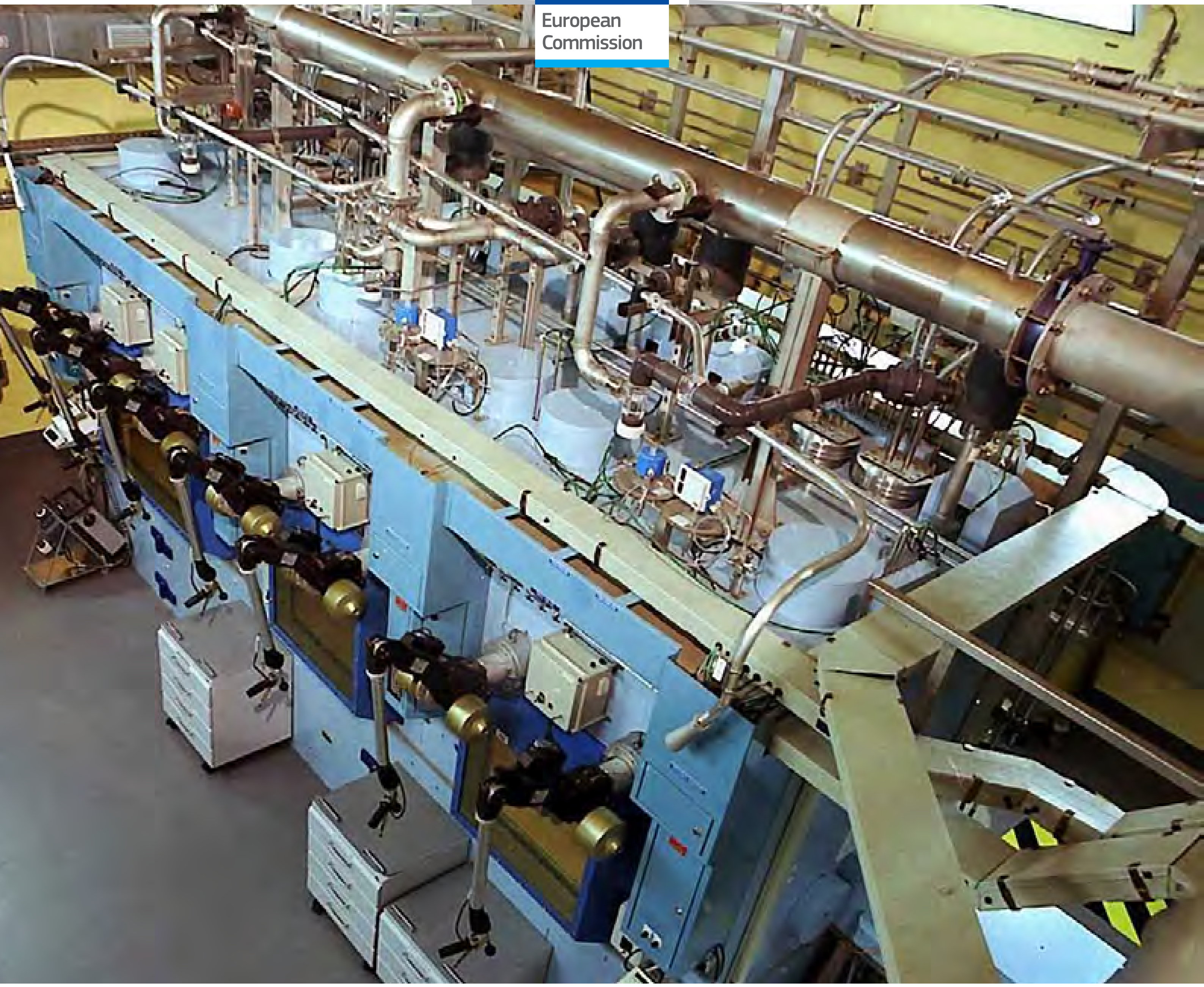
European Commission



JRC research and development in nuclear safeguards

Joint Research Centre

EXECUTIVE SUMMARY

This brochure provides a brief overview of nuclear safeguards activities carried out by the European Commission, Joint Research Centre (EC JRC) in areas of research and development as well as in outreach and international cooperation.

Many of these activities are carried out under the European Commission Cooperative Support Programme (EC-SP), officially created on 7 May 1981, providing a framework for European Commission support to the IAEA for research and development in nuclear safeguards. Since its establishment, the EC-SP has been operated by the EC JRC in close collaboration with the EC Directorate General for Energy responsible for implementing the Euratom safeguards inspectorate.

So far, the EC-SP engaged in 132 tasks targeting IAEA safeguards research and development needs in areas of:

- Measurement technology,

- Surveillance and containment,

- Training courses and

Information data treatment and evaluation.

Approximately 30% of the 47 currently ongoing tasks are conducted in cooperation/coordination with other IAEA Member States Support Programmes.

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INTRODUCTION

The 1957 Treaty establishing the European Atomic Energy Community (the Euratom Treaty) has foreseen a clear role for the EU in ensuring safe and sustainable use of nuclear energy across Europe.

Moreover, the treaty introduced a strict system of safeguards throughout the EU to ensure that nuclear materials are used only for declared, peaceful purposes. In accordance with provisions of Chapter 7, it is a responsibility of the European Commission to verify that ores, source materials and special fissile materials are not diverted from their intended uses as declared by the users.

The presence of the whole nuclear fuel cycle in the EU, from uranium enrichment, to fuel production, power reactors, spent fuel reprocessing and final disposal, makes the implementation of the Euratom safeguards and security requirements a challenging task.

The Joint Research Centre (JRC), the European Commission's (EC) in-house science service, supports the Commission in fulfilling obligations set up by the Euratom Treaty in the areas of nuclear research, training and education.

JRC's nuclear research activities for 2014-2018 are defined by a Council Regulation (EURATOM) No 1314/2013 on the Research and Training Programme of the European Atomic Energy Community and in areas of nuclear safeguards, non-proliferation, combating illicit trafficking, and nuclear forensics they focus on the following topics:

- Development of enhanced methodologies and detection/verification methods and technologies to support the Community safeguards and strengthening of international safeguards;

- Development and application of enhanced methods and technology to prevent, detect and respond to nuclear and radioactive incidents, including qualification of detection technology and development of nuclear forensics methods and techniques in the fight against illicit trafficking in synergies with the global CBRN (Chemical, Biological, Radiological, Nuclear) framework;

- Support for the implementation of the Treaty on the Non-Proliferation of Nuclear Weapons and Union-related strategies through analysis studies and follow-up of the technical evolution of export control regimes to support relevant Commission and Union services.

For over 50 years, the JRC provides scientific, technical and operational support to the European Commission Directorate General for Energy responsible for nuclear safeguards inspections in the European Union. The JRC support includes nuclear materials measurements (methods and standards for non-destructive measurements and destructive assays), containment and surveillance, process monitoring/modelling, development of in-field tools for inspectors, non-proliferation studies (open source analyses, nuclear country profiles), export control and training for Euratom inspectors.

In addition, the JRC operates analytical on-site laboratories at the two largest European reprocessing plants in the nuclear sites of Sellafield (UK) and La Hague (France), whose throughput represents 80% of the world's reprocessed spent nuclear fuel. JRC experts, carry out on average 800 spent fuel analyses per year, thus allowing Euratom inspectors to check the fissile material chain and inventory of the nuclear facilities.

INTERNATIONAL COOPERATION

At the international level, key partnerships have been developed in the field of nuclear safeguards with the US Department of Energy (R&D agreement on nuclear safeguards and security), Russia, Japan and China.

In the early 90', the European Commission initiated a program for Technical Assistance to the Commonwealth of Independent States, TACIS support program, (1994-2006), which in addition to enhancing border monitoring, measures to combat illicit trafficking and nuclear forensics capabilities also included projects related to nuclear safeguards. Some of these projects are still running with the main focus on safeguards actions in Russia and with 2014 as the target closing date for the implementation.

EU outreach activities in nuclear safeguards continue under the Instrument for Nuclear Safety Cooperation (INSC) [1] including a project to support the South American regional safeguards organisation ABACC (the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials).

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1. *Council Regulation (Euratom) No 300/2007 of 19 February 2007 establishing an Instrument for Nuclear Safety Cooperation, OJ L 2007:81/1*

Moreover, JRC researchers participate actively at the European Safeguards Research and Development Association (ESARDA) Working Groups, which provide a platform for technical cooperation and exchange, thus contributing to effective and efficient implementation of nuclear safeguards.

Euratom safeguards are strongly interlinked with safeguards of the International Atomic Energy Agency. The JRC provides a support to the IAEA by development of instruments, tools and methodologies for the control of nuclear materials and facilities to avoid proliferation or diversion.

Since 2010, the EU supports the IAEA ECAS project: Enhancing the Capabilities of the International Atomic Energy Agency Safeguards Analytical Services with a financial contribution of €10 million from the European Commission Instrument for Stability. Under this project, the JRC provides technical/scientific advice within its area of expertise to identify appropriate activities and the most efficient ways for using the EU contribution.

EUROPEAN COMMISSION COOPERATIVE SUPPORT PROGRAMME (EC-SP)

Established in 1981, the European Commission Cooperative Support Programme (EC-SP) provides a framework for the technical support to the IAEA in the field of nuclear safeguards. The EC-SP was involved in altogether 132 tasks with currently 47 tasks ongoing. The JRC operates the EC-SP in close cooperation with the EC Directorate General for Energy.

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

- Measurement techniques: including destructive analytical techniques and particle analysis, non-destructive assays;

- Containment, surveillance and sealing/identification techniques;

- Development of reference materials and particles targeted to IAEA safeguards needs;

- Information technologies for non-proliferation studies – e.g., information collection and trade analysis;

- Process monitoring techniques – some being prototyped and tested at a EU facility;

- Concepts, approaches and methodologies;

- Training of inspectors: jointly with EURATOM inspectors or targeted to IAEA needs.

The support to IAEA includes the analysis of nuclear materials, analysis of environmental particle samples, and provision of reference/QC materials. These activities are performed by JRC's laboratories in the frame of IAEA's Network of Analytical Laboratories (NWAL).

The EC-SP actively collaborates with other Members States Support Programmes (MSSPs) through Joint Tasks. Currently, approximately 30% of the EC-SP tasks are executed jointly or in close collaboration with other MSSPs. Especially close coordination has been established with ten European Union's MSSP[2] and the US-SP[3], whose representatives are invited to participate at the EC-SP Annual Review Meetings.

In recent years, six JRC developments were approved for IAEA safeguards use – also known as category A equipment:

- COMPUCEA (COMbined Product for Uranium Concentration and Enrichment Assay);

- 3DLR: 3D Laser Range Finder;

- Ultrasonic Seals;

- Laser Item Identification System;

- LMCV: 3D Laser Surface Mapping of Canister Closure Welds.

- USBS: Ultrasonic Optical Bolt Seal

The following sheets illustrate JRC research and development activities in nuclear safeguards.

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2. *European Union states participating at the IAEA's Member States Support Programme: Belgium, Czech Republic, Finland, France, Germany, Hungary, the Netherlands, Spain, Sweden and the United Kingdom.*

3. *Within the framework of the Nuclear Material Safeguards and Security Research and Development Agreement between the Unites States Department of Energy and the Euratom Community.*

European Commission and the IAEA

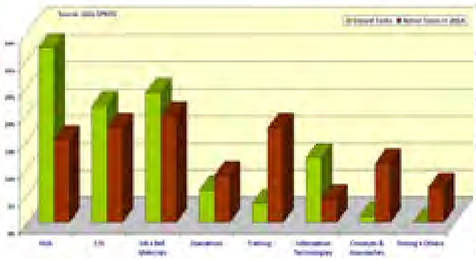
Scientific and Technical Cooperation

Modes of Operation:

- Operated by Joint Research Centre in close cooperation with DG-ENERGY - EURATOM
- Exchange of Information: targeting IAEA Safeguards R&D needs
- Tasks (with well-specified contents, deliverables and milestones)
- Workshops, Expert Groups, Networks
- Analysis of Nuclear Materials and Environmental Particle Samples – NWAL
- Scientific and Technical Support to EC Services supporting the IAEA
- Collaboration with other MS Support Programmes

European Commission Support Programme

Tasks by Application Area (%)



From 1981 to 2014:

130 tasks = 46 active + 84 closed

Task No.	Support/Activity Description
	NDA: EQUIPMENT, MODELLING AND MEASUREMENTS
EC-A-01362	Modelling Testing and Training for NDA and URM Equipment
JNT-A-01510	Prototype Tomographic Spent-Fuel Detector System
JNT-A-01684	Sustainability and Maintenance of Software for Pu-isotopics and U-enrichment
JNT-A-01879	Evaluation of Data Collected from Operator Systems at Enrichment Plants
JNT-A-01955	Unattended Gamma Emission Tomography (UGET) for Partial Defect Detection - Phase I
JNT-A-01979	EC Viability of an Unattended Cylinder Verification Station (UCVS) for Enrichment Plant Safeguards
EC-A-02003	COMPUCEA: Adaptation to the Analysis of Uranium Hexafluoride Material
	SEALING, CONTAINMENT AND SURVEILLANCE
EC-E-01549	3D Laser Surface Mapping of Canister Closure Welds
EC-E-01559	Update of the Ultrasonic Sealing Bolt
EC-E-01636	Software Engineering Support for 3D Camera Development
EC-E-01696	L2IS: Laser Item Identification System
EC-E-01849	Development of a Low Cost Active Electronic Seal
EC-E-01899	Remote Identification and Tracking System Demonstration
EC-E-01992	Research, Development and Evaluation of a Surveillance Review Software based on Automatic Image Summaries (VideoZoom)
EC-E-01993	Scientific and Technical Support for 3D Laser Range Finder (3DLR)
	TRAINING
EC-B-00620	NM Solution Accountancy and Verification Training
EC-B-01563	Workshop on Additional Protocol Activities
EC-B-01702	Advanced NDA Training
EC-B-01750	Plutonium Diversion Detection
EC-B-01752	Training on Mass Spectrometry and other Analytical Techniques
EC-B-01844	Training of Safeguards Inspectors 3DLR (3D Laser Range Finder).
EC-B-01876	Development of Virtual Reality Tools for Safeguards Training
JNT-C-01914	Textbook on International Safeguards

Task No.	Support/Activity Description
	ANALYTICAL AND REFERENCE TECHNIQUES
EC-A-00267	Analytical Quality Control Services
EC-A-00318	Special Reference and Source Materials for Destructive Analysis
EC-A-01606	Study on Optimisation of New LSD Spikes
EC-A-01753	Experimental Investigation of Behaviour of Trace Elements during the Concentration and Conversion Processes
EC-A-01806	Verification of Mixed U-Pu Spikes
JNT-A-01946	Analysis of HALW Samples containing Particles
EC-A-01966	Production of Particle Reference Materials
EC-A-01967	Analysis Results and Metadata for the Springfields Sample Collection
EC-X-01969	Analysis of Environmental and Nuclear Samples Supplied by IAEA
	SUPPORT to IAEA OPERATIONS
EC-A-01391	Support for the Rokkasho On-Site Analytical Laboratory
EC-A-01661	Consultation for Improvement, Evaluation and Testing of Solution Monitoring Software (SMS)
EC-A-01778	Support for the Safeguards Systems at the JNFL MOX Fuel Fabrication Plant (J-MOX)
EC-D-01779	Support for the Data Collection and Evaluation System (JADE) at the JNFL MOX Fuel Fabrication Plant (J-MOX)
	SAFEGUARDS TOOLS, CONCEPTS and APPROACHES
JNT-C-01611	Application of Safeguards to Geological Repositories - ASTOR Network
EC-D-01662	Improving Analysis of Covert Nuclear Trade
EC-C-01726	Guidance for Designers and Operators on Design Features and Measures to Facilitate the Implementation of Safeguards at Future Nuclear Fuel Cycle Facilities
JNT-C-01871	Acquisition Path Analysis Methodology and Software Package
EC-D-01880	Collection, Analysis and Dissemination of Open Source
EC-D-01917	Contribution to a Safeguards Technical Report on Pyroprocessing
JNT-C-01959	Member State Contributions to IAEA Topical Guidance on Safeguards Implementation
	TESTING + OTHERS
EC-A-00860	Qualification Testing of New Safeguards Equipment
EC-A-01634	MSSP Umbrella Task – Support for Novel Technologies
JNT-C-01980	Support for the 2014 Safeguards Symposium

Reference:

- J.G.M.Gonçalves, S.Abousahl, Y.Aregbe, W.Janssens, K.Lützenkirchen – *"The European Commission Cooperative Support Programme: 30 Years of Activities"*, ESARDA Annual Meeting, Budapest, 17-19 May 2011.
- J.G.M.Gonçalves, S.Abousahl, Y.Aregbe, W.Janssens, K.Lützenkirchen, M.Boella, P.Schwalbach– *"The European Commission Cooperative Support Programme: Activities and Cooperation"*, Proc. INMM Annual Meeting, Palm Desert, USA, 14-18 July 2013

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EC-SP DEVELOPED INSTRUMENTS APPROVED FOR SAFEGUARDS USE

COMPUCEA 2nd generation

The **Com**bined **P**rocedure for **U**ranium **C**oncentration and **E**nrichment **A**ssay (COMPUCEA) is a measurement technique for the uranium element and ^{235}U-enrichment assay routinely applied to the analysis of uranium product materials (powders and pellets). The analyses are performed with mobile equipment in fuel fabrication plants for **L**ow-**E**nriched **U**ranium (LEU) fuels during the physical inventory verification (PIV) activities of international nuclear safeguards authorities (Euratom, IAEA). The samples are selected by the Safeguards inspectors and directly measured by analysts on-site during the PIV week.

General

COMPUCEA = high-accuracy transportable analytical tool for in-field Safeguards accountancy verification.

Benefits:

- analytical results immediately available → timely conclusion of PIV
- observed discrepancies can be investigated directly
- no/reduced sample shipment to Safeguards labs

Responsibilities:

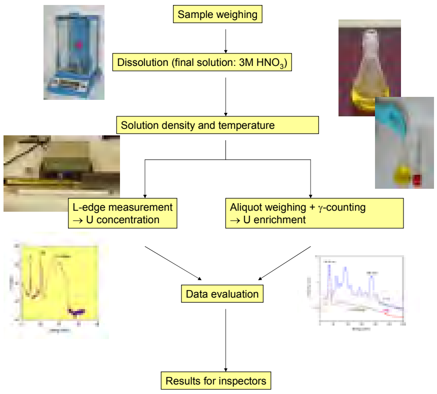
Analysts:

- perform analyses in-field during PIV
- preparation/maintenance of equipment
- upgrades/new developments

Safeguards Authorities:

- procurement of equipment
- logistics of equipment transport
- sampling
- interpretation of results, discussions with operator

Analytical Procedure



COMPUCEA 2nd generation EC setup.
The equipment is compact, rugged for transport.

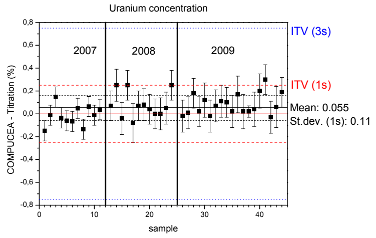
Before Shipment: Checking with reference material

In-field: Calibration with certified reference material and daily quality assurance with reference pellets (stored at each facility under IAEA/Euratom seal)

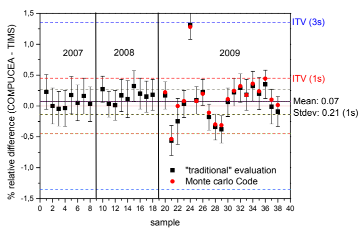
Validation

- comparison with primary reference methods
- comparison with well-specified reference values
- data from round robin tests

LED: comparison of in-field results with primary reference method titration

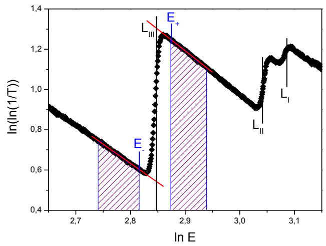


Enrichment: Comparison of in-field $LaBr_3$ data and primary reference method TIMS



Data evaluation

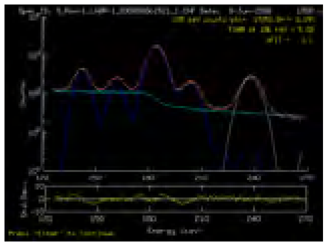
LED: U spectrum is measured relative to a reference spectrum (3M HNO_3), then linearized



Extrapolated value: derived by fitting to L_{III}-edge → independent of matrix effects

Difference between extrapolated and non-extrapolated value → change in matrix, e.g. due to Gd (= burnable neutron poison, added to fuel)

Enrichment: adapted NaIGEM analysis code provided by R. Gunnink, can handle recycled U

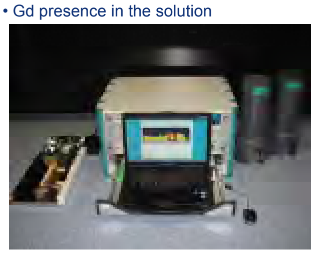


To obtain the final enrichment, the following corrections are considered (either by using separate factors or by Monte Carlo modeling):

- container bottom thickness
- uranium concentration in solution
- Gd presence in the solution

Common achievement EC-IAEA Support Programme

- Tested for IAEA outside Europe: Kazakhstan (Nov. 2011 / Sept. 2012)
- Classified as IAEA Cat. A Safeguards equipment in 2012
- Modified by IAEA to needs in 2013
- User friendly software provided by IAEA, implemented, tested during EC/IAEA Safeguards Campaigns and under validation at the JRC
- Outlook: Adaptation to the Analysis of Uranium Hexafluoride Material



COMPUCEA IAEA setup

The equipment is compact and already ready-to-use directly after transport.

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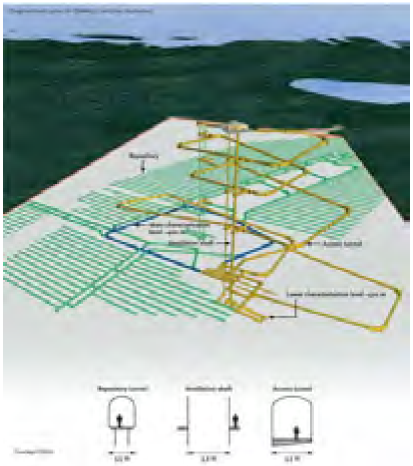
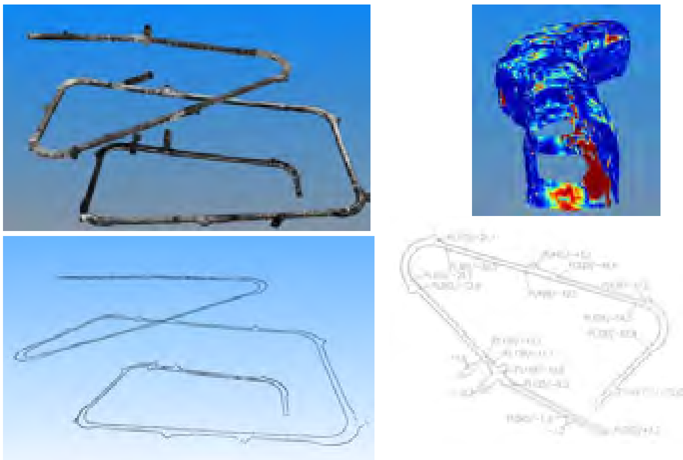
DIV for Final Disposal (ONKALO)

- **Objective**: Acquisition of accurate as-built 3D models for verification of design information.
- **Proof-Of-Concept**: Scanning of 2km of ONKALO access tunnel for proof of concept was carried out in 2007. One and half days of scanning in Stop&Go mode.
- **Initial DIV** is planned for 2014 using Stop&Go scanning.
- Estimated effort is 5 days for a team of 4 inspectors.
- The result will be a high-accuracy 3D model for initial verification and for future reference.
- DIV will be based on comparing 2D operator drawings against cross sections of scan data.
- Discussions between ENER, IAEA and national authorities are on-going.
- **Current R&D at JRC**: Scan-while-drive/walk technologies for fast and efficient re-verification.
- Reference data can be used for position authentication and registration of inspection data.
- Verification data can be compared against 2D operator drawings and/or against 3D reference data.

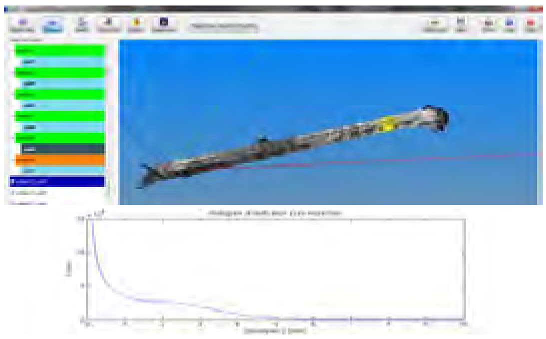


ONKALO schematic drawing

3D sensors



3D as-built data and design information verification



Position authentication

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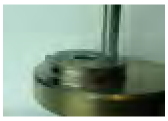
JRC CANDU Sealing System (JCSS)

Seal:

- Ultrasonic bolt seal designed to comply with CANDU requirements
- Patented by JRC
- Stainless steel bolt particularly resistant to harsh environment conditions
- Maintain identity while broken

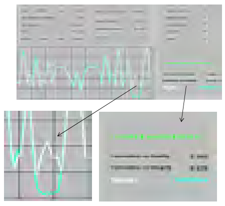






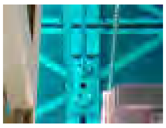
Analysis software:

- Read identity signature and integrity status
- Manage signature database
- Upgraded for each particular application



Handling Tools:

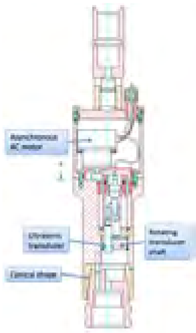
- Used to remotely handle the seals and the reading head underwater

Reading Head:

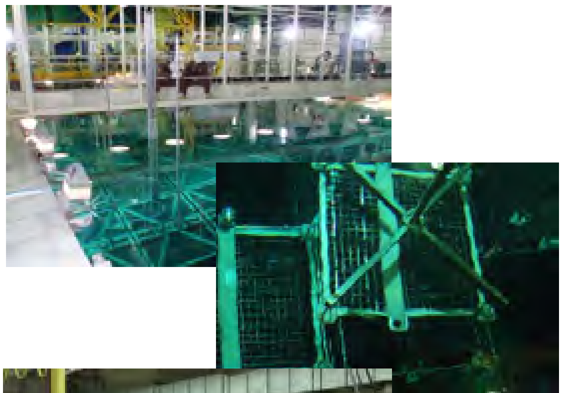
- Actuation of the ultrasonic transducer
- Low tech motor radiation resistant
- Conical shape to align seal with axis of rotation of transducer
- Stainless steel
- Waterproof





Implementation:

- More than 600 JCR CANDU Seals were delivered to the IAEA and DG ENER (EURATOM Safeguards)
- Seals are used in Romania, Cernavoda, by DG ENER and by the IAEA in Pakistan, Karachi Nuclear Power Plant (KANUPP) and in Canada, Darlington




Acquisition system:

- Off the shelf USB ultrasonic box
- Assembled in a box with motor control
- Industrial Toughbook

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Joint Research Centre

European Commission Support Programme to the IAEA

L2IS: Laser Item Identification System

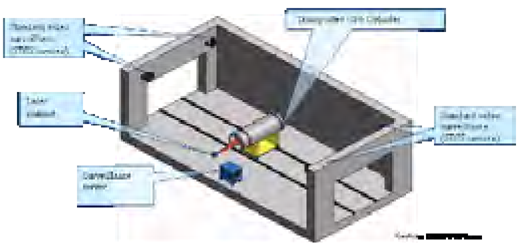
Unique Identification of UF6 Cylinders

The need and challenge:

- Unique identification of UF6 cylinders entering and exiting an enrichment plant
- Complementary approach to surveillance and weighing, in order to maintain Continuity of Knowledge

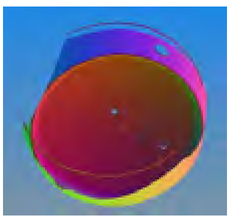
The idea:

- do not rely on labels / ID plates
- do not use dedicated tags (tampering, cost, …)
- use the intrinsic spatial irregularities and manufacturing tolerances of the surfaces

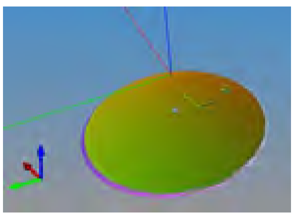


L2IS Instrumentation

- Laser Line scanner mounted on a rotation stage. Scans an approximate 800x800 mm area in 4.5 s
- Point density: 2.5 points / mm
- Range resolution: 150 µm
- Laser class: 3B (650 nm)
- Portable and Fixed (unattended) solution



3D scan of the front of a mock-up cylinder.

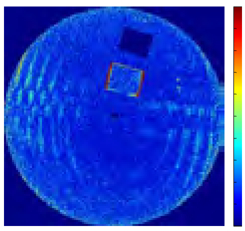


Scan after normalization. The cylinder outer collar is removed in the normalized representation.

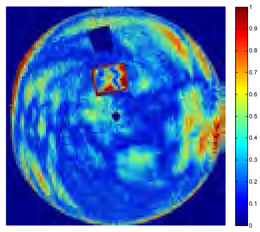
Identification

Matching vs. non-matching inspection

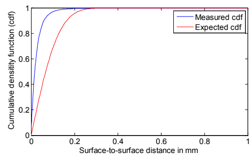
1. The colour or each point is the distance between the inspected scan and the respective reference scan
2. Matching scan: Most distances can be explained by uncertainty of the instrument; follow normal (Gaussian) distribution
3. Non-matching scan: In many areas, distances are above instrument uncertainty
4. Decision based on distribution (histogram) of distances

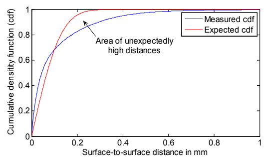


Matching case: measured distribution is left of "theoretical" distribution



Non-matching case: measured distribution cannot be explained by instrument uncertainty





Project Summary

- **September 2006:** first feasibility demonstration at JRC Ispra, using four lab mock-ups of UF6 cylinder
- **December 2006, July 2007:** field tests with real cylinders (30B and 48Y,Z) in two different enrichment facilities. Conclusions from field tests:
  - there are sufficient variations between the cylinder surfaces to allow unique self-authentication
  - no incorrect identification
  - a number of false alarms (no or ambiguous identification) under exotic conditions
  - class 3B laser necessary (class 2M laser to weak for dark or shiny surfaces)
  - thermal expansion is not a problem
- **September 2007:** First pilot installation at an Enrichment Plant in Japan
- **March 2009:** Dynamic L2IS. Completely autonomous not requiring intervention from Plant Operator.

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European Commission Support Programme to the IAEA

LMCV: Laser surface Mapping for Containment Verification

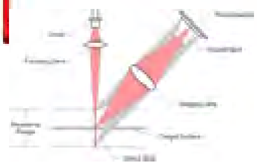
Fingerprinting of dry storage casks using unique signature of weld geometry

The need and challenge:
- find an alternative technique for integrity verification of Dry Storage Casks (DSC)

Approach:
- select a technique, demonstrate ability, develop instrument, conduct VA, run field trial

Results:
- successful demonstration of LSM (Laser Surface Mapping), positive VA, conclusive and positive outcome of field trial

LMCV Instrumentation



- The laser triangulation method requires a light source, imaging optics, and a photo detector
- Depending on the distance to the surface the light spot changes its position along the photo detector

Photo Credit: IAEA

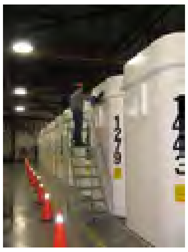
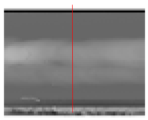
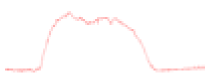


Photo Credit: IAEA

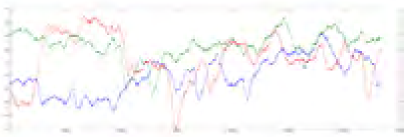
Scanning along weld



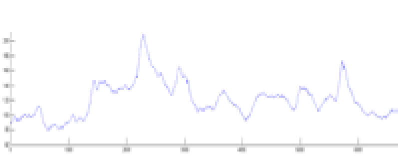
Vertical section of the weld

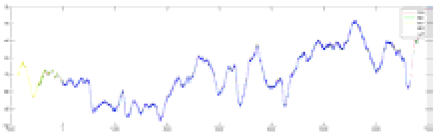


Signature of the weld (vertical section areas w.r.t. the supporting surface)



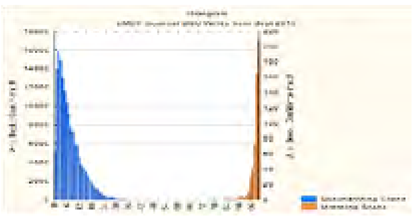
Signatures of three different welds





Signatures obtained from different scans for same weld

Results from Field Trial in Canada



Courtesy: IAEA

Project Summary

- Needs definition – October 2010
- 1st demo at Pickering Dry storage – December 2010
- Prototype development 2011 - March 2012
- VA team recommends to consider LMCV for Safeguard applications
- Field Trials in Canada March 2012 / September 2012
- Approved by IAEA for “Inspection Use” – April 2013
- IAEA orders 2+4 units

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ANALYTICAL AND REFERENCE TECHNIQUES

Examples of Safeguards Analytical Activities at JRC

On-site laboratories

at reprocessing plants in La Hague and Sellafield

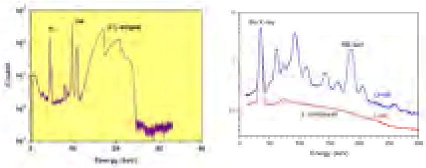
- independent verification of nuclear material (uranium and plutonium); non-destructive assay, chemistry, mass spectrometry
- on-site labs avoid time-consuming and costly transport of nuclear material

⇒ enhanced timeliness of verification

In-field support

COMPUCEA – at European LEU fuel fabrication plants

COMPUCEA: a transportable system for in-field determination of uranium concentration and enrichment in pellet and powder samples after dissolution



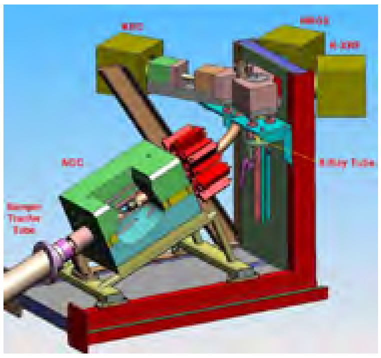
Typical COMPUCEA L-edge absorption (left) and γ-spectrum (right; with $LaBr_3$ detector).

- each year: PIV at 5 sites
- highly accurate results (within ITV) immediately available for Euratom and IAEA inspectors

⇒ enhanced timeliness of verification

Novel developments

Analysis of process samples from pyrochemical separations



Measurement station for the analysis of highly active samples using a combination of non-destructive measurement techniques. The equipment is directly attached to a hot cell.

- novel solutions for non-standard nuclear samples
- automation
- improved measurement uncertainty
- development of novel techniques

Analytical Service

High-accuracy analytical measurements of nuclear material (bulk & particles)

Radiometric methods
- Neutron coincidence counting
- X-ray fluorescence
- X-ray absorption
- α- and γ -spectrometry
- calorimetry

Analytical Chemistry
- Chemical separations
- Mass spectrometry: ICP-MS, SIMS, TIMS

Activities
- measurement of samples for in- house and external customers
- in-field analytical support
- particle analysis on swipe samples

ICP-MS attached to a glove box for the handling of nuclear material

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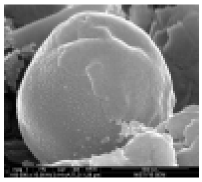
Nuclear Safeguards and non-proliferation

High Performance Trace Analysis - HPTA

- Sub micrometer to micrometer sized particulate material are often released in the handling of nuclear material. The normal nuclear monitoring systems can not detect the material by radiation measurements as the activity is below the detection limit.
- The released particles are highly mobile and can be found in many locations at a nuclear facility.
- It is difficult to clean up and remove released particles.
- Samples taken at a facility that has been operated over a long period can provide an insight into the entire history of the operation.
- HPTA is an effective tool for detecting undeclared nuclear activities.



A 1 µm, 2.6 x 10^{-12}g **uranium aerosol particle** having only a few radioactive decays per year.(Picture D.Simons NIST)

Sampling for HPTA

Inspectors are provided with **sample kits.**

→

Dust sampling at a nuclear facility.

→

cotton swipe sample with the collected dust particles.

Particle Analysis by Large Geometry - Secondary Ion Mass Spectrometry (LG-SIMS)

The analytical task for the laboratory specialised in isotopic aerosol particle analysis can be divided into two steps. The first is the "Needle in the hay stack problem" of locating sub-micron uranium particles in a matrix of millions of other particles. Once a particle is found the second analysing step follows where the particles are measured with state of the art mass spectrometry techniques to determine the uranium isotopic composition.

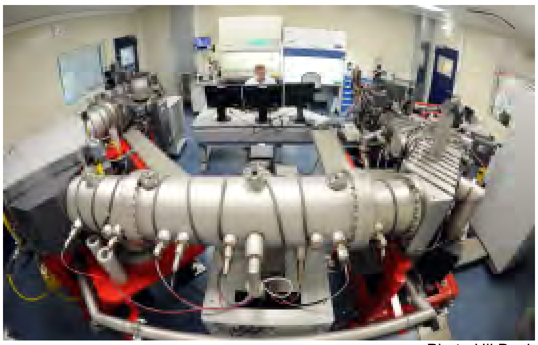
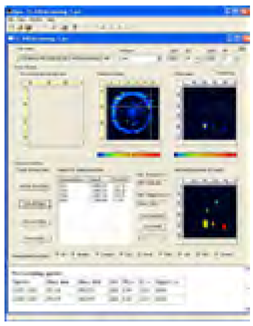
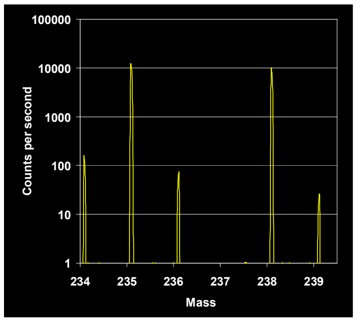


Photo Uli Deck

A **CAMECA IMS 1280 LG-SIMS** can be operated both as an ion microscope for fast searching for uranium particles and as a mass spectrometer for the final isotopic measurements.



An **Automated Particle Measurement** software is used to search through a matrix of several tens of millions of particles within a few hours to determine the location and the enrichment of individual uranium particles.



Final Isotopic measurement are made using a primary micro beam in mass spectrometer mode. The example above shows a mass spectra of a high enriched uranium particle.

Recent publications on particle analysis by LG-SIMS:

Improved particle location and isotopic screening measurements of sub-micron sized particles by Secondary Ion Mass Spectrometry. P. M. L. Hedberg, P. Peres, J. B. Cliff, F. Rabemananjara, S. Littmann, H. Thiele, C. Vincent and N. Albert. (2011) J. Anal. At. Spectrom., DOI: 10.1039/C0JA00181C

Improved isotopic SIMS measurements of uranium particles for nuclear safeguard purposes Y. Ranebo, P. M. L. Hedberg, M. J. Whitehouse, K. Ingeneri and S. Littmann (2009) J. Anal. At. Spectrom., DOI: 10.1039/b810474c

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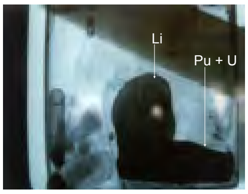
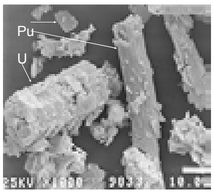
Milestones of Nuclear Forensic Investigations Performed at JRC

Munich airport 1994

Illicit trafficking of
363 g plutonium + 121 g uranium and 201 g lithium



X-ray photo of the suitcase.



Electron microscope picture of the U/Pu powder.

- weapons usable Pu (87,6 % ^{239}Pu)
- Pu produced in RBMK reactor
- low enriched U (1,6 % ^{235}U)
- Pu + Li = possible military application

Origin of the material? ⇒ Russia

Karlsruhe 2001

Theft of
a few mg of radioactive waste

WAK reprocessing plant.

Vacuum cleaner bag from the thief's apartment.

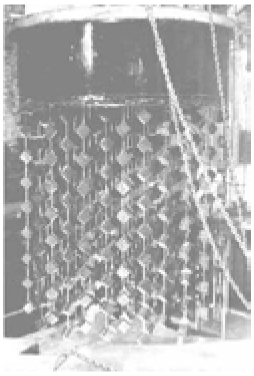
- main elements Pu, U, Am, Cs
- contamination in apartment, on clothes and in car are consistent with stolen items

More material stolen? ⇒ No evidence

"Uranium machine" 2002

Authentication of
a uranium cube

Uranium metal cube



Heisenberg's "Uranium machine".

•metallic natural uranium

•Natural uranium from Joachimstal was used

•Uranium metal production took place in the last quarter of 1943

Is the cube authentic i.e. dating back to the German nuclear program during WW II ?
⇒ Authentic cube from the "uranium machine"

Lauenförde 2007

Source attribution of
14 uranium pellets

Uranium fuel pellet.

• Height 10,95 – 11,35 mm

• Diameter 9,21 – 9,25 mm

• Mass 7,5 – 7,8 g

• U content 88 %

• ^{235}U enrichment 3,46 %

• Last chemical purification Nov. 1990

Origin? ⇒ Siemens Hanau, Germany
Intended use? ⇒ PWR reactor (Philippsburg-2)

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IRMM-1027 Large-Sized-Dried (LSD) spikes

Preparation and certification

Introduction

IRMM-1027 Large-Sized Dried (LSD) Spikes are widely used as a fundamental part of the fissile material control of spent nuclear fuel and have been provided to safeguards authorities and industry for more than 10 years. These spikes are applied for the accurate measurement of the U and Pu amount contents by isotope dilution mass spectrometry (IDMS). High purity uranium and plutonium metals are used as starting materials to prepare the mother solution, which is then dispensed into individual units by an automated robot system, dried and covered with an organic polymer, cellulose acetate butyrate (CAB), as a stabilizer. Each unit of IRMM-1027 LSD spike is certified for the mass of Pu and U and isotope amount ratios. About 1200 units of LSD spikes are prepared annually.

Preparation of the mother solution

- accurate weighing of high purity metals (substitution weighing)
- natural U (EC NRM 101), enriched ^{235}U (93 %, NBL CRM-116) and enriched ^{239}Pu (98%, CETAMA MP2)
- dissolution in hot nitric acid
- concentration of about 0.8 mg Pu/g and 20 mg U/g (enrichment below 20% ^{235}U)
- verification measurements by IDMS prior to dispensing into penicillin vials

Certification process

- The certification is based on the gravimetrical preparation of the mother solution (mass, purity of metals, isotopic composition, etc.)
- Each unit is certified for the mass of ^{239}Pu, ^{235}U and ^{238}U and isotope amount ratios
- Certified values are verified by IDMS on randomly selected vials
- Chemical purification prior to isotopic measurements on Triton TIMS is done by anion exchange
- Uncertainties are estimated using the Guide to the Expression of Uncertainty in Measurement (GUM) and include uncertainties from the gravimetric preparation, dispensing and homogeneity assessment

Dispensing by an automated system, drying and application of CAB

- About 2.5 g of the mother solution is dispensed and weighed in each unit by an automated system
- The solution is evaporated to dryness at low temperature (max T at 60°C)
- About 0.7 mL of 10wt% CAB (35-39wt% butyryl content) solution in acetone is applied on the dried spike, evaporated at room temperature and then dried completely at about 45°C
- CAB is applied to preserve the integrity of the spike during transport and long-term storage
- The vials are closed with an iso-versilic stopper and an aluminum cap and sealed in PVC bag

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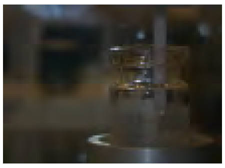
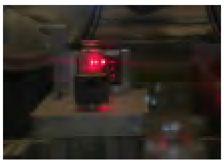
IRMM-1027 Large-Sized-Dried (LSD) spikes

Preparation with an automated system





Introduction

A nitrate solution prepared from high purity metals of high enriched uranium and plutonium, is dispensed, dried and covered with an organic polymer (CAB) to prepare batches of IRMM-1027 Large-Sized Dried (LSD) spikes. They are applied for the fissile material control of spent nuclear fuel by isotope dilution mass spectrometry (IDMS). Individual units are prepared by aliquoting of about 2.5 g of the solution into penicillin vials and careful drying. The manual dispensing and weighing of the solution used in the past was extremely time consuming and laborious. Therefore, an automated robot system was installed and validated at IRMM. The robot system has been used since the IRMM-1027k batch.

Automatisation of a robot controlled by a dedicated software

- Control of all movements inside a glove box
- Unambiguous identification of the vials
- Dispensing of the mother solution into vials
- Accurate weighing of the amount dispensed

Operating conditions

- Functionality in a corrosive environment
- Aliquoting of 2.5 g into penicillin vials with an uncertainty of less than $5{\cdot}10^{-4}$ on the certified mass (traceable to SI)
- JRC IRMM safety procedures for working with radioactive materials implemented
- Electronic components outside the glove box to allow easy maintenance (replacement and adjustment) or protected by special measures
- Smooth movement when handling, gripping and positioning of the vials to avoid spilling and cross-contamination

Validation of an automated weighing

- Comparing results obtained from an automated system and from manual weighing (substitution weighing)
- Four series, in each series 2.5 g of a solution dispensed into 10 pre-weighed vials, to validate the results of the automated system
- Vials with solution were subsequently transferred into the mass metrology laboratory and weighed using substitution weighing

Conclusion

- Relative bias between automated system and substitution weighing is less than $2{\cdot}10^{-4}$
- Normal variability for this type balance 0.3 - 0.5 mg (3 - 5 scale divisions).
- Raw data from the automated system are corrected for buoyancy effects
- In the uncertainty budget an additional component of uncertainty of $3{\cdot}10^{-4}$ g is added (balance performance)

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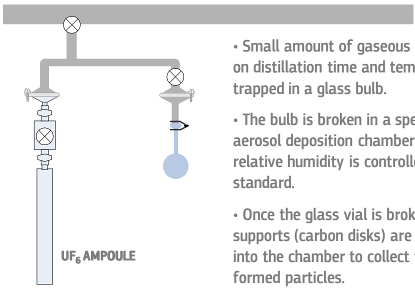
Joint Research Centre

Preparation, characterization and analysis of uranium reference particles for nuclear safeguards

IRMM has recently expanded its capabilities for the preparation and characterization of single uranium reference particles for nuclear safeguards. The procedure was optimized for a single enrichment deposition and applied to prepare well characterized certified test samples for NUSIMEP (Nuclear Signatures Interlaboratory Measurement Evaluation Programme). NUSIMEP-6 was the first interlaboratory comparison on uranium isotope amount ratios in uranium particles. In addition, an improved method was developed for the isotopic analysis of individual micrometer-sized uranium reference particles. This method includes particle manipulation using a Scanning Electron Microscope (SEM) and analysis by Thermal Ionization Mass Spectrometry (TIMS) combined with filament carburization and Multiple Ion Counting (MIC) detection. Individual reference particles produced from certified UF_6 with high, low and close to natural ^{235}U enrichment were analyzed. Reliable measurements with significantly smaller uncertainties were obtained, not only for the major isotope ratio $n(^{235}U)/n(^{238}U)$, but also for the minor ratios $n(^{234}U)/n(^{238}U)$ and $n(^{236}U)/n(^{238}U)$.

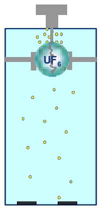
Production of uranium reference particles



- Small amount of gaseous UF_6 (dependent on distillation time and temperature) is trapped in a glass bulb.
- The bulb is broken in a specially-made aerosol deposition chamber, where the relative humidity is controlled by a humidity standard.
- Once the glass vial is broken, the particle supports (carbon disks) are quickly inserted into the chamber to collect the freshly formed particles.

HUMIDITY AND TEMPERATURE SENSOR

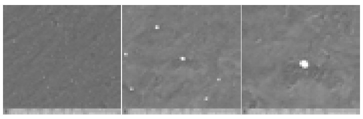
AEROSOL DEPOSITION CHAMBER



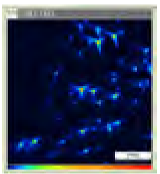
$UF_6 + 2\,H_2O \rightarrow UO_2F_2 + 4\,HF$

Characterization of U-reference particles

SEM and secondary ion mass spectrometry (SIMS) were used to characterize U-reference particles deposited on the graphite planchet. The particles are isolated and spherical. This method will be used to prepare NUSIMEP samples with two different uranium enrichments.



SEM images of U-reference particles, single deposition. SEM analysis performed at JRC IRMM.

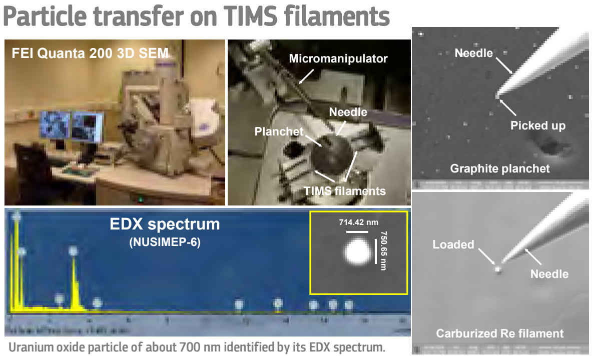


Ion image of particles, single deposition. SIMS analysis performed by JRC ITU.

Isotopic analysis of single uranium reference particles

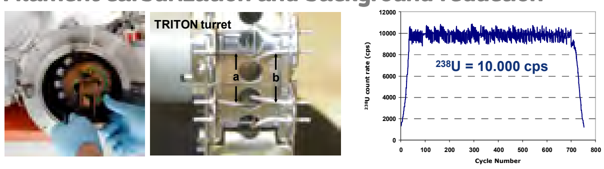
Isotope ratios measurements were carried out with a TRITON TIMS instrument (Thermo Fisher Scientific, Bremen, Germany) using the MIC technique. Filament carburization was performed using pure benzene gas as a ^{238}U-free carbon provider for enhancing the uranium ionization efficiency (0.2 %–0.3 %). A baking procedure that employs a modified side filament mounted close to each sample filament helped in reducing the background levels by a factor of 5-10. Individual particles were measured together with JRC IRMM standard solutions for intercalibration of the counters

Particle transfer on TIMS filaments



Uranium oxide particle of about 700 nm identified by its EDX spectrum.

Filament carburization and background reduction



Carburization chamber a) Sample filament; b) Side filament

^{238}U count rate vs. cycle number for a particle measurement

TIMS results for individual highly (HEU) and low (LEU)-enriched, and natural (NU) uranium particles

Table 1. MIC measurements of single NBS-200 uranium standard particles

Corrected Sample Ratio	$n(^{235}U)/n(^{238}U)$		$n(^{234}U)/n(^{238}U)$		$n(^{236}U)/n(^{238}U)$	
NBS-200, certified value	0.25126		0.0015643		0.0026566	
Uncertainty (k=2)	0.00025		0.0000038		0.0000074	
Set number (n≥7)	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
Average	0.2485	0.2467	0.00155	0.001552	0.00267	0.002687
Uc (k=2)	0.0015	0.0049	0.00013	0.000072	0.00012	0.000082
Rel. Uc (k=2) %	0.6	1.9	8.5	4.4	4.6	2.9
Trueness (%)	-1.1	-1.8	-0.6	-0.8	0.5	1.2

Table 2. MIC measurements of single NUSIMEP-6 and IRMM-722 uranium standard particles

Corrected Sample Ratio	$n(^{235}U)/n(^{238}U)$		$n(^{234}U)/n(^{238}U)$		$n(^{236}U)/n(^{238}U)$	
CRM	NUSIMEP-6	IRMM-722	NUSIMEP-6	IRMM-722	NUSIMEP-6	IRMM-722
Certified value	0.0070439	0.020803	4.9817 × 10–5	0.0001826	5.2048 × 10–7	3.2 × 10–6
Uncertainty (k=2)	0.0000035	0.000034	4.8 × 10–8	0.0000011	8.6 × 10–10	2.7 × 10–8
Average	0.00713	0.02110	0.000070	0.000226	–	–
Uc (k=2)	0.00021	0.00032	0.000042	0.000031	–	–
Rel. Uc (k=2) %	1.4	1.5	60.6	13.8	–	–
Trueness (%)	1.2	1.4	40.4	24.0	–	–

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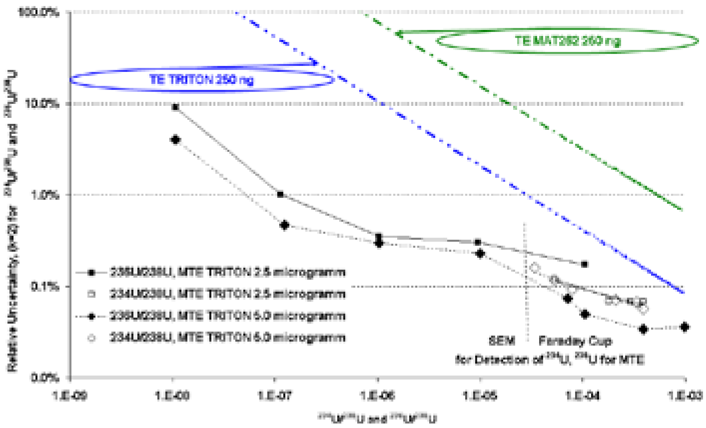
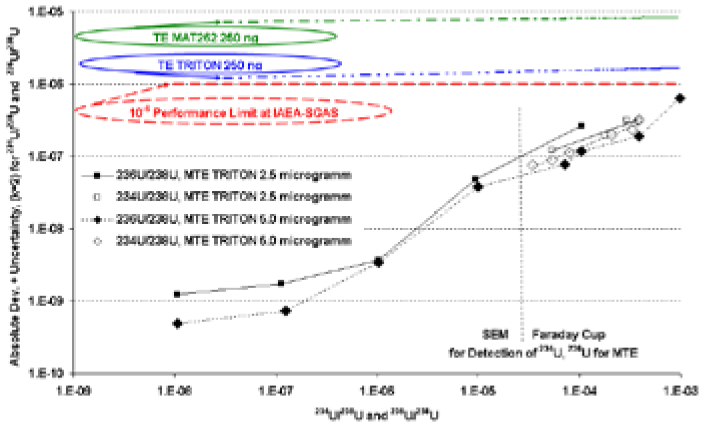
The Modified Total Evaporation (MTE) Method

Collaboration between JRC IRMM (leading), JRC ITU, NBL (U.S. DOE), IAEA-SGAS, Thermo Fisher Scientific. More laboratories expected to join MTE "network"

The International Atomic Energy Agency (IAEA) states: "The MTE method enables the IAEA to achieve an unprecedented level of accuracy for the measurement of the ^{234}U and ^{236}U isotopes in nuclear material samples which significantly improves the verification of State declarations regarding the origin and processing history of nuclear material under safeguards".





MTE: 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 $^{236}U/^{238}U$)

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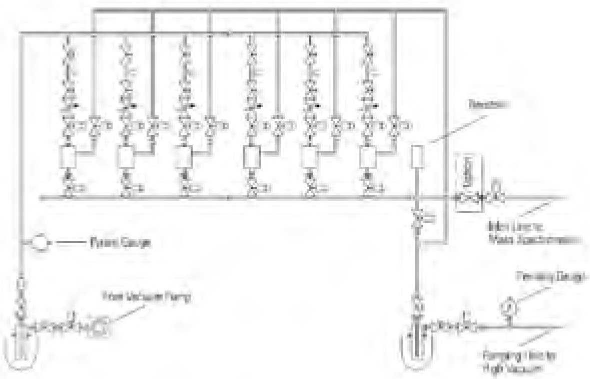
Uranium Hexafluoride (UF_6) Gas Source Mass Spectrometry for Certification of Reference Materials and Nuclear Safeguards

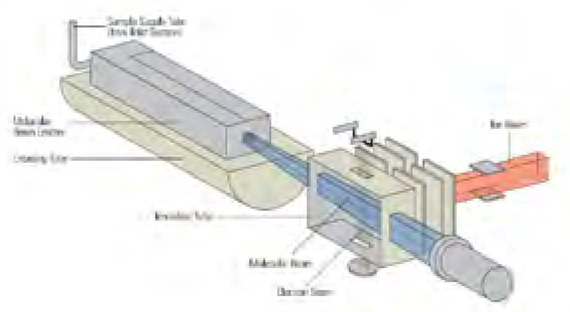
Main features of URANUS, the new UF_6 gas source mass spectrometer:

- Capability to measure minor isotopes ^{234}U, ^{236}U simultaneously with major isotopes ^{235}U, ^{238}U
- Sample inlet system for automated measurement sequences
- Automatic filling system for uninterrupted liquid nitrogen supply
- Recertification for UF_6 reference materials IRMM-019-029 on-going
- Used to satisfy requests from DG ENERGY, enrichment industry

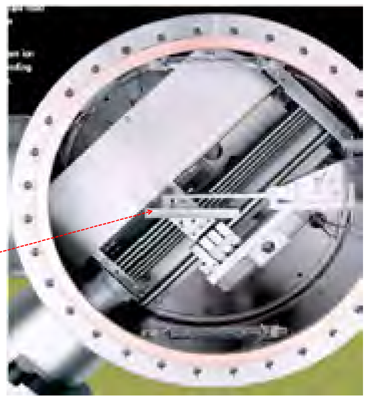
The Design of the URANUS:

- Sample introduction system for automatic sequences (equipped with 9 inlets), e.g. for double standard method
- Electron Impact (IE) Source, cooled with liquid nitrogen





- "Triple-Faraday Collector" for masses 329 ($^{234}U^{19}F_5^+$ ions), 330 ($^{235}U^{19}F_5^+$ ions) and 331 ($^{236}U^{19}F_5^+$ ions),
- Following the installation at IRMM carbon-coated slit used to reduce scattering of positive ions



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Joint Research Centre

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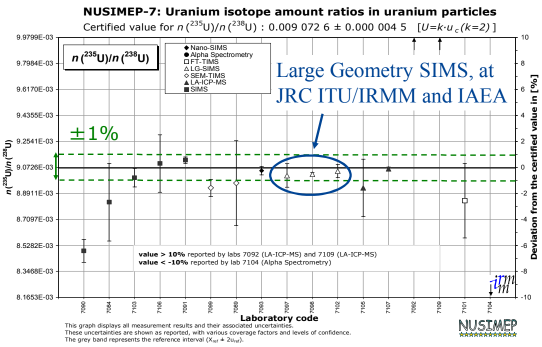
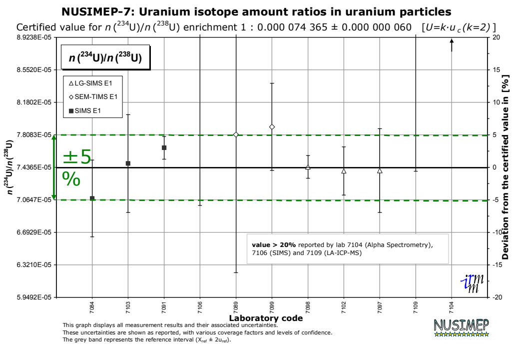
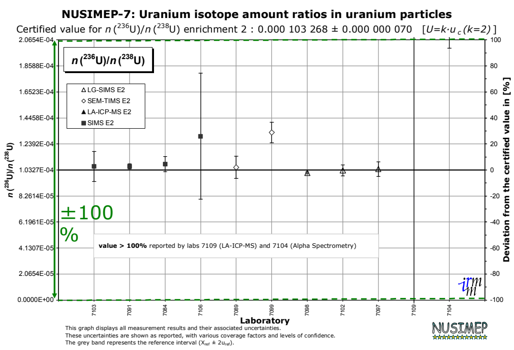
NUSIMEP-7:
Uranium isotope amount ratios in uranium particles

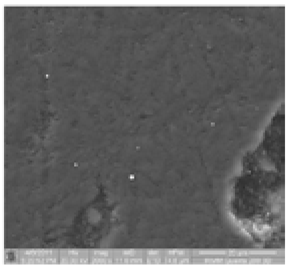
The Director of the Division of Concepts and Planning at the IAEA Department of Safeguards: *The difficult-to-produce JRC IRMM particle standards were of exceptionally high quality and proved to be very valuable for the IAEA.*

- <u>Nu</u>clear <u>S</u>ignatures <u>I</u>nterlaboratory <u>M</u>easurement <u>E</u>valuation <u>P</u>rogramme
- EC support programme task to the IAEA - Tool to support the NPT/additional protocol
- 24 participants from 21 institutes:
  IAEA-ESL, 6 NWAL, 2 JRC, research institutes & universities
  → All nuclear weapons states were represented
- 2 graphite planchets (<u>single</u> deposition & <u>double</u> deposition)
- Measurement of $n(^{234}U)/n(^{238}U)$, $n(^{235}U)/n(^{238}U)$ & $n(^{236}U)/n(^{238}U)$
- Verification by Scanning Electron Microscopy & Secondary Ion Mass Spectrometry









- Measurement capabilities for uranium major and minor ratios were in general satisfactory taking the stringent assessment criteria into account

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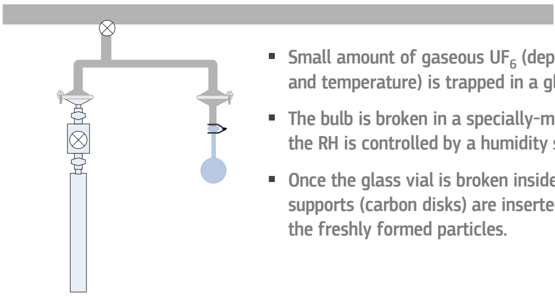
Uranium reference particles for environmental swipe sample analysis in nuclear safeguards

Detection of undeclared nuclear activities through environmental sampling

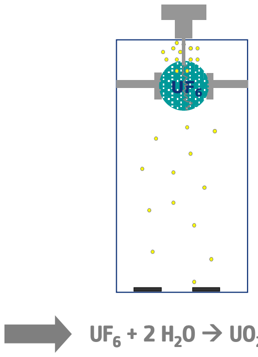
Uranium enrichment → Increase of relative concentration of ^{235}U using UF_6 gas → Reaction with atmospheric moisture → UO_2F_2 particles → Particles settle onto various surfaces inside and around the facility → Collection of particles in swipes by inspectors → Analysis & verification

Development of U reference particles at JRC:

Production of uranium reference particles

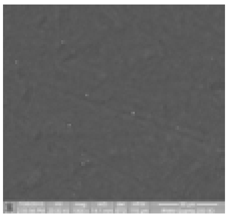


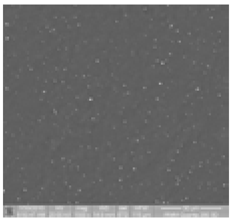
- Small amount of gaseous UF_6 (dependent on distillation time and temperature) is trapped in a glass bulb.
- The bulb is broken in a specially-made aerosol chamber, where the RH is controlled by a humidity standard.
- Once the glass vial is broken inside the chamber, the particle supports (carbon disks) are inserted into the chamber to collect the freshly formed particles.



$UF_6 + 2\,H_2O \rightarrow UO_2F_2 + 4\,HF$

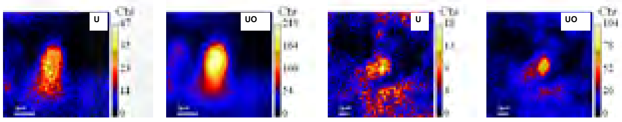
Single deposition





The quality of U reference particles is affected by the rate of UO_2F_2 formation, related to how UF_6 is released into the air in the aerosol chamber. The SEM pictures of uranium oxyfluoride particles show two single depositions. Imaging was carried out using a tungsten-filament FEI Quanta 200 3D scanning electron microscope (SEM).

Double deposition



Ion images of particles on the planchet with double deposition. Some spots with a uranium background are still detectable. Secondary ion mass spectrometry (SIMS) measurements performed with a NanoSIMS (CAMECA SAS); 10 µm x 10 µm ion images of particles with a spatial resolution of 300-400 nm using an O-primary ion beam of about 50 pA.

→ **NUSIMEP-6 & NUSIMEP-7**

Single particle measurement

- Transfer of single particles using an optical microscope with micromanipulators
- Measurement by TIMS with multiple ion counting technique (total evaporation)
- EC support task to the IAEA to certify monodisperse uranium particles produced from the IRMM-023 UF_6 standard (3.2% ^{235}U, 11ppm ^{236}U)

↳ first certified reference material for uranium containing particles

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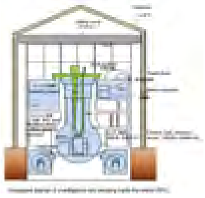
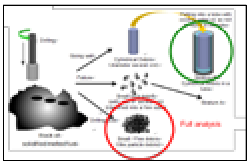
Nuclear Material Accountancy

Post-Fukushima method development

Collaboration JAEA/JRC

Nuclear material accountancy of melted fuel debris





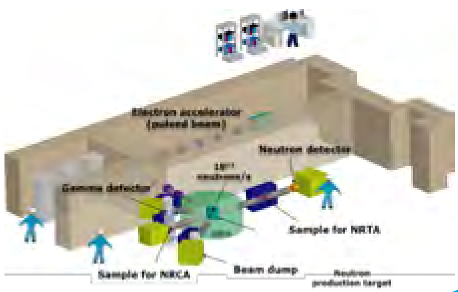
Removal of core material

The fuel present in the core are partially or entirely melted down. Ordinary material accounting and control methods cannot be applied.

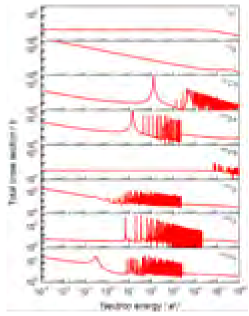
Challenges:

- Diversity in shape and size of particle like debris
- Thickness of particle like debris
- Presence of neutron absorbing matrix materials
- Presence of high radioactive fission products
- Temperature of particle like debris

Ultimate goal: NRD facility at Fukushima



Development of Neutron Resonance Densitometry (NRD)



GELINA :
linear accelerator facility at JRC-IRMM Geel

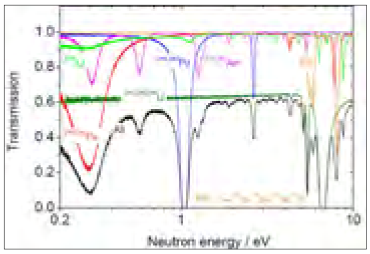
NRD:

Use of the unique neutron resonance structure of each nuclide as a fingerprint to identity and quantify special nuclear material by measuring the transmission $\boldsymbol{T}$

$$\boldsymbol{T} = \frac{C_{in}}{C_{out}} = e^{-n\ \sigma}$$

$\boldsymbol{n}$ known → accurate determination of cross section $\boldsymbol{\sigma}$

$\boldsymbol{\sigma}$ known → accurate determination of material amount $\boldsymbol{n}$



First feasibility test finalised in 2014 at GELINA

Full NRD demonstration at GELINA in 2015

Aim : 2 % accuracy on U/Pu content

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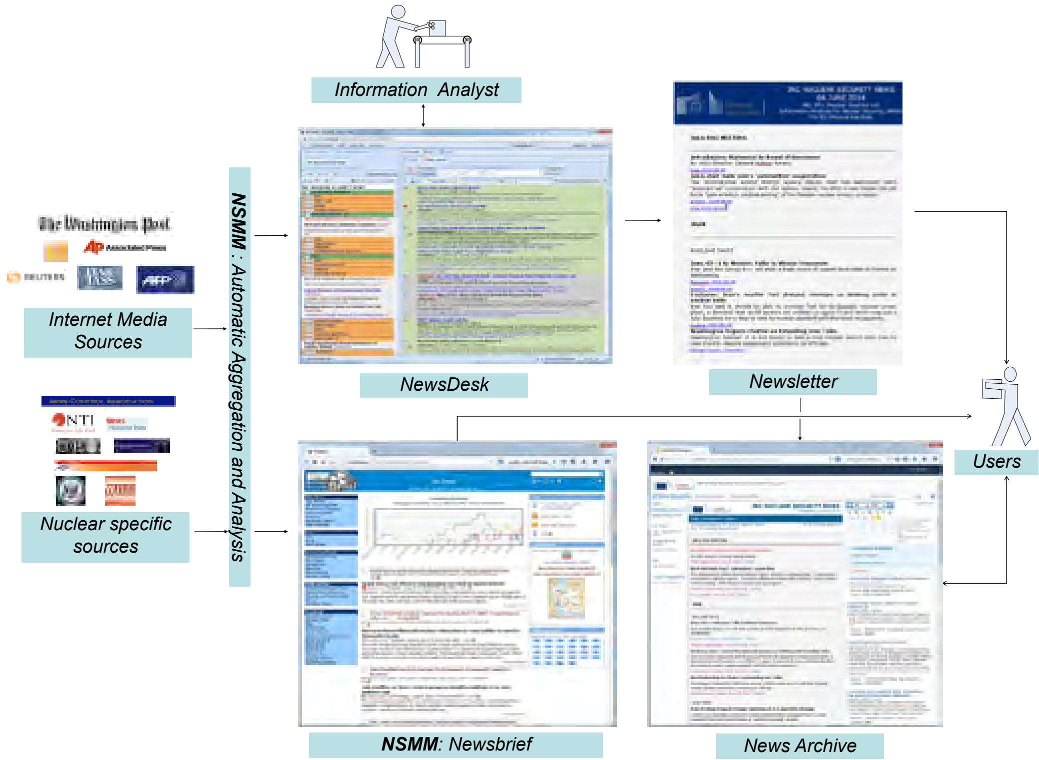
SAFEGUARDS TOOLS, CONCEPTS AND APPROACHES

Open Source Information for Nuclear Security

Application and Tools



What we do

- Provide EC services and EU stakeholders with unbiased technical information on non proliferation and nuclear security issues.
- Nuclear security news are regularly monitored from open sources. Important issues are highlighted in the news review process and are disseminated in a nuclear security newsletter.
- Develop dedicated tools to facilitate the in-house non-proliferation analysis. The tools also support open source analysis activities at the IAEA.

Nuclear Security Media Monitor (NSMM)

- Continuously monitors pre-defined web sources for new information.
- Based on the Europe Media Monitor (EMM) developed by JRC which automatically aggregates and analyzes news information from over 4000 pre-defined web sites.
- NSMM Includes approx. 150 additional nuclear information sources which were identified in collaboration with IAEA [1].
- Filters all incoming information according to nuclear relevance.

[1] G. G.M. Cojazzi, E. van Der Goot, M. Verile, E. Wolfart, M. Rutan Fowler, Y. Feldman, W. Hammond, J. Schweighardt, M. Ferguson "Collection and Analysis of Open Source News for Information Awareness and Early Warning in Nuclear Safeguards". *ESARDA Bulletin No. 50*, December 2013.

Information Review and Newsletter Production

- Daily collection of nuclear related information. Most relevant articles are selected by a domain expert.
- The newsletter is for EU internal use and is sent to more than 200 users for early warning and information awareness.

Nuclear Security News Archive

- Searchable archive of JRC Nuclear Security News since January 2011 (JRC internal use only).
- Automated import of newsletter content and metadata. Custom taxonomy (Location and Topic) extracted from newsletter sections.
- Used internally as repository and information source for Nuclear Security and Non-Proliferation studies.

Information Source Categories Monitored by NSMM.

Category Name	Content	Frequency
General News and Aggregators	Directly-accessed news sources, news aggregators.	Very High
Nuclear News Aggregators	Articles news aggregators that customarily or primarily report on issues related to nuclear industry and safeguards.	High
NGO & Academic	Detailed reports and added value assessments concerning State's nuclear programmes and activities, and general nuclear nonproliferation issues.	Medium
Government & Intergovernmental	Information from relevant intergovernmental organizations and competent authorities at national level.	Low / Medium
Nuclear Industry	Information on companies including location(s), products, capabilities, activities.	Low / Medium

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European Commission

Strategic Trade Analysis for Non Proliferation

Trade analyses on **strategic goods* in support to non proliferation**, IAEA nuclear safeguards, and to inform EU policies for export controls and EU outreach activities.

Research and development on strategic trade analysis techniques, mutated from statistical and economic methods.
Design and development of information technology tools to host structure, visualise and present trade data by commodities, geopolitical areas, regulations and export guidelines on strategic trade.

(*) **Strategic goods** are dual-use goods and technologies with civil and military uses whose export is controlled as a measure of non proliferation.

WHAT WE DO

DATA TOOLS STUDIES

FOR

NUCLEAR SAFEGUARDS – IAEA EC Support Task – since 2007

Catalogue of trade data sources

Test cases

THE BIG TABLE

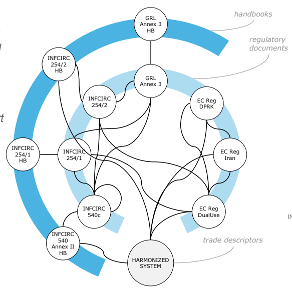
IAEA independent work on, e.g., Additional Protocol declarations on exports

THE BIG TABLE + IAEA's PHYSICAL MODEL

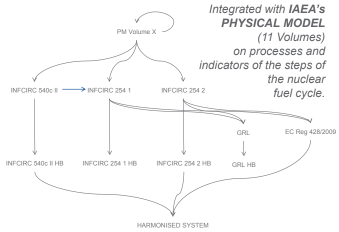
GTA

TRADE FLOW TOOL

THE BIG TABLE is a tool to relate strategic goods (listed in regulatory documents and technical handbooks) and descriptors of the Harmonized System used in trade data sources where customs import/export flows between countries are recorded.



*THE BIG TABLE is Integrated with **IAEA's PHYSICAL MODEL** (11 Volumes) on processes and indicators of the steps of the nuclear fuel cycle.*



EU POLICY FOR EXPORT CONTROLS

DG TRADE Admin. Arr. – since 2011

THE BIG TABLE

Commission Staff Working Document

COMEXT

TRADE FLOW TOOL

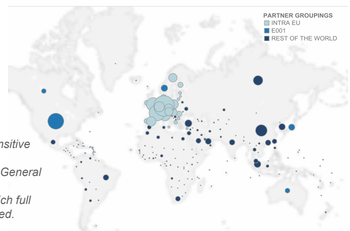
Questionnaire to Member States on license data

Commission Report to Council and European Parliament

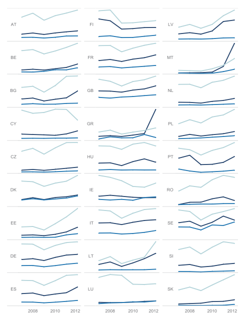
Exports of dual-use items from EU Member States are subject to controls depending of the export destination country.

*Built with the **TRADE FLOW TOOL**, the map shows estimated flow value of dual-use goods to **three areas**:*

- *Intra-EU, where only few sensitive items are controlled*
- *E001* countries covered by General Export Authorisations*
- *and the rest of world, for which full licensing of exports is required.*



E001 countries: Australia, Canada, Japan, New Zealand, Norway, Switzerland and the United states*



The line charts feature the value of exports over time by Member States and by worlds areas. MS have different export patterns. However most MS exports are dominated by intra-EU transfers.

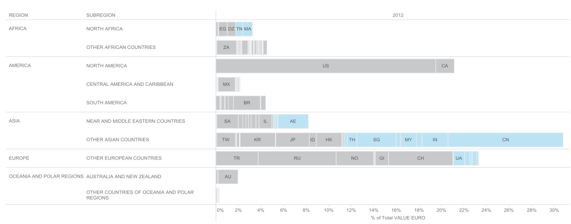
EU OUTREACH PROGRAMME

DG DEVCO Admin. Arr. – since 2014

Study for the selection of countries for EU outreach activities

UN COMTRADE

WORLD TRADE ATLAS



Outreach activities aim at promoting the use of effective controls and implementation standards across countries in the world.
The bar chart features the value of EU exports to Third Countries in order to identify the main trade partners of the Union in the dual-use commodity area.
Countries are presented by geographical areas.
Countries highlighted in blue are currently included in the EU Outreach Programme (LTP III).

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Joint Research Centre

Strategic Export Control activities at JRC

The control of the export of **dual-use goods** , with both civil and military applications, represent a key barrier against proliferation of Weapons of Mass Destruction, developed in parallel to the international non-proliferation framework.

The **EU legal framework** for the control of dual use goods is ruled by EC Regulation 428/2009 and amendments, implemented at national level..

DG TRADE fosters the EU harmonised implementation of dual-use goods controls through the activities of the Dual Use Coordination Group.

DG DEVCO manages the cooperation programmes including the EU Long Term Programme on export control.

The **Non Proliferation Treaty** includes requirement to send nuclear items and technology only to safeguarded facilities.

The **Additional Protocol** to Comprehensive Safeguards Agreements requires countries to provide declarations on exports of Trigger List items.

The **IAEA** does not implement export controls but benefits from their existence, called for by UNSCR 1540.

The **International export control regimes** develop guidelines and control lists including items, software and technologies instrumental to nuclear, chemical, biological WMD and their means of delivery

Policy support

The JRC fulfils its mission of supporting the policy of Strategic export control by a portfolio of activities included in the STREX project and mainly geared to DG TRADE for the harmonised implementation of Strategic Export Controls in EU-28 and DG DEVCO for cooperation with partner countries.

JRC's support to harmonised implementation acknowledged in recent Commission's reports to the European Parliament and European Council;

New Lines of Action reports for the implementation of the EU WMD strategy.

Technical advice

The JRC operates 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

The **European Union dual-use control list** integrates the various international export control regimes control lists and is contained in Annex I to the Dual-Use Regulation.

Related activities:

- review and comment on the proposals discussed at **Nuclear Suppliers Group** (nuclear technology) and **Australia Group** (bio- and chemical technology)
- contribution to the amendment of Annex I's dual-use control list under the new Delegated Act to the Commission.
- Denials analysis

Support to EU outreach

The EU fosters the harmonised implementation of controls through a variety of instruments and initiatives, including support measures to Member States and EU partner countries to improve their export control systems. The JRC provides support to DG DEVCO for the evaluation and development of the EU Long Term Program on export control.

Capacity building and technical support

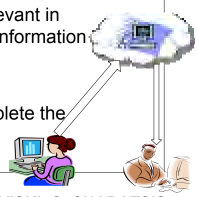
The JRC increasingly develops dual-use capacity relying on a core team and ad-hoc expertise.

Technical seminars are regularly provided to licensing officers, in cooperation with the US Dept. of Energy and EU national authorities. The JRC also organises technical workshop on export control best-practices for the Enlargement & Integration countries.

Research activities on various dual-use topics are developed in with **ESARDA** and **IAEA**. These include:

- Internal Compliance of suppliers, a key element of export control. Management commitment, awareness raising, regular trainings and mapping of technology and goods facilitate the fulfilment of requirements..
- Intangible Technology Transfers issues, especially relevant in dual-use research, traditionally open to exchanges of information
- Technical and legal framework updates

JRC internal compliance and awareness raising complete the portfolio of activities.



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European Commission

JRC BUILDING EXPORT CONTROL CAPACITY

Training experience and projects

In cooperation with partners

- *Technical seminars for EU licensing officers*
- *Enlargement & Integration workshops*
- *EUSECTRA module on export control for customs/border guards*
- *IAEA Safeguards import-export trainings*
- *JRC internal awareness raising seminars*
- *2014 licensing/customs pilot exercise project*

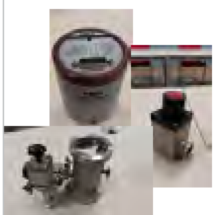
Collaboration

NNSA

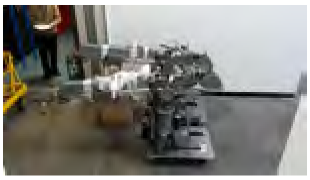
Centres of Excellence

IAEA

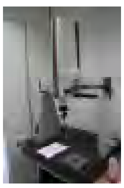
Infrastructure

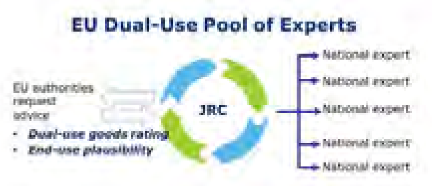


- *Demo components and equipment*
- *Installations (nuclear Fuel cycle)*
- *On site dual use equipment*



- *Legal and technical experts and network*





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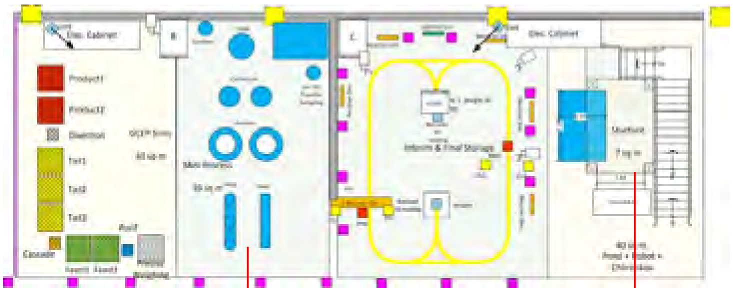
PROCESS MONITORING, SEALING, CONTAINMENT AND SURVEILLANCE

AS3ML

Advanced Safeguards Measurement, Monitoring and Modeling Laboratory



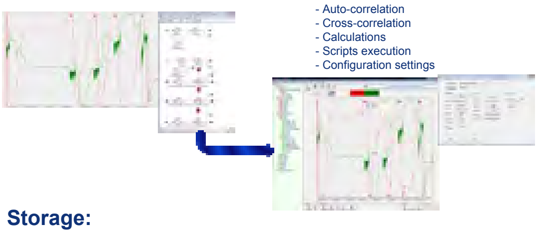
Introduction:

The most safeguards sensitive plants are the spent fuel reprocessing facilities and the uranium enrichment plants…
AS3ML will host existing equipment and software pieces but also new ones for testing and benchmarking purposes.

Data Analysis & Interpretation (DAI):

The JRC software DAI is used for the process monitoring (without feedback). DAI interprets the signals and verifies the consistency and coherency with predefined criteria.

- Auto-correlation
- Cross-correlation
- Calculations
- Scripts execution
- Configuration settings



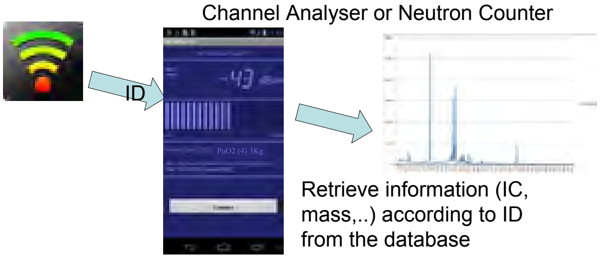
Storage:

Neutron and gamma simulators will be used to reproduce nuclear material movements through the facility.
Reviewing systems such as DAI will be used to ensure the analysis of relevant information, gamma spectrum, neutron counting & video.

Principle neutron and gamma simulator :

A Wi-Fi emitter sends its signal with ID

A Wi-Fi receiver measures the signal strength and based on the ID generate the appropriate Pulse for the Multi Channel Analyser or Neutron Counter



Retrieve information (IC, mass,..) according to ID from the database

Principle of neutron & gamma simulators

The pulse rate will be proportional to the signal strength

Mini Process:

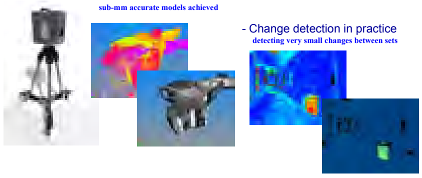
Process monitoring includes a two-fold task: firstly, a continuous survey of the health status of the instrumentation and process conditions and, secondly, a comprehensive real-time interpretation of the dynamic of the process.
The process data collected are the Pressure, Density (Dip Tubes) and Temperature. The Near Real Time Analysis is done using a dedicated software called DAI.

Platform and Pond:

Stable and safe platform for simulation of the bridge over the underwater storage pond.
Reproduction of spent fuel racks.
Mimic operational sealing conditions.
Real handling sealing components and tools.

3D laser based verification:

- Hands-on Scanner operation
- 3D Model construction
sub-mm accurate models achieved
- Change detection in practice
detecting very small changes between sets



Head Quarter Office:

The HQ Office together with the Server Room will be used to test data transmission by different means: phone lines, network. Injection of noise, transfer interruption and techniques for encryption and authentication will be studied.

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Joint Research Centre

PuO_2 MAGNOX Store Project

Implementing advanced/enhanced safeguards requires a design leading to a win-win situation for both Operator's and Inspectorate's sides.

Win-win situation:

The new design for enhanced safeguards will:

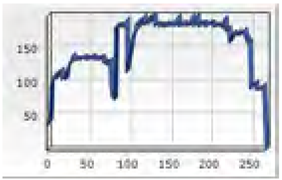
- allow the Operator to access the PuO_2 storage at any time even when the Inspectors are not present,
- allow the Inspectorate to save resources (manpower, time, money).

This was possible by designing and making use of some novelties in the safeguards field:

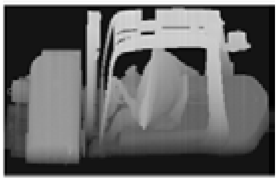
Double Laser Curtain (DLC):

Able to distinguish entry and exit events but also to categorize them according to the profile. A short video sequence is also automatically recorded.

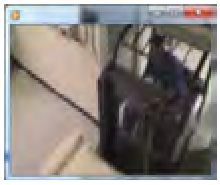
Picture of the implementation of the DLC and neutron portals



2D-profile of a forklift truck (FLT) and its charge block



Reconstructed image from the profile of a forklift truck



FLT image from associated video record

RFID reader:

Duly authorized equipment is automatically identified.

UCMS:

Unattended Combined Measuring System equipped with a balance, a neutron counter, a CdZnTe detector and identification systems.

Picture of the implementation of the RFID reader

Picture of the implementation of the UCMS at the entrance of the PuO2 storage

Picture of the UCMS showing the balance. 38 He-3 tubes are embedded in the walls. ID systems are placed over the container lid

Reporting windows:

Display of the most important information in single windows with direct video review capabilities and links to other relevant information.

By selecting an event spotted by the DLC, the Inspector has the possibility to select cameras, to perform direct video reviewing and to visualize other relevant info: neutron count rates, tag IDs…

UCMS measurements: the Inspector has the possibility to visualize the can ID and check it with the displayed picture, the weight, the raw neutron counting information and the gamma spectrum via a link

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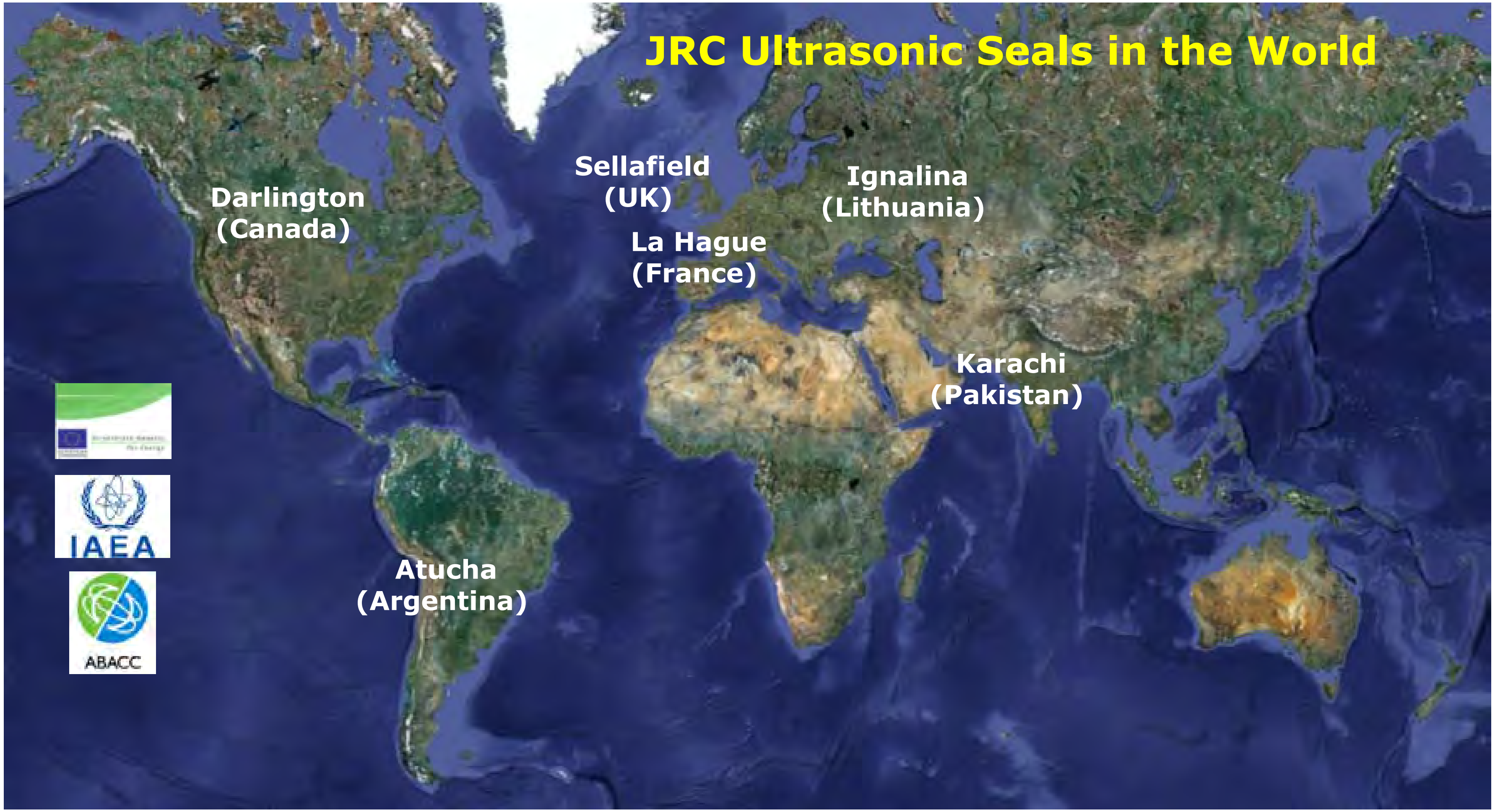
JRC Ultrasonic Seals in the World



* Future implementation at Atucha

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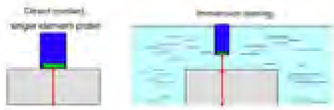
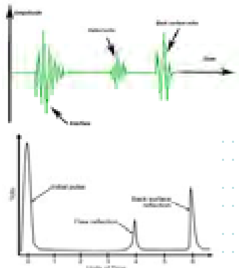
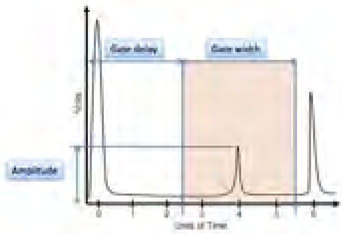
Ultrasonic Seals Basics

Principle:

- Ultrasonic sound waves are reflected at interfaces and by internal flaws
- Transducer with piezoelectric crystal which resonates at 10 MHz
- Pulse-echo mode (one single transducer sends & receives the pulsed waves)
- Water used as coupling





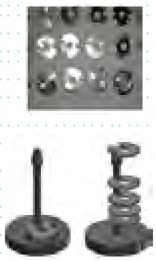


Pulse–echo representation:

- Amplitude of received pulse versus travel time of emitted pulse
- Gate or window (delay & width) to increase gain on specific defect zone

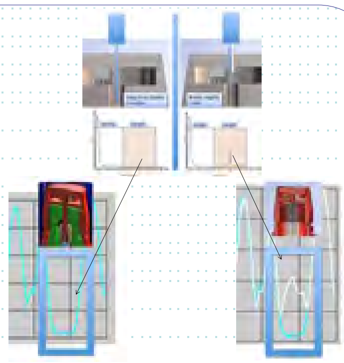
Ultrasonic seal:

- Identity: Artificial flaws made on stainless steel disks brazed (T> 1000°C) together to form a unique signature
- Integrity: Breaking zone in the ultrasonic window



Ultrasonic readings:

- Rotating transducer above the disks gives the unique signature
- Transducer above the integrity: echo = broken



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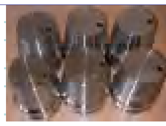
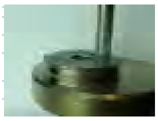
European Commission

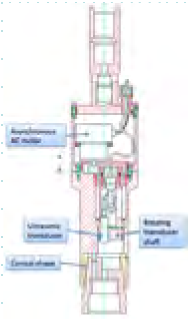
JRC CANDU Sealing System (JCSS)

Seal:
- Ultrasonic bolt seal designed to comply with CANDU requirements
- Patented by JRC
- Stainless steel bolt particularly resistant to harsh environment conditions
- Maintain identity while broken

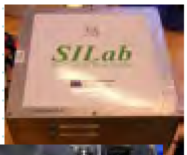





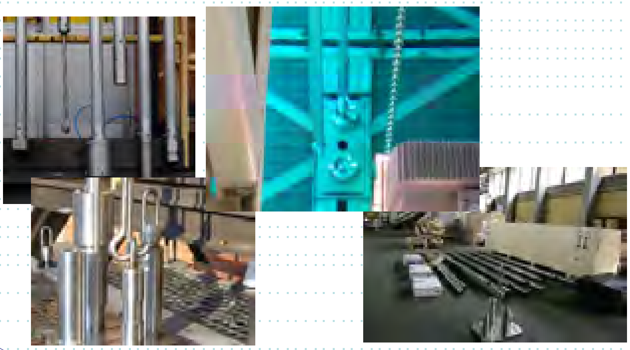


Reading Head:
- Actuation of the ultrasonic transducer
- Low tech motor radiation resistant
- Conical shape to align seal with axis of rotation of transducer
- Stainless steel
- Waterproof

Acquisition system:
- Off the shelf USB ultrasonic box
- Assembled in a box with motor control
- Industrial Toughbook



Analysis software:
- Read identity signature and integrity status
- Manage signature database
- Upgraded for each particular application



Handling Tools:
- Used to remotely handle the seals and the reading head underwater
- Degrees of freedom added to comply with teleoperation errors & increase feedback to the operator (breaking torque)

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Joint Research Centre

JRC Electronic Seal - JES

Scope of the project
The JRC electronic seal is being developed to fill a gap in current sealing technologies in nuclear safeguards.
The most widely used seals are currently passive seals which have a low cost, but are complex to verify and cannot provide any information on the wire integrity.
Existing electronic seals perform a large number of functions, not all essentials, and are quite expensive.
The JRC electronic seal aims at combining the simplicity of a passive seals with the core advantages of electronic seals, namely the continuous monitoring of the wire and the possibility to interact with the seal through a reader, simplifying the inspector's work and providing more complete information.

Key requirements

- Low Cost
- Low power consumption
- Wire integrity monitoring
- Authentication
- Security / Data encryption
- Simple communication
- Event logging
- Anti-tampering
- Harsh environment
- Single event upset

DG ENER

IAEA

2011-2013
- Feasibility study
- Design & Development (HW & SW)
- First prototype 2012
- Preliminary tests
- Prototypes delivered to Customers on Sept 2013

2014
- Pre-industrial prototype delivered to customers on May 2014 for feedbacks and preliminary VA
- Finalize project according to feedbacks

Next
- New project for more powerful seal with additional functions (remote interrogation, public key infrastructure …)

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Copper brass seal verification with automated image acquisition

Old System

- Repetitive actions
- Time consuming
- No aid in the verification
- Old hardware
- Closed system

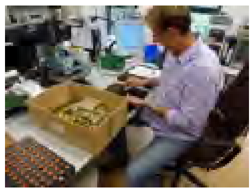

Verification of EURATOM seals

New system (delivered May 2013)

- Automated acquisition of seal batches
- Preprocessing of acquired seal images:
  - Automatic image overlapping
  - Automatic digital image rotation
  - Image blinking

Results

- New copper brass seal verification systems delivered in May 2013n and June 2014
- About 20,000 seals already processed
- DG ENER approved system efficiency and improved quality of work
- Potential interest of IAEA for its own copper brass seals



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European Commission

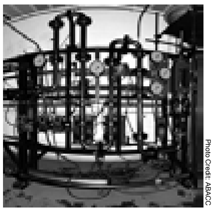
3D Surveillance Laboratory

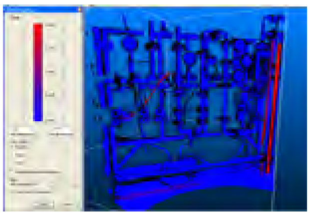
Laser Based Identification and Verification Techniques

The poster overviews different 3D laser based systems and their potential in safeguards. 3D technologies can be used for improved continuity of knowledge in several application areas including site modelling and verification of design changes both indoors and outdoors, identification of nuclear containers by unique surface maps and the verification of containment and closure welds.

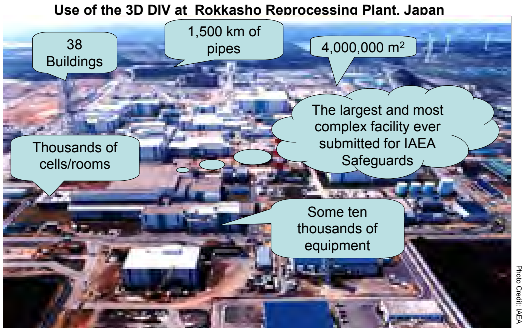
3D Laser Range Finder (3DLR) for Design Verification

3D DIV system consisting of a laser range scanner and software for the acquisition, processing and analysis of the 3D data. The system is able to identify changes in positions and modifications with millimetre precision.





Use of the 3D DIV at Rokkasho Reprocessing Plant, Japan



Reference Task: EC-E-01425

Laser Item Identification System (L2IS)

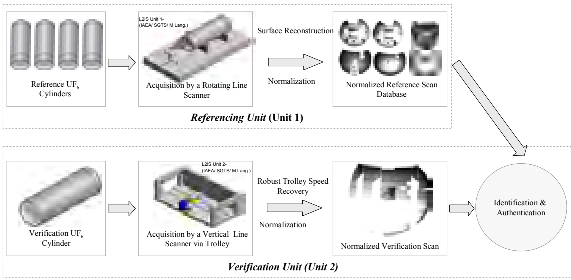
UF6 cylinder identification and authentication based on the "fingerprint" of the cylinder side surface.

Portable L2IS unit 1

Unattended Measurement Station L2IS Unit 2

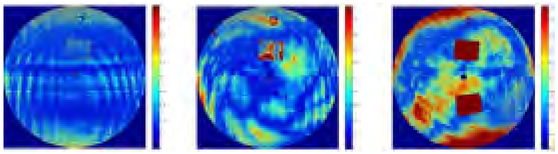
Reference Task: EC-E-01696

Referencing Unit (Unit1): Portable unit used by the IAEA inspectors to acquire the cylinder identity and populate the reference database.



Verification Unit (Unit2): The unattended L2IS Unit is fix installed in the facility. All cylinders entering and exiting the enrichment process area recorded by the system.

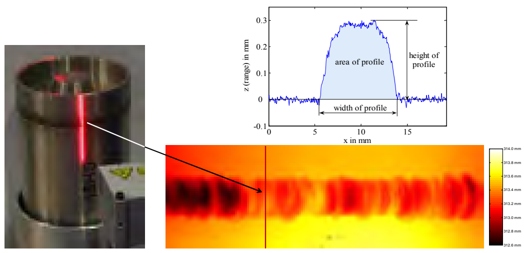
Forensics analysis software



Results of matching a verification scan against the correct reference (left) and against two other reference scans (centre and right). Each point indicates the error between the reference and the verification surfaces, from dark blue (0 mm), to green (0.5 mm), to dark red (1 mm or above).

Laser Surface Mapping for Containment Verification (LMCV)

3D laser imaging techniques are also used for containment and weld verification on containers with nuclear materials. Opening a sealed container and closing it again will inevitably cause changes to the three-dimensional structure of the surface which can be detected using 3D laser techniques.



Reference Task: EC-E-01549

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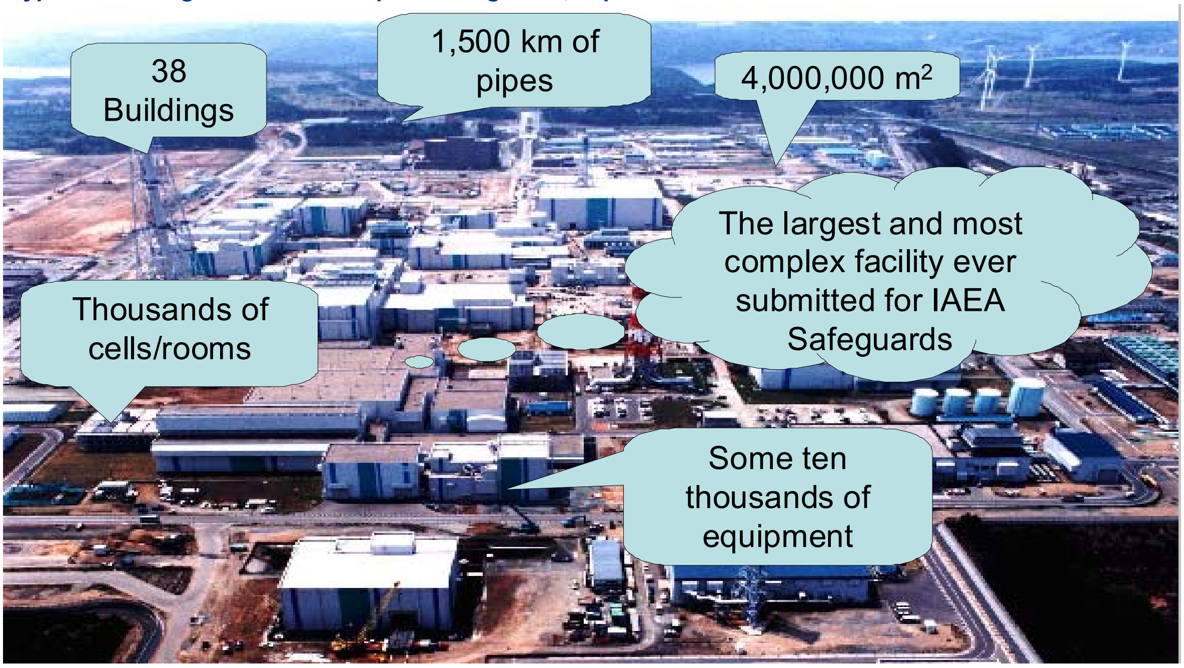
Joint Research Centre

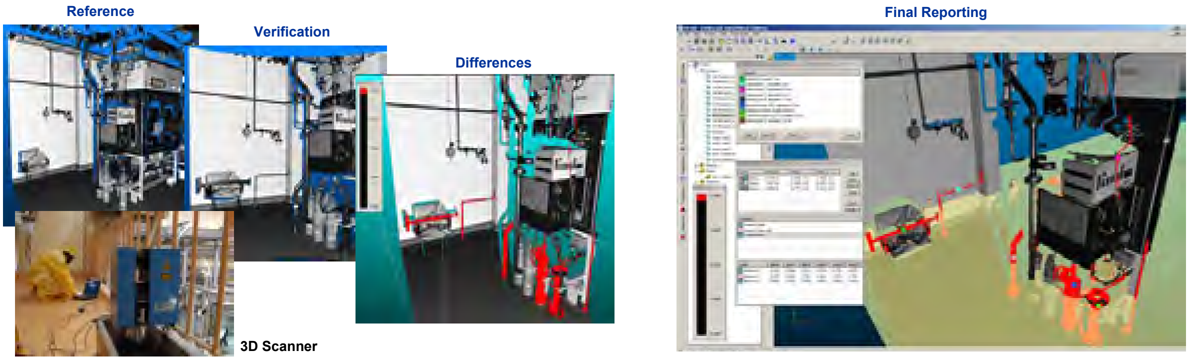
Design Information Verification

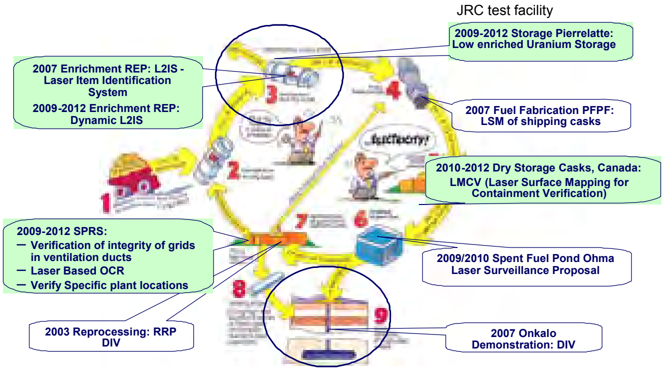
JRC 3D Reconstructor

Typical Challenge: Rokkasho Reprocessing Plant, Japan



DIV: Data Acquisition and Processing





From innovation to field application and technology transfer

- Multiple scientific awards, e.g. best paper publications, patents
- In use by IAEA, ENER, under trial in US DoE and ABACC facilities
- Technology Transfer: About 1M€ in Royalties

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3D Vision Laboratory

Laser Based Techniques for the Verification of Dry Storages

Objective:

Use laser-based analysis technique to provide a more efficient/effective method to identify changes in large dry storages.

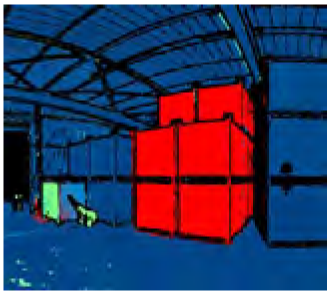
Typical view

History:

- Proof of concept performed 2009
- Acceptance from state inspectorate and operator 2009
- Routine operation since 2010

Typical activities:

- Scan of parks (6-20 scans). Currently some 30 parks are under control.
- Verification scans of parks (6-20 scans)
- Change identification between verification scans and earlier acquired scans

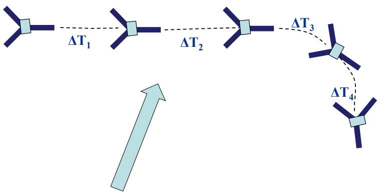


View with changes marked in color

Remote controlled motorized trolley:

Benefits:

- Less dose for the user
- Automated acquisition
- Faster post-processing



Maintaining its trajectory during movement and acquisition

Scanner

On-board computer

Motors on wheels

Remote control on tablet

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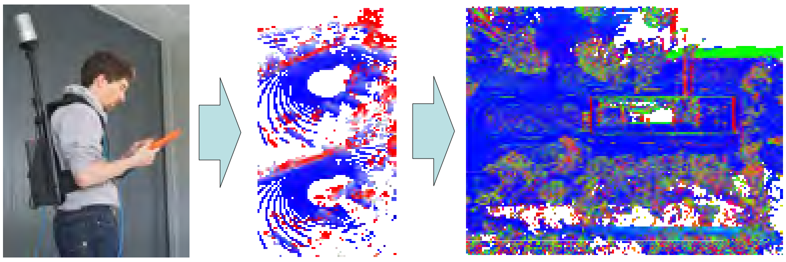
Indoor Localization and Mapping using Mobile 3D Sensors

Real-time 3D Laser Scanners

✓Laser-array scanner, e.g. Velodyne:
- ✓ 32 laser/detector pairs measure distance simultaneously
- ✓ 10Hz frame rate
- ✓ Weight: 1.4 kg

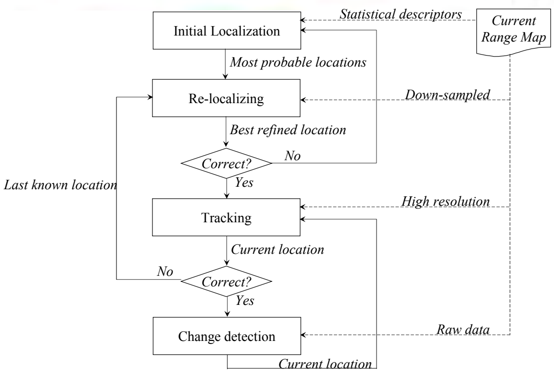
➜Allows movement during data acquisition. Scanner can be car-mounted or carried by operator.



Known Environments

Application

- ✓ Fast (re-) verification of design information (DIV) in large environments (e.g. geological repository)
- ✓ Position authentication
- ✓ Tracking and navigation



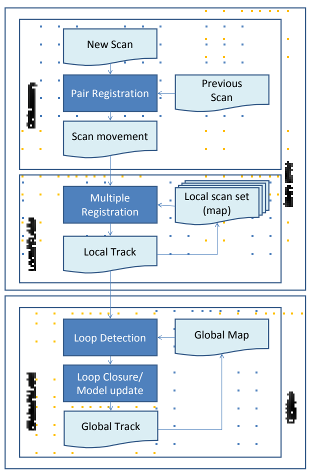
Unknown Environments

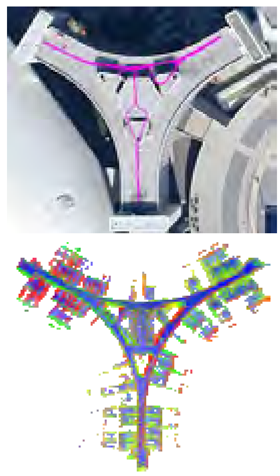
Application

Autonomous Navigation and Positioning System for Safeguards (ANPS):

"The IAEA is exploring options to acquire the capability of positioning, including indoor positioning, of an individual inspector during their field work."

- ✓*Geo-tagging/Location-based services*
- ✓*Mapping*
- ✓*Position authentication*





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VIDEOZOOM for surveillance stream reviews

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 anomalies
Inspectors see image details or context information on-demand

Photo © D.Calma/IAEA

BACKGROUND

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.*

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**.*

SCENE CHANGES

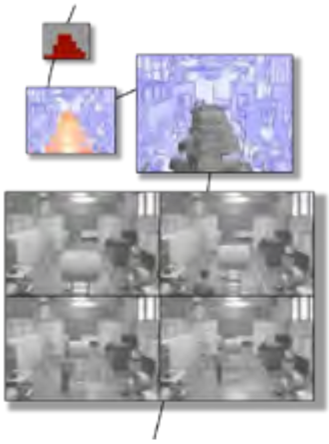
*The current approach to image reviews makes use of **scene change detection (SCD) within areas of interest (AOIs)**.*
AOIs are locations where safeguards-relevant events are expected to take place given the process under review.
*Filtering the image stream by AOIs reduces the SCD events to be reviewed. This can be **effective for regular processes, but not for the irregular ones** (if any) as these may take place outside expected AOIs.*

VIDEOZOOM

SUMMARISATION

*JRC-ITU 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 collage of the images as taken by the camera.

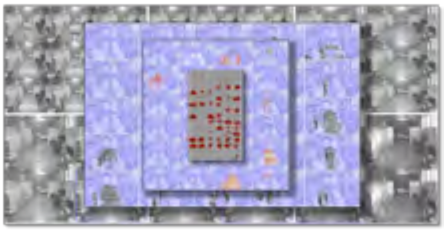


STORYBOARD

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.

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.



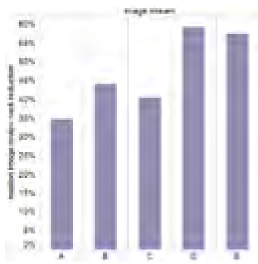
EFFICIENT AND EFFECTIVE REVIEWS

VideoZoom was tested by a group of EURATOM and IAEA inspectors on a benchmark of image reviews. Each inspector ran 5 reviews in blind, i.e. with no operator's declaration in their hands.

Using VideoZoom inspectors were able to identify the safeguards-relevant events. These included few anomalies artificially introduced in the streams by the benchmark preparing team. These events, taking place 'outside traditional areas of interest', would have been missed by standard review tools.

The VideoZoom review efficiency was measured by estimating the amount of images seen by inspectors during a review. Comparing this number with the number of scene changes in areas of interest gives an indication of the relative workload reduction when reviewing 'regular' processes using VideoZoom. The minimum median workload reduction measured in the benchmark was of 35% less images to be reviewed by the inspectors.

Positive qualitative feedback was given by the inspectors on the use of VideoZoom.
On the standard System Usability Scale questionnaire, VideoZoom scored 85 over 100.



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Joint Research Centre

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

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