How to safeguard nuclear material – with an emphasis on reprocessing plants

10th anniversary of the
Euratom On-Site Laboratories at Sellafield and La Hague
Karlsruhe, 14-15 June 2010

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Contents

Nuclear safeguards has a long history in the European Union:

→ *European Atomic Energy Community* – Euratom Treaty (1957)

with the JRC to provide scientific & technical support for the safeguards duties

► implementation of Safeguards by DG Energy, Luxembourg

► scientific & technical support by DG JRC

EUROPEAN COMMISSION

Legal Framework - Euratom

- Euratom treaty is binding European law
  (applies to ALL member states, including nuclear weapon states UK & FR)

'The Commission shall satisfy itself that

- *nuclear material is not diverted from intended use'*
- *'obligations under international agreements are complied with'*
  (-> NPT/IAEA; Infcirc 193 etc: *enabling non-proliferation*)

» Operators are obliged to

- Declare basic technical characteristics "BTC" (design)
- Account for nuclear material (see Euratom regulation 302/2005)

» Commission has right to

- Send inspectors who *'shall at all times have access to all places, data, persons,…'*
- Enforce: apply *sanctions* from *warning* up to *withdrawal of nuclear material*

What is subject to safeguards controls?

- **Uranium**
  - depleted
  - natural
  - enriched (low LEU / high HEU)
- **Plutonium**
  - irrespective of type or composition
- **Thorium**

The aim of safeguards controls:

detect diversion of nuclear material from peaceful use
deter diversion by early detection

Materials	Significant
Plutonium	8 kg Pu
U-233	8 kg U-233
HEU	25 kg U-235
U (<20% U-235)	75 kg U-235
Thorium	20 t Th

Timeliness goal:

Plutonium conversion time to metal compound:
1 week to 3 months, depending on chemical form

The EC's Safeguards Tasks (DG Energy, Luxembourg)

- Full fuel cycle, including Pu and U bulk handling, e.g.
  - Enrichment: DE, FR, NL, UK
  - Fuel fabrication:
    - LEU: BE, DE, ES, FR, SE, UK
    - HEU: FR (UK)
    - MOX: FR, UK
  - Reprocessing FR, UK

Generaldirektion Energie und Verkehr

Three Types of Control

- *Compliance control*
  - Accounting checks
  - BTC declarations verifications
- *Performance control*
  - NMAC system quality auditing
- *Credibility control*
  - Physical verifications

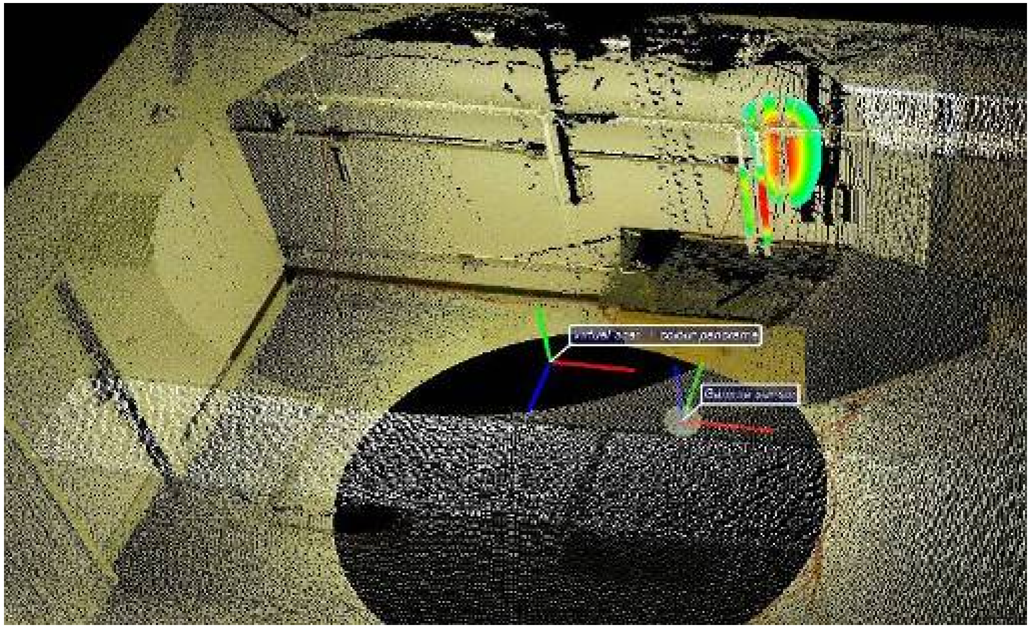
BTC verification (Basic Technical Characteristics)

- New, clean plants are verified during construction – particularly complex for reprocessing plants and automatic facilities (e.g. MOX fuel fabrication) or enrichment plants
- Re-verification at regular intervals, at least annually (PIV)
- Tools, e.g.:
  - 3D-Laser scanning
  - …..

Gamma-ray imaging with 3-D laser scanning

Perceived need: Design information and nuclear materials distribution for complex nuclear facilities

Novel features: Integration of 3D-modelling technologies (JRC) with gamma imaging (US-DOE Livermore & Oak Ridge, …)



Physical Verification of Material Declarations

- The objective is to detect:
  - diversion of a “significant quantity” of plutonium (1 month)
  - diversion of a “significant quantity” of uranium (1 year)
  - inconsistencies in the BTC & accounting / measurement systems
- The methods (simplified)
  - item counting (e.g. fuel element in ponds) ⟷ Gross defect
  - non destructive assay ⟷ Partial defect
  - destructive and non-destructive assay

    ⟷ Bias defect
    small defect, systematic error
    with deviation in one direction

Physical Verification: Destructive and Non-Destructive Assay

- Methods of highest precision are applied for
  - ‘bias defect’ control and
  - verification of quality of operators measurement systems

- samples are randomly taken from process, e.g.
  - in enrichment facilities (particles)
  - in fuel fabrication facilities
  - in reprocessing facilities

- analysis in EC laboratories:
  - on-site laboratories Sellafield(UK) and La Hague (F)
  - JRC labs at Karlsruhe and Geel
  - portable lab: COMPUCEA

What is reprocessing about?

The aim of reprocessing spent nuclear fuel:

separate uranium and plutonium from one another and from the waste (fission products and some other actinide elements)

→ recover about 96% of the useful material

The process used for the separation is called PUREX:

Plutonium – **U**ranium **R**ecovery by **EX**traction.

– cutting and dissolution of the fuel rods

– co-extraction of uranium/plutonium into an organic liquid

– separation of uranium from plutonium

Further use of uranium and plutonium:

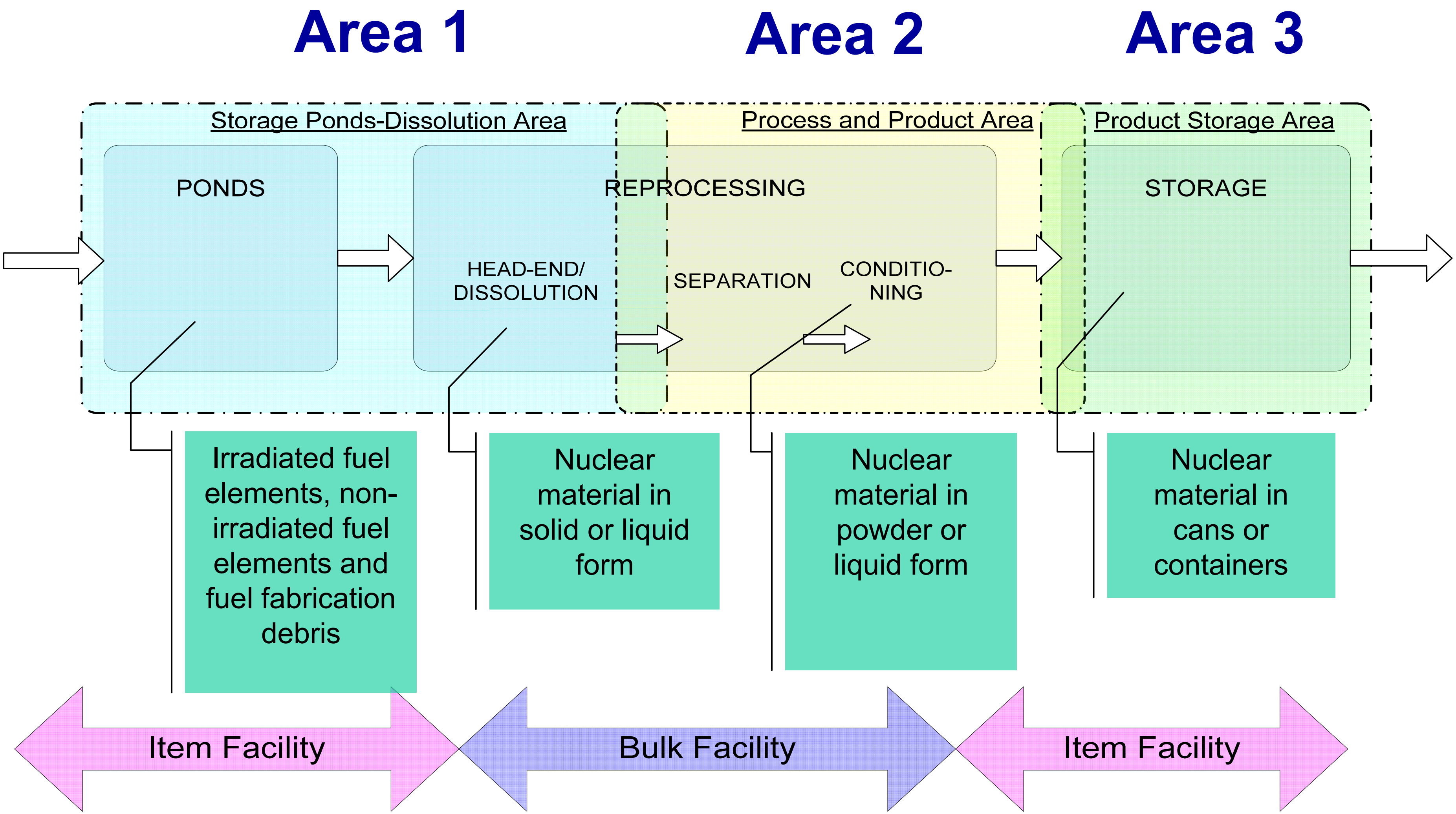
- uranium: isotopics of recovered uranium close to U-nat; enrich again or use in MOX fuel
- plutonium: use in MOX fuel composed of a mixture U-nat + 3-4% Pu-239

How to safeguard a reprocessing facility?

The verifications performed are based upon a 3-area-structure:

1. ***Pond and dissolution area:***
   storage ponds, head-end and dissolution area up to the input accountancy tank;
2. ***Process and product area:***
   chemical process area (separation, purification and conditioning areas) from the input accountancy tank to the entrance to the storage;
3. ***Storage areas for final products.***

Inspections – plant description



Inspections

Inspections are based upon verification of flows into and out of the main processing area as shown.

- Physical verification of fuel elements into the plant.
- (Non-) Destructive Assay of feed input into the plant and samples from the separation process.
- Non Destructive Assay of the product material (e.g. PuO2) coming from the plant.
- Verification of the nuclear material accountancy declarations.

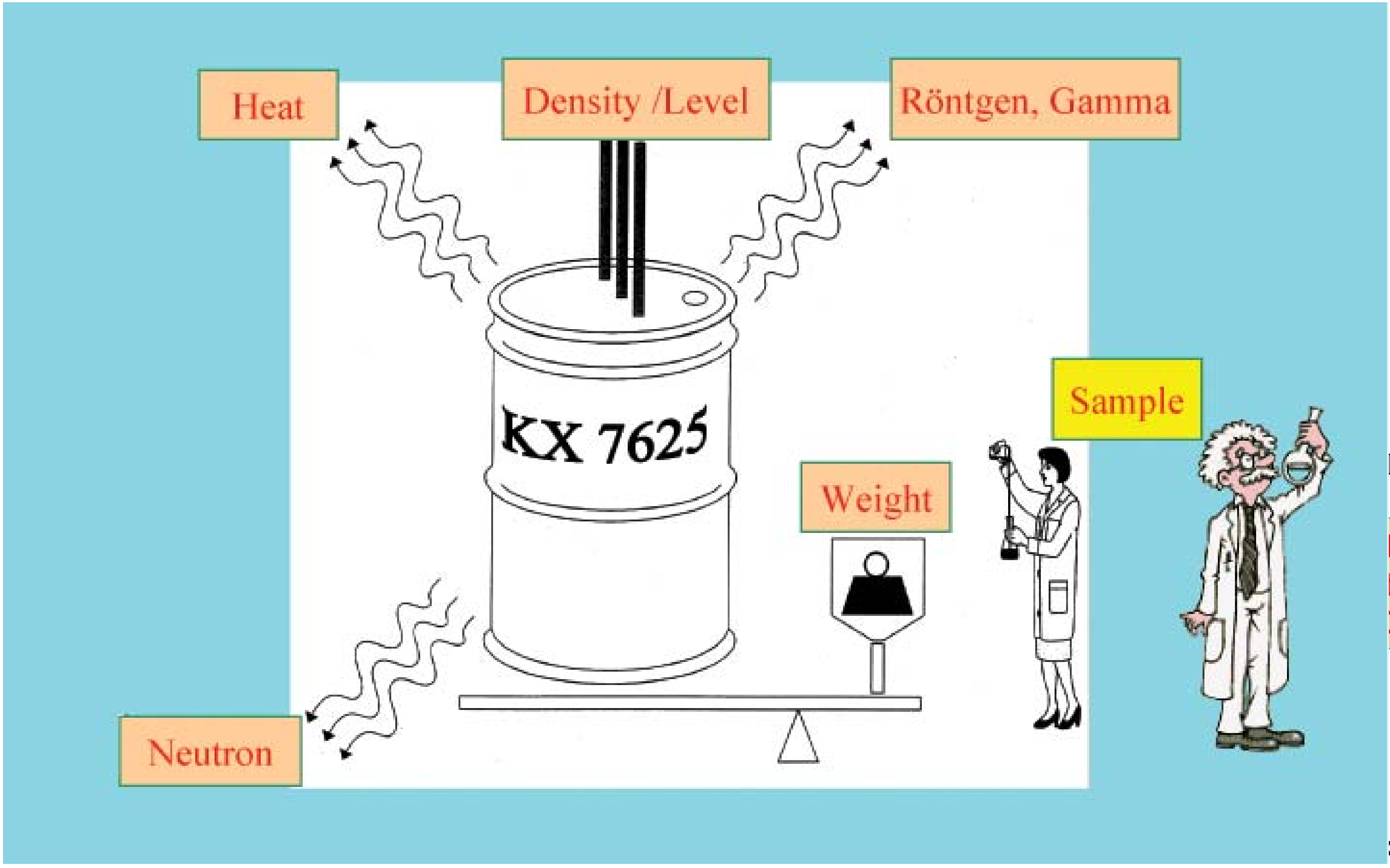
How to measure the collected samples ?

Material Balance:
bulk handling ➡ high throughput

- Reprocessing:
  - ~ 800 t HM/y ~ 8000 kg Pu/y
- MOX fuel fabrication
  - ~ 100 t HM/y ~8000 kg Pu/y
- LEU Fuel Fabrication ~700 t HM/y
- Assume Target Accuracy of e.g.
  - 1% ➡ 80 kg Pu
  - What can be achieved?

P. Schwalbach (ENER)

Verification techniques: radiation detection and mass spectrometry



lass
trometry
DMS

ch (ENER)

In-Field Timely and Accurate Measurements – Fundamental to the Safeguards of Reprocessing Facilities

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Safeguards of a reprocessing plant

- Safeguarding nuclear material involves Quantitative Verification by an independent measurement
  - Radiometric and chemical analysis of samples
  - Bias defect detection

- In the past
  - Off-site analysis in a European Commission financed laboratory (ITU)

How to safeguard commercial reprocessing plants?

Sellafield Ltd

Sellafield Ltd., Sellafield, UK

On-Site Laboratory
Start-up October 1999

OSL

AREVA

Areva NC, La Hague, France

Laboratoire Sur-Site
Start-up June 2000

LSS

1992 – EC decision to install On-Site Laboratories

- No transport (of hundreds of samples per year)
- Timely analysis on-site
- Quick response to discrepancies
- Analysis of unstable samples, high active samples
- Waste disposal to site waste streams
- Economically more efficient than sample transport off-site

Take the analysts to the nuclear material,
not the material to the analyst

Sellafield, UK

- Installation of Euratom On-Site Laboratory
- Inside a building that is part of Sellafield Ltd. Analytical Services
- Start-up October 1999

On-Site Laboratory

- Two active laboratories
  One cold laboratory

- Glove box environment
- Hot cell environment at THORP

Robotised glove box for small spiking, separation chemistry and alpha counting

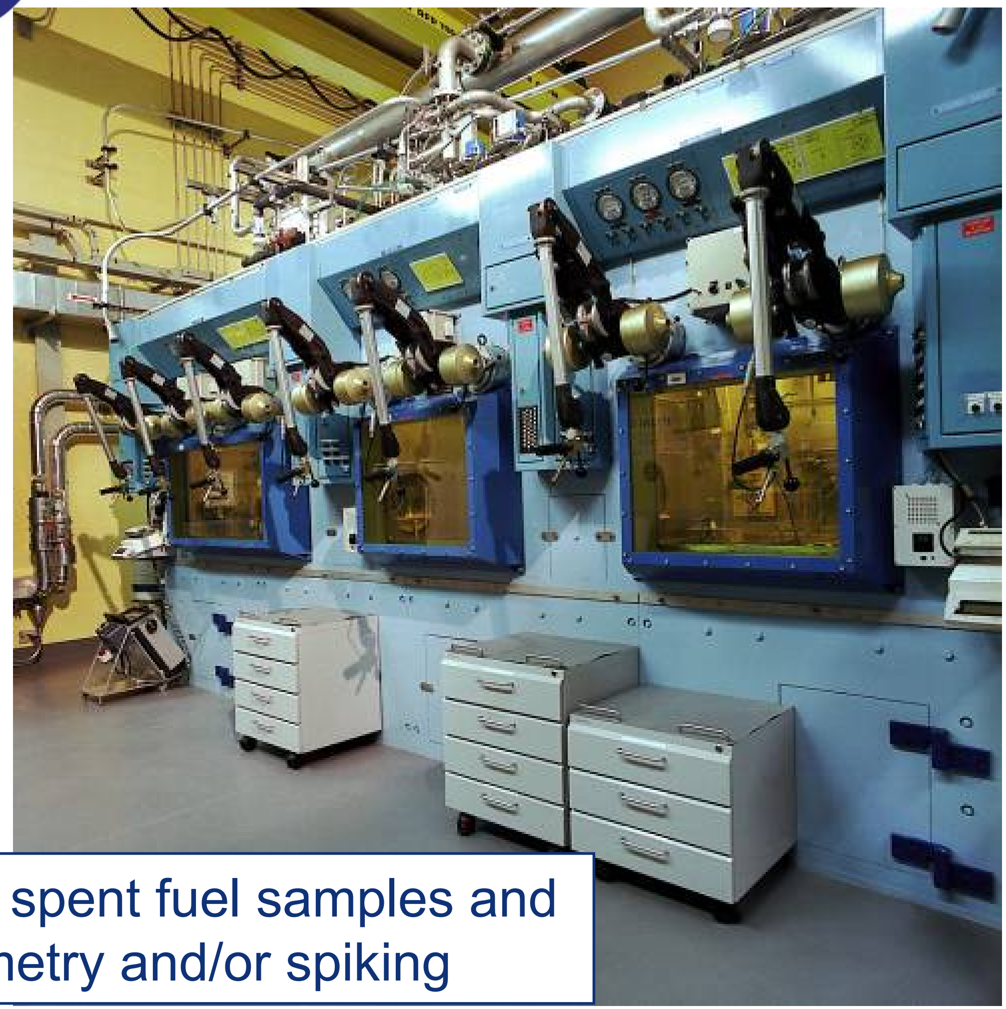
La Hague

- Installation of Euratom Laboratoire Sur-Site

- In an annex building to the Areva UP3 plant
- Start-up June 2000

Laboratoire Sur-Site

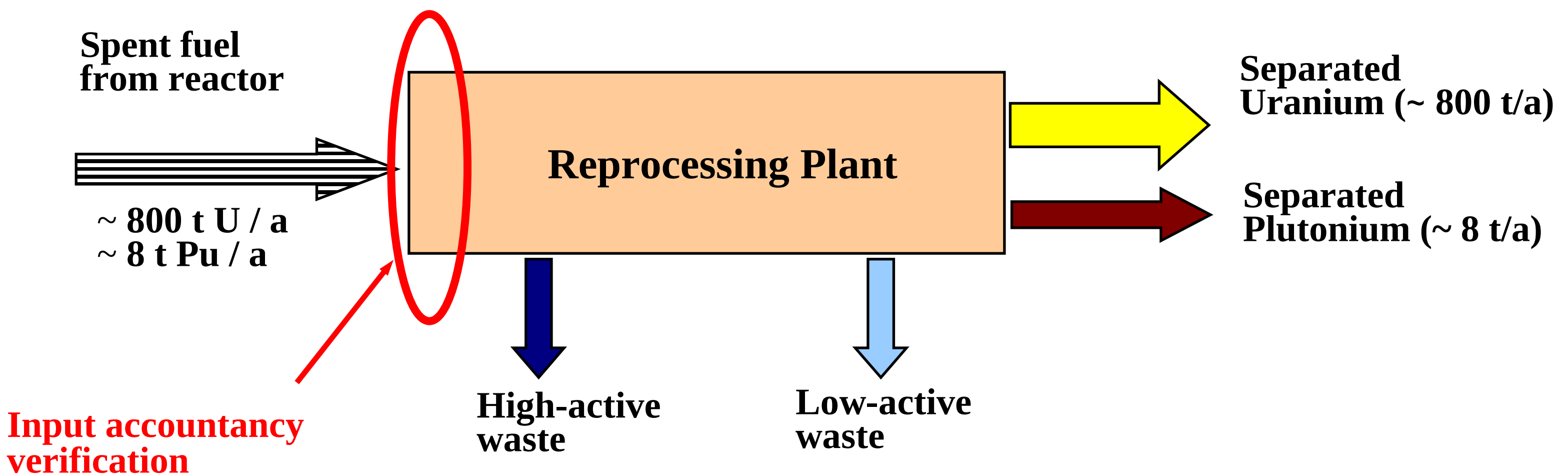
- Three active laboratories
  - Hot cell facilities
  - Product laboratory
  - Mass spectrometry laboratory
- Hot cell environment plus glove boxes for low activity work



Hot cell suite for handling of dissolved spent fuel samples and their assay by Hybrid K-edge densitometry and/or spiking

Tasks of an on-site laboratory

- Determine the concentration and isotopic composition of plutonium and uranium in process liquors sampled from various process tanks
- The same in solid product samples (powders)
- Achieve best measurement accuracies, at the permille uncertainty level (= 0.1%) for a conclusive verification
- A Safeguards key measurement point par excellence is the repro-cessing input (the point where the amount of plutonium generated in a reactor can be accurately determined for the first time)



Material received

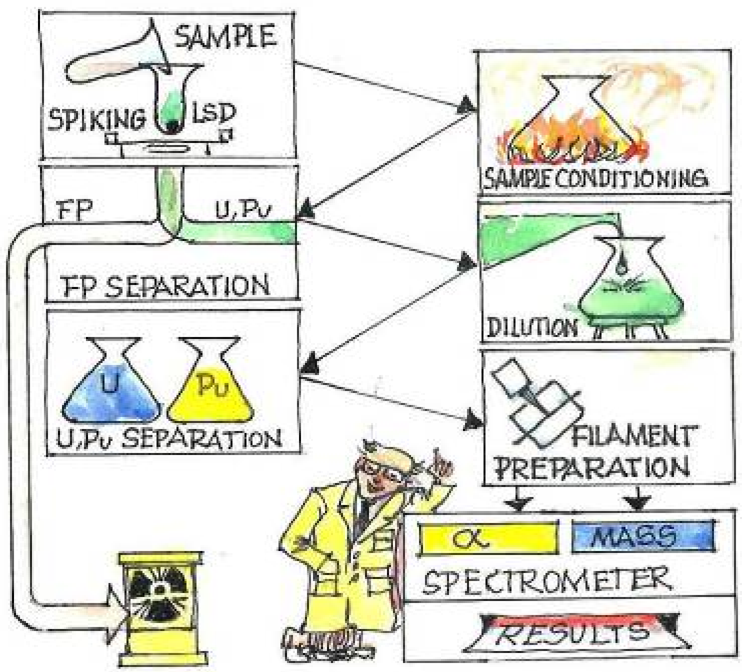
OSL

- Product material
  (plutonium und uranyl nitrates, Pu and U oxides)
- MOX (pellets and powders)
- Spent fuel (THORP), diluted dissolved spent fuel, oxalates

LSS

- Concentrated input solutions, rinsing solutions
- Plutonium nitrate solutions from re-dissolved Pu
- Uranyl nitrate product, oxalates
- Plutonium product (PuO_2)

Measurement techniques for plutonium and uranium analysis in reprocessing input solutions



Isotope Dilution Mass Spectrometry (IDMS)

- *Primary reference method*
- *Highest accuracy, but sophisticated*
- *Analysis not completed within 1 day*

Hybrid K-Edge Densitometry (HKED)

- *An alternative X-ray technique*
- *Not as accurate as IDMS, but simple*
- *Analysis completed within 1 hour*

How to measure U / Pu concentrations and isotopics? (1)

- radiation detection:

  concentrations from attenuation of an X-ray beam and from X-ray fluorescence (Hybrid K-edge densitometry, HKED), all samples,

  uncertainties about 0.2% for U and 0.6% for Pu

  isotopics of Pu from gamma spectrometry

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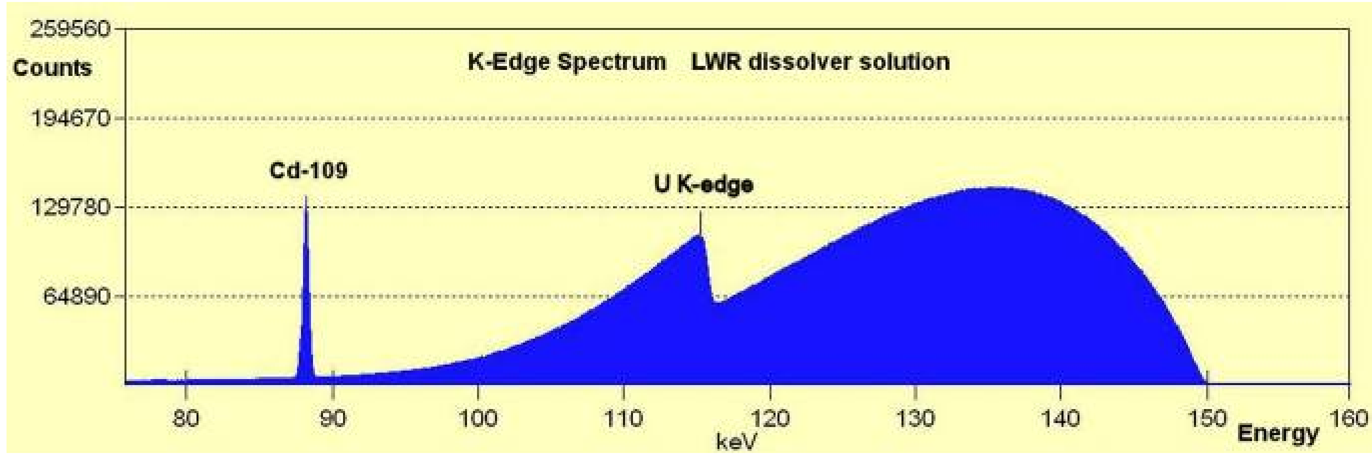
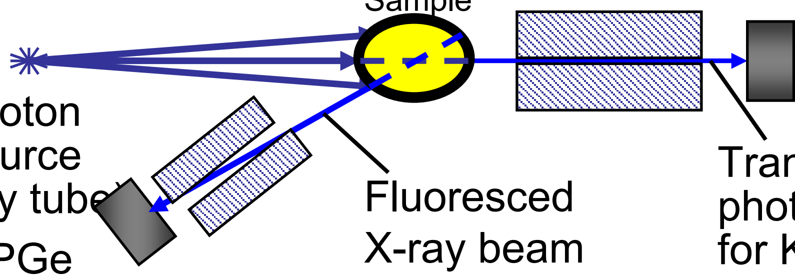
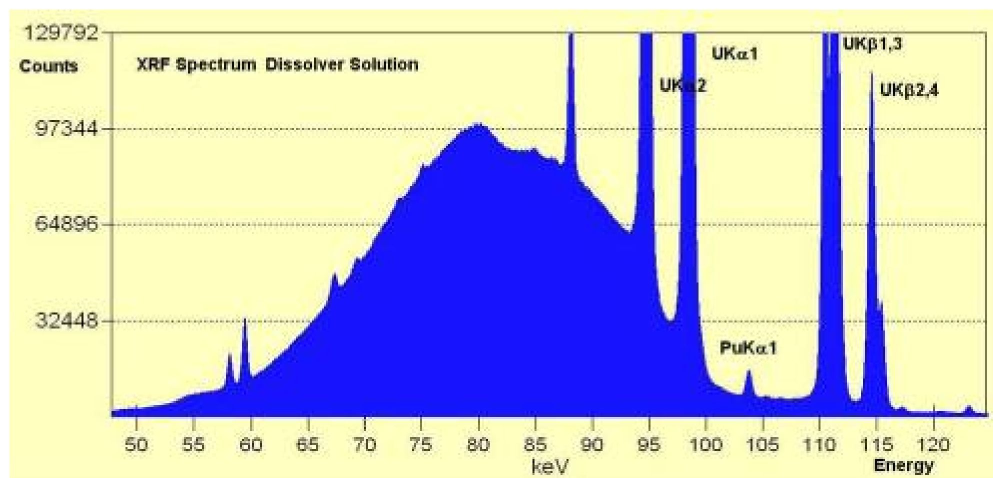
Hybrid K-edge densitometry

K-edge densitometry
Pu and U, 40-300 g/l





XRF
Pu and U, 0.5-40 g/l



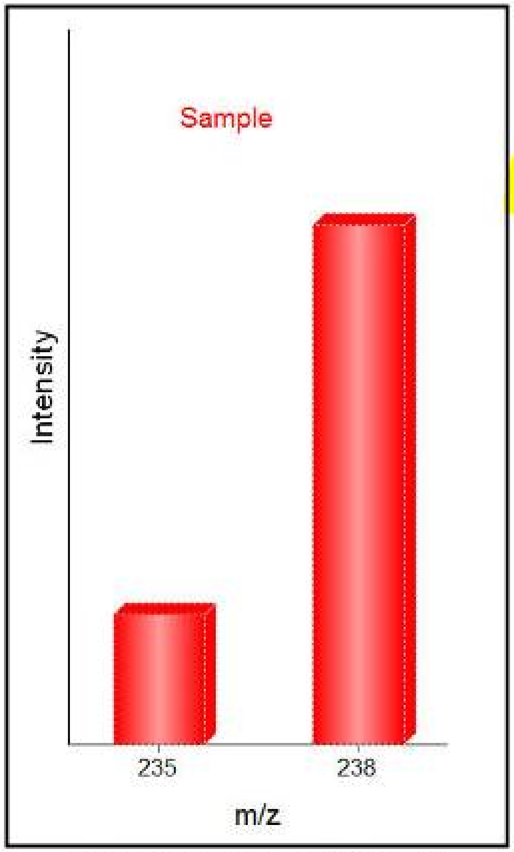
How to measure U / Pu concentrations and isotopics? (2)

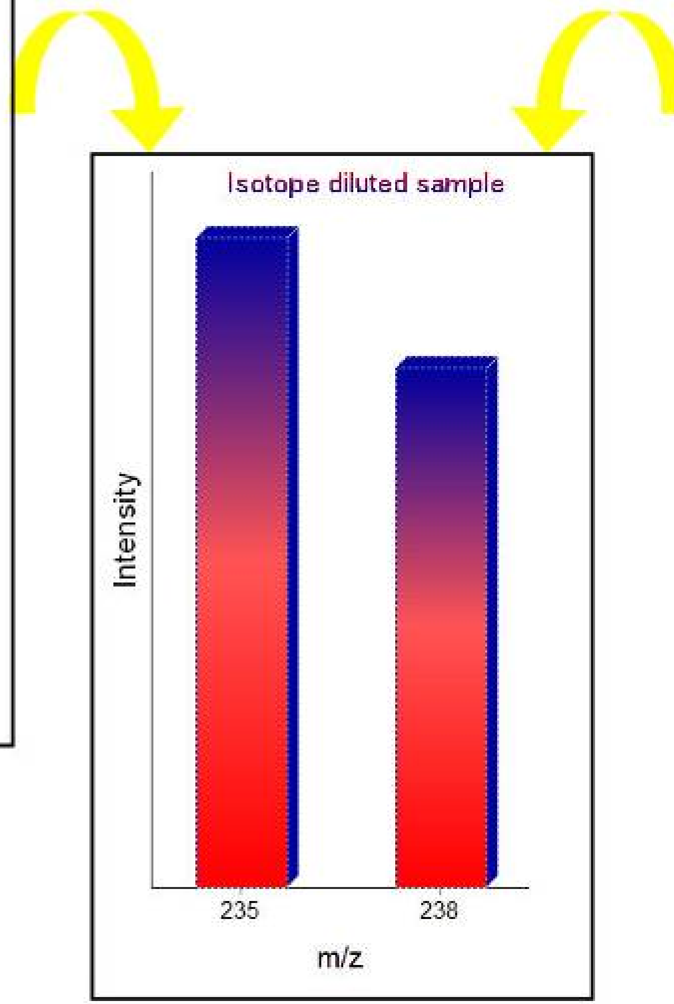
- Isotope dilution mass spectrometry (IDMS):
  concentrations and isotopics, labour intensive, 10% of samples
  uncertainties about 0.1% for U and Pu

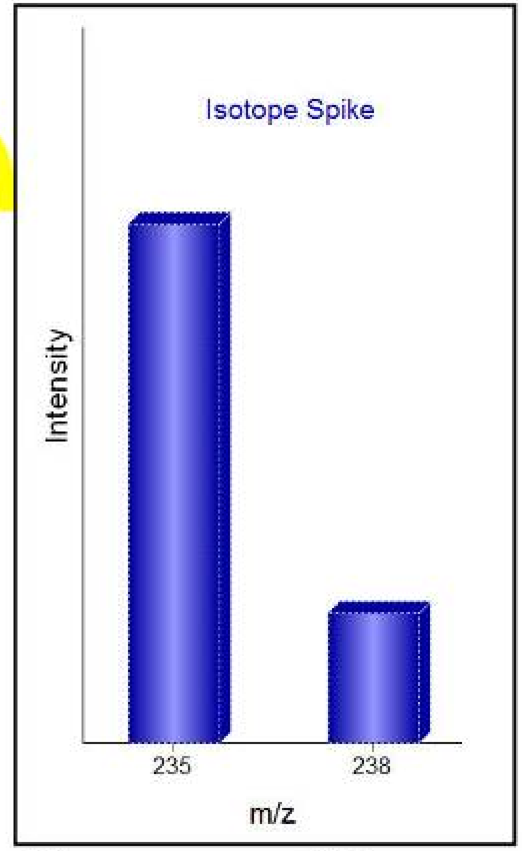
  for quality control and calibration of HKED

→ **uncertainties improved over the past 10 years from 1% down to 0.08 % for U and Pu**

Isotope Dilution Mass Spectrometry IDMS







Know quantities:
- sample amount
- isotope ratio

Known quantities:
- spike amount
- isotope ratio
- spike concentration

Measured quantity: isotope ratio mixture

Analytical techniques (summary)

- K-edge densitometry (Pu and U concentration)
- X-ray fluorescence (U/Pu ratio, also absolute low Pu or low U)
- Gamma spectrometry (Pu isotopics, Am/Pu ratio)
- COMPUCEA (uranium concentration + enrichment)
- Alpha spectrometry
- Thermal Ionisation Mass Spectrometry (Pu and U isotopics)
- Isotope Dilution Mass Spectrometry (large and small spikes)

LSS

- Three Hot Cell Hybrid K-edge/XRF densitometers fitted with automated sample changers

■ Radiometric techniques ■ Destructive assays

Logistical aspects

- Operated by ITU staff during regular working hours
- Around 270 on-site analyst weeks
- 2 to 4 analysts on a weekly basis for ± 48 weeks per year
- Analytical work:
  - Verification measurements on samples
  - Preparation and characterisation of reference materials
- Managerial and safety related responsibilities
- Technical advice to Euratom inspectors
- Laboratories embedded in operator's infrastructure

Measurements performed

OSL

- Product material
  (plutonium und uranyl nitrates, Pu and U oxides)
- MOX (pellets and powders)
- Spent fuel (THORP), diluted dissolved spent fuel, oxalates

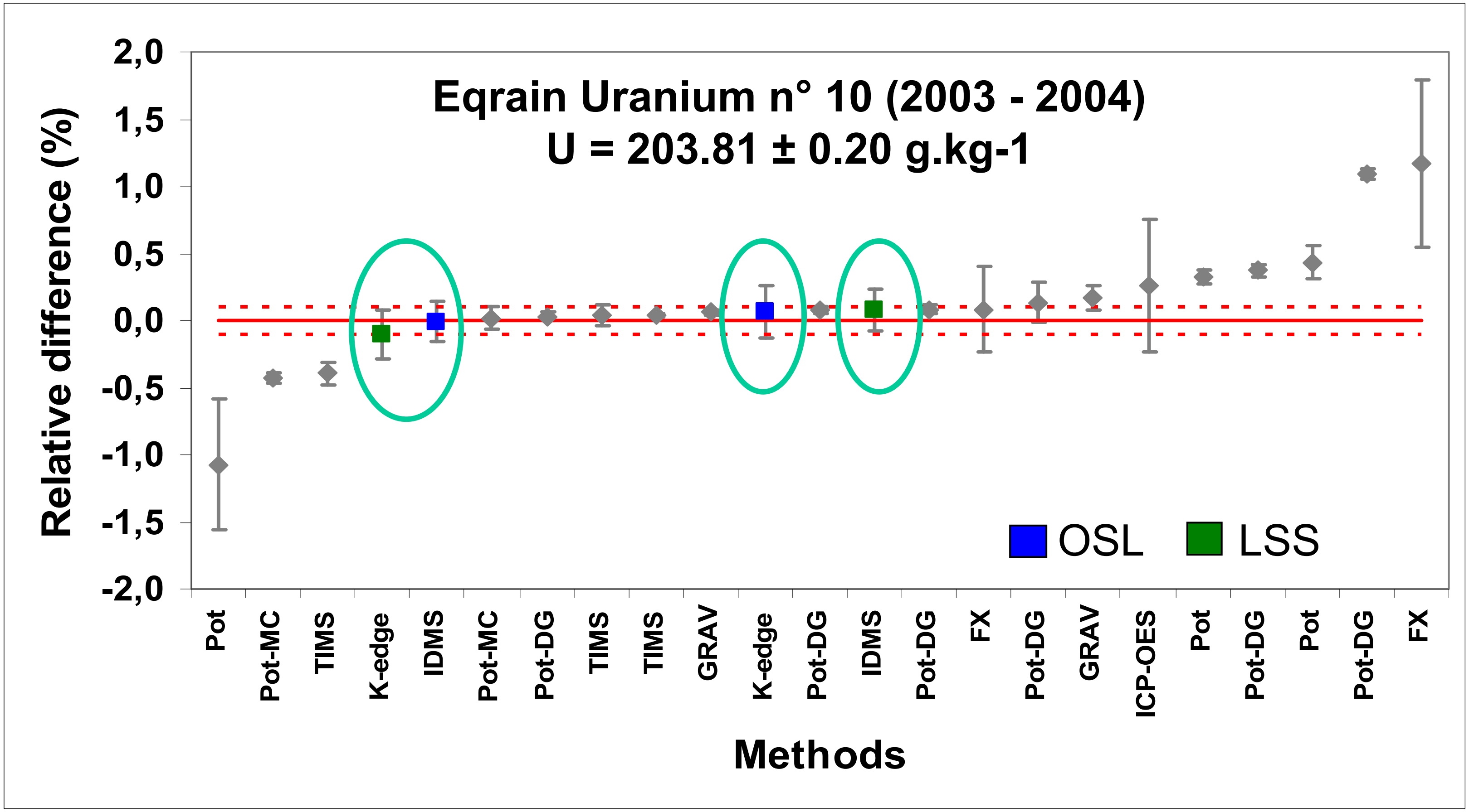
8400 measurements over 10 years

LSS

- Concentrated input solutions, rinsing solutions
- Plutonium nitrate solutions from re-dissolved Pu
- Uranyl nitrate product, oxalates
- Plutonium product (PuO_2)

13000 measurements over 10 years

External Quality Control



Results of an external quality control programme, underpinning the performance of the LIS for uranium assay using different analytical methods.

The Safeguards Approach

- Role of on-site laboratory:
  - Analysis of samples to verify amounts of nuclear materials
  - Timely availability of measurement results on parallel samples
- Data evaluation by inspectorate:
  - Consistency of information
  - Verify declaration
  - Immediate check on each tank, vessel, container by paired comparison
- Strategy adopted by IAEA (on-site laboratory in Japan)

Summary / Conclusion

- Direct physical verification of nuclear material is fundamental to the ability for diversion detection.
- JRC supports DG Energy which has the task to ensure that nuclear material within the EU is not diverted.
- The Euratom On-Site Laboratories make an important contribution to assure the public that the
    - Duties under the Euratom Treaty and the
    - Commitments to the Non-Proliferation Treaty

are honoured in the EU

Questions?

Some members of the team

Thank you.