Problems of Applied Spectrometry and Radiometry

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Instrumentation and Methods in Support of International Safeguards Implementation

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Department of Safeguards

Division of Technical and Scientific Services (SGTS)

Section of Non-Destructive Assay (TND)

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International Atomic Energy Agency

Outline

- Our mission
- Verification of declared NM
  - Fresh NM
  - Irradiated NM
- Verification of declaration completeness
- Conclusions

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Our mission

- INFCIRC/153: Comprehensive Safeguards Agreements give the right and obliges the IAEA to verify the correctness and completeness of State's declaration. To this end, IAEA conducts safeguards activities, addressing the following generic objectives:
  - To detect any undeclared nuclear material or activities;
  - To detect any undeclared production or processing of nuclear material in declared facilities or locations outside facilities (LOF); and
  - To detect any diversion of declared nuclear material in declared facilities or LOFs.

Our mission

- INFCIRC/540: Model Protocol Additional to the Agreements between States and the IAEA for the Application of Safeguards, 1997 (Additional Protocol - AP):
  - Provision of additional information, which is not covered by the basic Safeguards Agreement between State and the IAEA, and which afterwards to be verified in
  - A special type of Agency's activities called **Complementary Access** (CA) with the purpose of strengthening the effectiveness and improving the efficiency of the safeguards system

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Our mission

- **Division of Technical and Scientific Services:**
  - **Section for Portable and Resident NDA**
    - NDA Instrumentation Team (NDAI)
    - NDA Services Team (NDAS)
    - Technology Foresight Team
  - **Section for Unattended Monitoring and Surveillance**
    - Unattended Monitoring Team (UMS)
    - Surveillance Systems Team (TUV)
  - **Section for Project Engineering and Integration**
    - Project Engineering Team
    - Seals Team
    - Remote Monitoring Team

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Our mission

- **Section for Portable and Resident NDA:**
  - **Provision of instruments and systems for inspector use in the field** (variety of NDA instruments, preparation, maintenance, troubleshooting)
  - **Implementation of new instrumentation and methods** (development, evaluation and authorization of new equipment, methods and measurement procedures)
  - **Expert support of SG verification activities in the field** (method selection / development, instrumentation preparation, field activities, evaluation of measurement results, provision of technical report to inspectors)

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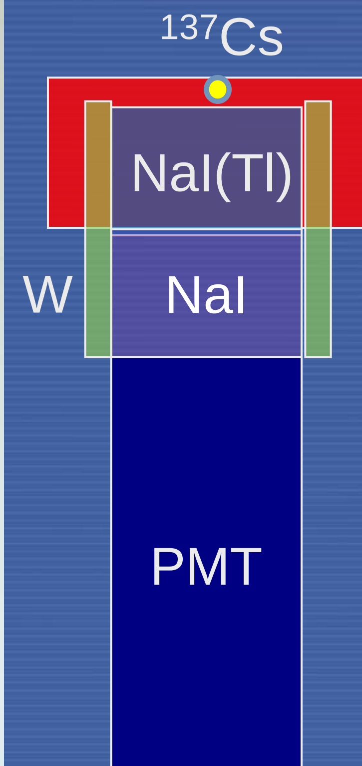
Verification of fresh NM: HM-5



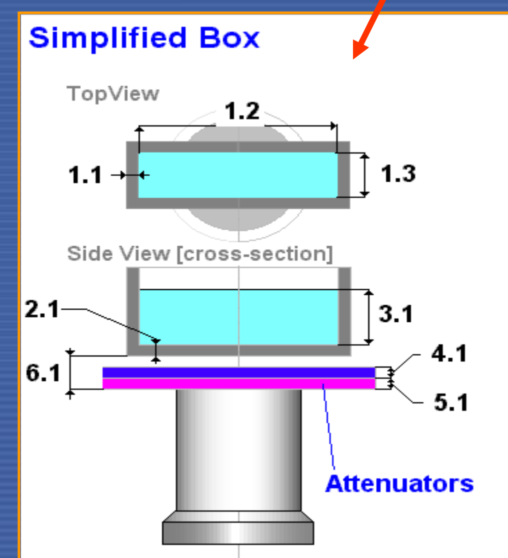
<u>HM-5 : SG Version of *IdentiFinder 2*</u>

- Dose rate indication
- Search / Localize
- Nuclide Identification
- Attribute tests:
  - Uranium
  - Plutonium
  - Thorium
- U-235 enrichment measurement
- Active length measurement

Verification of fresh NM: Quantitative gamma-spectrometry using ISOCS

- While a measurement setup can be calibrated in a traditional way, i.e. using prepared radioactive sources, the ISOCS based gamma-assay systems are **able to calculate absolute detection efficiencies** for the specified sample parameters, such as
  - the elemental composition,
  - density,
  - standoff distance, and
  - physical dimensions.

ISOCS approach: mathematical procedure for the efficiency calibration



Traditional approach: use of reference sources for the efficiency calibration

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Verification of fresh NM: ISOCS

Examples of deployed ISOCS systems:

U waste counting system (South Africa)

Verification of bulk form NM items

ISOCS based system for the uranium hold-up measurements (Kazakhstan)

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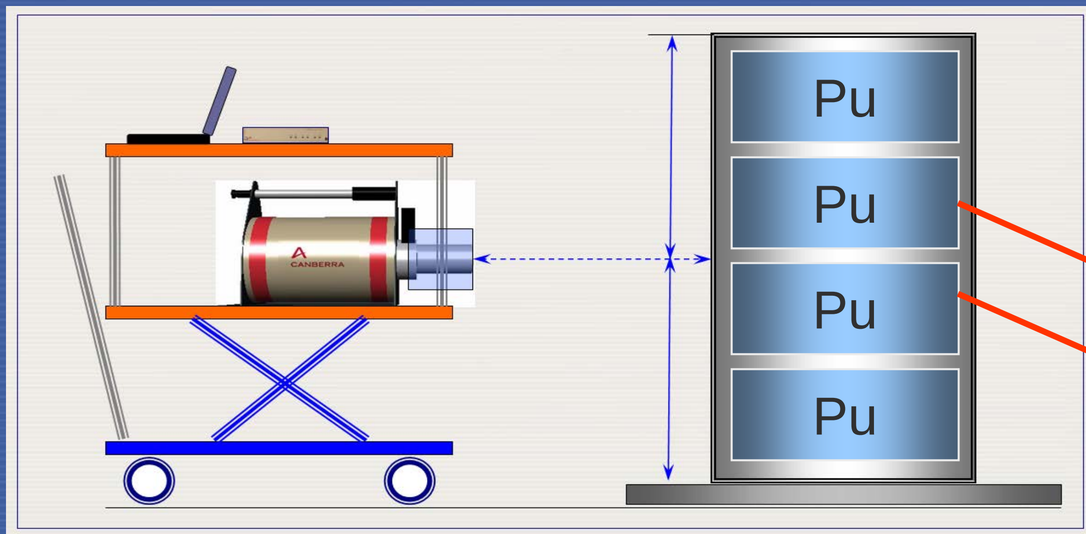
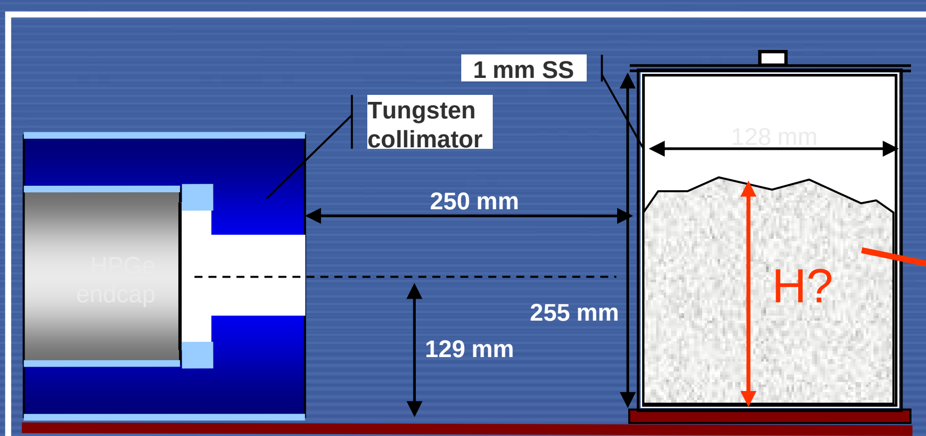
Verification of fresh NM: ISOCS



ISOCS for supercompacted Pu waste drums stored in 400 L containers (Belgium)



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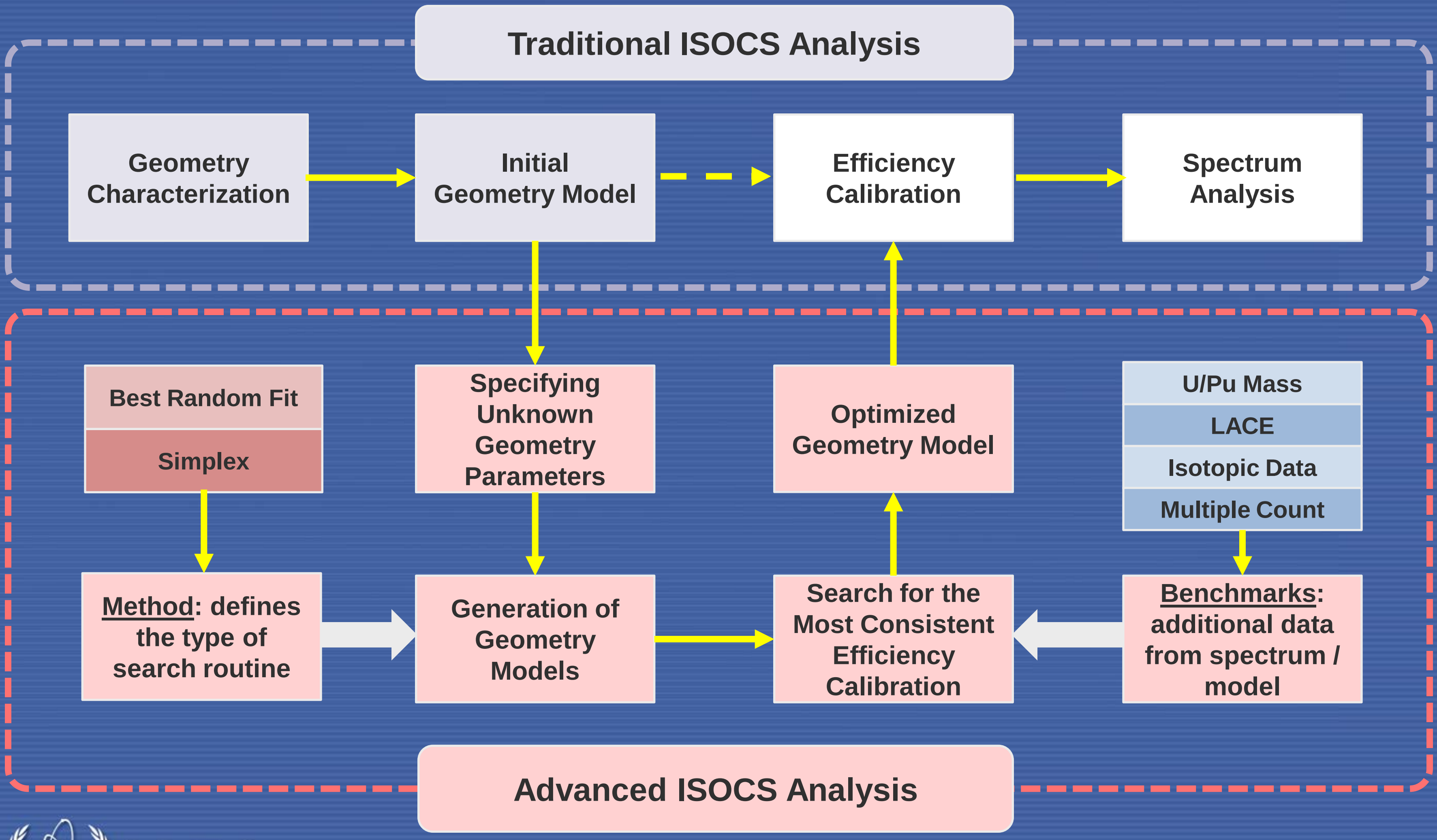
Unknown sample parameters / poorly defined geometries

Verification of fresh NM: Advanced ISOCS



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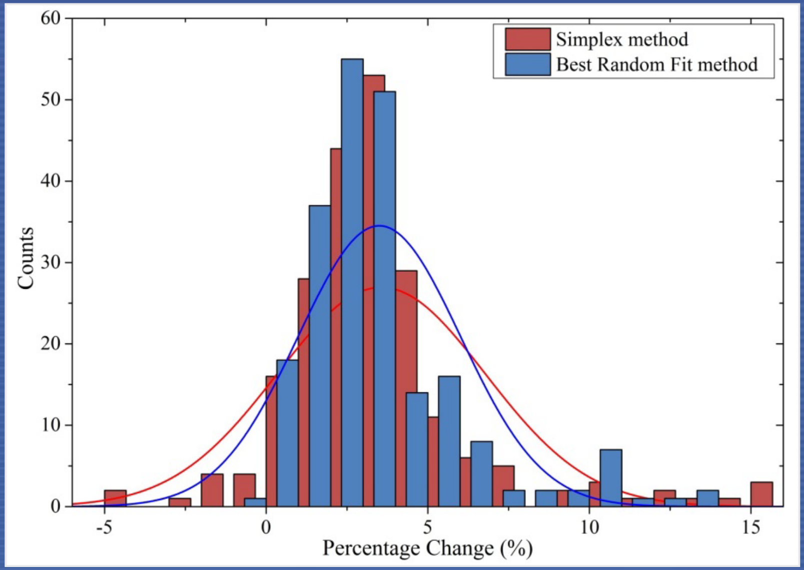
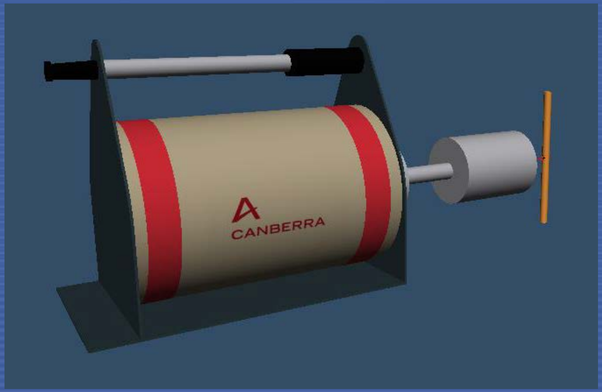
Verification of fresh NM: Advanced ISOCS

Example A : BWR Fuel Rod LEUO_2, active length - 20 cm

- Methods: Best Radom Fit & Simplex
- Benchmarks: U mass, LACE, MGAU
- “Unknown” parameters:
  - Fuel pellet diameter & density;
  - Cladding thickness & density;
  - U concentration.





Optimization method	Total U Mass		^{235}U Mass		Enrichment	
	M (%)	SD (%)	M (%)	SD (%)	M (%)	SD (%)
Simplex	3.56	3.21	5.86	8.36	1.98	5.34
Best Random Fit	3.50	2.51	5.48	6.57	1.72	4.47

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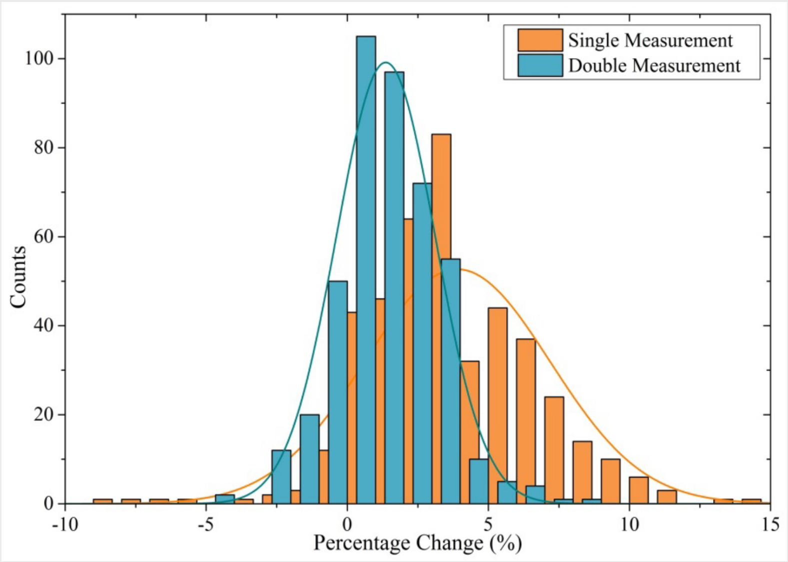
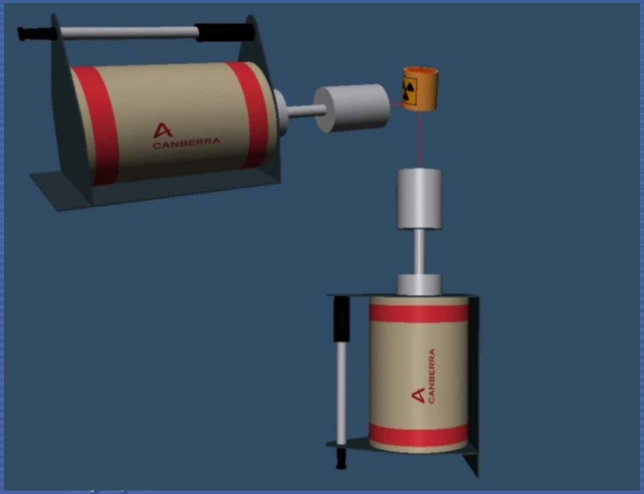
Verification of fresh NM: Advanced ISOCS

Example B : SRM-969, 4.4% ^{235}U, U_3O_8, 200 g

- Methods: Best Radom Fit & Simplex
- Benchmarks: U mass, LACE, MGAU, multiple count
- "Unknown" parameters:
  - Powder fill height & density;
  - Container wall thickness & density;
  - U concentration.



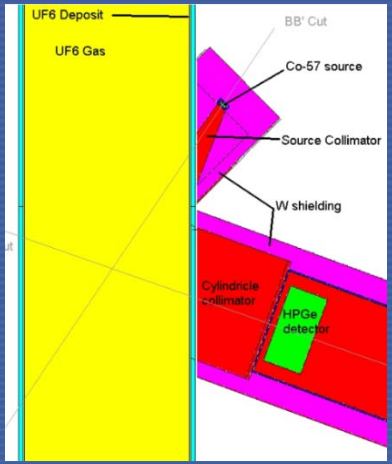


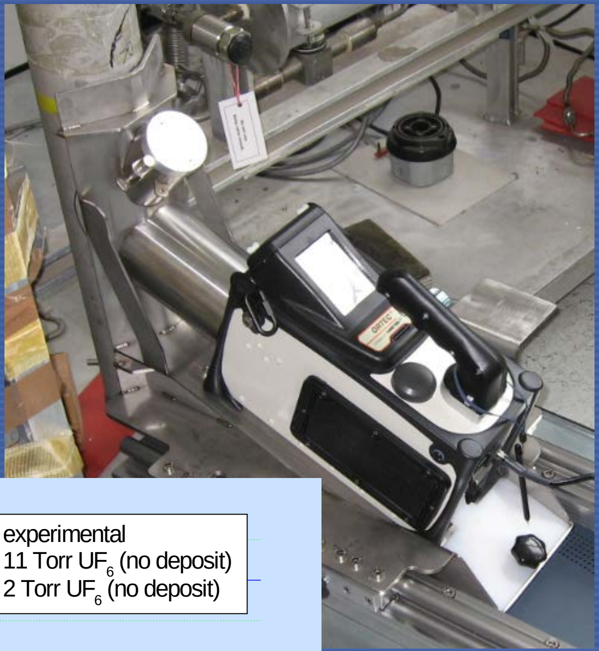
Optimization method	Total U Mass		^{235}U Mass		Enrichment	
	M (%)	SD (%)	M (%)	SD (%)	M (%)	SD (%)
Simplex	0.89	1.80	1.02	3.98	0.17	2.96
Best Random Fit	1.36	1.98	1.64	3.83	0.32	2.95

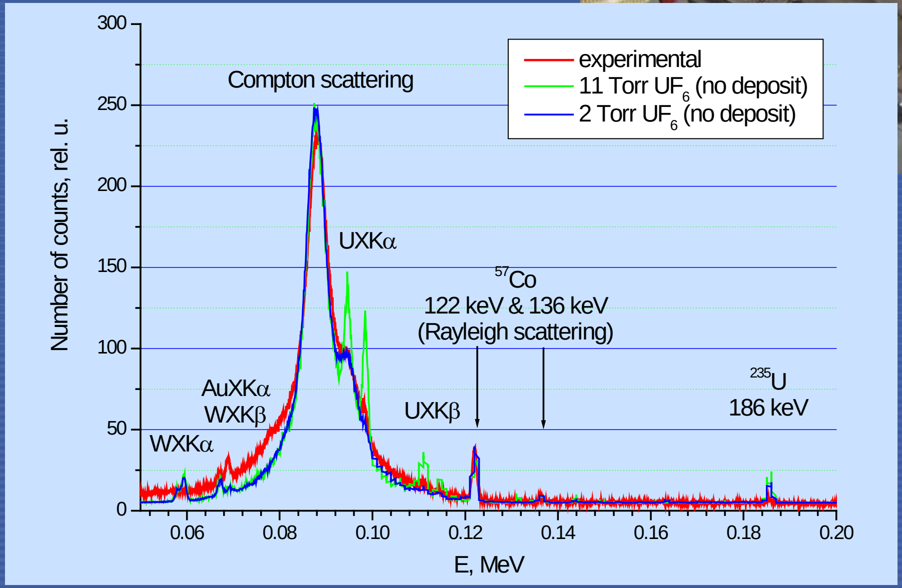
Verification of fresh NM: ECGS & CHEM

Verification of U-235 enrichment in UF6 cylinders

Cascade Header Enrichment Monitor







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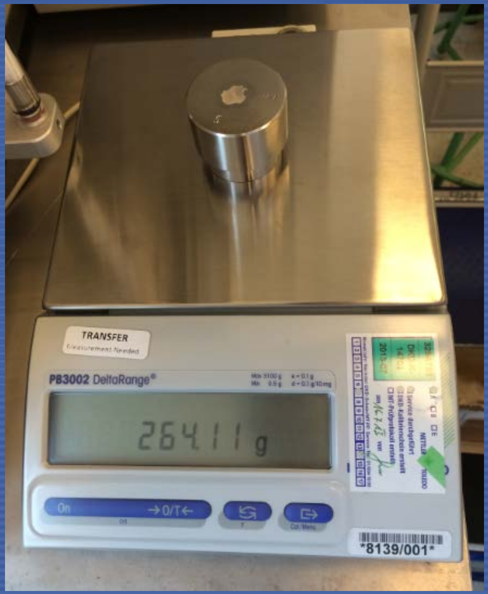
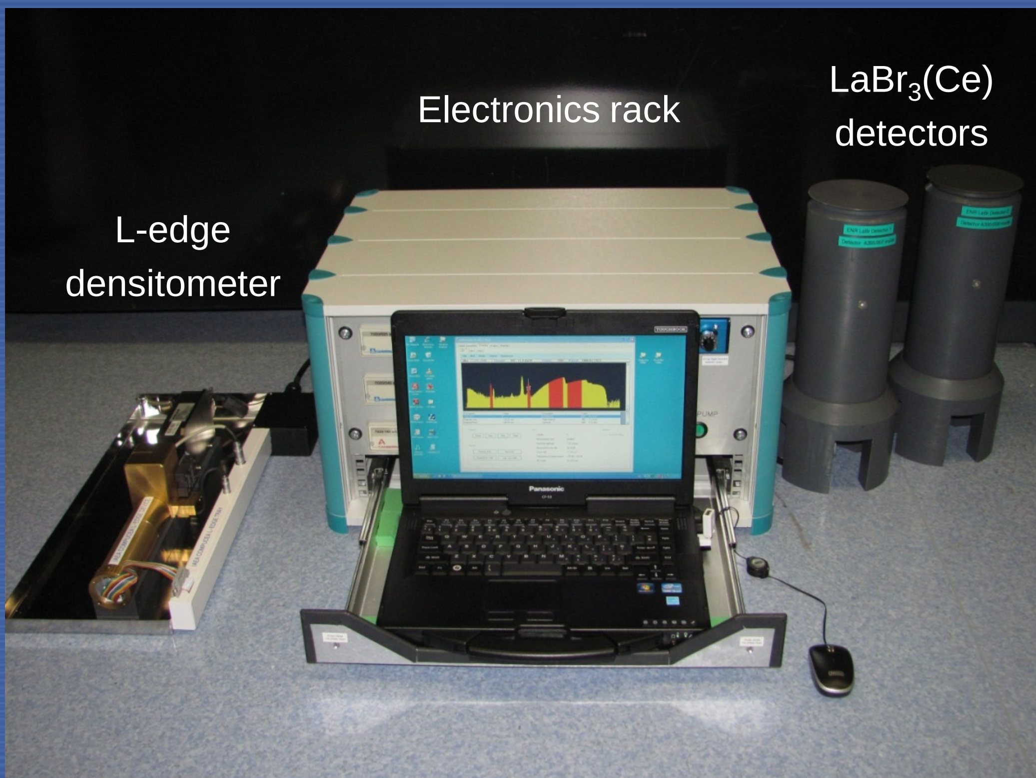
Verification of fresh NM: ECGS

- Field gamma-spectrometer for U and Th concentration assay: different U/Th compounds and forms (powders, solutions, slurry, scrap etc.)
- System calibration: against SRMs in SAL
- Relative accuracy: 1% for Th; 1-2% for U

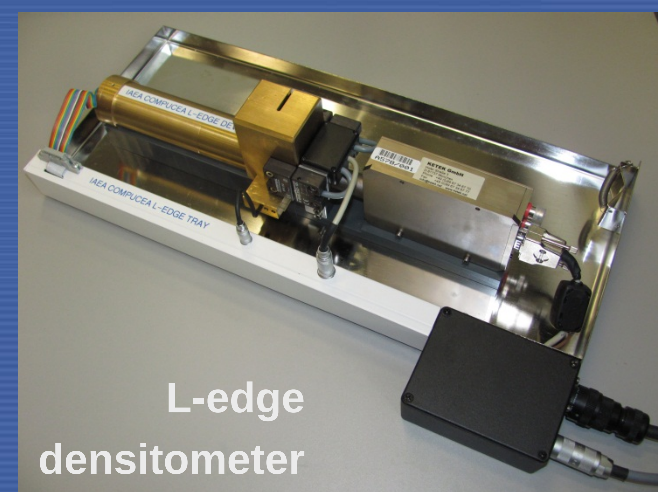


Verification of fresh NM: COMPUCEA

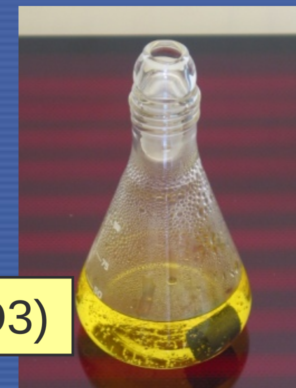
Combined Procedure for High Accuracy Uranium Concentration and Enrichment Assay



compact + transportable system



Verification of fresh NM: COMPUCEA



Sample weighing

↓

Dissolution (final solution: 3M HNO3)

↓

Solution density and temperature

↓ ↓

L-edge measurement
→ U concentration

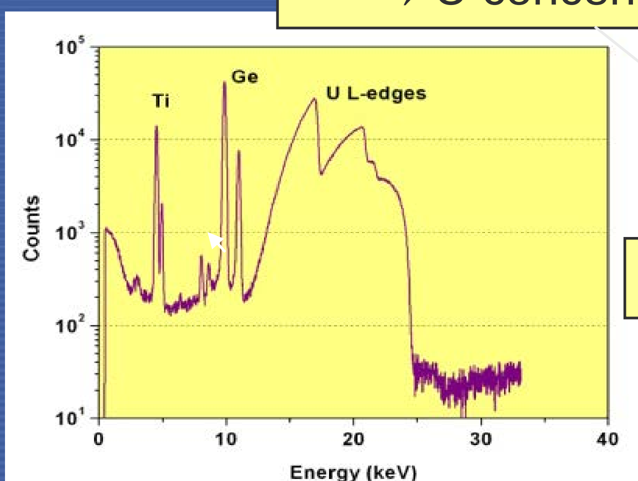
Aliquot weighing + γ-counting
→ U enrichment

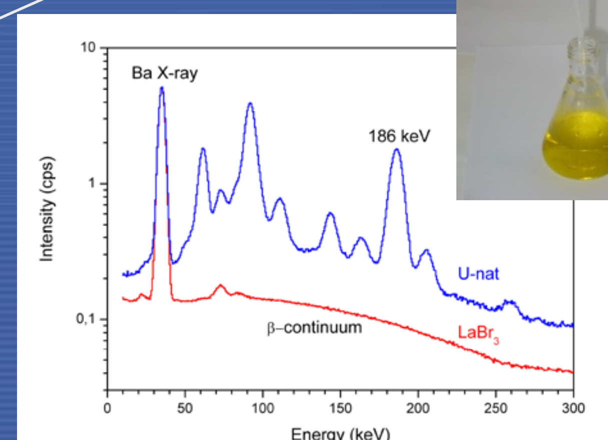
↓ ↓

Data evaluation

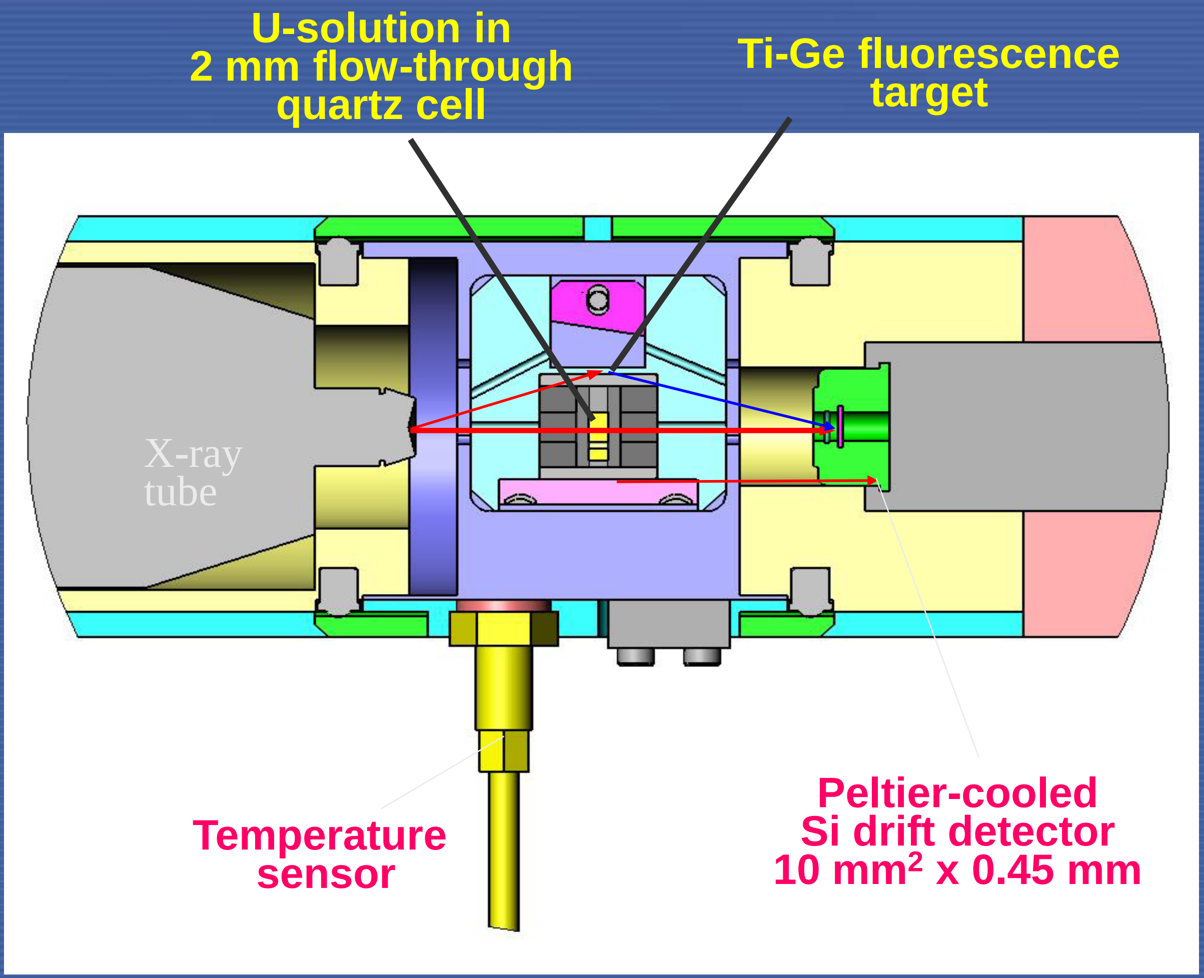
↓

Results for inspectors





Verification of fresh NM: COMPUCEA



L-edge densitometer

Basic components:

- Mini X-ray system, 30 kV/100 µA
- Si drift detector, Peltier-cooled, with integrated electronics
- Digital signal processor

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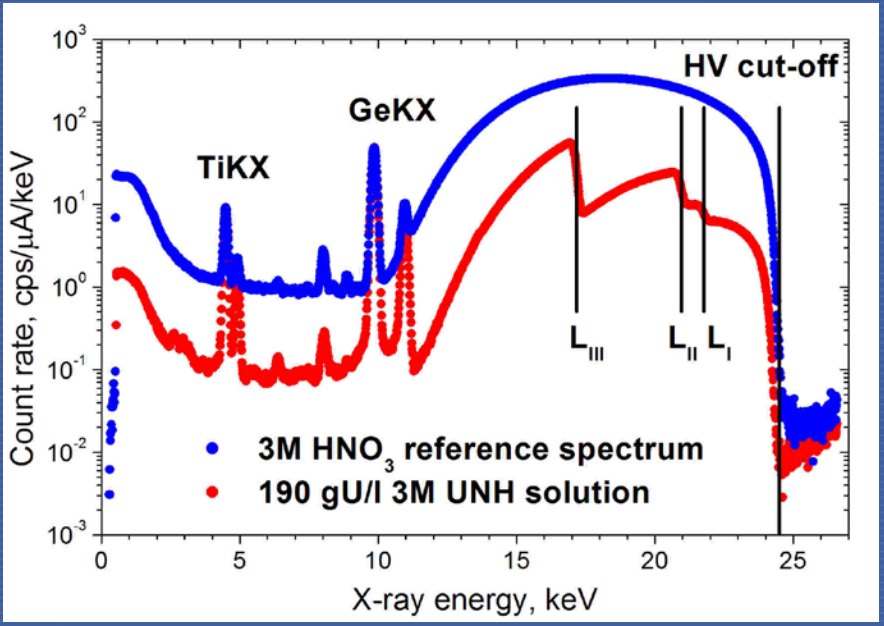
Verification of fresh NM: COMPUCEA

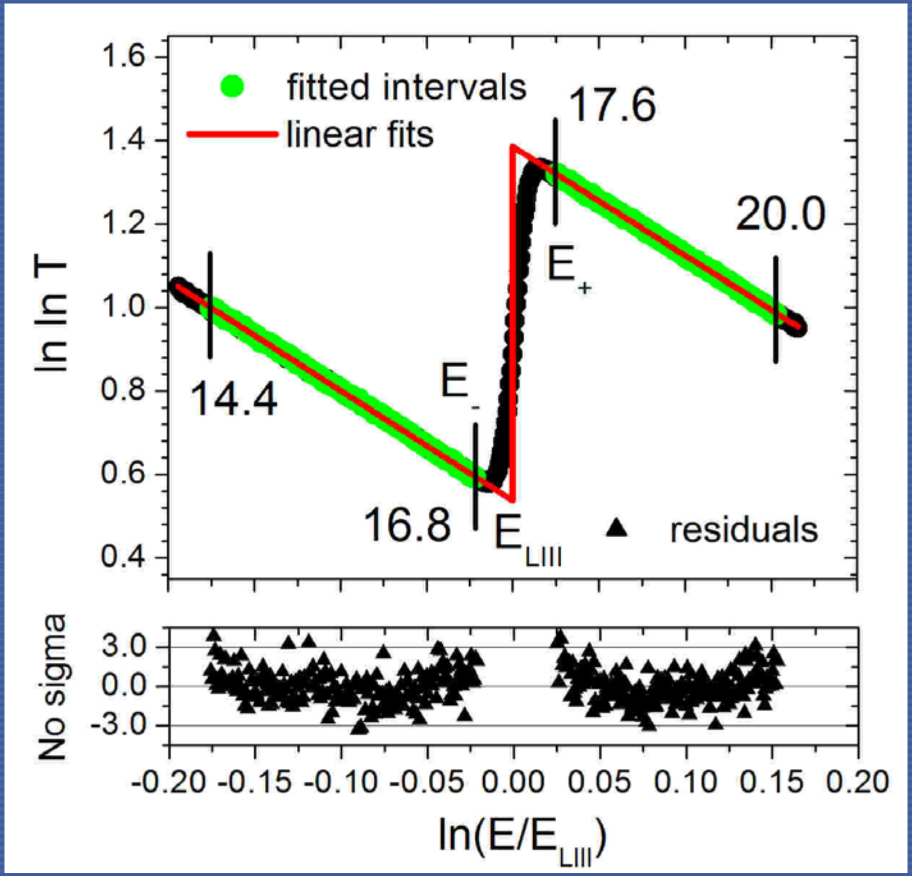
Measurement:
•Spectrum of UNH solution is measured relative to 3M HNO_3



→ U concentration in solution (in g/L)
typical value: 170 - 195 g/L

Data evaluation:
- non-extrapolated fit: derived from the change in transmission at E_+ and E_-

→ extrapolated fit: derived directly at L_{III}



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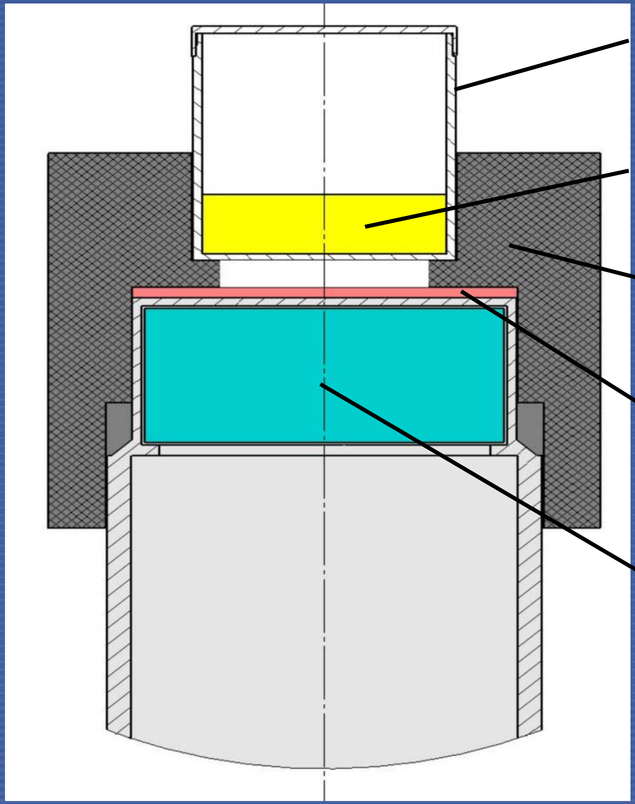
Verification of fresh NM: COMPUCEA

Count 186 keV gammas from an accurately known amount of U in a well-defined calibrated geometry

Evaluate 186 keV peak count rate from spectrum fitting using customized version of NaIGEM code (R. Gunnink)



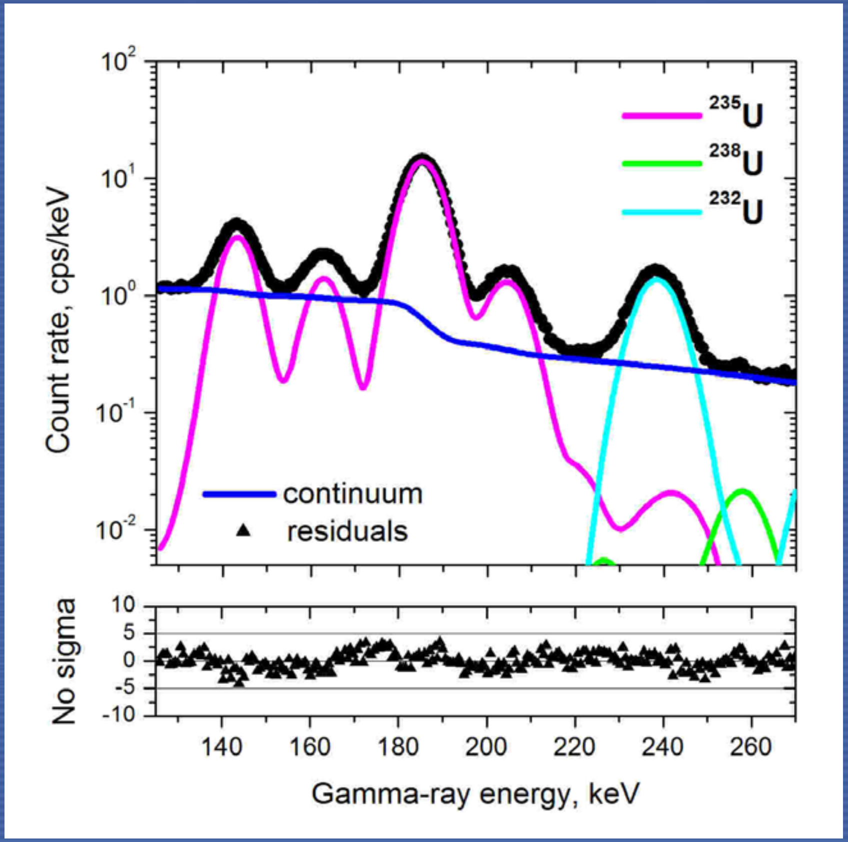
Sample container (polysterene)

10 ml of U-solution (~190 mgU/ml)

Tungsten shielding/ collimation

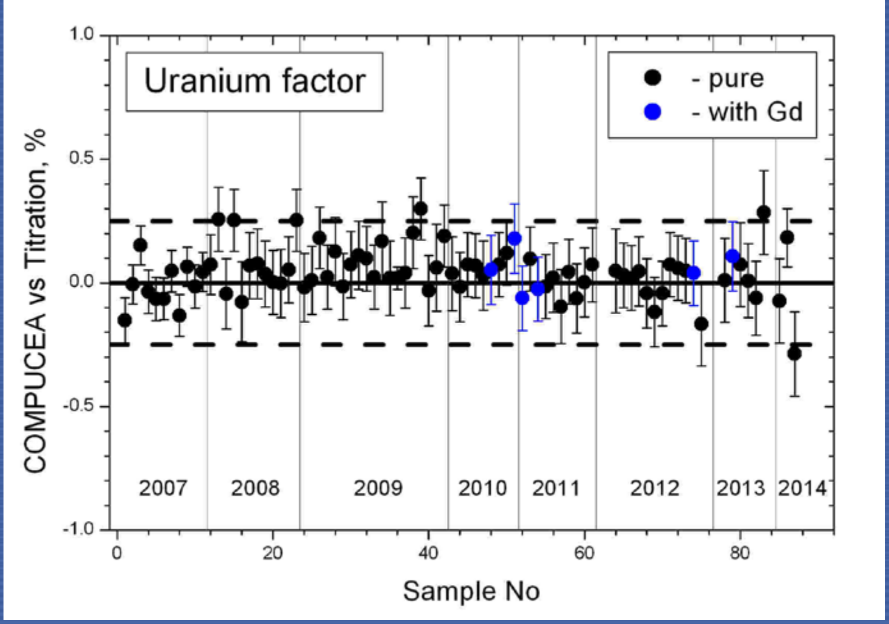
Cu filter (0.5 mm)

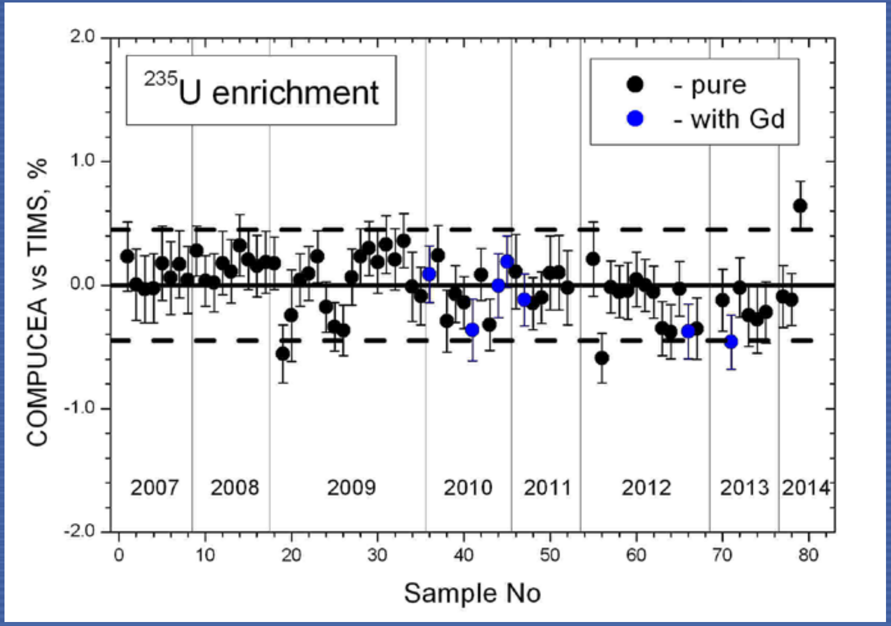
2”x0.5” LaBr3 detector



Verification of fresh NM: COMPUCEA

- Combined relative standard uncertainty of the analysis:
  - 0.22% for U-235 enrichment;
  - 0.11% for U concentration.





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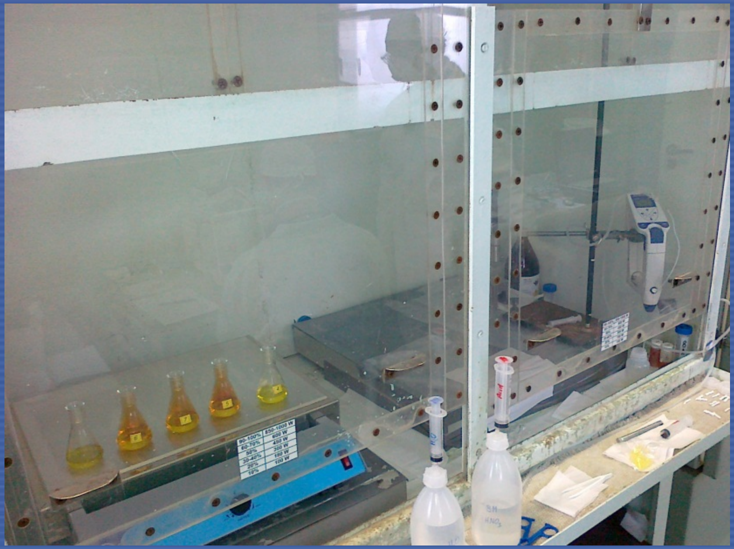
Verification of fresh NM: COMPUCEA

Physical Inventory Verification (typical)

- 24 LEU samples = 4 pellets + 13 powders + 6 scrap + 1 liquid
- Material types: UO_2, U_3O_8, TBP, etc.
- Concentration range: 3.5 – 88%
- Enrichment range: 2.7 – 19.9%



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Verification of irradiated NM: approach

Predict –> Measure –> Compare

- **Predict** neutron and gamma emissions from design and operation data (fuel type, initial enrichment, irradiation history, cooling time)
- **Predict** and apply the instrument function to convert simulated emissions into simulated instrument response

- **Measure** gross neutron and gamma (gross or spectrometric)

- **Compare** simulated and measured responses, to verify some elements of the declaration while accepting others:
  - Assuming: fuel type, initial enrichment, cooling time
  - Verify: burn up and integrity

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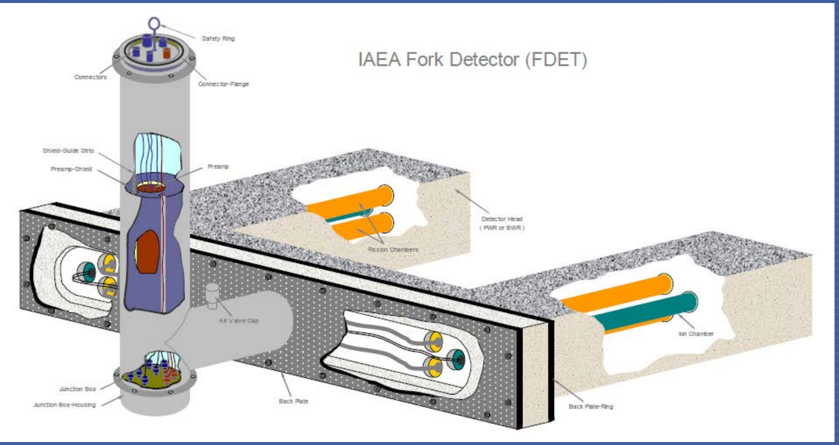
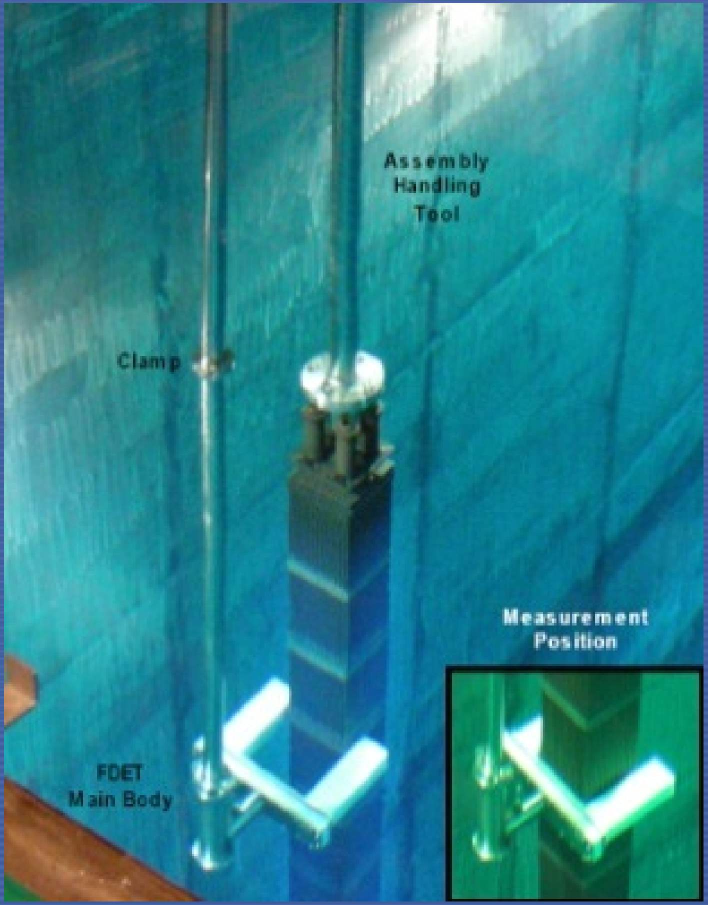
Verification of irradiated NM: FDET

- **Fork Detector for verification PWR/BWR spent fuel:**
  - 4 fission chambers – gross neutron
  - 2 ion chambers – gross gamma





High confidence detection level for at least 50% missing rods

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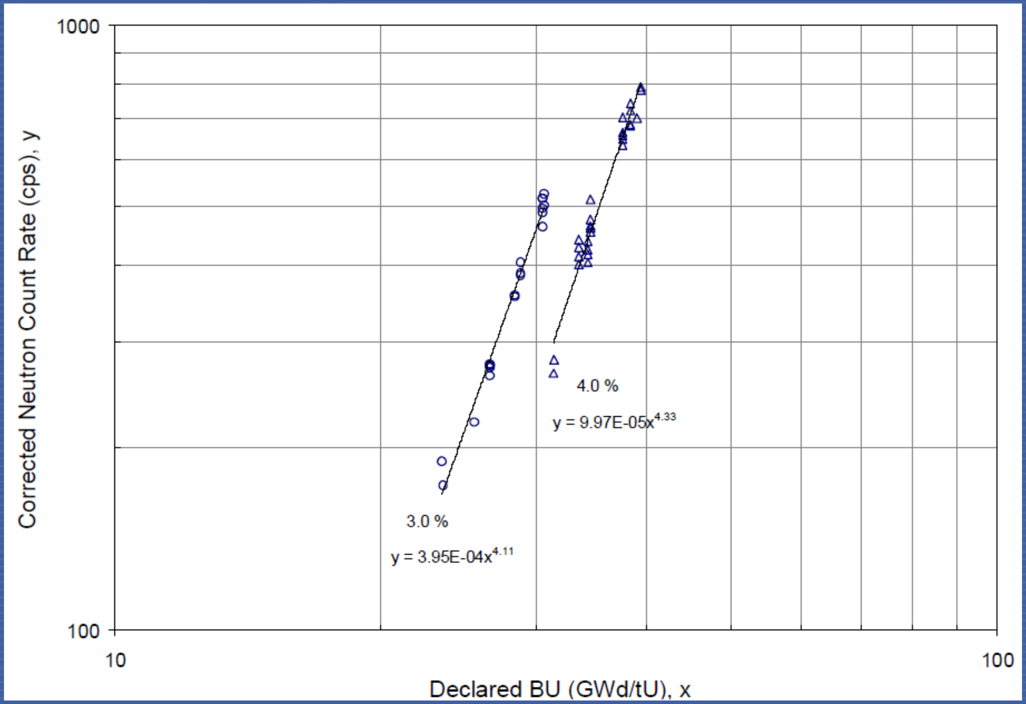
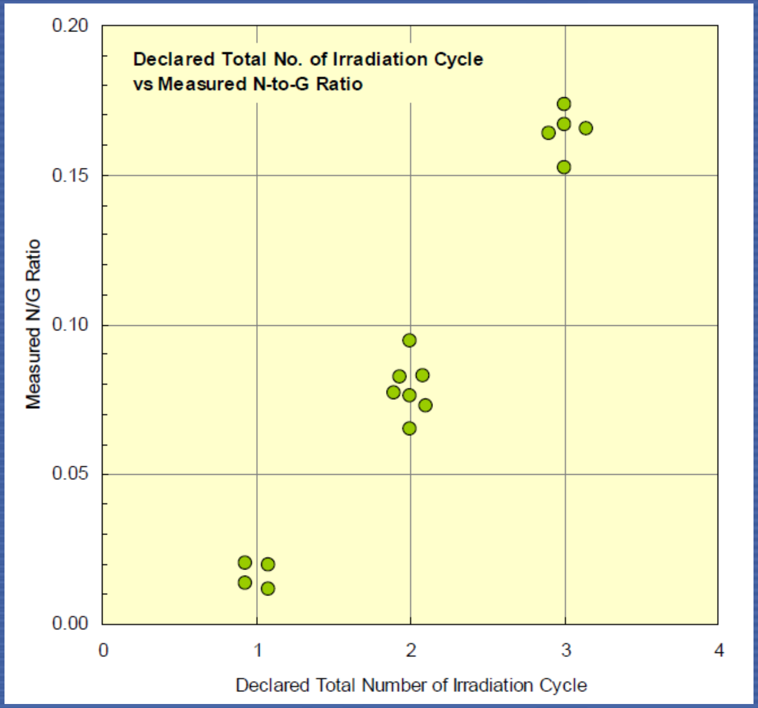
Verification of irradiated NM: FDET

Data interpretations:



Confirmation of fuel burnup



Confirmation of number of irradiation cycles

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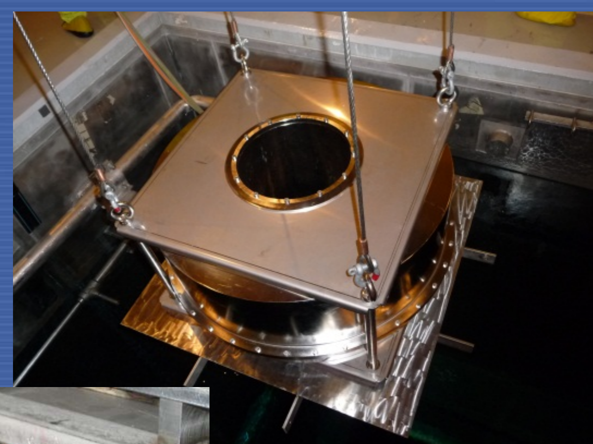
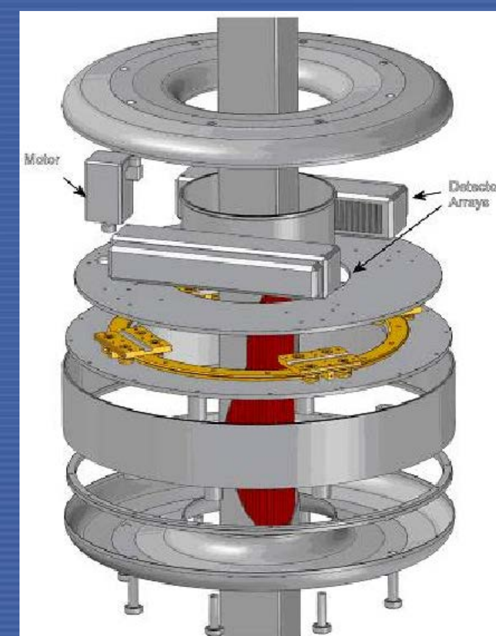
Verification of irradiated NM: PGET

Passive Gamma Emission Tomographic System:

- 2 rotating heads x 104 CdTe 2 x 5 x 10 mm^3 (ACRORAD, Japan)
- Electronics: prototype - BSI / final version – GBS Elektronik
- Collimator: 1.5 mm slit x 10 cm long W per detector
- Scanning every 3 degrees =. 120 steps to cover 360 degrees
- Acquisition: 3 h (BSI), expected with new electronics - 10 min (GBS)





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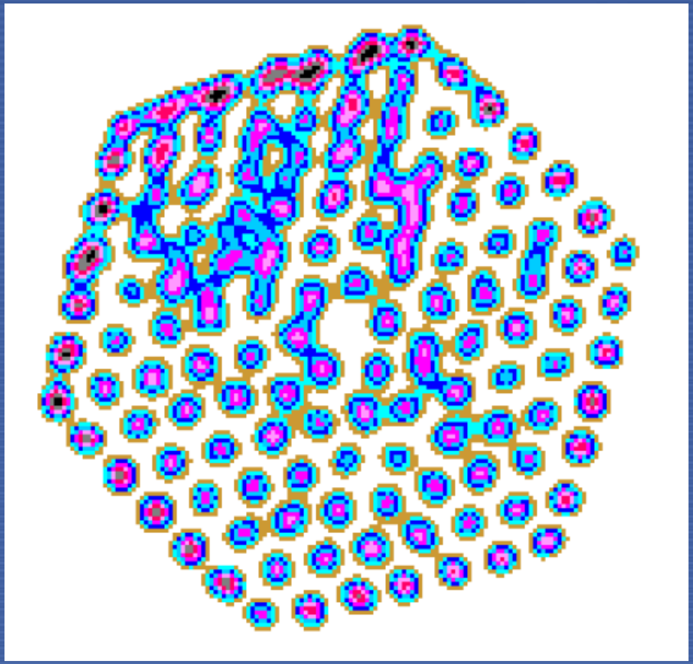
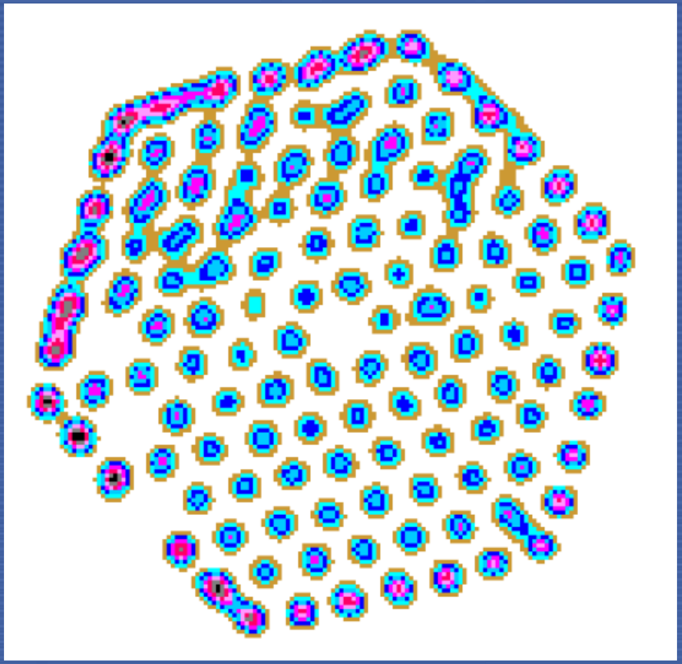
Verification of irradiated NM: PGET

Examples of test measurements in VVER NPP Lovisa (Finland, 2014): 33 GWd/tU, ≈12 y cooling time



Complete assembly



Assembly with three missing pins

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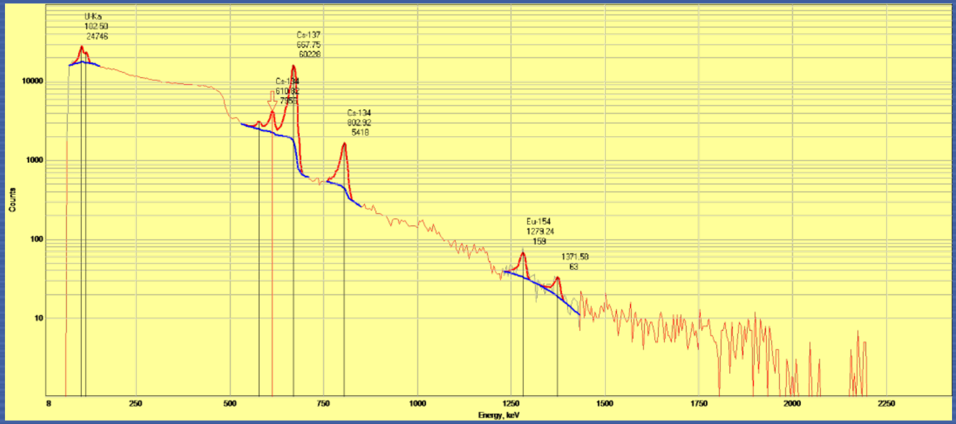
Verification of irradiated NM: SMPY

- Combined active neutron – passive gamma underwater measurement system using He-3 proportional counter and a collimated spectrometric CZT detector
  - Active neutron interrogation with AmLi source for the amount of ^{235}U
  - Gamma-spectrometry for fuel burnup confirmation using isotope ratio method



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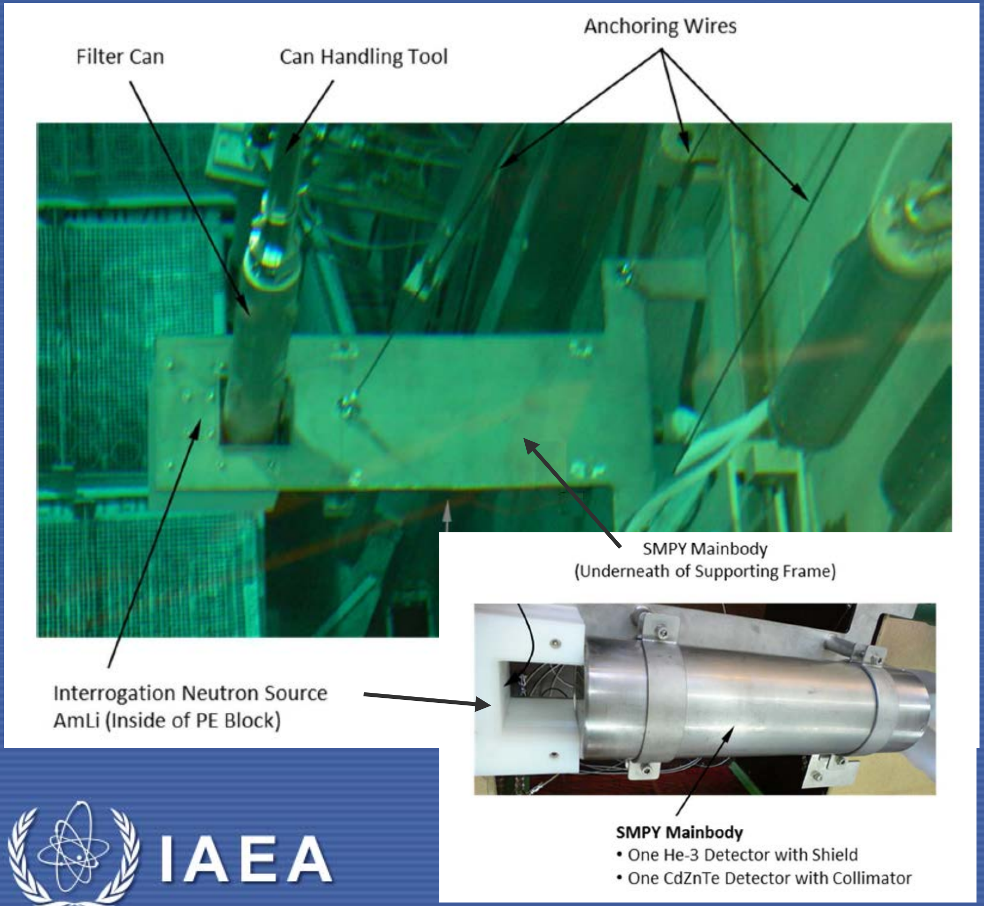
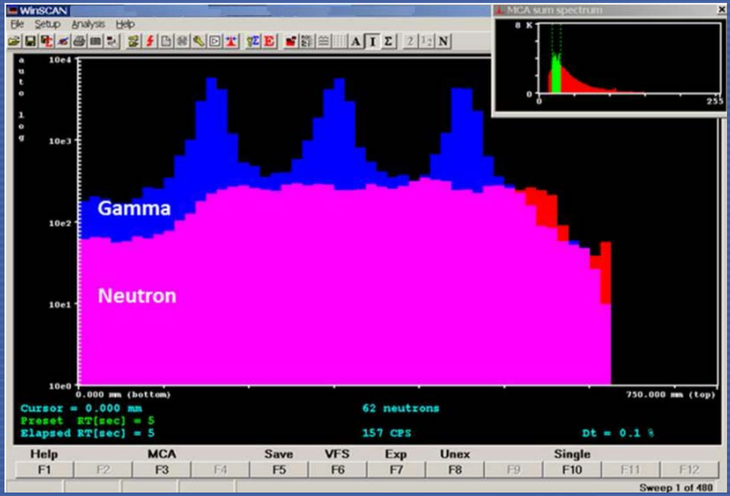
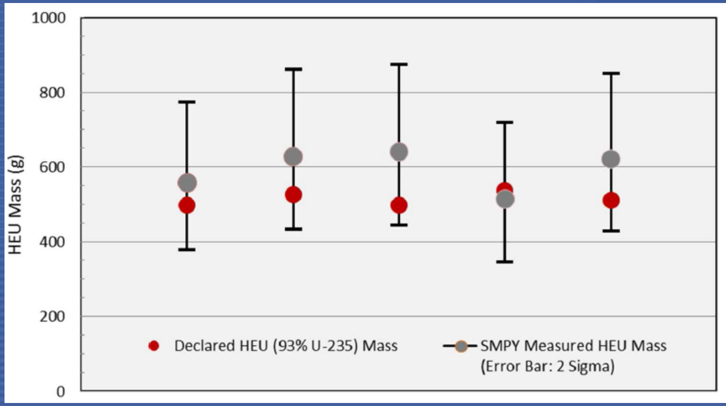
Verification of irradiated NM: SMPY

- Application example: Verification of U-235 mass in HEU containing filters at Mo-99 production facility







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Verification of declaration completeness

- IAEA's CA kit (basic set used on a regular basis)

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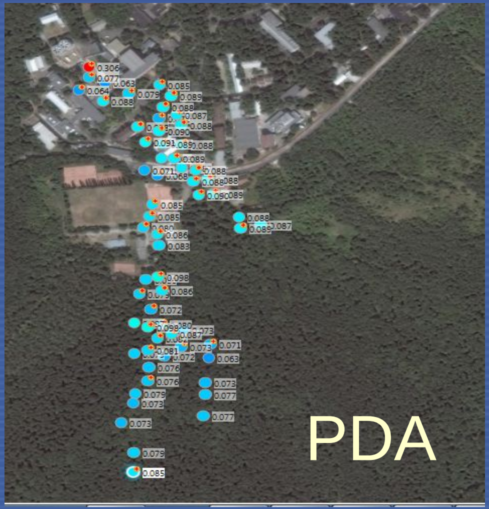
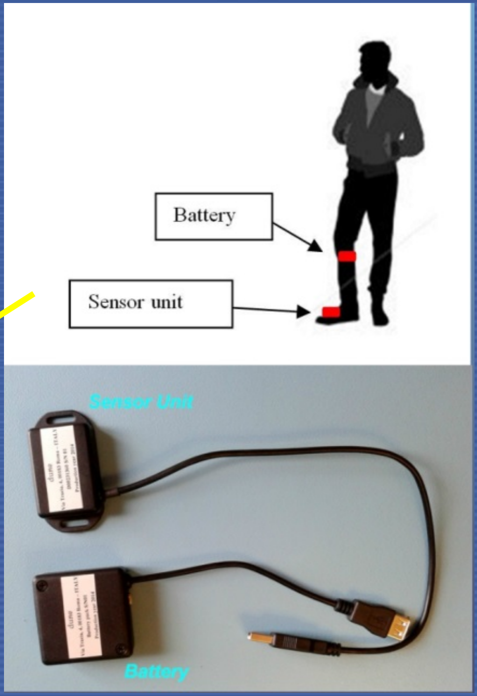
Verification of declaration completeness

SG version of Atomtex backpack scanner

Backpack spectrometric portable radiation scanner



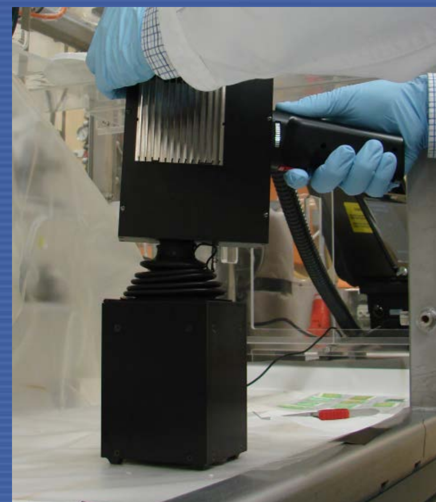
- Extended energy range (< 5 MeV)
- Prompt gamma ID
- Inertial positioning capability



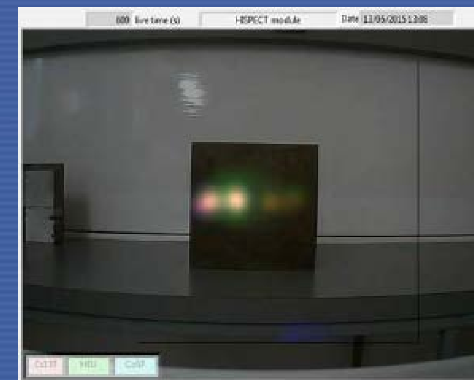
Verification of declaration completeness

Portable 3D-laser

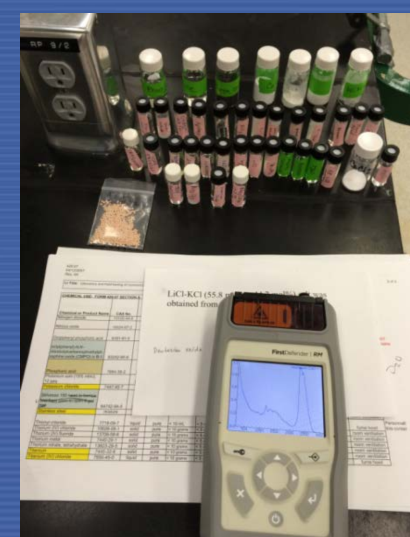
Portable LIBS



Portable gamma-camera



Hand-held Raman



Hand held IR camera

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Thank you for attention