Grand Challenges for Safeguards

Arden D. Dougan

Associate Program Leader

Next Generation Safeguards Initiatives Summer Lecture Series

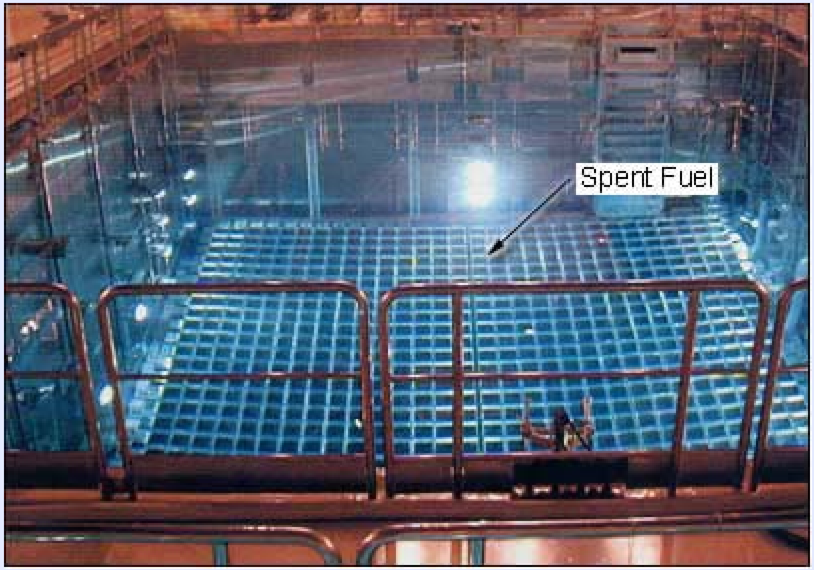
July 21, 2009

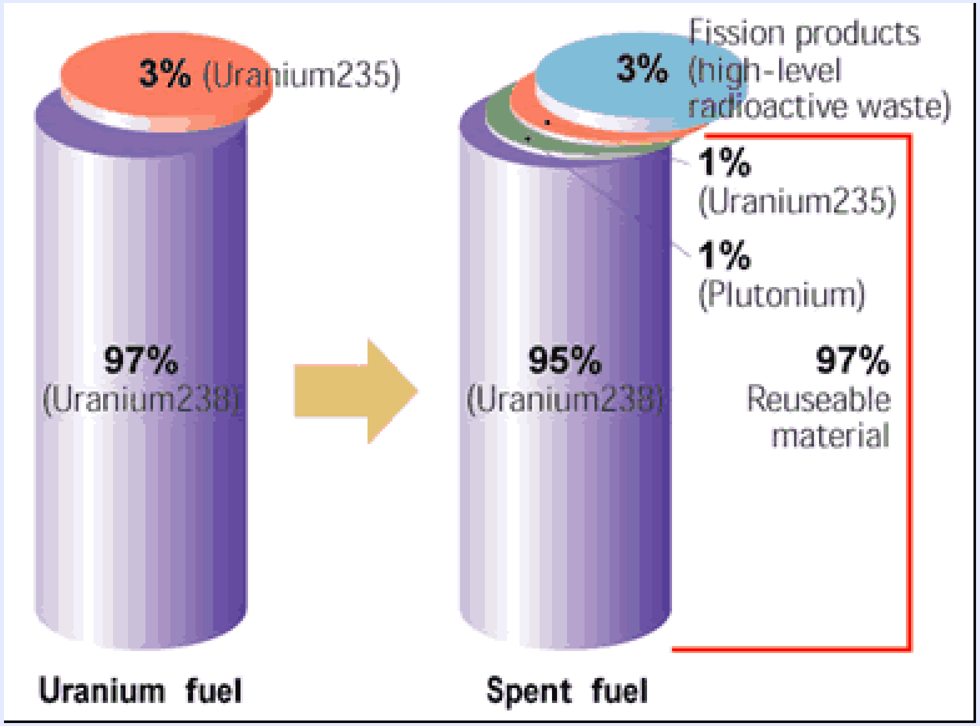
Outline

- Case Studies AKA Some Grand Challenges

  1. Verifying Spent Fuel
  2. Verifying Plant Design
  3. Safeguarding Geologic Repositories
  4. Undeclared activities

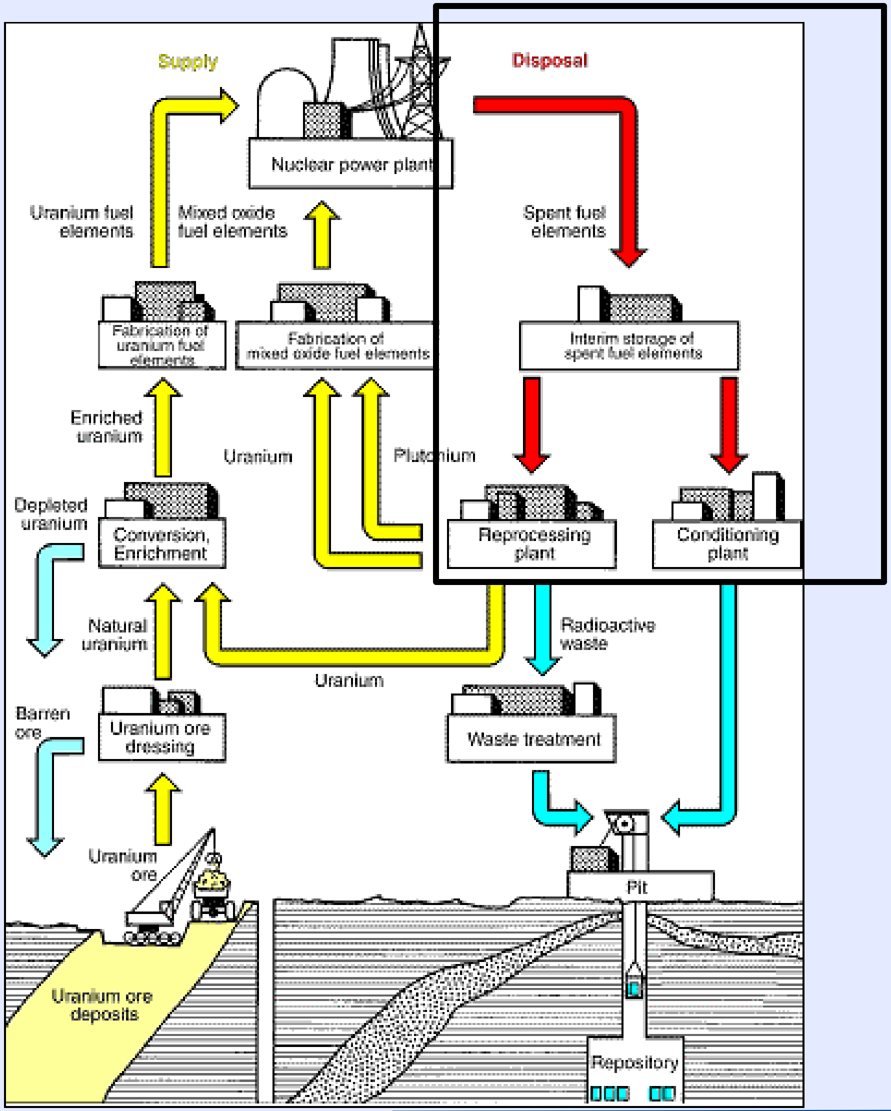
Challenge #1 - Verifying Spent Fuel





http://www.japannuclear.com/nuclear power/program/waste.html

(Note: The above graphic on spent fuel contents refers to the case of 3% enrichment level.)

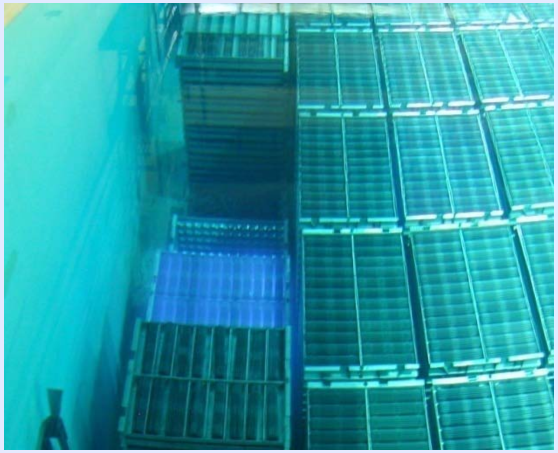


http://www.euronuclear.org/info/encyclopedia/n/nuclear-fuel-cycle.htm

Challenge #1 Verifying Spent Fuel *in situ*

- Need: Direct measurement of Pu in used fuel and actinide bearing materials
  - Current technology: item counting, identification number check, gross radiation attributes *(e.g. was it irradiated or not?)*
  - (Cerenkov Viewing Device)
- Issues:
  - Not suitable for spent fuel with very low burn-up and long cooling times
  - Unclear water
  - Not directly viewable from the top

Cerenkov Viewing Device

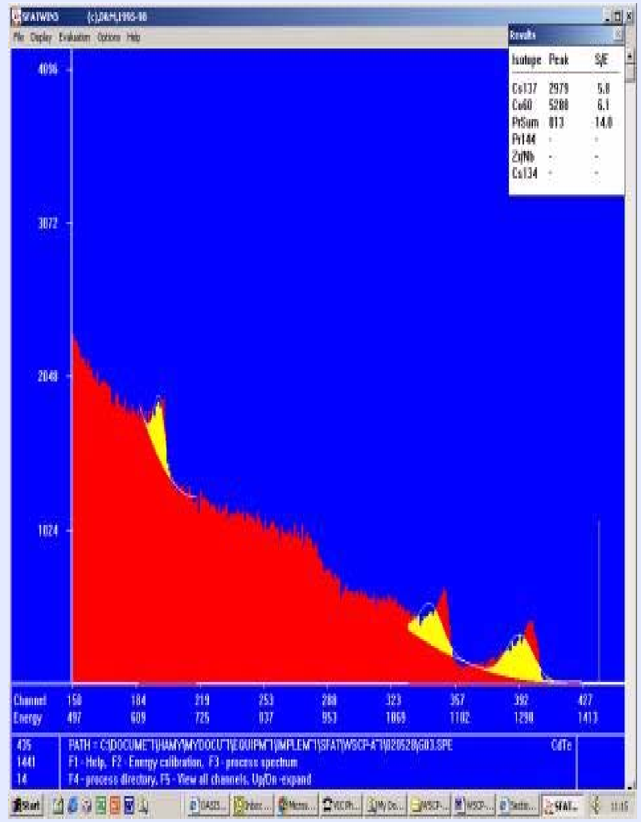


This slide adapted from "In-Situ Safeguards Verification of Low Burn-up PWR Spent Fuel Assemblies," by Y. Ham

Challenge #1 Verifying Spent Fuel *in situ*
Current technologies

SFAT-Spent Fuel Attribute Tester

- Look for Cs-137 peaks
- In-situ verification
- Detector: CdZnTe
- Not applicable to
  - Old PWR spent fuel with inserts
  - PWR/BWR SFAs with blanket material in fuel
- Only access to the top portion of the spent fuel



This slide adapted from “In-Situ Safeguards Verification of Low Burn-up PWR Spent Fuel Assemblies,” by Y. Ham

Challenge #1 Verifying Spent Fuel *in situ*
New technology: Safeguard Pin Diversion System

Problem Statement

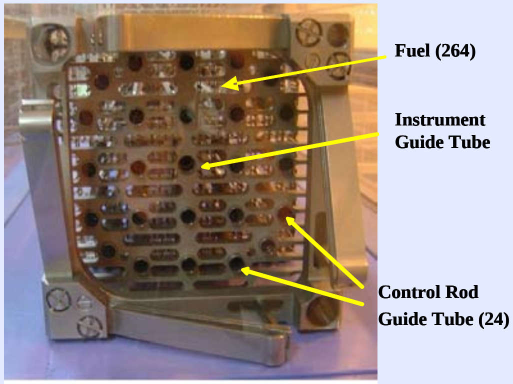
No method/instruments exist , either domestically or internationally, for detection of partial removal of fuel from spent fuel assemblies including MOX

Project Objective

Develop, build and demonstrate a novel safeguards verification method and instrument to detect spent fuel element (pin) diversion from pressurized water reactor (PWR) and MOX spent fuel assemblies.

Proposed Methodology

Simultaneous measurement of thermal neutron and gamma signals inside guide tubes of spent fuel assemblies for detection of partial removal of fuel rods from pressurized water reactor (PWR) spent fuel assemblies.



17 x 17 PWR Westinghouse Type

The method proposes insertion of tiny neutron and gamma detectors inside guide tubes to detect partial removal of spent fuel

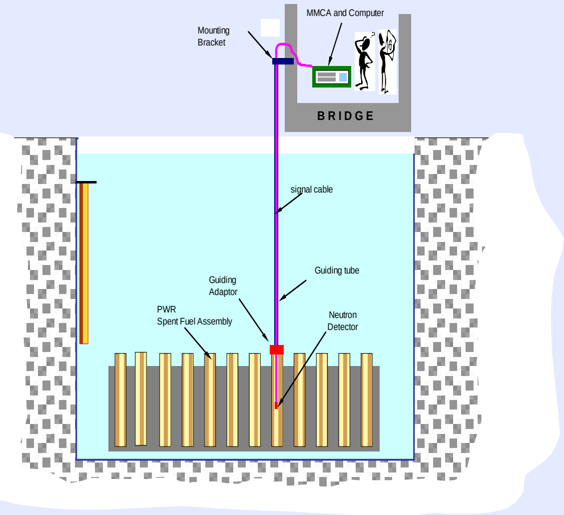


Figure 1: Conceptual design for proposed PWR Verification system

A conceptual method and measurement system for in-situ verification of reactor spent fuel assemblies

Spent Fuel verification – the problem

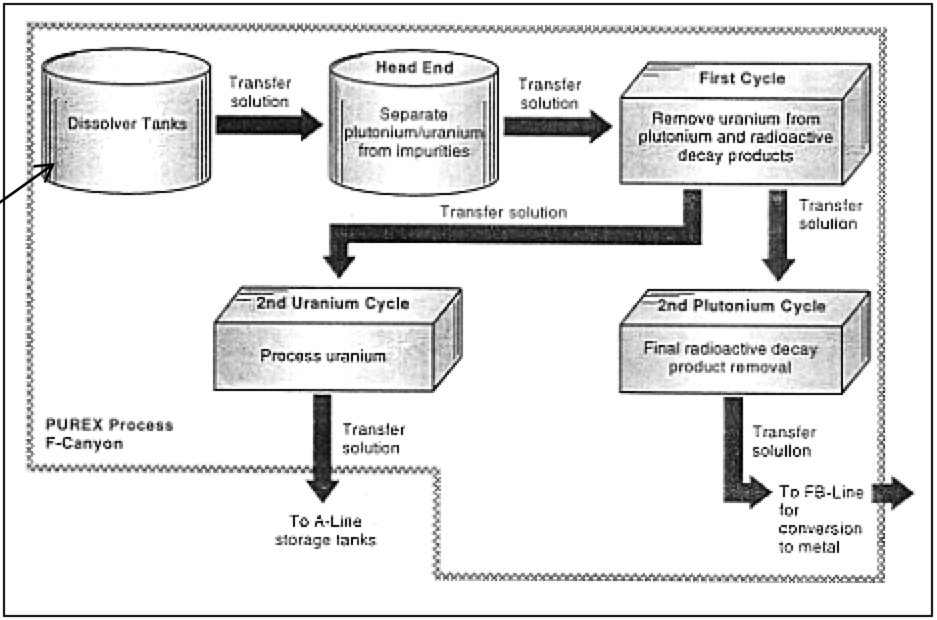
- Not verified at reactor
  - If full, no seals applied to cask
- Shipper's Values
  - Based on burnup codes
  - Could be 10-15% off
- Verification upon Receipt
  - Item count
  - Random id check
  - Gross radiation (was it radiated?)
- Shipper-Receiver Difference
  - the difference between the nuclear material content declared by the reactor operator in a given assembly and that measured in the corresponding dissolver solution at the reprocessing plant

Currently it is difficult to determine if the SRD is a result of poor reactor calculations, undeclared/unmeasured losses to waste in the head-end process, or a potential diversion of nuclear material.

Source: Advanced Safeguards for New Fuel Cycle Facilities - Developments and Recommendations, 2009

Where do the measurements take place?

- Aqueous reprocessing plant – could take samples at input accountability tank



- Electrochemical plant
  - Electrorefiner is difficult to assess

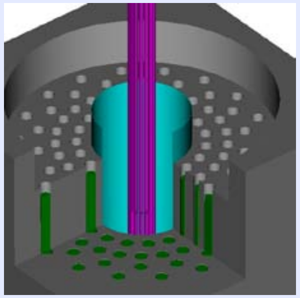
Challenge #1 Verifying Spent Fuel: New technologies

GlobalSecurity
Anticipate • Innovate • Deliver

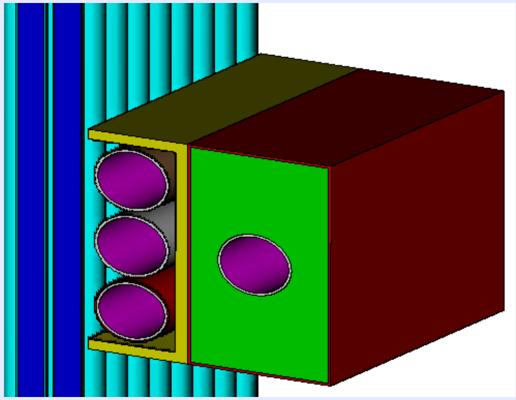
Problem: Shipper/receiver validation of Pu

Needed for electrochemical/pyrochemical plants

- Delayed gamma radiation
- Delayed neutron radiation
- Differential Die-away
- Lead Slowing Down Spectrometer
- Advanced Multiplicity Counting
- X-Ray Fluorescence
- Passive Neutron Albedo Reactivity
- Self-Interrogation Neutron Resonance Densitometry



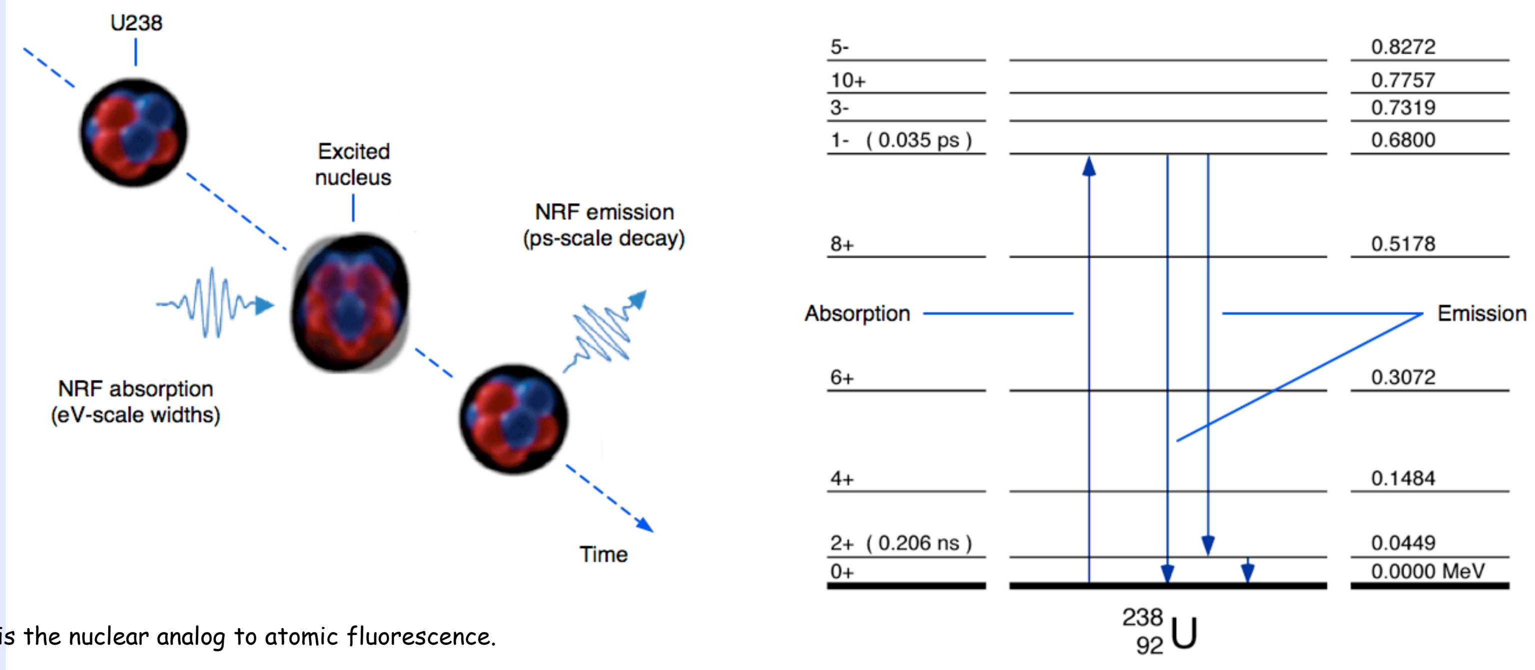
Passive Neutron Albedo Reactivity



Self-Interrogation Neutron Resonance Densitometry

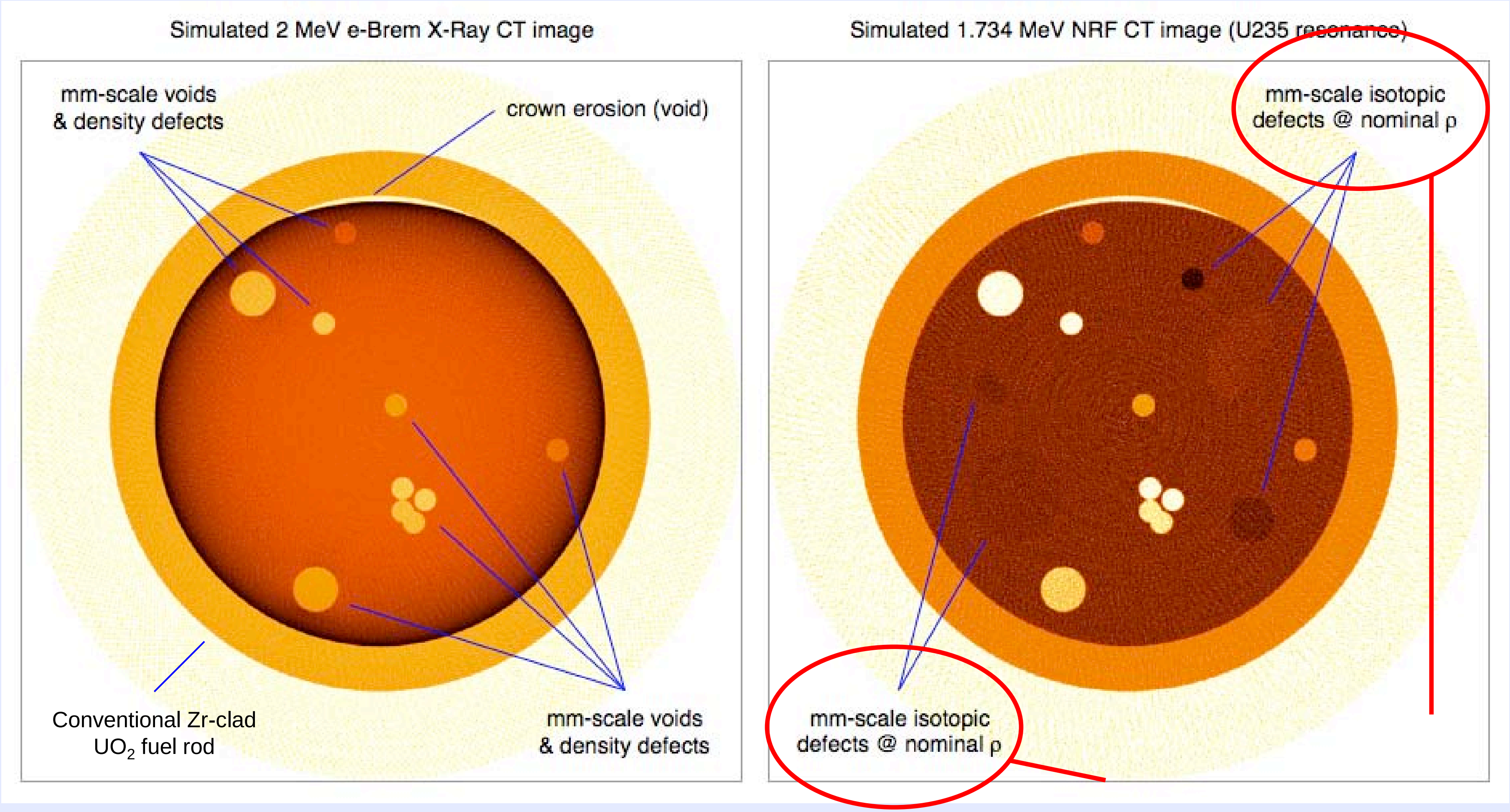
Nuclear Resonance Fluorescence (NRF)*

- Energetic photons (γ-rays) at the resonant energy of a particular isotope can excite the nucleus.
- The excited nucleus then decays to its ground state by emitting a set of characteristic γ-rays
  - **<u>Each isotope has its own unique signature!!!</u>**



* NRF is the nuclear analog to atomic fluorescence.

Characteristic NRF γ-ray emissions can be used to determine the isotopic content in fuel rods



Note: While the simulated voids and density defects are clearly discernable in both cases, only the NRF image reveals the presence of potential isotopic defects (modeled here at nominal density).

Challenge #2 Verifying Facility Design

A BANK OF CENTRIFUGES AT A URENCO PLANT

Sverdlovsk centrifuge enrichment plant

Challenge #2 Verifying Facility Design: The Problem

- "Design information is information concerning nuclear material subject to safeguards under the agreement and the features of facilities relevant to safeguarding such material."
  - *(INFCIRC/153, paragraph 8, similarly INFCIRC/66, paragraph 32).*
- *"Activities carried out by the IAEA at a facility to verify the correctness and completeness of the design information provided by the State. An initial DIV is performed on a newly built facility to confirm that the as-built facility is as declared. A DIV is performed periodically on existing facilities to confirm the continued validity of the design information and of the safeguards approach. The IAEA's authority for performing a DIV is a continuing right throughout all phases of a facility's life cycle until the facility has been decommissioned for safeguards purposes."*
  - International Atomic Energy Agency (IAEA): *IAEA Safeguards Glossary – 2001 Edition*, International Nuclear Verification Series No. 3, Vienna, Austria, 2002.

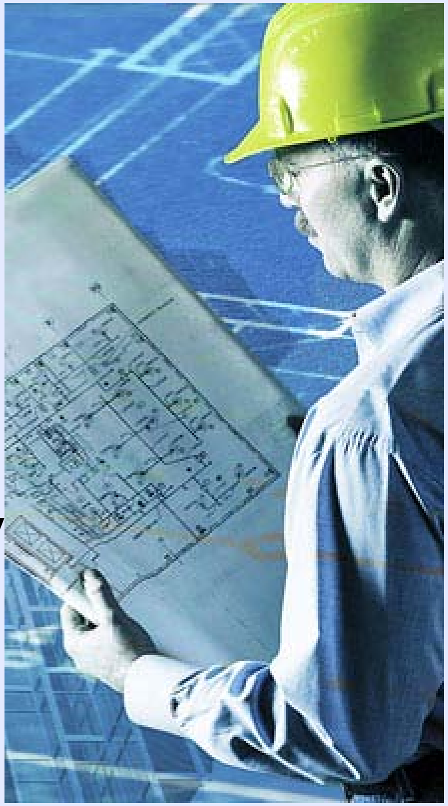
Challenge #2 Verifying Facility Design: Example – Rokkasho Reprocessing Plant

- Basic stats
  - 3.8 square km
  - 14 major process buildings and dozens of smaller support facilities
  - ~100 process cells and work areas
  - DIV began during construction in 1996 and continues today

This slide adapted from “DIV Experience at The Rokkasho Reprocessing Plant,” by P. Durst

Challenge #2 Verifying Facility Design: Tools

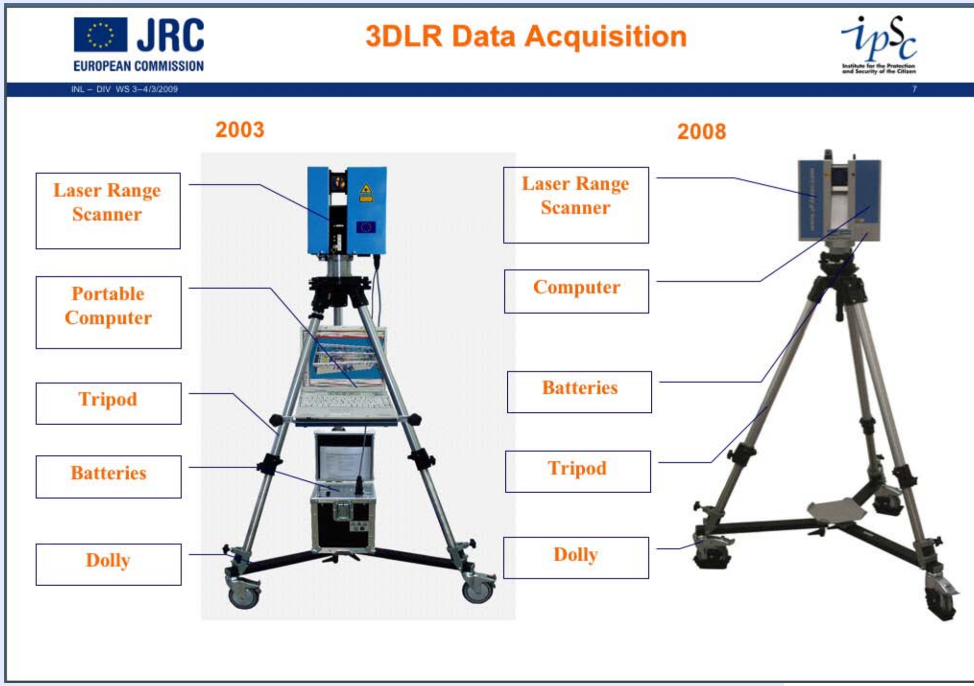
- Current tools
  - Visual observations
  - Blueprints and drawings
- Issues
  - Limited time
  - High radiation areas, limited accessibility
  - Blueprints must be left at plant



* In development

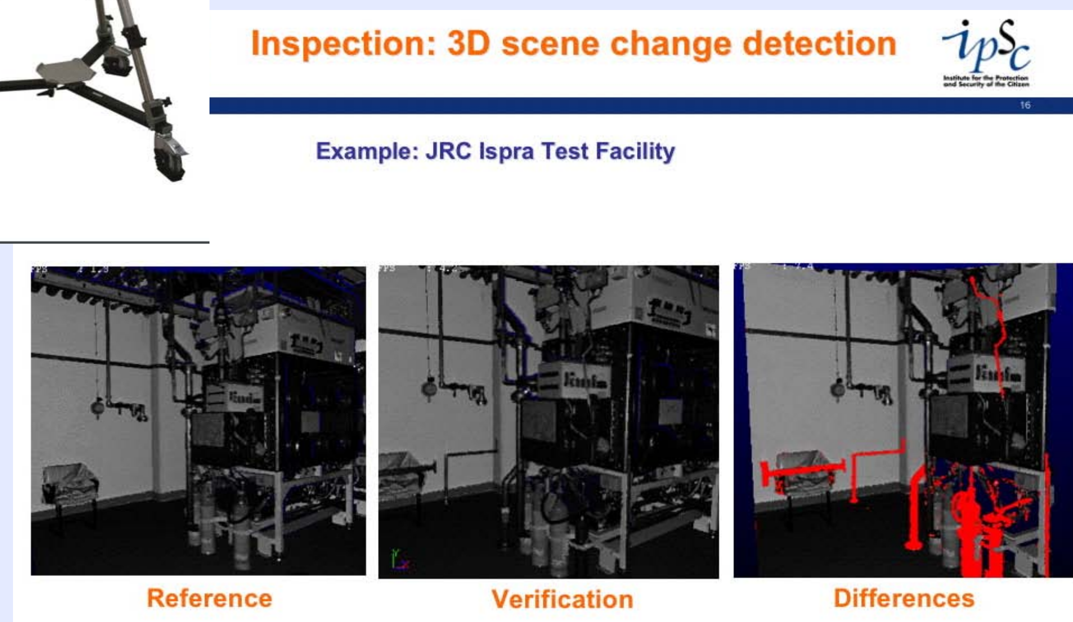
(Source – European Commission Joint Research Centre - Ispra, Italy)

Challenge #2 Verifying Facility Design: Tools



3DLR can survey a large and complex nuclear material process area or cell and render a high-resolution 3-D computerized model of the area

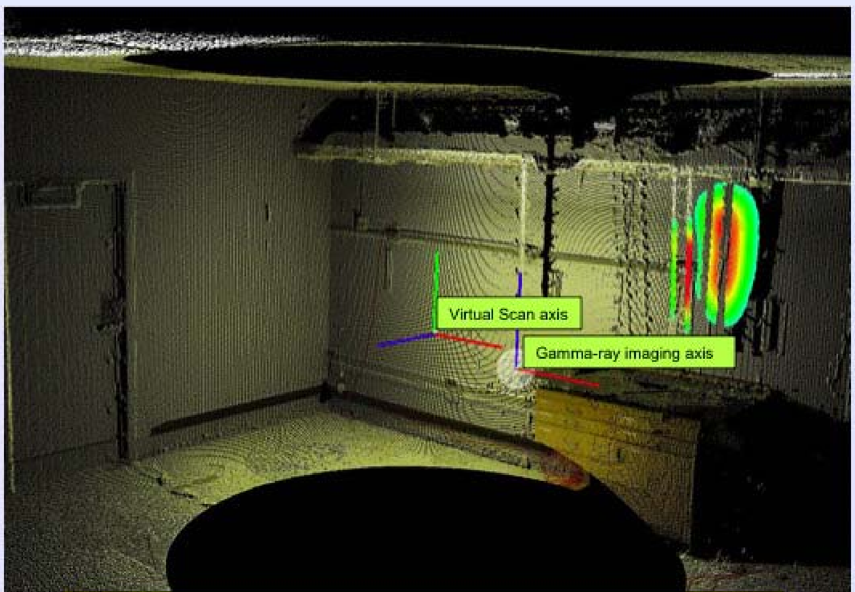
- Automated, fast re-verification



(Source – European Commission Joint Research Centre - Ispra, Italy)

Challenge #2 Verifying Facility Design: Tools

- High-resolution gamma radiation detection and imaging device that uses a large integrated array of cryogenically cooled strips of semiconductor detectors.
  - to detect and visualize the presence of gamma radiation emitting hot-spots in 3D.
  - to detect the presence and map undeclared or concealed process piping and equipment handling highly radioactive material.



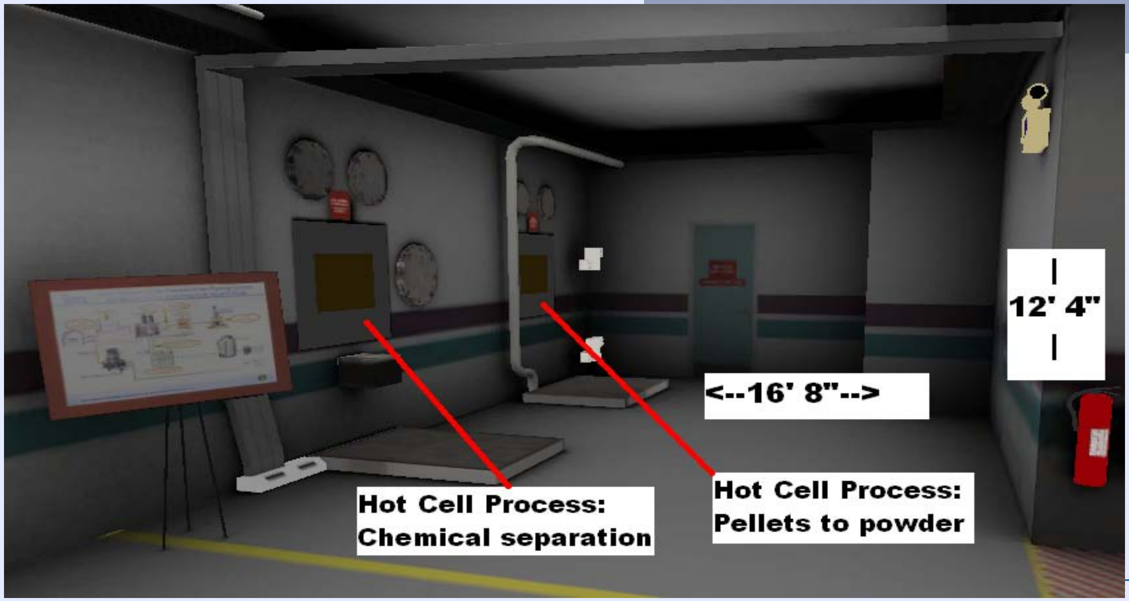
A gamma-ray image is back-projected onto the range map – snapshot of the 3D model (side view)

Lidar scans will provide the map of objects in the environment. The Compton camera measures the gamma-ray image.

(M. Burks, LLNL, L.. Mihailescu, LBNL)

Challenge #2 Verifying Facility Design: Tools

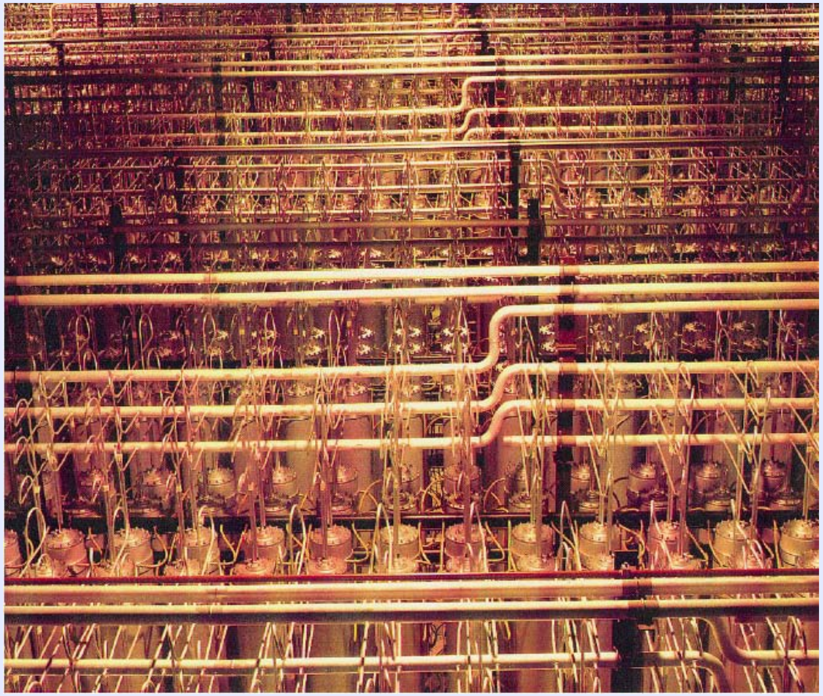
- Projected Virtual Reality (VR) Modeling for constructing computer-based reference facility models for use by inspectors during DIV.



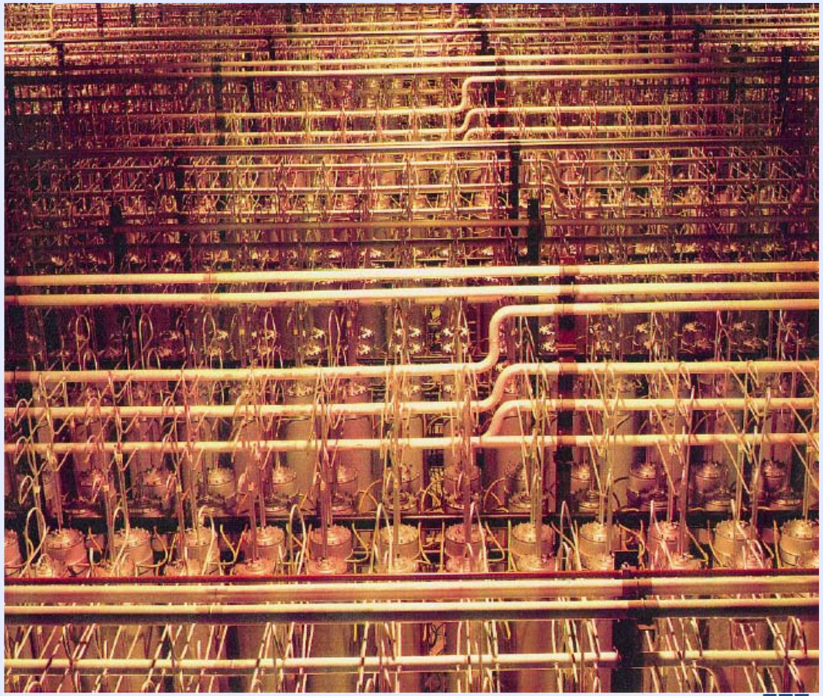
(Kelly Michel, LANL)

Challenge #2 Verifying Facility Design: Tools

- Change detection software accurately, rapidly and reliably detect differences in digital images
- Novel system that aligns two images to similar reference points, revealing previously unnoticeable differences
- Example: Centrifuge enrichment plant

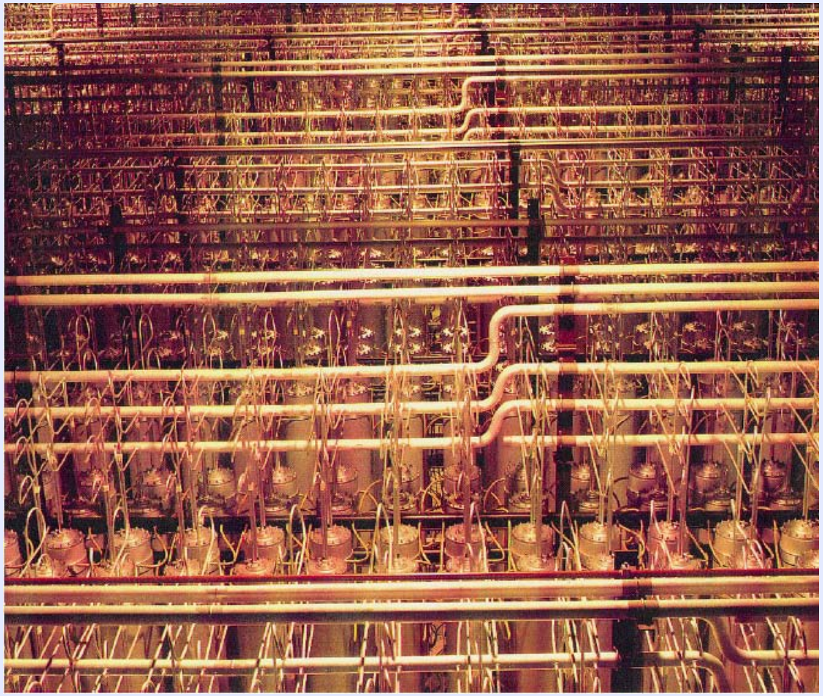


Before

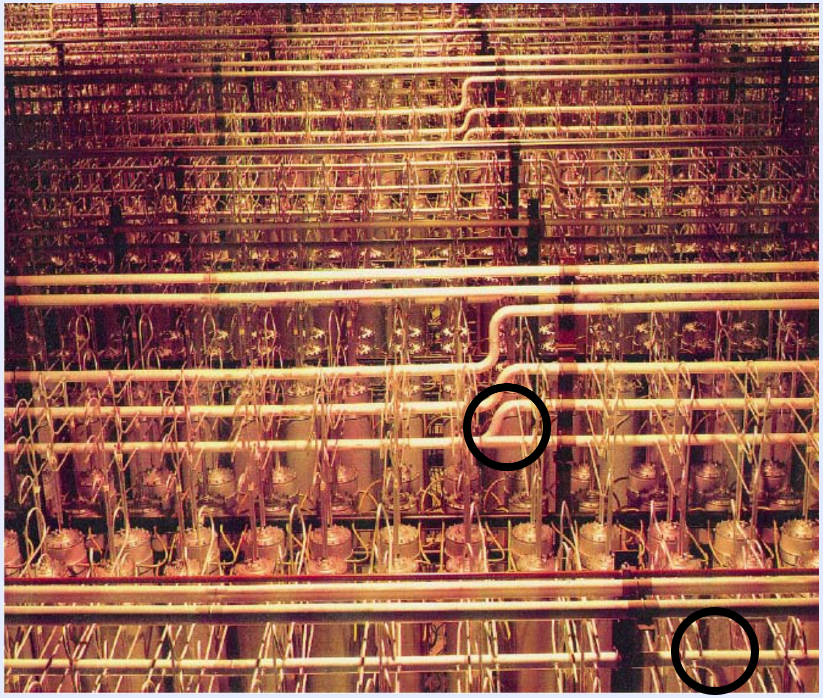


After

(Source – Greg Lancaster, INL)



Before



After

(Source – Greg Lancaster, INL)

Challenge #3 Safeguarding Geologic Repositories

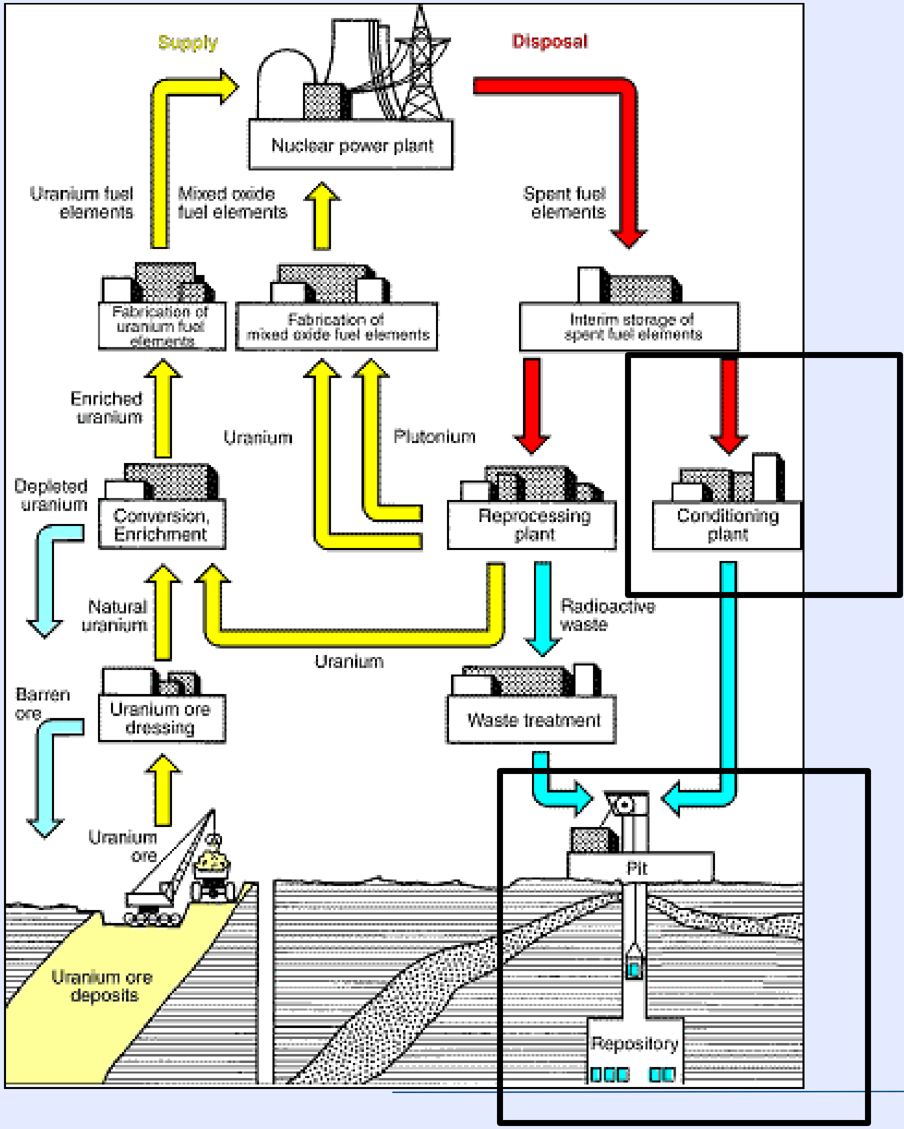
Finland

- Repository
  - Start excavation of Onkalo characterization facility – 2004
  - EC Declaration, DIQ/BTC, DIV – mid 2009
  - Construction license – 2012
  - Operation -- 2020
- Conditioning Plant – TBD

Sweden

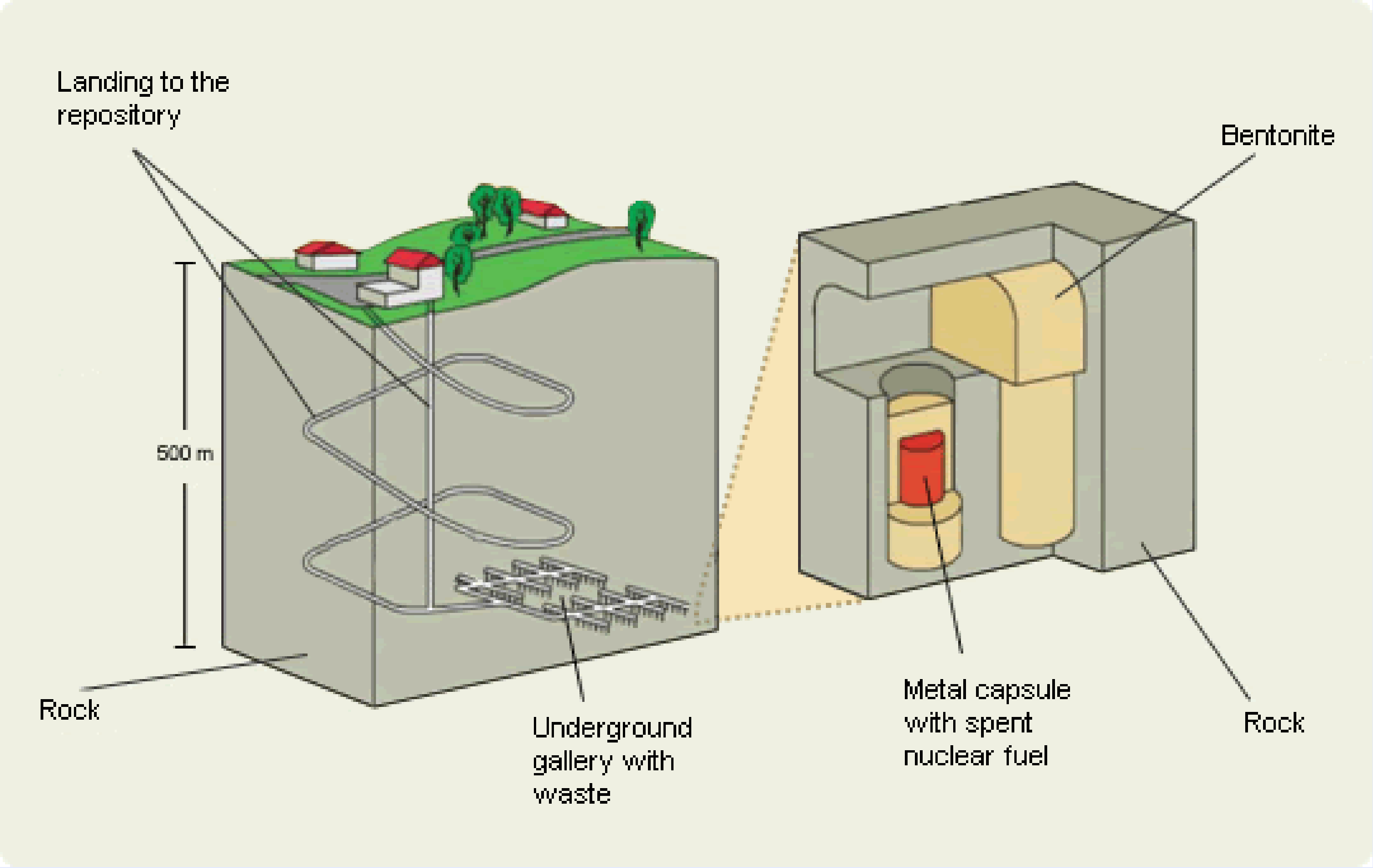
- Conditioning Plant
  - Preliminary licensing information submittal – 2006
  - Construction license submittal -- 2010
  - Construction – 2012
  - Operation -- 2020
- Repository
  - Selection of Site – 2009
  - Construction license submittal – 2010
  - Construction – 2012
  - Operation -- 2020

This slide adapted from "Geological Repository System: Safeguards Approach and Technical Requirements," by B. Moran



http://www.euronuclear.org/info/encyclopedia/n/nuclear-fuel-cycle.htm

Challenge #3 Safeguarding Geologic Repositories



http://www.vae.lt/en/pages/management_of_long_lived_radioactive_waste

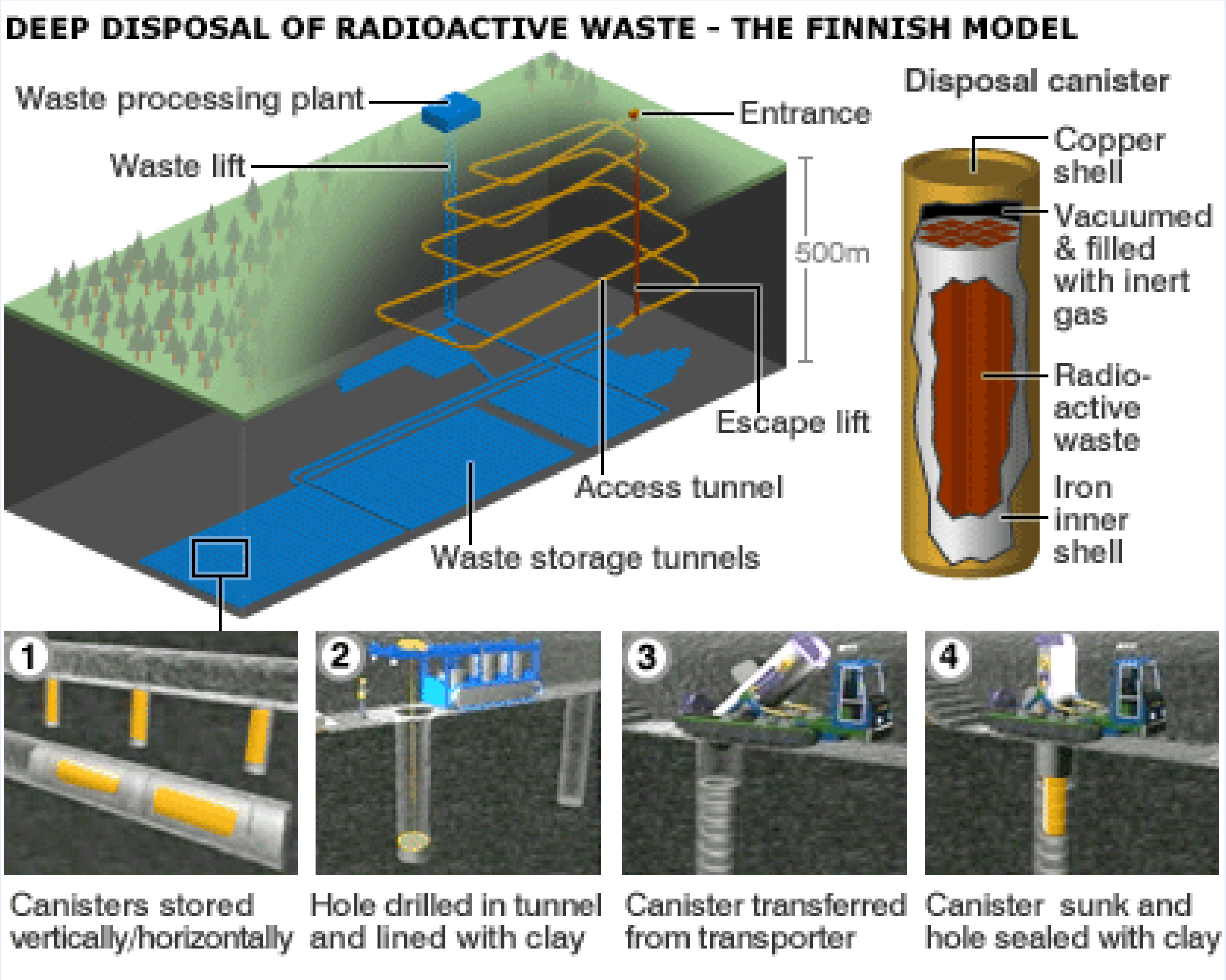
Challenge #3 Safeguarding Geologic Repositories

- Challenges
  - Conditioning plant
    - Method to determine amount of Pu, U in spent fuel
    - Containment and surveillance system for spent fuel canisters and casks
  - Repository
    - Containment and surveillance in tunnels
    - Underground survey methods to confirm integrity of repository site
    - Design information verification
    - Verification measurements

Challenge #3 Safeguarding Geologic Repositories: Disposal canister for spent fuel

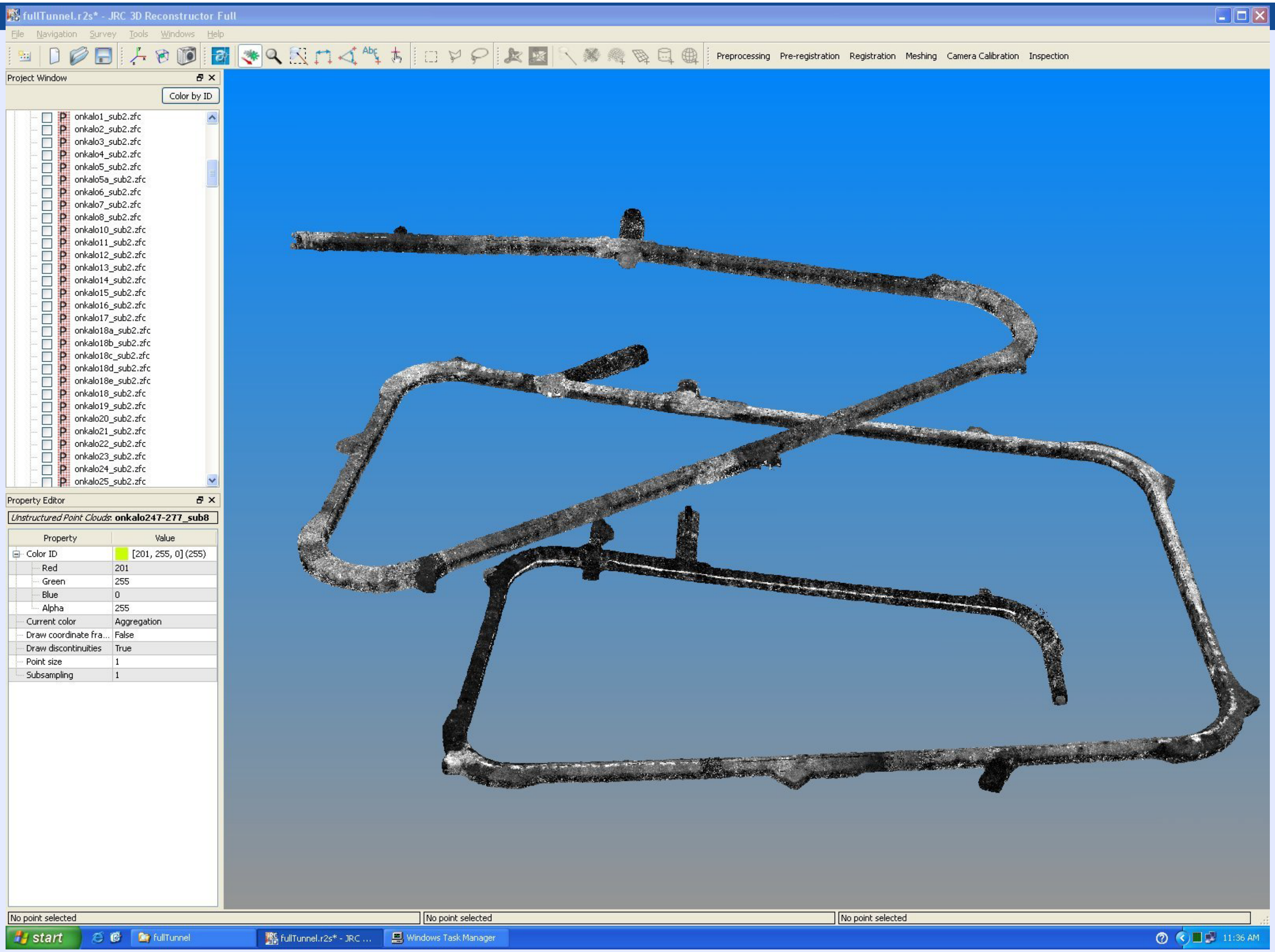
This slide adapted from “Geological Repository System: Safeguards Approach and Technical Requirements,” by B. Moran

Challenge #3 Safeguarding Geologic Repositories: The Finnish Model



http://news.bbc.co.uk/2/hi/science/nature/4948378.stm

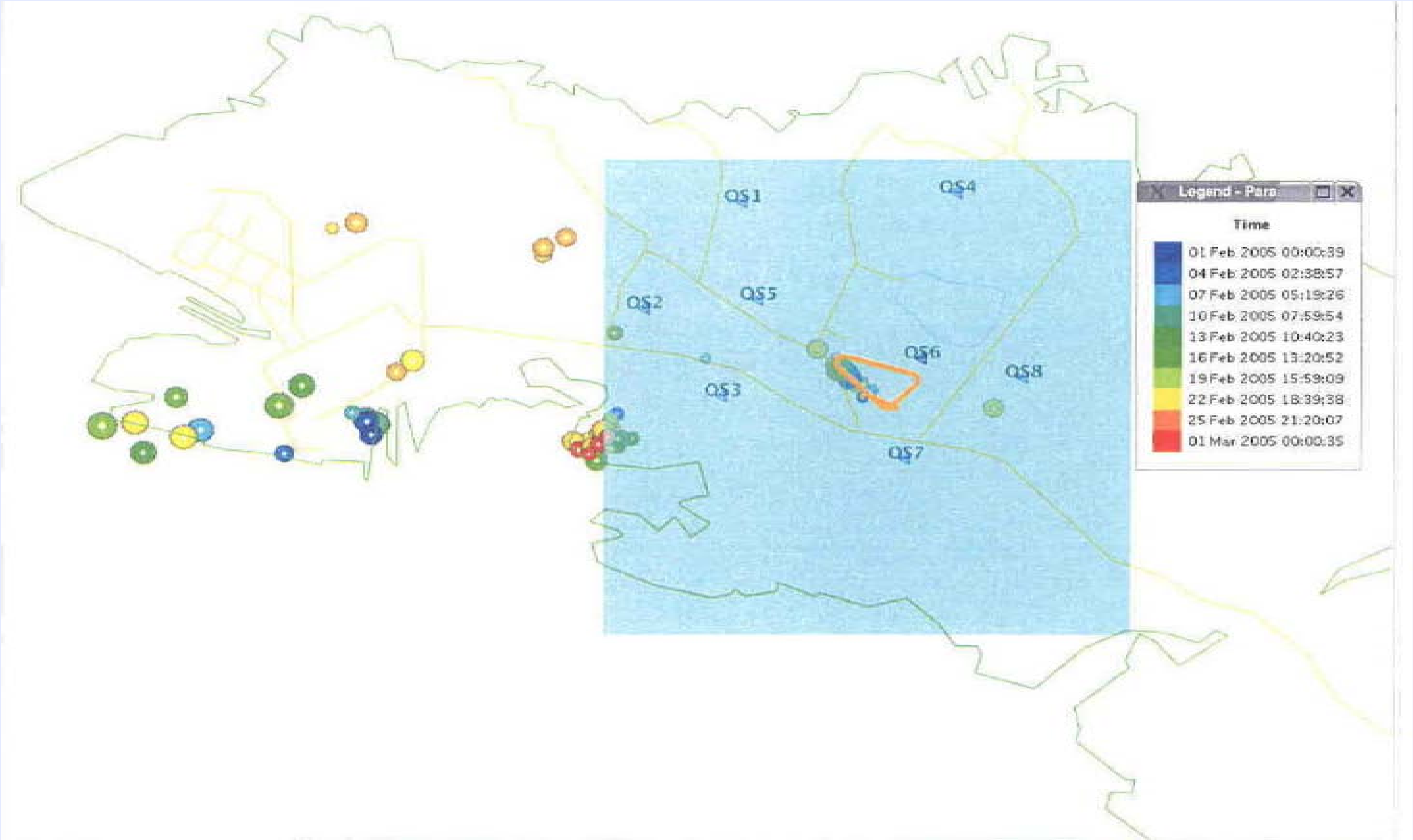
Challenge #3 Safeguarding Geologic Repositories: 3-D laser-scanning data (by JRC)



This slide adapted from “Geological Repository System: Safeguards Approach and Technical Requirements,” by B. Moran

28

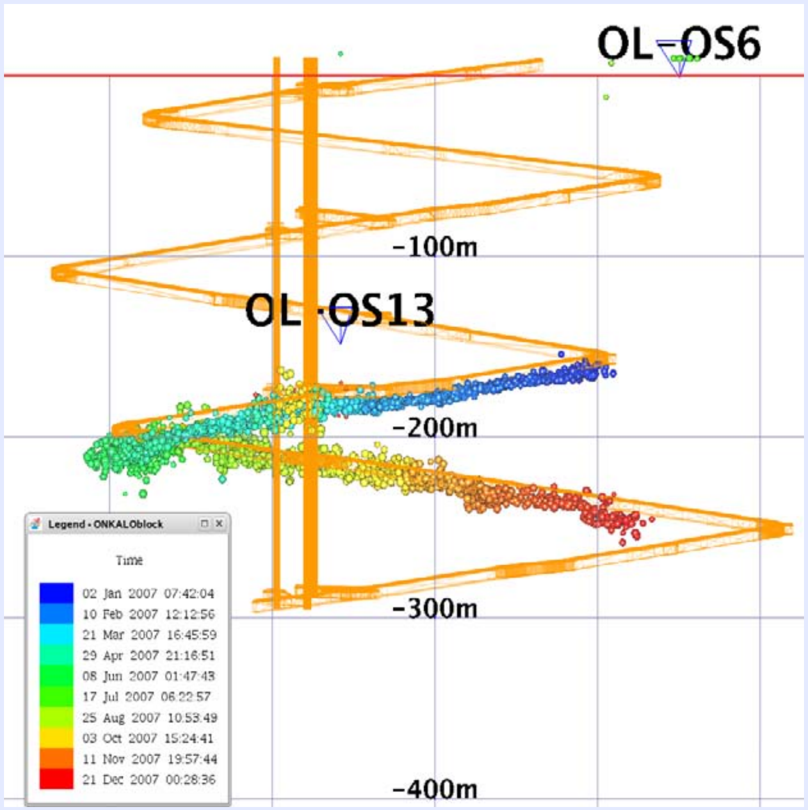
Challenge #3 Safeguarding Geologic Repositories: Passive Seismic Monitoring

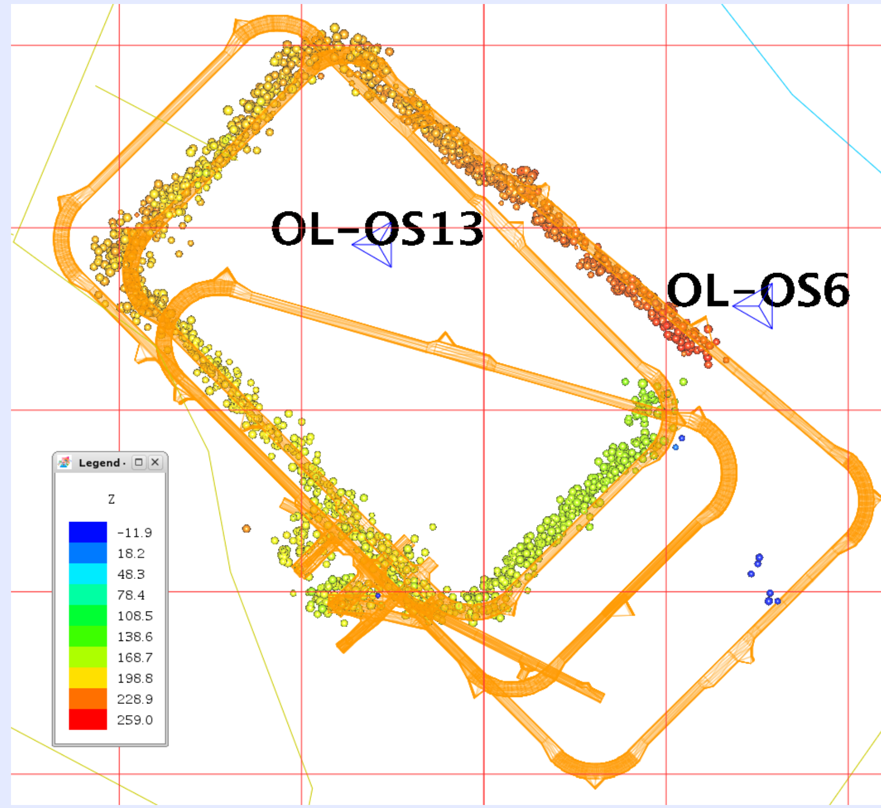


This slide adapted from “Geological Repository System: Safeguards Approach and Technical Requirements,” by B. Moran

Challenge #3 Safeguarding Geologic Repositories: Passive Seismic: Blasting and micro-seismic events in 2007

GlobalSecurity
Anticipate • Innovate • Deliver



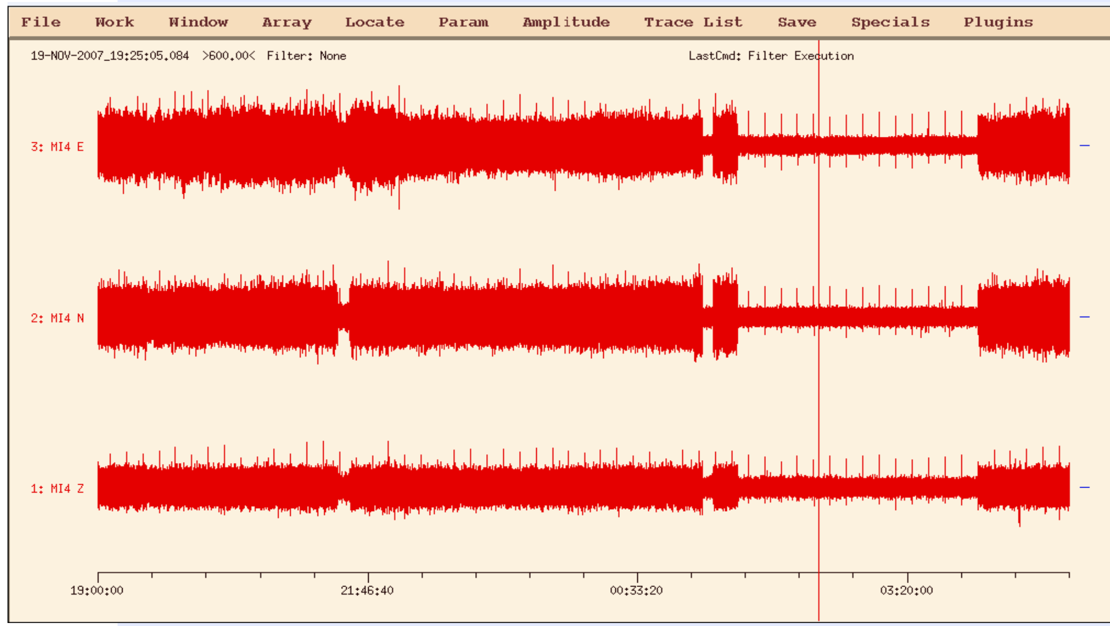


Seismic source locations by depth and position show the as-built design of the repository and locate other construction activities

This slide adapted from “Geological Repository System: Safeguards Approach and Technical Requirements,” by B. Moran

Challenge #3 Safeguarding Geologic Repositories: Tunnel boring

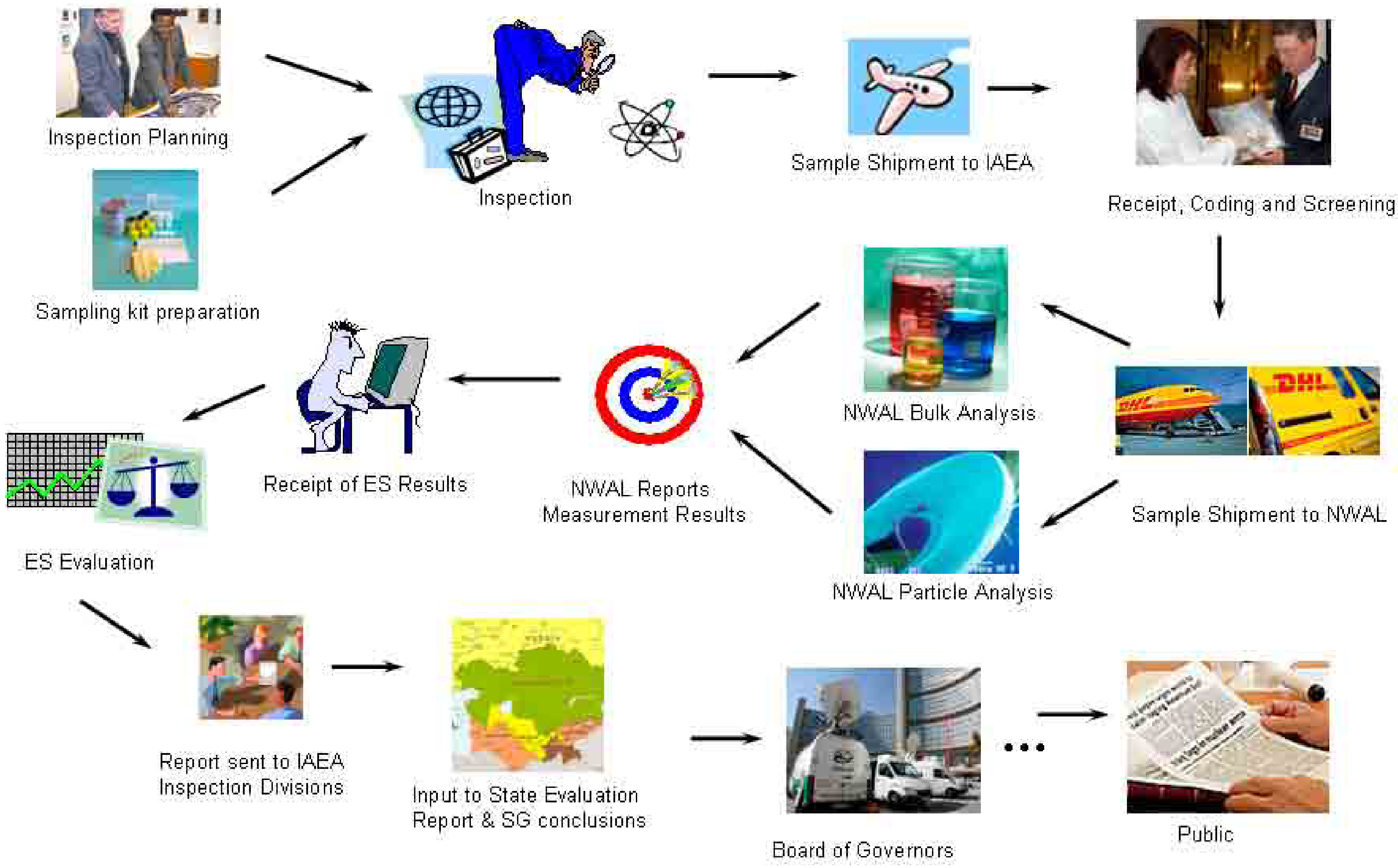
Figure 2-1. The raise boring machine at the level -90 m (upper Figure) and the reamer at the level -180 m before the raise boring started (lower Figure) in November 2007.



Raise boring of a shaft produces seismic vibrations similar to tunnel boring.

This slide adapted from “Geological Repository System: Safeguards Approach and Technical Requirements,” by B. Moran

Challenge #4 Undeclared Facilities



Challenge #4 Undeclared Facilities

- **Legal Basis: 1997 INFCIRC 540, the IAEA task: Providing credible assurance of the absence of undeclared nuclear activities in a State.**

- **Signatures: An identifying characteristic or mark of one or more physical characteristics associated with a proliferant process or activity. *Examples: acoustic signal, chemical*.**

- **Observables: A physically measurable phenomenon, which can be observed, generated by an object of interest that conveys information about the object's properties. *Examples: particles, waves, chemicals, effluent, electromagnetic signal.***

Challenge #4 Undeclared Facilities
Tools: Environmental Sampling

- The most common method involves wiping surfaces with a specially prepared cloth
- Specific procedures are followed to avoid cross-contamination and ensure audit trail
- Other methods:
  - Vegetation
  - Soil
  - (Water sampling)

- 1 large outer bag (30×30 cm), with a CL identification number and security seal
- 6 cotton swipes (10×10 cm Texwipes®) bagged in a small mini-grip bag (15×15 cm)
- 6 small mini-grip bags (15×15 cm) to bag the swipes in individual bags
- 6 medium mini-grip bags (20×20 cm) for double-bagging the swipes
- Peel-off labels for samples that are stored in the facility or given to the Facility/State Authorities
- 2 pairs of latex or plastic clean-room gloves (medium size)
- 1 blank working paper *WP EM1* (see Annex 2)
- 1 pen

This slide adapted from "An Overview of International Safeguards," by G. Anzelon

Challenge #4 Undeclared Facilities
Tools: Laboratory analysis

GlobalSecurity
Anticipate • Innovate • Deliver

- Two main types of analysis
  - Bulk analysis looks at a whole sample
  - Particle analysis looks at individual microscopic particles (more sensitive, more expensive)
- Analytical instruments include
  - Radiation detectors
  - Mass spectrometers
  - Scanning electron microscope, electron microprobe
- Isotopic ratios, age, chemical form, morphology, etc. all can provide clues

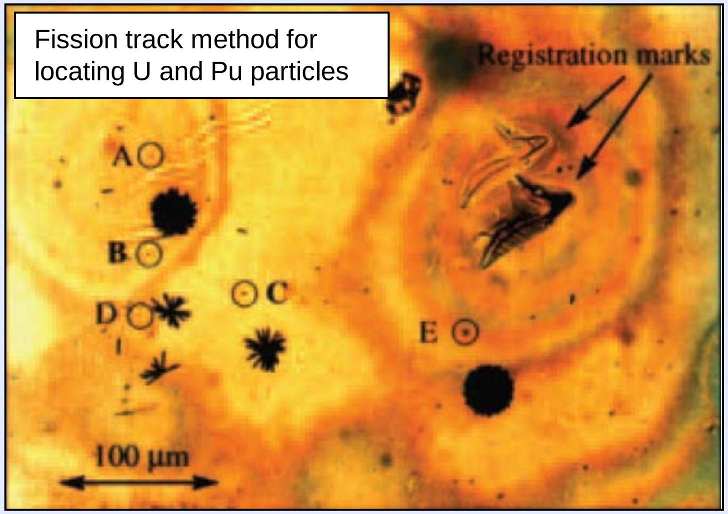


Photo: IAEA

Photo: IAEA

Sources:
--IAEA STR-348, *Environmental Sampling for Safeguards,* September 2005;
--*Safeguards Techniques and Equipment, 2003 Edition* (IAEA Nuclear Verification Series)

This slide adapted from “An Overview of International Safeguards,” by G. Anzelon

Challenge #4 Undeclared Facilities
Evaluation: What information can be inferred?

GlobalSecurity
Anticipate • Innovate • Deliver

A few examples:

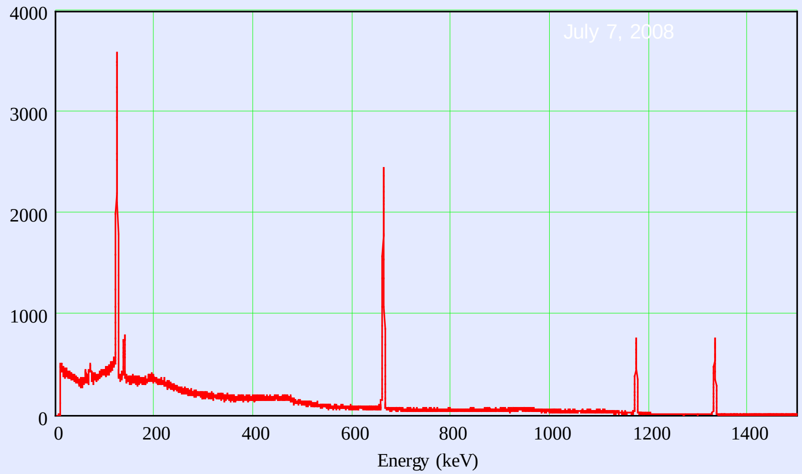
- Uranium isotope ratios that differ from natural composition indicate enrichment activity
- Minor isotope ratios can indicate additional detail about enrichment processes and feed materials
- Presence of fission products can indicate processing of spent fuel
- Plutonium isotope ratios ($^{240}Pu/^{239}Pu$) indicate fuel burnup
- Radioactive parent-daughter ratios (e.g., $^{241}Am/^{241}Pu$) serve as “chronometers” to indicate time since last chemical separation

Source: IAEA STR-348, *Environmental Sampling for Safeguards*, September 2005

Challenge #4 Undeclared Facilities
New Tools

- Inspector tools for in-field analysis of radionuclides
- Must be rugged, simple to operate

0.5% @ 662 keV (3.3 keV)
0.7% w/ cooler running

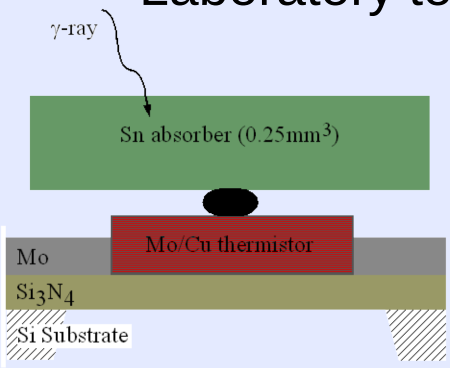


GeMini

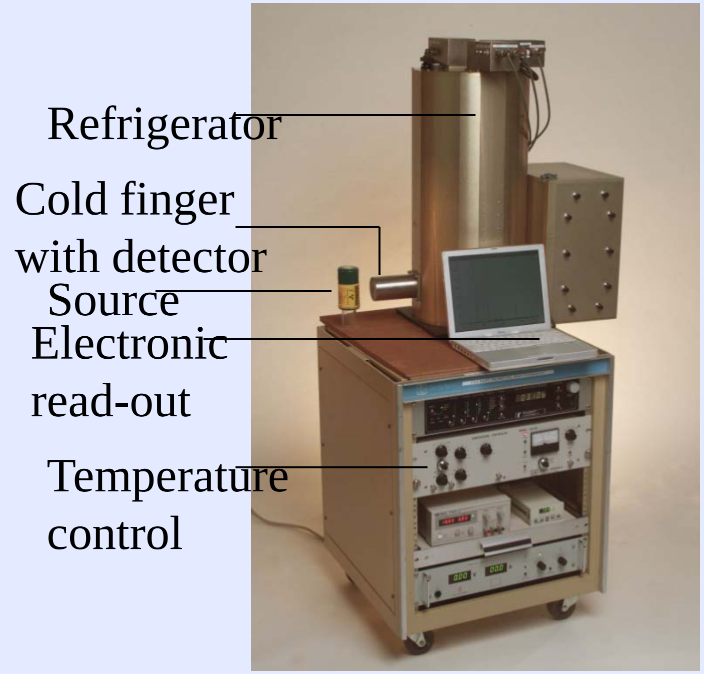
Morgan Burks, LLNL

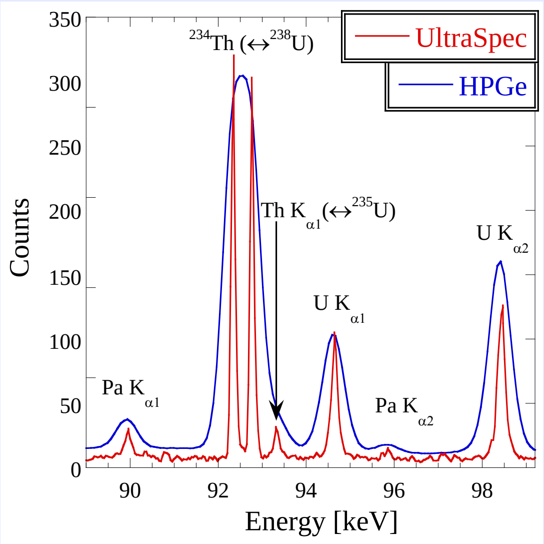
Challenge #4 Undeclared Facilities
New Tools

- Laboratory tool for ultra-high resolution gamma spectroscopy



Gamma-ray absorption increases absorber temperature, which is measured with a superconducting thermometer

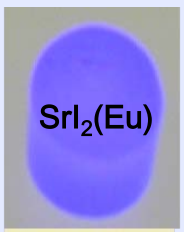




Low-temperature operation enables ultra-high energy resolution, <80 eV FWHM.

Challenge #4 Undeclared Facilities
New Tools

- Tool Kit of the Future – what would it look like?
  - New radiation detector materials

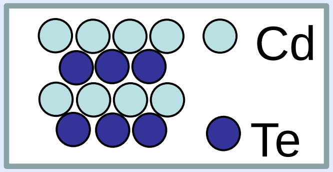


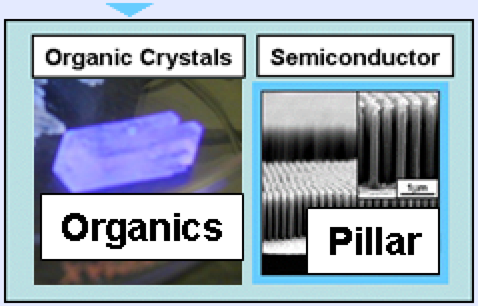
Polymers

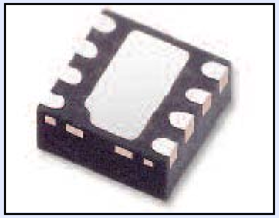
Ge detector

GaTe

CZT Contacts







Acoustic

This slide adapted from "LLNL Radiation Detector Materials Campaign," by S. Payne

The Next Generation Safeguards Inititative

- Scientists of all fields needed
  - Information analysts
  - Fuel cycle generalists and specialists
  - Technical and equipment specialists (satellite imagery, environmental sampling analysts, NDA, C/S, RM, PM)
  - IT and communication specialists
  - Systems analysts
  - Trainers
  - Project managers


YES,
WE CAN!

References

1. IAEA Safeguards Glossary
2. Safeguards Techniques and Equipment
3. IAEA R&D Programme for 2008-2009