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US Safeguards Long Term R&D

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Office of Nonproliferation Research and Verification
Defense Nuclear Nonproliferation
National Nuclear Security Administration

US DOE Support to International Safeguards

- International safeguards are a key pillar of the global nuclear nonproliferation regime.
- Through our programs, DOE/NNSA is developing the concepts, technologies, and expertise necessary to sustain the international safeguards system as it evolves to confront current and future challenges.

DOE Safeguards Technical Thrusts

Material Control and Accountability	Analytical Tools for Laboratory and Field Sample Analysis
Improve the efficiency and effectiveness of current safeguards at declared facilities	Strengthen existing safeguard measures to detect material diversion at declared facilities

- Nondestructive Analysis
- Containment and Surveillance
- Destructive Analysis
- Standards and Testing Infrastructure
- Detector Materials

DOE Safeguards Technical Thrusts (I)

Material Control and Accountability

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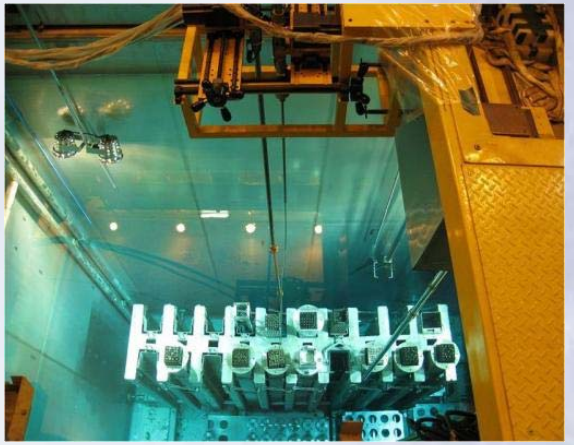
Fuel Measurements

Challenge: Independent verification and characterization at key stages of fuel cycle

- Why are we interested?
  - Assay of fresh fuel
  - Partial defect measurement
  - Reestablish continuity of knowledge
  - Fingerprinting
  - Establish/confirm input accountancy for processing
  - Establish disposition accountancy
  - Determine reactor operating history



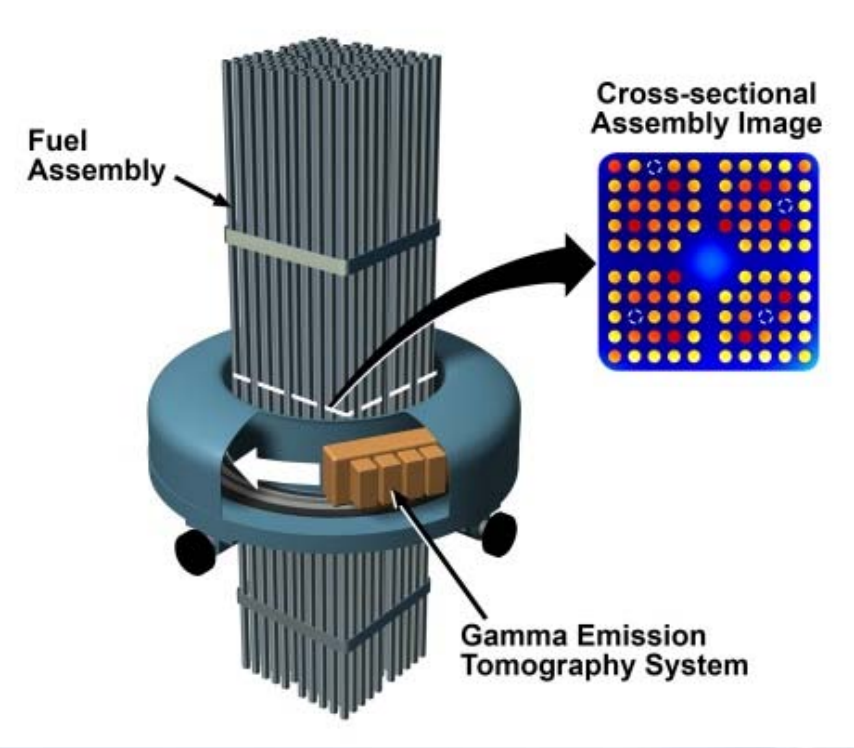
Spent fuel assemblies at KAERI

Geological repository storage

(Source: LLNL, IAEA)

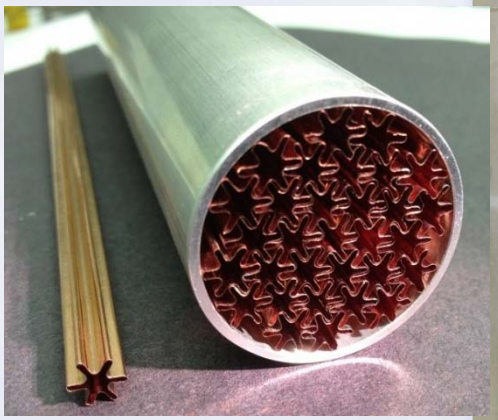
Hybrid Gamma Emission Tomography for Un-Irradiated Fuel

- Design and simulation study to determine the plausibility of measuring pin-wise
  - ^{235}U enrichment and mass
  - Plutonium isotopics and total Pu mass
- Investigate the use of active interrogation with a neutron generator to look at delayed gamma rays



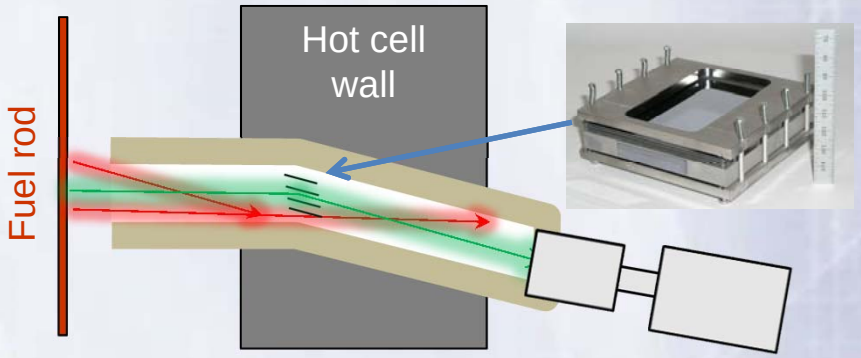
Advanced Neutron Measurements for Fresh Fuel

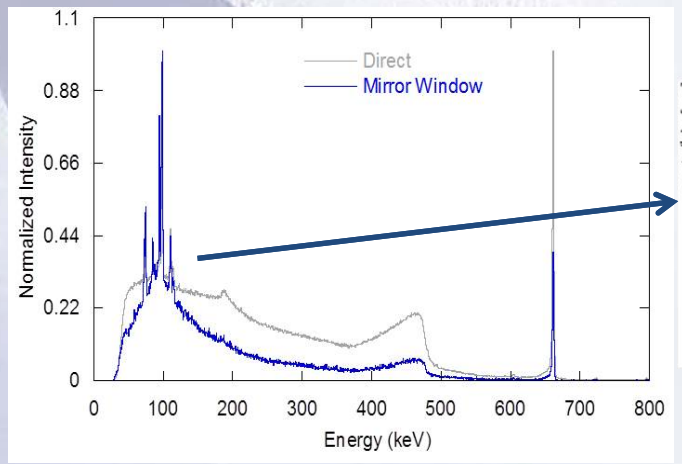
- Goal: to simulate/evaluate commercially available ^{3}He-alternative detector materials to design an instrument to accurately assay fresh fuel containing burnable poisons
  - ^{4}He detectors
  - Corrugated boron straws
  - Boron-^{3}He hybrid
  - Pulse shape discriminating plastics
- Compare capabilities relative to the Uranium Neutron Coincidence Collar (UNCL)
  - The objective is to design a new instrument that exceeds the capabilities of the current UNCL

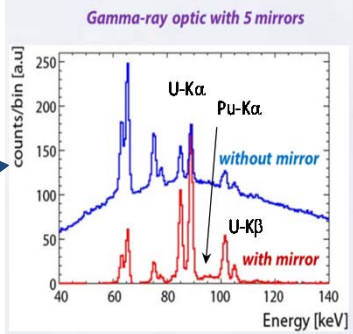


Gamma-ray Mirrors as a Band Pass Filter for Spent Fuel Assay

Direct measurement of specific lines from fissile species with hard X-ray mirrors and 2D detectors





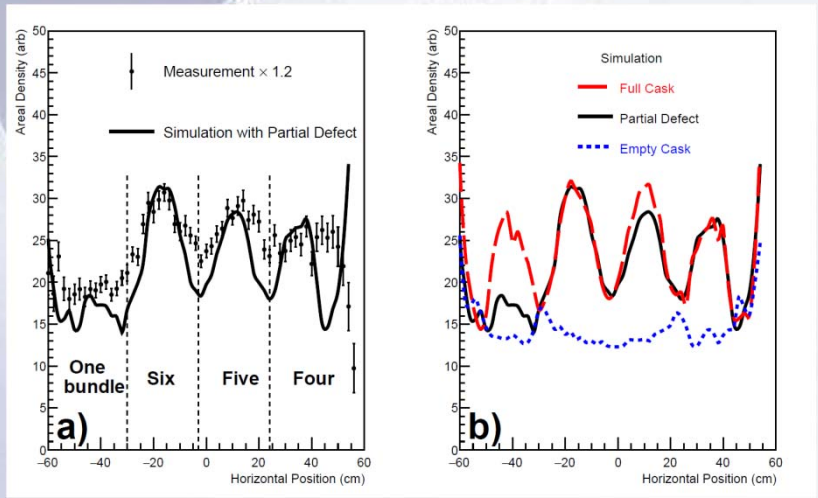


Spent fuel emission measurements show improved signal-to noise ratio for U X-rays

Demonstrated to 644 keV

Cosmic Ray Muons for Imaging Used Fuel in Dry Storage Casks

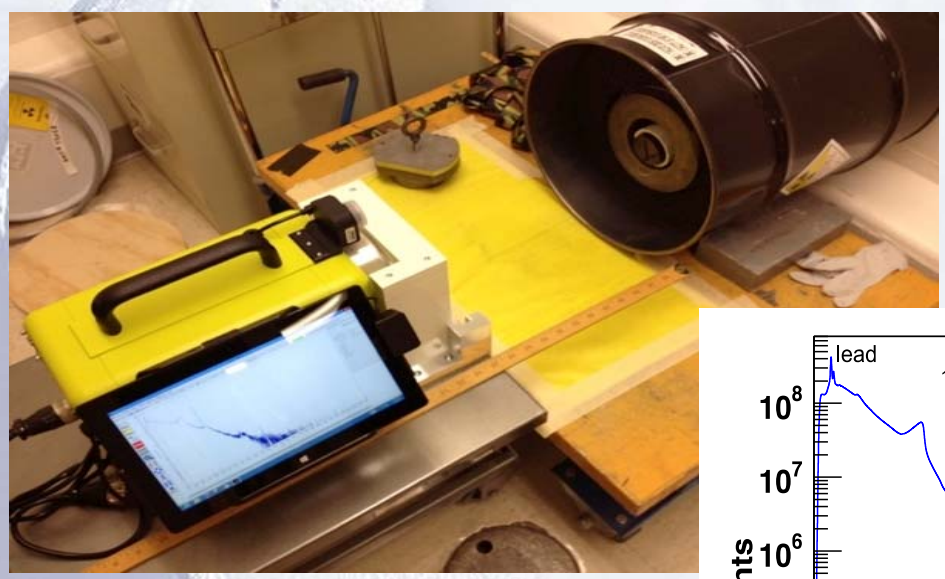
Highly energetic cosmic ray muons penetrate cask shielding providing tomographic information to determine if declared fuel bundles are present



First test of partially loaded dry storage cask

Los Alamos NATIONAL LABORATORY EST. 1943

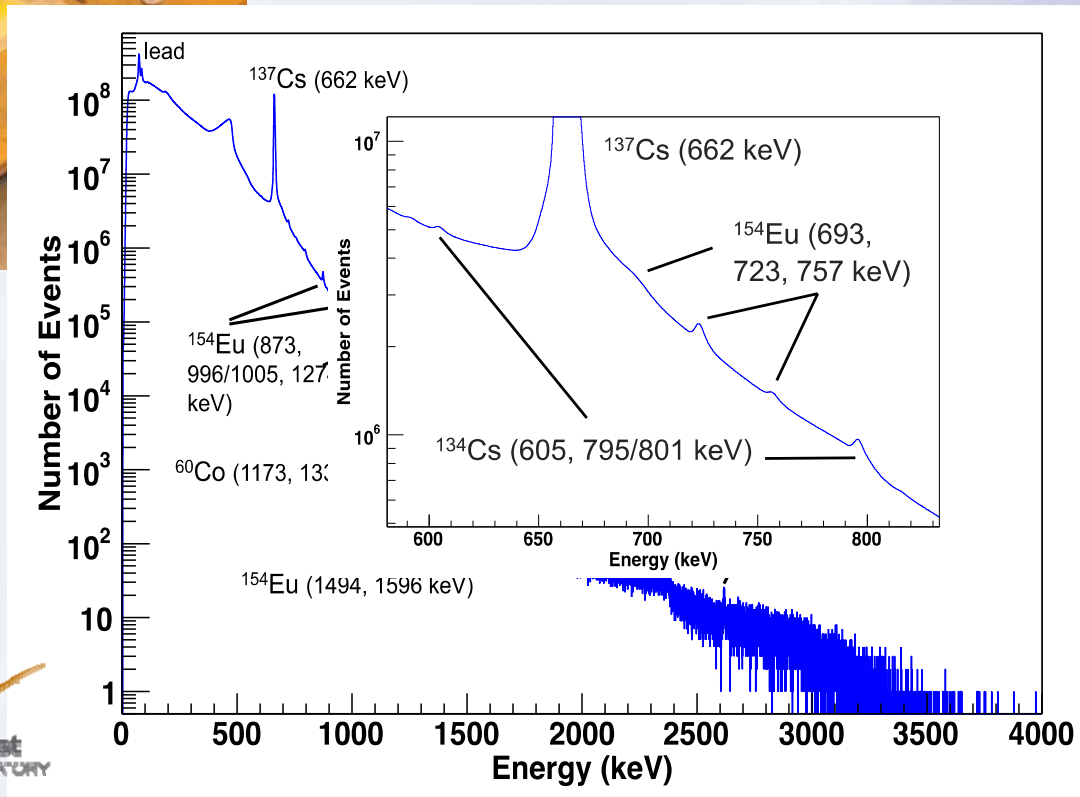
Germanium Spectroscopy System for Ultra-high Count Rates



Coaxial HPGe detector demonstrated rates of 1 Mcps input count rate and over 250 kcps to energy spectrum

Energy resolution of <4 keV FWHM at 662 keV at high rate (>650 kpcs)

Spent nuclear fuel measurement. The spectrum contains 2.4 x 10^{11} counts dominated by ^{137}Cs and U X-rays



Pacific Northwest NATIONAL LABORATORY

Uranium Enrichment Plant Verification

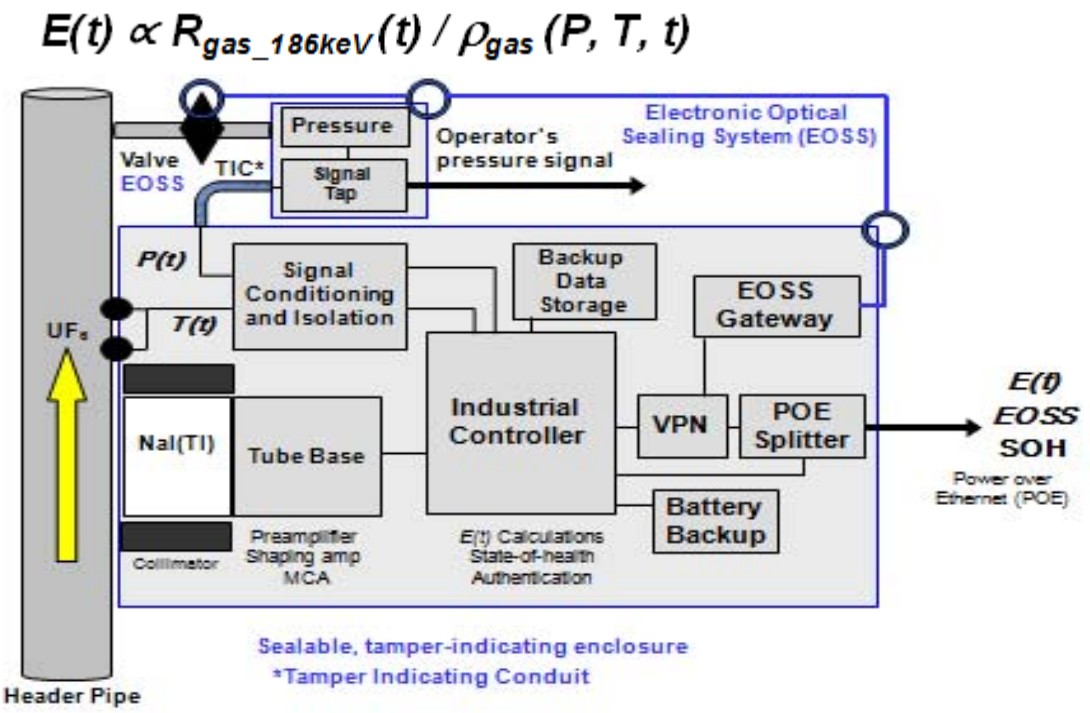
Goal: Tools and techniques to enable timely detection of HEU production in LEU enrichment facilities

(Source: IAEA)

On-Line Enrichment Monitor (IAEA MSSP project)

- Collimated NaI(Tl) detector (186 keV count rate)
- Gas pressure and temperature (gas density)
  - E(t) relative enrichment of the gas as a function of time

- Accurate enrichment monitoring of UF_6 circulated in unit header pipes of GCEPs
  - verification of the isotope mass balance
  - limit the need of destructive analysis samples.



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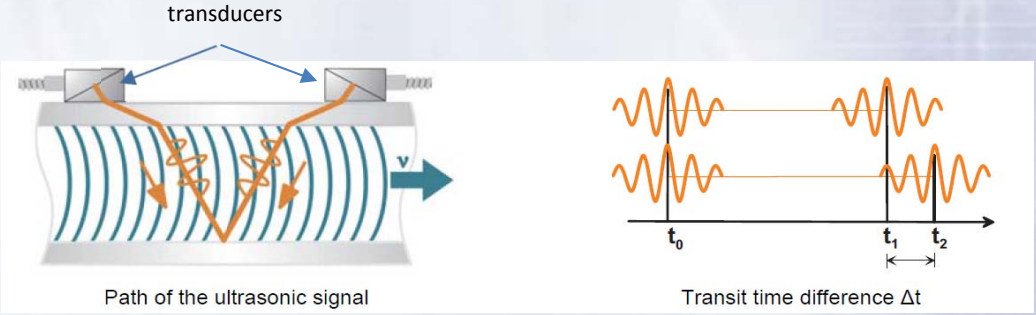
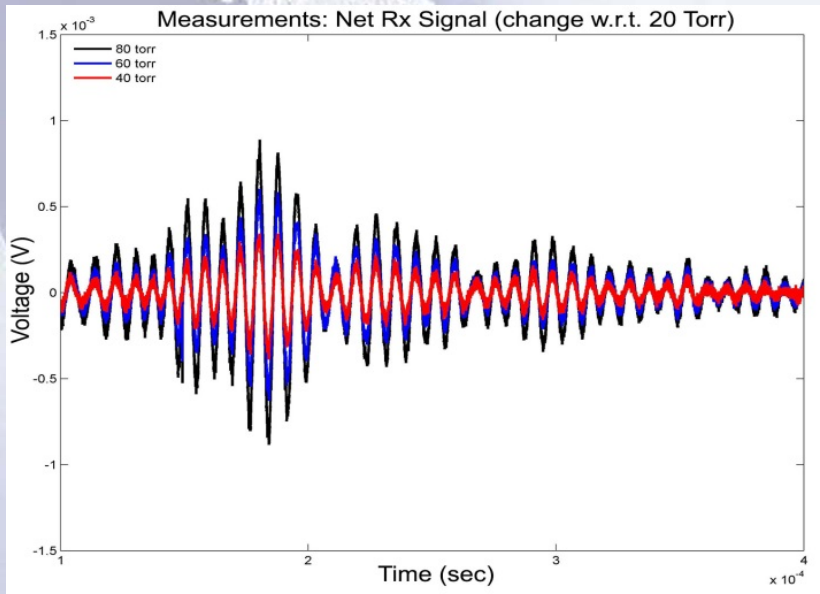
Acoustic Techniques for Monitoring Enrichment Facilities

Non-invasively measure mass flow rate of UF_6 gas





Preliminary demonstration of acoustic signal versus gas pressure

Prototype instrument will measure flow and gas density under relevant conditions

Containment and Surveillance

Continuity of knowledge systems provide confidence in item identity, integrity and health

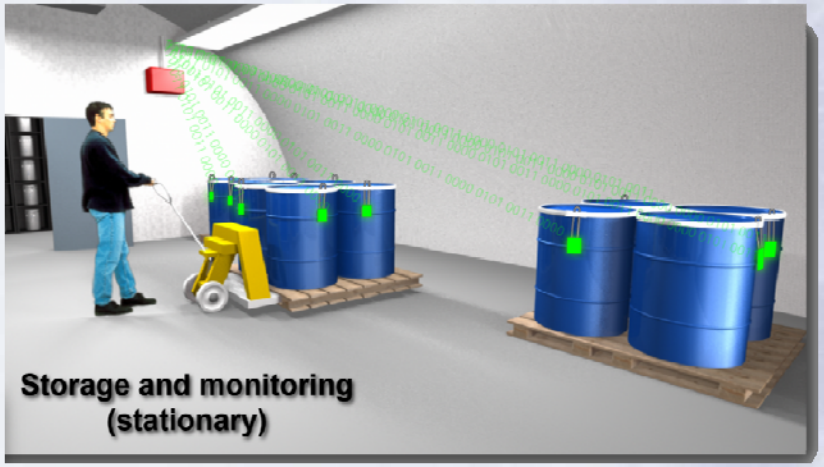
- Technologies must be tamper-resistant and tamper indicating and be able to operate in harsh physical conditions while not interfering with facility operations

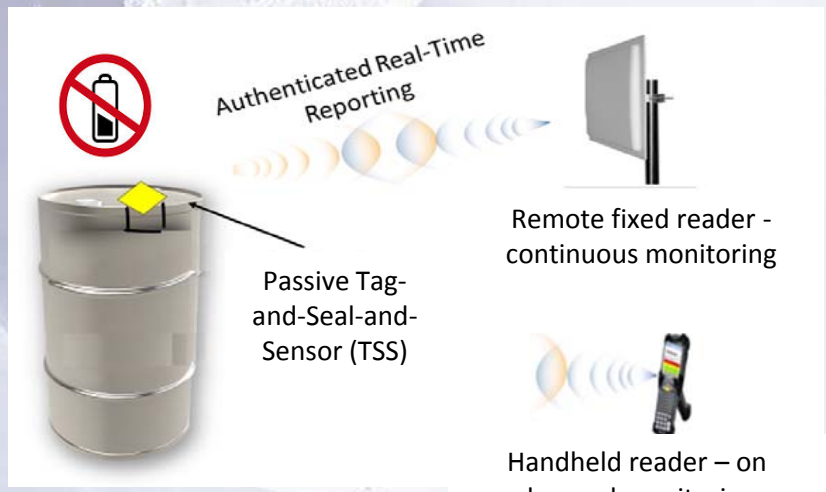
Inspector checking seals of containers containing fresh fuel (Source: IAEA)

(Source: IAEA)

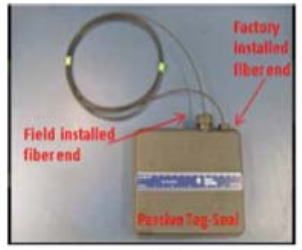
Tag-and-Seal-and-Sensor

- Secure, battery-free RF/fiber optics seal integrated with passive RF tags





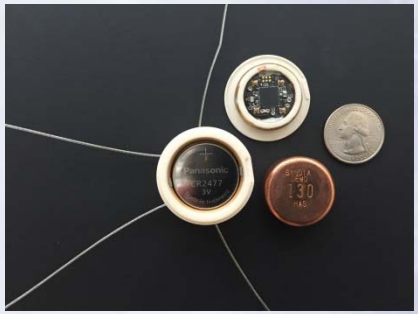
Conceptual diagram of the RFID Tag/Seal system



Passive RF tag reader Antenna

Advanced Tamper-Indicating Loop Seal

- Ceramic seal alternative to single use loop seals
- Frangible alumina with self-securing wire design
- External fluorescent tamper-indicating coating
- Electronic monitoring of unauthorized opening or penetration of seal



Sandia National Laboratories

SRNL SAVANNAH RIVER NATIONAL LABORATORY

RF Energy Harvesting for Seals

- The operating efficiency of unattended, battery-powered safeguards equipment — most notably seals — is limited by battery life.
- Wireless, radio-frequency (RF) energy harvesting is a proven, commercially available technology that extends battery life by providing consistent, predictable, and un-tethered power over distances up to 15m.
- Current work involves:
  - Selecting an appropriate energy storage mechanism for the harvested energy.
  - Characterizing energy conversion efficiency across a range of distances, environments, and antenna configurations.
  - Integrating a selected energy harvester into a battery-powered seal.
  - Evaluate energy harvesting performance in extending battery life.

DOE Safeguards Technical Thrusts (II)

Analytical Tools for Laboratory and Field Sample Analysis

Strengthen existing safeguard measures to detect material diversion at declared facilities

- Nondestructive Analysis
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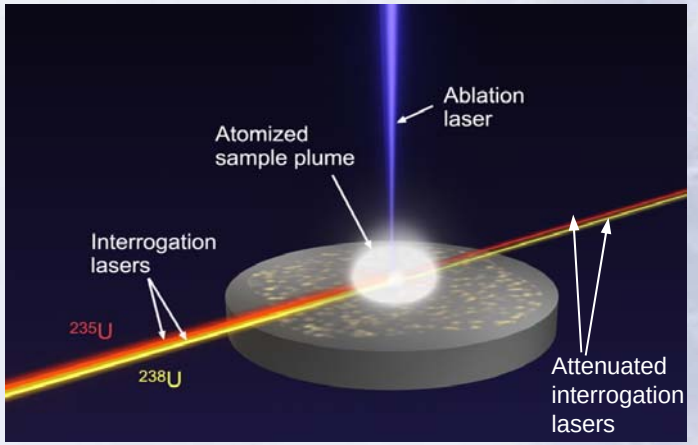
- Standards and Testing Infrastructure
- Detector Materials

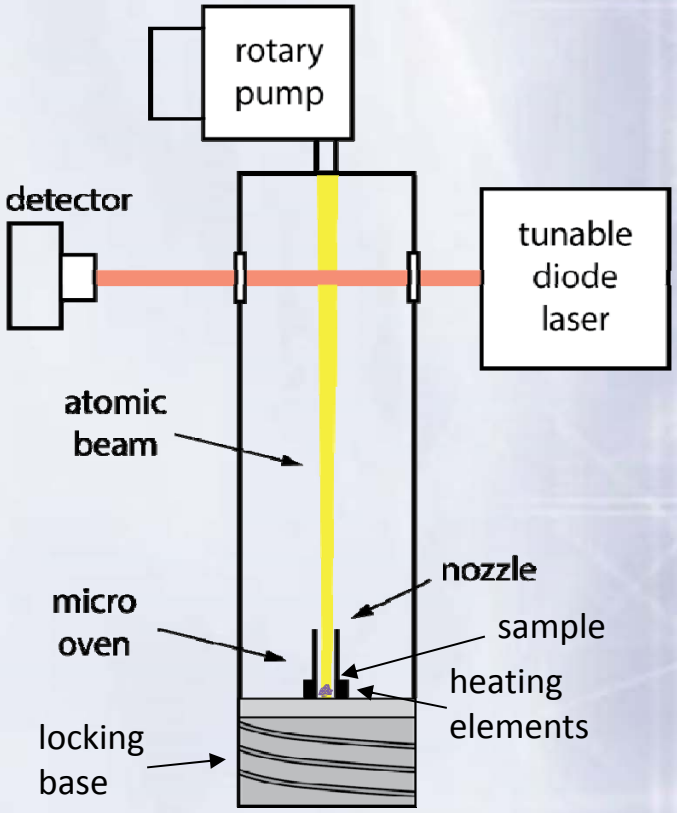
Laser Ablation Absorption Ratio Spectroscopy (LAARS) for Uranium Assay

- LAARS Isotopic Analysis
  - Short pulse-width laser atomizes UF_6 sample
  - Plume of atomic vapor formed
  - Laser diodes measure ^{235}U relative to ^{238}U
  - Motorized stage enables sample scanning
  - Single point assay every 13 ms
- Strengths
  - Potential onsite assay
  - Rapid sample throughput
  - Eliminates/reduces sample shipping
  - Requires < 1 µg uranium sample
  - Eliminates complex sample preparation
  - Optimization underway to approach international target values



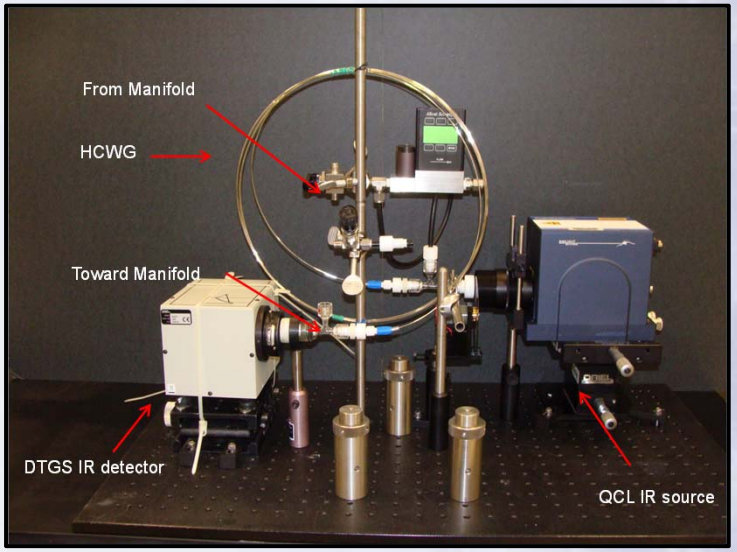
Fieldable Atomic Beam Laser Spectrometry for Isotopic Analysis

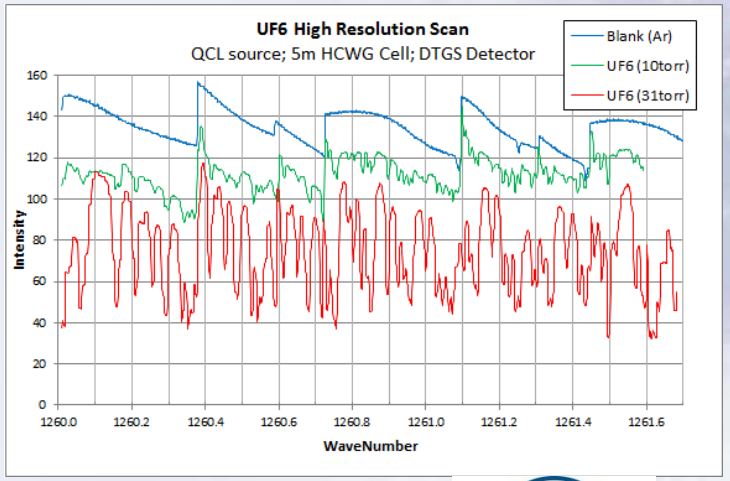
- Laser absorption spectroscopy in an atomic beam generated by a high temperature micro-oven
- Isotopic spectra obtained in a few minutes with a signal-to-noise-ratio > 100.
- No sample preparation
- Goal: uranium enrichment with precision of <10% for nanogram sample



Fieldable High Performance Infrared Spectroscopy for Ultra-low isotopic analysis of UF_6

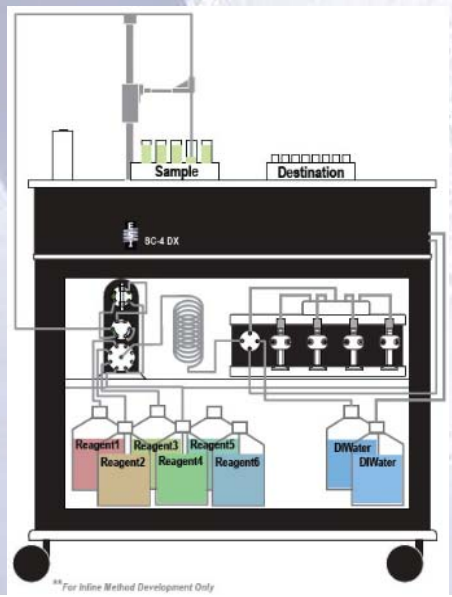
- Goal: $^{235}U/^{238}U$ isotope ratios to within $\pm$ 0.5%
  - Similar precision to Thermal Ionization Mass Spectrometer in the field
- Prototype lab system shows signal at 1256-1266 wavenumbers for UF_6

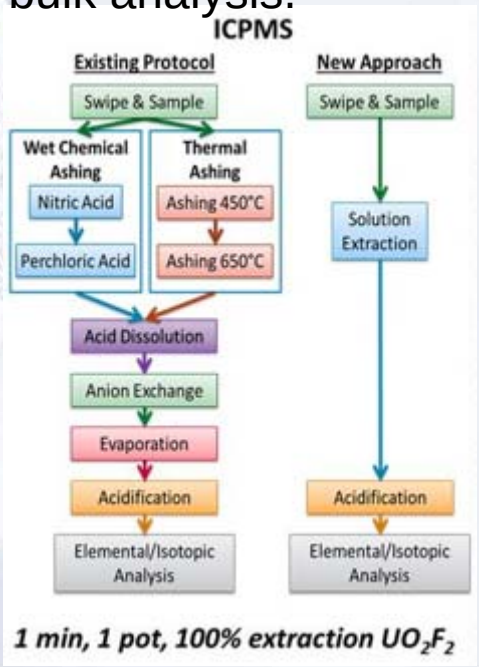


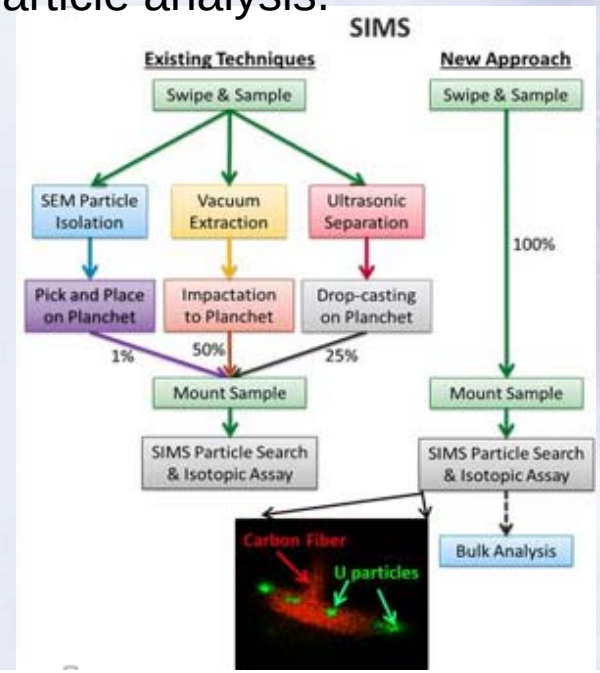


Enhancements to Mass Spectroscopy Sample Preparation

- Chemical processing and assay of the environmental samples (ES) by mass-spectrometry is slow using current methods, which can delay reporting results and lead to sample backlogs
- Enhancements being developed include:
  - Screening ES by various technologies to prioritize sample analysis.
  - Automating and streamlining sample preparation for bulk analysis.
  - Direct mounting of swipes for particle analysis.

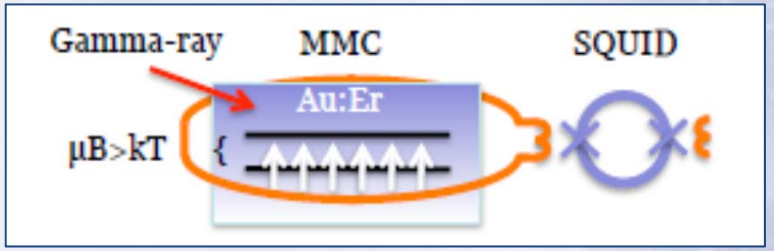


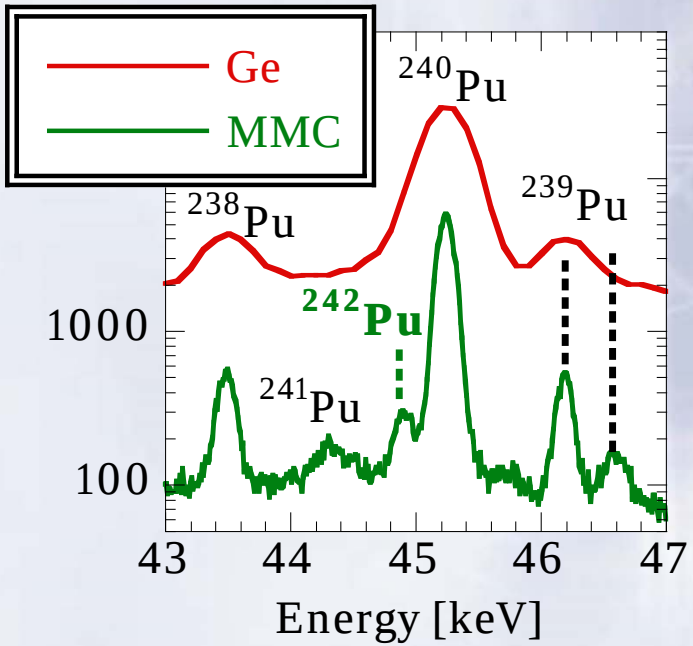




Magnetic Microcalorimeter Gamma-Ray Detector (MMC) for Ultra-High Resolution Nondestructive Analysis

- MMC measures change in magnetization of Er ions at ultra-low temperatures upon γ-absorption
- Laboratory instrument
- 10 x higher energy resolution than HPGe (<50 eV FWHM)
- Higher count rate, improved linearity, reproducibility than transition-edge sensors





Summary

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  - Material control and accountability
  - Analytical Tools for Laboratory and Field Sample Analysis