Inventory of Performance Monitoring Tools for Subsurface Monitoring of Radionuclide Contamination

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Office of Radiation and Indoor Air
Acknowledgement

- U.S. Environmental Protection Agency
- Office of Radiation and Indoor Air
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Outline

- Performance Monitoring
- Regulatory Perspective
- Laboratory Technologies
  - Beta
  - Gamma
  - Alpha
- Field Technologies
  - Beta
  - Gamma
  - Alpha
Performance Monitoring

- Loosely Defined in the Literature, and Needs Strong Clarification
- The Continuous or Periodic Measurement of the Effectiveness of Contaminant Isolation Systems Once it has been Employed
- The Term Performance Monitoring is Often Associated with the Performance of the Physical System.
- Monitoring is Used to Demonstrate the Effectiveness of Efforts to Remove, Treat or Contain Contamination
Governance, Objectives, Assessment and Tools/Technologies (G-O-A-T)
Multi-media, multi-pathways Monitoring

- **Media**
  - Soil
  - Water
  - Air

- **Pathways**
  - Groundwater
  - Ingestion
  - Surface water
  - Inhalation

<table>
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<tr>
<th><strong>Soil</strong></th>
<th><strong>Water</strong></th>
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<th><strong>Biology</strong></th>
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<td>Soil Water Tension</td>
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<td>SO₃</td>
<td>DNA/geonomic Technology</td>
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<td>Organic Carbon Content</td>
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<td>Meteorological Data</td>
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<tr>
<td>Partitioning Coefficient</td>
<td>Constituent Coefficient</td>
<td>Data</td>
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<td>Constituent Chemical and Physical Properties</td>
<td>Constituent Degradation Rate and Pathway</td>
<td>Ozone</td>
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</tr>
<tr>
<td>Constituent Degradation Rate and Pathway</td>
<td>Water balance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Environmental Pathways of Concern
Technical Approaches to Monitoring

- **Direct Monitoring**
  - Chemical Analysis
    - Groundwater Monitoring Wells
    - Lysimeters

- **Indirect Monitoring**
  - Surrogates
    - Water balance
    - Remote Sensing
Inventory of Monitoring Technologies

- Water Potential
- Water Content
- Saturated Hydraulic Conductivity
- Unsaturated Hydraulic Conductivity
- Groundwater Measurements
- Water Flux and Infiltration
- Groundwater Sampling Methods
- Remote Sensing
- Surface/Seismic
- Drilling and Solid Sampling
- Cone Penetration
- Geophysical Borehole
- Vadose Zone Soil/Solute and Gas Sampling and Monitoring Methods
- Chemical Field Screening and Analytical Methods
- **Field Survey Equipment for Radiological Contaminants**
- **Laboratory Equipment for Radiological contaminants**
Laboratory Techniques

- **Alpha**
  - Alpha Spectroscopy with multichannel Analyzer gas flow proportional counter
  - Liquid Scintillation spectrometry
  - Low resolution alpha spectrometry

- **Beta**
  - Gas flow proportional counter
  - Liquid scintillation spectrometry

- **Gamma**
  - Germanium detector with multichannel analyzer
  - Sodium iodide detector with multichannel analyzer

- **Advantages**
  - Resolution
  - Accuracy
  - Data Quality

- **Disadvantages**
  - Cost
  - Not Real Time
Field Survey Equipment for Radiological Contaminants - Alpha

- Alpha Spectroscopy
- Alpha Scintillation Survey Meter
- Alpha Track Detector
- Electret Ion Chamber
- Gas Flow Proportional Counter Field
- Long Range Alpha Detector
- Gas Flow Proportional Counter
- Liquid Scintillation Counter
Field Survey Equipment for Radiological Contaminants-Beta

- GM Survey Meter with Beta Pancake Probe
- Gas Flow Proportional Counter Field
- Gas Flow Proportional Counter (lab)
- Liquid Scintillation Counter
Field Survey Equipment for Radiological Contaminants-Gamma

- Electret Ion Chamber
- GM Survey Meter with Gamma Probe
- Handheld ion Chamber survey meter
- Handheld Pressurized Ion Chamber Survey Meter
- Geranium Detector with Multi-channel Analyzer
- Portable Germanium Multi-channel Analyzer
- Pressurized Ionization Chamber
- Sodium Iodine Survey Meter
- Field x-ray Fluorescence Spectrometer
- Thermoluminescence Dosimeter
- FIDLER
- Sodium Iodine Detector with Multi-channel Analyzer
Field Survey Equipment for Radiological Contaminants-Radon

- Activated Charcoal Adsorption
- Alpha Track Detectors
- Continuous Radon Monitoring
- Electret Ion Chamber
- Large Area Activated Charcoal Collector
Innovative Technologies

- E-Perm® Alpha Surface Monitor
- BETAScint Fiber Optic Sensor
- Online-Real Time Alpha Radiation Measurement System
- Global Positioning Radiometric Scanner
- Photodetector Fiber Optic Sensors for Soils
- Membrane Rapid Sampling Technology
- Multisensor Dig Face Characterization
- Pipeline Slurry Monitoring for Sludge
- Position Sensitive Monitoring for Flat Open Areas
- Spectral Gamma Probe
- Sectrometer Monitor for Transuranics in Glass
- Thallium Activated Sodium Iodide Detector
Next Generation Sensors-Smart Dust

- Minaturization of sensors
- Developed by DARPA and UCLA
- Sensors into measure sunlight, temperature, humidity, pH

MOTES-wireless and battery powered
Development of Remote Sensing-assisted Natural and Technological Hazards Decision Support Systems

- Savannah River Site
- Improved management of technological hazards using a remote sensing-assisted hazardous waste site monitoring
- Satellite Imagery
- New spatial decision support systems related to natural and technological hazards
- Contact: Mike Serrato
Challenges

- New Technologies are Needed for Subsurface Monitoring
- These Technologies Need to be Self Calibrating
- Both Invasive and Non-invasive
- Up to 10000 years of Monitoring
- Remote Operations
- Adaptive Management
What is the Next Steps for the Inventory?

- Benchmark Technologies
  - Data Quality
  - Repeatability
- Development of Strategies for Implementation
- Developing Protocols on What to Use, Where to Use it, and When to Use it?
Appendix
<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
<th>Application</th>
<th>Cost</th>
</tr>
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<tbody>
<tr>
<td>Alpha Spectroscopy with multi-channel Analyzer</td>
<td>Consist of alpha detector housed in light tight vacuum chamber, bias supply, amplifier, analog to digital convert, multi-channel analyzer and computer.</td>
<td>Identifies and quantifies various alpha emitters.</td>
<td>Equipment $10-100K Measurement $250-400</td>
</tr>
<tr>
<td>Liquid Scintillation spectrometry</td>
<td>Detection of light pulse by photo-multiplier tube by using a cocktail to allow the radionuclide to scintillate</td>
<td>Measuring concentrations in soil, water, air filters, and swipes.</td>
<td>Equipment $20-70K Measurement $50-200</td>
</tr>
<tr>
<td>Low resolution alpha spectrometry</td>
<td>Consist of a 2 in diameter silicon detector, small vacuum chamber, pump, multi-channel analyzer, and computer.</td>
<td>Method for measuring alpha activity in soil</td>
<td>Equipment $11K Measurement $25-100</td>
</tr>
</tbody>
</table>
# Laboratory Equipment for Radiological Contaminants-Beta

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<tr>
<td>Gas flow proportional counter</td>
<td>A detector through which P10 gas flows and which measures alpha and beta radiation. &lt; 1-10 mg/cm² window, probe face area 50-100 cm² for hand held detector up to 600 cm² if cart mounted</td>
<td>Surface scanning, surface activity measurement or field evaluation of swipes. Serves as a screen to determine if more nuclide-specific analysis are needed.</td>
<td>Equipment $4-5 K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Measurement $30-50</td>
</tr>
<tr>
<td>Liquid scintillation spectrometry</td>
<td>Detection of light pulse by photo-multiplier tube by using a cocktail to allow the radionuclide to scintillate</td>
<td>Measuring concentrations in soil, water, air filters, and swipes.</td>
<td>Equipment 20-70K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Measurement $50-200</td>
</tr>
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## Laboratory Equipment for Radiological Contaminants - Gamma

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<th>Cost</th>
</tr>
</thead>
</table>
| Germanium detector with multichannel analyzer         | Intrinsic germanium semiconductor I p- or n-type configuration and without beryllium window | Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclide in a sample | Equipment $35-150K  
Measurement $100-200 |
| Sodium iodide detector with multichannel analyzer     | Sodium iodine crystal with a large range of size and shapes connected to a photo-multiplier tube and MCA | Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclides in a sample. | Equipment $35-150K  
Measurement $100-200 |
<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
<th>Application</th>
<th>Cost</th>
<th>Remarks</th>
<th>References</th>
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</thead>
<tbody>
<tr>
<td>Activated charcoal adsorption</td>
<td>Activated charcoal is opened to the ambient air, then gamma counted on a gamma scintillator or a liquid scintillation counter</td>
<td>Measure radon concentration in indoor air</td>
<td>Equipment $10-30K</td>
<td>Detector is deployed for 2 to 7 days. LLD is 0.007 -0.04 Bq/L</td>
<td>MARSSIM, 1997</td>
</tr>
<tr>
<td>Alpha track detector</td>
<td>A small piece of special plastic or film inside a small container. Damage tracks from alpha particles are chemically etched and tracks counted.</td>
<td>Measure indoor or outdoor radon concentration in air.</td>
<td>Measurement $5-25</td>
<td>LLD is 0.04 Bq/L/d</td>
<td>MARSSIM, 1997</td>
</tr>
<tr>
<td>Continuous radon monitor</td>
<td>Air pump and scintillation cell or ionization chamber</td>
<td>Track the real time concentration of radon</td>
<td>Equipment $1-5K</td>
<td>Takes 1-4 hours for system to equilibrate before starting. LLD is 0.004-0.04 Bq/L.</td>
<td>MARSSIM, 1997</td>
</tr>
<tr>
<td>Electret Ion Chamber</td>
<td>This is a charged plastic vessel that can be opened for air to pass into</td>
<td>Measure short term or long term radon concentration in indoor</td>
<td>Rented</td>
<td>Must correct reading for gamma background. LLD = 0.007-0.02 Bq/L.</td>
<td>MARSSIM, 1997</td>
</tr>
<tr>
<td>Large Area Activated Charcoal Collector</td>
<td>A canister containing activated charcoal is twisted into the surface and left for 24 hours</td>
<td>Short term radon flux measurement</td>
<td>Equipment rented</td>
<td>LLD = 0.007 Bq/m²/s</td>
<td>MARSSIM, 1997</td>
</tr>
</tbody>
</table>
# Summary of Innovative Technologies

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<tr>
<th>Technology</th>
<th>Description</th>
<th>Contaminant</th>
<th>Demonstration Location</th>
<th>Company</th>
<th>Date</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermo Alpha Monitor (TAM) technology</td>
<td>Counts alpha emitters, such as uranium 238 and 234 and plutonium 239, in water</td>
<td>Uranium</td>
<td>Oak Ridge National Laboratory</td>
<td>Thermo Power Corporation</td>
<td>1999</td>
<td>$25,000</td>
</tr>
<tr>
<td>Global Positioning Radiometric Scanner System for Surface Soils</td>
<td>Portable sodium-iodide detector to perform real time, in situ analyses to conduct routine large area surface radiation surveys</td>
<td>Gamma</td>
<td>Idaho National Engineering and Environmental Laboratory</td>
<td>TSA Systems</td>
<td>1999</td>
<td>$57,800</td>
</tr>
<tr>
<td>Large area plastic scintillation (LAPS) detector</td>
<td>Large area plastic scintillation (LAPS) detector was used in conjunction with a global positioning system (GPS) to collect and log information about concentrations of radionuclides in soil</td>
<td>Uranium (DU) or thorium (Th)-232</td>
<td>Kirtland Air Force Base/Sandia National Laboratory in New Mexico</td>
<td></td>
<td>1999</td>
<td>$60-120 per acre</td>
</tr>
<tr>
<td>Long-term, Post-closure Radiation Monitoring System (LPRMS)</td>
<td>Gamma detection and monitors radionuclides to depths of 50 meters below ground surface. A nanoprobe, consisting of a coupled thallium-doped, sodium iodide scintillator/photomultiplier tube and a multichannel analyzer. The nanoprobe is lowered into a PVC c</td>
<td>Gamma</td>
<td>Fernald</td>
<td>McDermott Inc.</td>
<td>1998-1999</td>
<td>$200,000</td>
</tr>
<tr>
<td>Membrane Rapid Technology</td>
<td>Enmeshing sorbent, surface active particles in a web-like matrix which are formed into a membrane. Particles selectively adsorb heavy metals and radionuclides</td>
<td>Technetium, Strontium, Cesium, and lead</td>
<td>Savannah River, Paducah, West Valley</td>
<td>Empore 3M</td>
<td>1999</td>
<td>$25-35 per sample</td>
</tr>
</tbody>
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<th>Company</th>
<th>Date</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>BetaScint Fibers</td>
<td>Uses photodetectors to determine beta particle radiation in soils.</td>
<td>Strontium and Uranium</td>
<td>Oakland Operations Office Laboratory</td>
<td>BetaScint Inc.</td>
<td>1999</td>
<td>$175 per sample</td>
</tr>
<tr>
<td>Pipeline Slurry Monitors</td>
<td>Slurry monitor to measure slurry properties during pipeline transfer. The two monitors were the Endress-Hauser Promass 63M Coriolis Meter and the Lasentec M600P Analyzer.</td>
<td>Waste slurry properties, density, particle population, particle dimension</td>
<td>Oak Ridge National Laboratory</td>
<td></td>
<td>1999</td>
<td>$10,000</td>
</tr>
<tr>
<td>Position Sensitive Radiation Monitor</td>
<td>Documents radiological surveys of large, open, flat areas and smooth surfaces before, during and after decon.</td>
<td>Alpha, beta, and gamma</td>
<td>Hanford</td>
<td>SRA</td>
<td>1997</td>
<td>$50,000</td>
</tr>
<tr>
<td>Spectral Gamma Probe</td>
<td>Gamma radiation detection probe that is driven into the subsurface using a cone penetrometer.</td>
<td>Cesium 137</td>
<td>Savannah River Company</td>
<td>Savannah River Company</td>
<td>1999</td>
<td>$3500 per sample</td>
</tr>
<tr>
<td>Spectrometer Monitor</td>
<td>The Real-Time Monitor for Transuranics in Glass is a monitor that can be used to determine the concentration of certain metals in a glass stream as it flows out of a melter. The monitor is based on the detection of the spectrum of light emitted by a high-Ytterbium, a plutonium surrogate, erbium, a surrogate for Americium and Curium, and neodymium, an americium surrogate.</td>
<td></td>
<td>Savannah River Company</td>
<td>Savannah River Company</td>
<td>1997-1999</td>
<td>$165-265K</td>
</tr>
<tr>
<td>Thallium Activated Sodium Iodine Detector</td>
<td>SAMs technology to make in situ isotopic radiation measurements in paint chips and soil. The SAM Model 935 is a handheld detector that uses a thallium activated sodium iodide detector to provide isotopic analysis in the field.</td>
<td></td>
<td>Idaho National Engineering and Environmental Laboratory</td>
<td>Berkeley Nucleonics</td>
<td>2000</td>
<td>$10000</td>
</tr>
</tbody>
</table>
Alpha Spectroscopy

- **Description**
  - A system using silicon diode surface barrier detectors for alpha energy identification and quantification.

- **Application**
  - Accurately identifies and measures the activity of multiple alpha radionuclides in a thin extracted sample of soil, water or air filter.

- **Cost**
  - Equipment $10-100K
  - Measurement $250-400

- **Remarks**
  - Sample requires radiochemical separation or other preparation before counting.
Alpha Scintillation Survey Meter

- **Description**
  - <1 mg/cm² window, probe face area 50 to 100 cm²
- **Application**
  - Field measurement of presence or absence of alpha contamination or nonporous surfaces, swipes, and air filters or on irregular surfaces if the degree of surfaces shielding is known.
- **Cost**
  - Equipment $1000
  - Measurement $5
- **Remarks**
  - Minimum sensitivity is 10 cpm or 1 cpm with headphones
Alpha Track Detector

- **Description**
  - Polycarbonate plastic sheet is placed in contact with a contaminated surface and kept in place

- **Application**
  - Measures gross alpha surface contamination on surfaces and in soils activity level or the depth profile of contamination
  - Radon

- **Cost**
  - Measurement $25

- **Remarks**
  - Alpha radiation produces holes that are enlarged chemically. Density of holes gives measure of the radioactive level
Electret Ion Chamber

- **Description**
  - A charged Teflon disk in an open face ion chamber

- **Application**
  - Measures alpha or beta contamination on surfaces and in soils plus gamma radiation dose or radon concentration

- **Cost**
  - Equipment $4000-5000
  - Measurement $8-25

- **Remarks**
  - The type of radiation is determined by how the electret is employed, e.g., the unit is kept closed and bagged in plastic to measure gamma
Gas Flow Proportional Counter Field

- **Description**
  - A detector through which P10 gas flows and which measures alpha and beta radiation. < 1-10 mg/cm² window, probe face area 50-100 cm² for hand held detector up to 600 cm² if cart mounted

- **Application**
  - Surface scanning, surface activity measurement or field evaluation of swipes. Serves as a screen to determine if more nuclide-specific analysis are needed.

- **Cost**
  - Equipment $2000-4000
  - Measurement $2-10/m²

- **Remarks**
  - Natural radionuclides in samples can interfere with the detection of other contaminants
Long Range Alpha Detector

- **Description**
  - 1m x 1 m detector measures ionization inside the box. Attached to tractor for movement. Has location finder and plots graph of contamination.

- **Application**
  - Measures surface contamination or soil concentration at grid points and plots curves of constant contamination. Intended for large areas

- **Cost**
  - Equipment $25000
  - Measurement $80

- **Remarks**
  - Alpha detector limit is 20-50 dpm/100 cm² or 0.4 Bq/g
GM Survey Meter with Beta Pancake Probe

- **Description**
  - Thin 1.4 mg/cm² window detector, probe area 10-100 cm²

- **Application**
  - Surface scanning of personnel, working area, equipment, and swipes for beta contamination. Laboratory measurement of swipes when connected to a scaler.

- **Cost**
  - Equipment $400-1500
  - Measurement $5-10

- **Remarks**
  - Relatively high detection limit making it of limited value in final status survey.
Liquid Scintillation Counter

- **Description**
  - Samples are mixed with LSC cocktail and the radiation emitted causes light pulses with proportional intensity.

- **Application**
  - Laboratory analysis of alpha or beta emitters include spectrometry capability

- **Cost**
  - Equipment $20-70K
  - Measurement $50-200

- **Remarks**
  - Highly selective for alpha or beta radiation by pulse shape discrimination. Requires LSC cocktail.
Scintillation Probe

● Description
  - A large area scintillation detector suitable for measurement of beta particles and low energy gamma radiation.

● Application
  - The Model 190-100BGS is designed to measure isotopes that are typically found in hospital nuclear medicine departments, radiopharmaceutical production facilities, and environmental surveying applications where large surface area Beta/Gamma detectors are required.
GM Survey Meter with Gamma Probe

- **Description**
  - Thick walled 30 mg/cm² detector

- **Application**
  - Measure radiation levels above 0.1 mR/hr

- **Cost**
  - Equipment $400-1000
  - Measurement $5

- **Remarks**
  - Its non-linear energy response can be corrected by suing an energy compensation probe
Hand held Ion Chamber Survey Meter

- **Description**
  - Ion chamber for measuring higher radiation levels than typical background.

- **Application**
  - Measure true gamma exposure rate.

- **Cost**
  - Equipment $800-1200
  - Measurement $5

- **Remarks**
  - Not very useful for site surveys because of high detection limit
Hand Held Pressurized Ion Chamber Survey Meter

- **Description**
  - Ion chamber for measuring higher radiation levels than typical background

- **Application**
  - Measure true gamma exposure rate with more sensitivity than the unpressurized unit

- **Cost**
  - Equipment $1000-1500
  - Measurement $5

- **Remarks**
  - Not very useful for site surveys because of high detection limit
Germanium Detector With Multi-channel Analyzer

- **Description**
  - Intrinsic germanium semiconductor in p- or n-type configuration and without beryllium window

- **Application**
  - Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclide in a sample

- **Cost**
  - Equipment $35-150K
  - Measurement $100-200

- **Remarks**
  - Very sensitivity for surface soil or groundwater contamination. Is especially powerful when more than one radionuclide is present in sample
Portable Germanium Multi-channel Analyzer

- **Description**
  - A portable version of a laboratory based germanium detector and multi-channel analyzer.

- **Application**
  - Excellent during characterization through final status survey to identify and quantify the concentration of gamma ray emitting radionuclides and in situ concentration of soil and other media.

- **Cost**
  - Equipment $40K
  - Measurement $100K

- **Remarks**
  - Requires a supply of liquid nitrogen or a mechanical cooling system as well as a highly trained operator.
Pressurized Ionization Chamber

- **Description**
  - A highly accurate ionization chamber that is rugged and stable.

- **Application**
  - Excellent for measuring gamma exposure rate during site remediation

- **Cost**
  - Equipment $15-50K
  - Measurement $50-500

- **Remarks**
  - It used in conjunction with radionuclide identification equipment
Sodium Iodine Survey Meter

- **Description**
  - Detector size up to 8” x 8”. Used in micro R-meter in smaller sizes.

- **Application**
  - Measures low levels of environmental radiation.

- **Cost**
  - Equipment $2000
  - Measurement $5

- **Remarks**
  - Its energy response is not linear so it should be calibrated for the energy field it will measure.
Field x-Ray Fluorescence Spectrometer

- Description
  - Uses silicon or germanium semiconductors

- Application
  - Determining the fractional abundance of low percentage metal ions

- Cost
  - $15-75K

- Remarks
Thermoluminescence dosimeter

- **Description**
  - Crystals that are sensitive to gamma radiation

- **Application**
  - Measure cumulative radiation dose over a period of days to months

- **Cost**
  - Equipment $5-50K
  - Measurement $25-125

- **Remarks**
  - Requires special calibration to achieve high accuracy and reproducibility
FIDLER

- **Description**
  - Field Instrument for Detection of Low Energy Radiation
  - Thin NaI and CsI crystals are used

- **Application**
  - Scanning of gamma/X radiation from plutonium and americium

- **Cost**
  - Equipment $6-7K
  - Measurement $10-20

- **Remarks**