JAEA- IAEA Workshop on Advanced Safeguards Technology for the Future Nuclear Fuel Cycle

(13-16 November 2007)

Novel Technologies for IAEA Safeguards

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Department of Safeguards

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IAEA Strategic Objectives 2006 – 2011

Include the following general goals:

- **Enhance detection capabilities**
- **Develop new, or improve, safeguards approaches and techniques**
- **Acquire more effective verification equipment**

IAEA Strategic Objectives 2006 – 2011

With the following specific activity:

- **Research and develop *novel* technologies for detection of undeclared activities, facilities and materials**
    - **Internal resources and expertise**
    - **Member State Support Programmes**

Verification & Detection Technologies

"New"

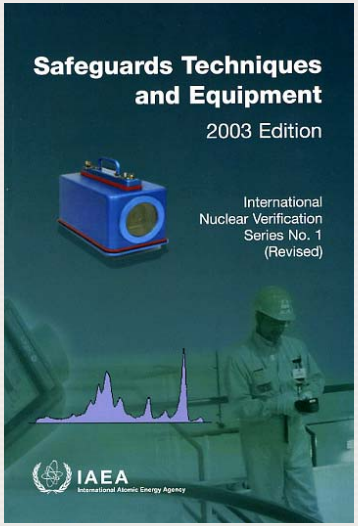
Instruments and methodologies already in use by the Agency for safeguards applications

"Novel"

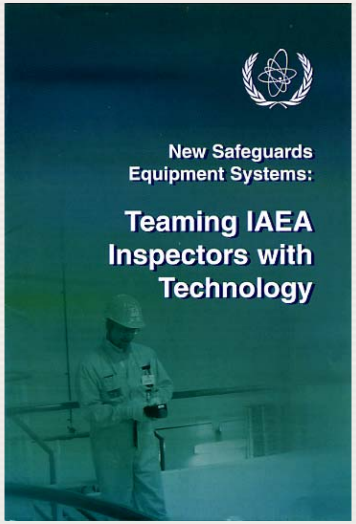
Instruments and methodologies not applied previously to safeguards applications

“New” Technologies

Find out more at:



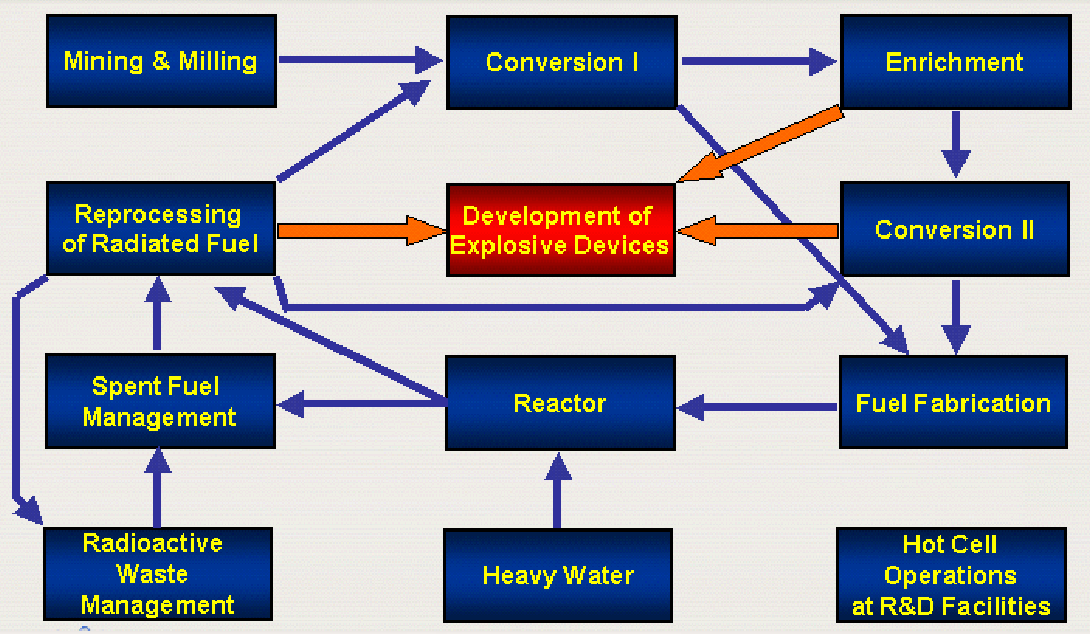
www.iaea.org/Publications/Booklets/sv.html



www.iaea.org/worldatom/Programmes/Safeguards/Teaming_Inspectors/

Novel Detection Technologies

Nuclear Fuel Cycle (NFC)



Nuclear Fuel Cycle (NFC)

Strategy:

Review nuclear fuel-cycle processes, identifying the most safeguards-useful activity *indicators* and emanating *signatures*

Novel Detection Technologies

NFC Indicators / Signatures

"Indicators"

Entities that go into making the process operative

Examples:

- Resources
- Required materials
- Facility design
- Related R&D
- …

Nuclear Fuel Cycle Process

NFC Process

e.g. Enrichment
Reprocessing
Conversion
Reactor

"Signatures"

Entities produced by the process when it is in operation

Examples:

- Produced materials
- Process by-products
- Energy emanations
- …
- …

Novel Detection Technologies

NFC Indicators / Signatures

Strategy (cont.)

- Review *indicators* and compile *signatures* for all critical nuclear fuel cycle (NFC) activities
- Identify those with the most promise for detection (at a distance)
- Perform a gap analysis
- Confirm need
- Define technical & procedural requirements
- Initiate necessary R&D and field tests

Novel Detection Technologies

NFC Indicators / Signatures

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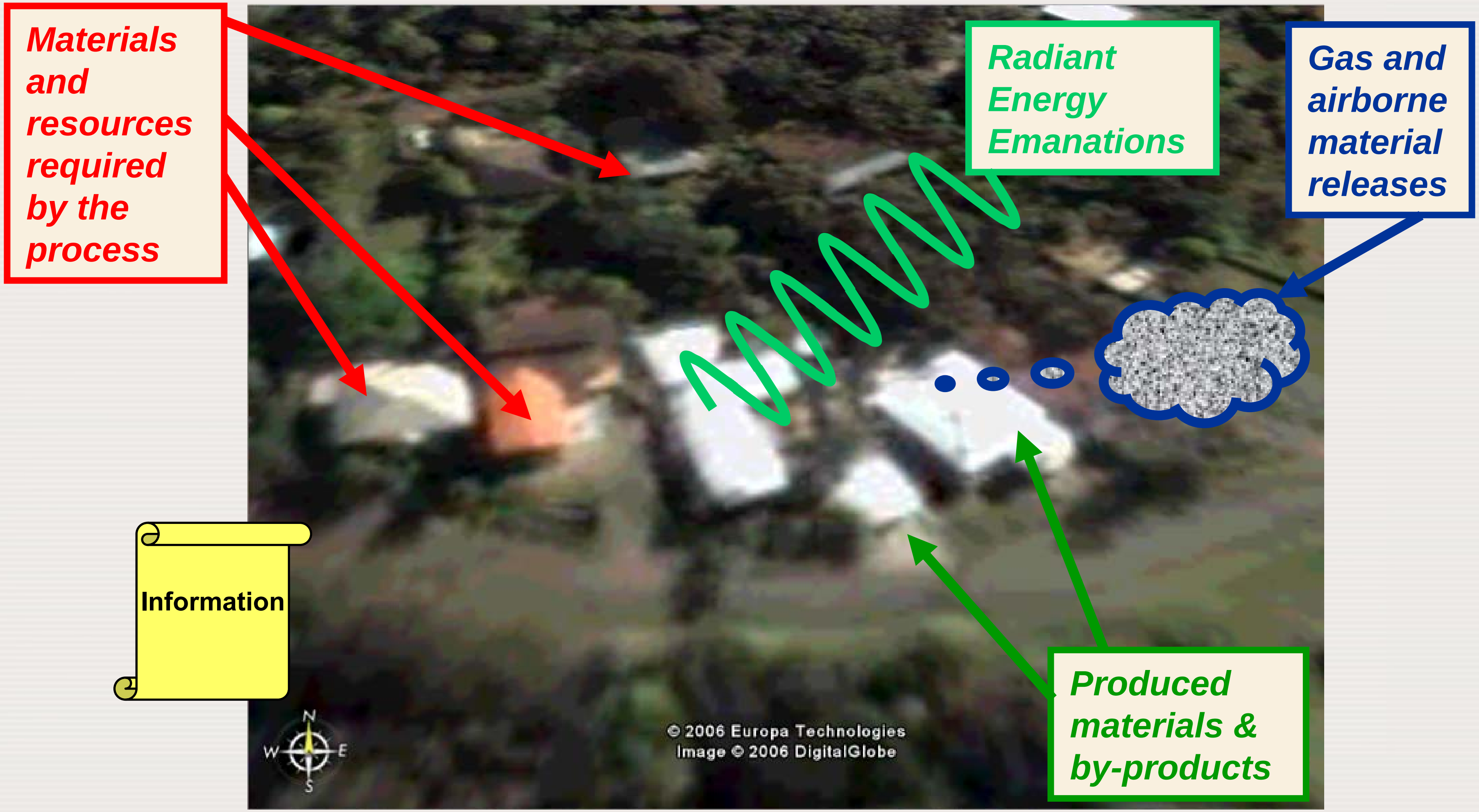
Novel Detection Technologies

Source Location



Need to define specific, useful process indicators & signatures that can travel from the source location!

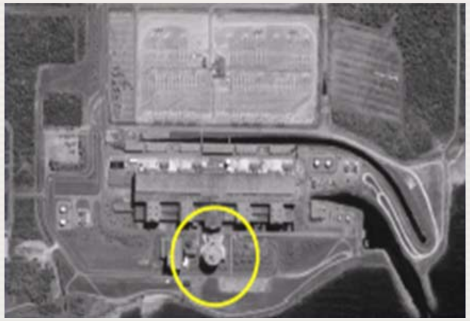
Novel Technologies

Target applications

Verification

Complementary access
& forensics

Detection



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Novel Technologies

Target example applications:

Verification	**Neutron imaging** **Tuneable diode laser spectroscopy (TDLS)** **Magnetic resonance for flow & enrich. mon.** **Antineutrino detection**
Complementary access & forensics	**Laser spectrometry techniques (LIBS, LALIF)** **Optically stimulated luminescence (OSL)** **Solid state chemical sensors** **Ground penetrating radar (GPR)**
Detection	**Mobile laser spectroscopy** **Mobile atmospheric gas sampling & analysis** **Energy emission detection and analysis**

Novel Verification Technologies

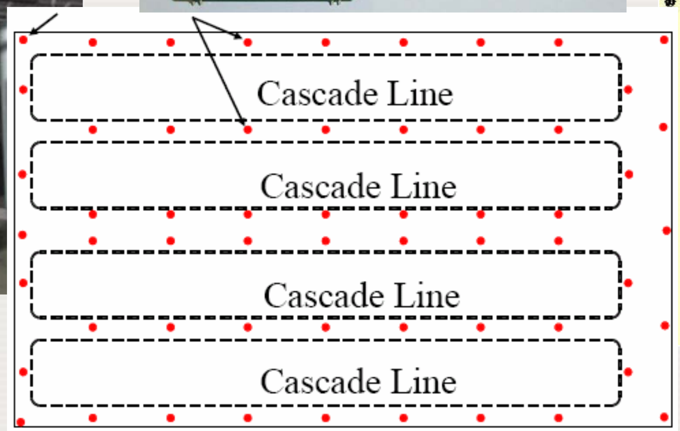
Neutron Detection Matrix & Imaging

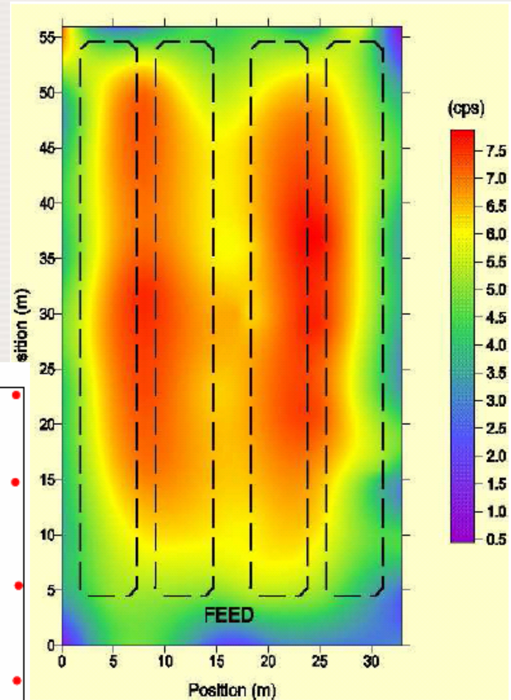
Source: LANL

Need: **To detect the presence (or to verify the absence) of enrichment above declared levels in a declared LEU GCEP** (e.g countering undeclared production or embedded micro-cascade scenarios)

Novel features: **Low-power, self-organizing network of neutron detectors**

Description:





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New/Novel Technologies

Tuneable Diode Laser Spectroscopy (TDLS)

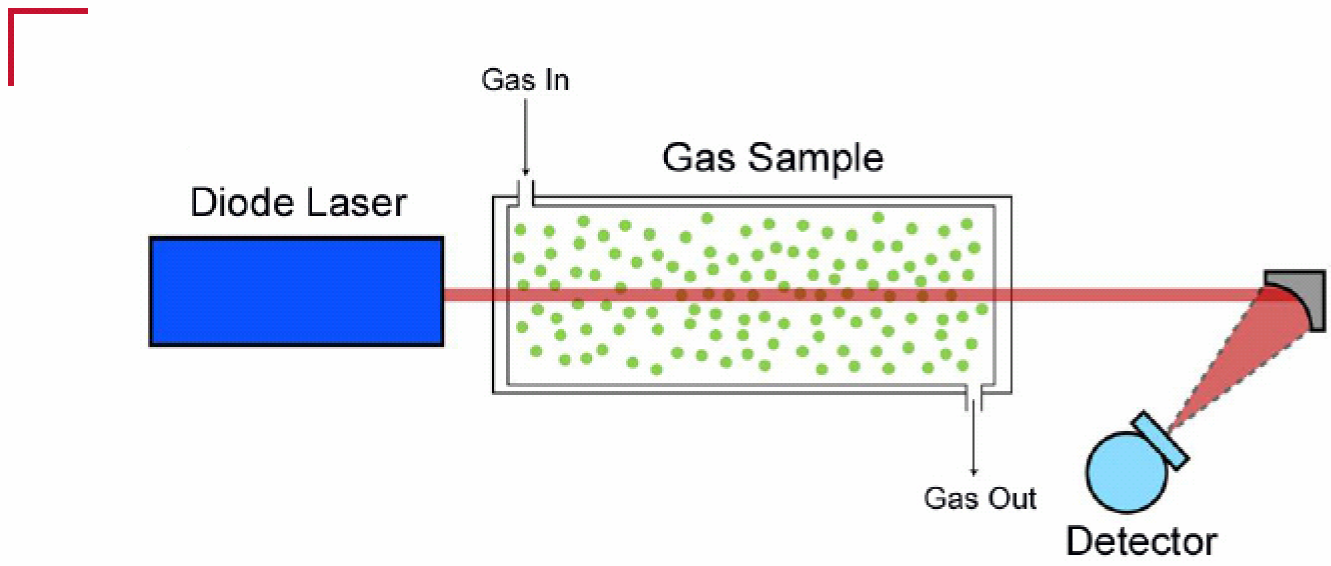
Source: Canberra

Need:

i) To monitor uranium enrichment in UF^6 continuously
(- based on precise specific isotopic species excitation)

ii) Non-intrusive, real time method to detect the presence of HF/UF6 in the vicinity of a suspected facility (***Novel!***)

Simplified TDLS Detection Process

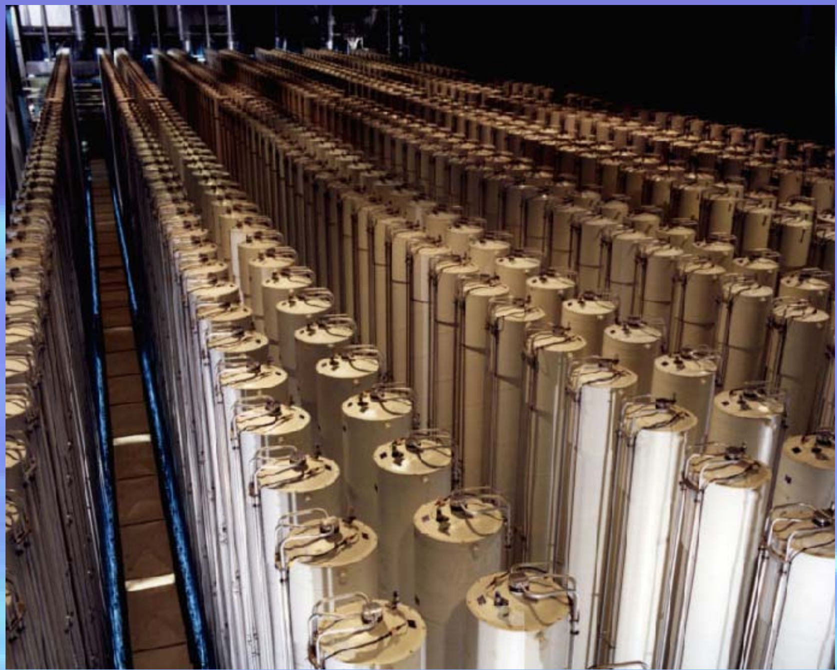


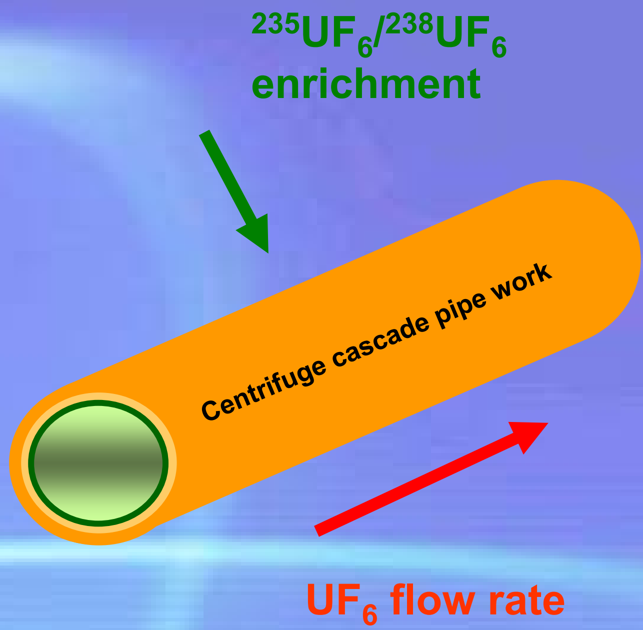
Novel Verification Technologies

Non-intrusive Enrichment & Flow Monitor based on Magnetic Resonance

Need: Non-intrusive enrichment and flow monitoring for a gas centrifuge facility

Determining UF_6 enrichment and flow without penetrating cascade pipe-work





Novel Verification Technologies

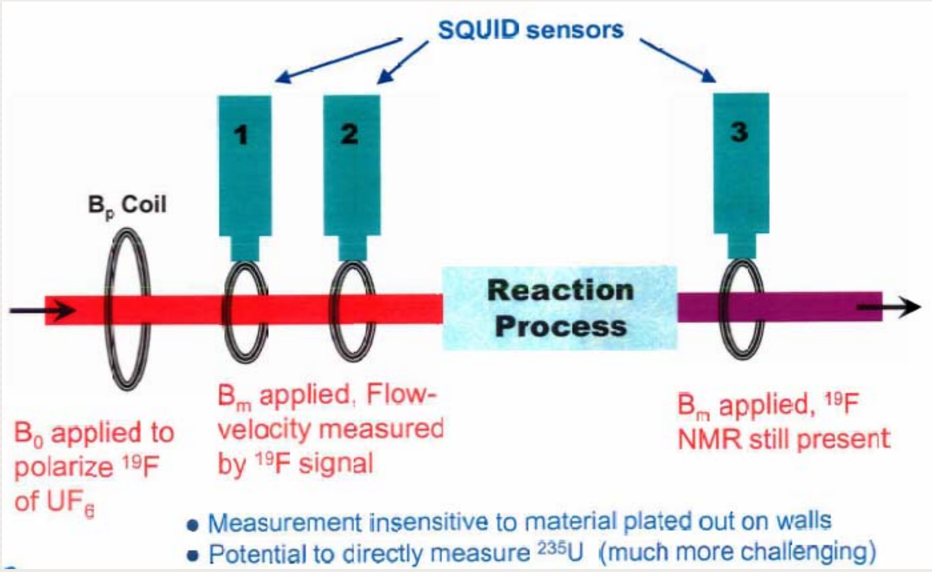
Source: LANL

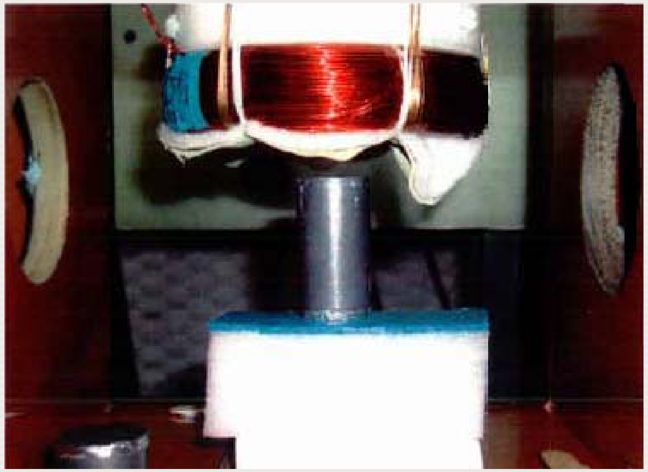
Non-intrusive Enrichment & Flow Monitor based on Magnetic Resonance

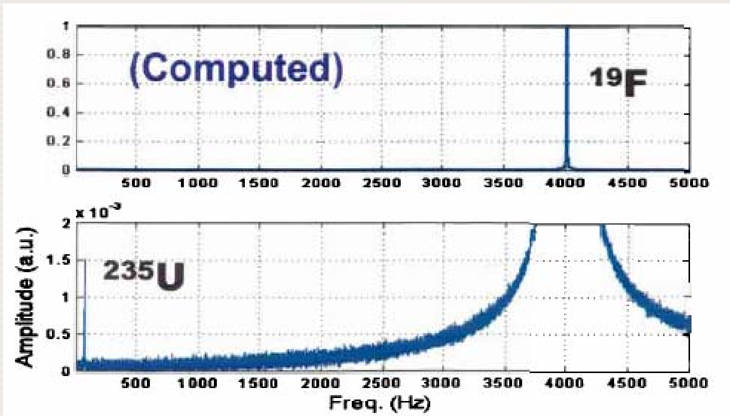
Novel features: Measures both enrichment and material flow rate without penetrating cascade pipe-work

Relatively low magnetic field requirement

Description:







Remark(s): Initial work on surrogate materials and studies, using uranium, look promising.

Novel Verification Technologies

Anti-neutrino Detectors for Reactor Monitoring   Source: LLNL/SNL

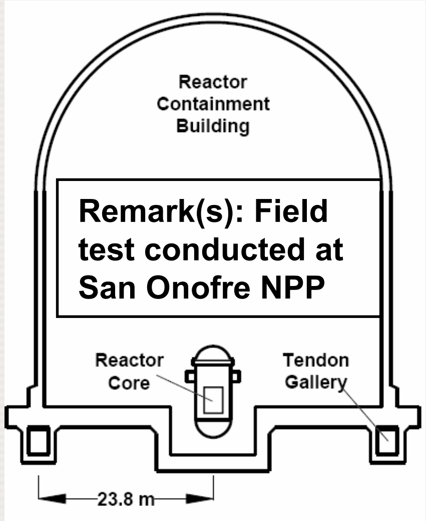
Need: Monitor the core operating conditions of a nuclear reactor (power)

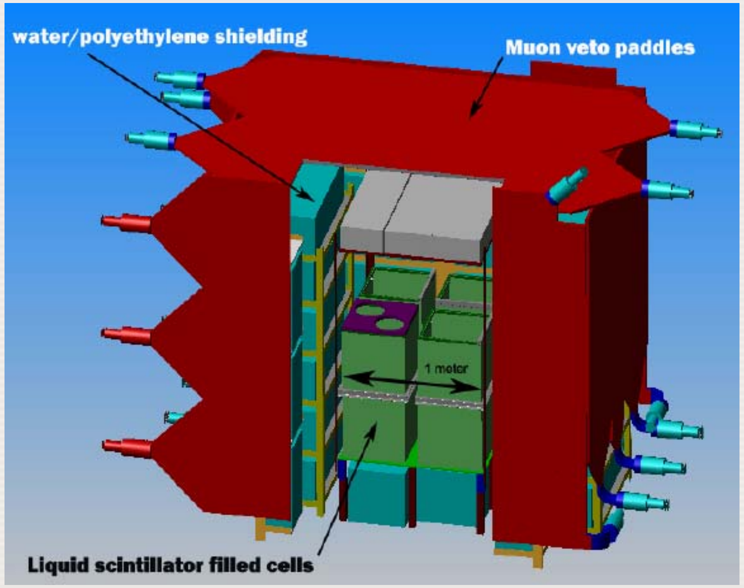
Novel features: Tracks the core operating conditions directly

Unattended continuous monitoring – rel. "non-intrusive"

Self-calibrating, & claimed low capital & maintenance costs

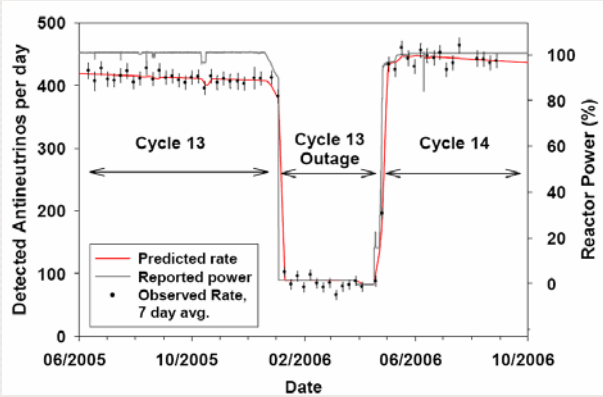
Description:





Remark(s):
Current "footprint" = 2.5 x 3 m
Projected "footprint" = 1.25 x 1.25 m

For research reactor monitoring?



Currently operational:
4 cells with 640 kg of scintillator;
0.5 m thick hermetic water shield
Muon veto system (plastic scintillator)

Novel Technologies

Target example applications:

Verification	Neutron imaging Tuneable diode laser spectroscopy (TDLS) Magnetic resonance for flow & enrich. mon. Antineutrino detection
Complementary access & forensics	**Laser spectrometry techniques (LIBS, LALIF)*** **Optically stimulated luminescence (OSL)** **Solid state chemical sensors** **Ground penetrating radar (GPR)**
Detection	Mobile laser spectroscopy Mobile atmospheric gas sampling & analysis Energy emission detection and analysis

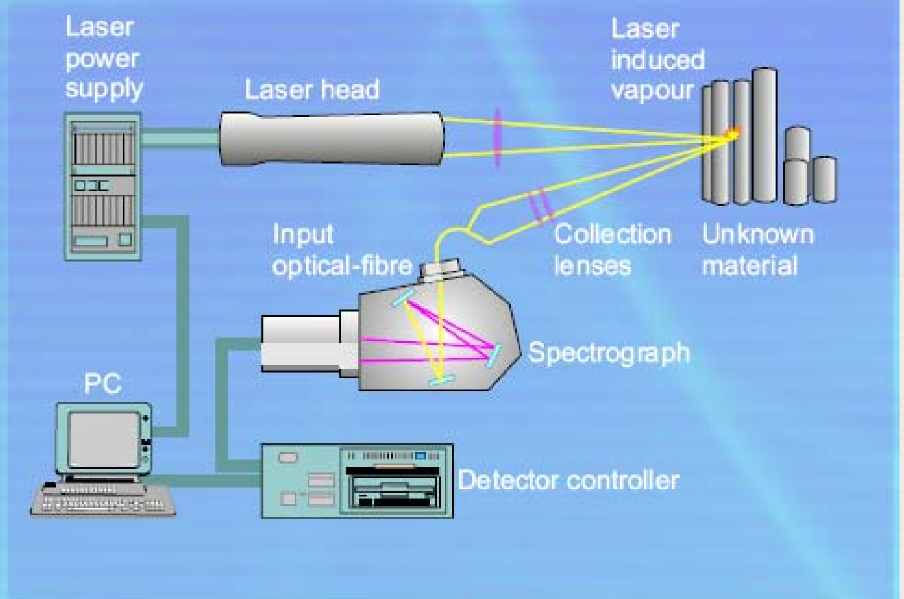
*LIBS = Laser-induced breakdown spectroscopy
LALIF = Laser ablation / laser-induced fluorescence

Novel CA & Forensics Technologies

Laser-Induced Breakdown Spectroscopy (LIBS)

Source: CSSP

Determining the nature and history of compounds and elements by on-site sampling and analysis using laser induced breakdown spectroscopy (LIBS)



1 A trained inspector operates the LIBS low power laser (λ) and vaporises a microscopic amount of material.

2 The resulting vapour is analysed by a second spectrometric laser (λ).

3 The resulting vapour spectra is scanned and its spectra captured.

4 The resulting vapour spectra is compared to a library of known spectra to determine material composition.

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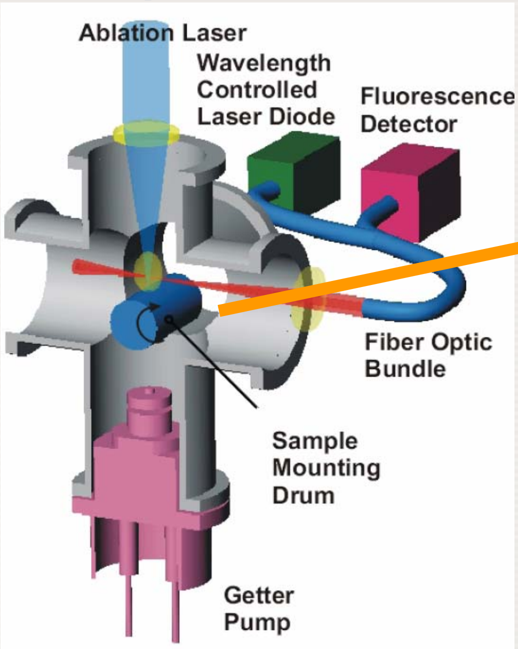
Novel CA & Forensics Technologies

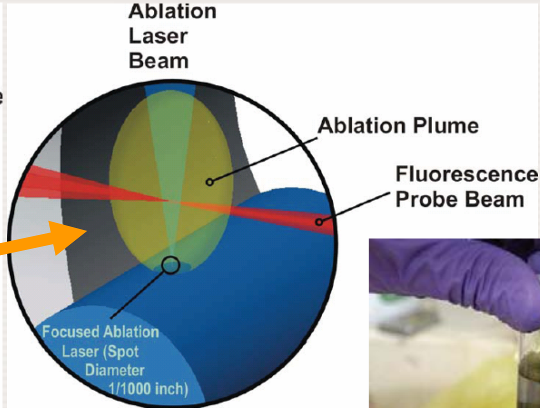
Laser Ablation / Laser-Induced Fluorescence (LALIF) Source: PNNL

Need: More rapid, on-site material analysis for the detection of undeclared enrichment, or reprocessing activities

Novel features:
- Tuneable for $^{235}U/^{238}U$, and other elements & isotopes
- Can easily detect 10µm particles (nanograms)
- Suggested method for pre-screening ES on-site

Description:





Remark(s): Technique is orders of magnitude less sensitive than NWAL route. However, it does provide other benefits, including on-site detection of ^{236}U.

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Novel CA & Forensics Technologies

Optically Stimulated Luminescence in Forensics (OSL)

Source: CSSP

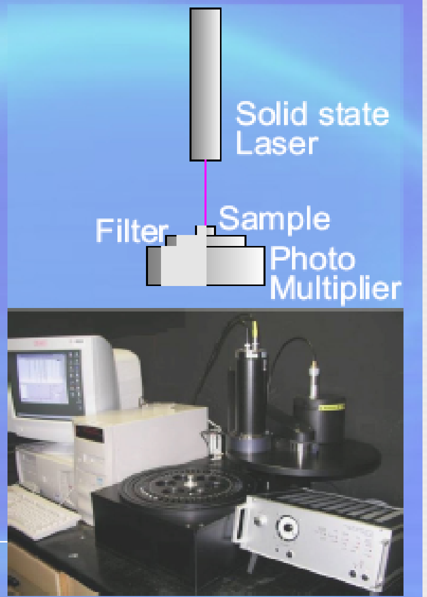
Need: **Method to detect if a suspected location has been used for the storage or use of nuclear materials**

Determining past storage locations of radiological material by measuring the radiation-induced signature, retained in many common building materials, by optical stimulation luminescence (OSL)

1 Stored radioactive material activates surrounding building materials.

2 Materials subsequently removed (leaving behind a nuclear signature.

3 IAEA inspector collects samples of the surrounding building materials.



4 Samples analysed for residual nuclear activation, indicating the previous presence of stored nuclear materials.

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Novel CA & Forensics Technologies

Solid-State Chemical Sensors

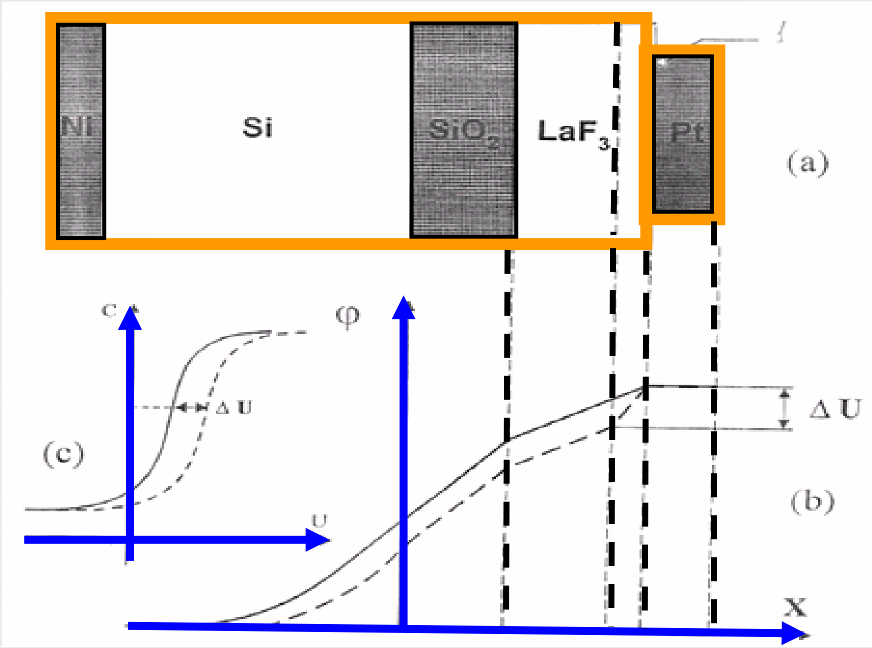
Source: SNL/RF MSSP

Need: To detect specific chemical compounds associated with NFC processes

Description:

Sandia's µChemLab™ BD (bio-detection) unit has detected seven different forms of the bio-toxin ricin successfully.

Photo by Bud Pelletier.



Proposed solid-state sensor for the detection of fluorine and HF, produced by the release of UF_6 from nuclear processes.

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Novel Verification Technologies

Ground Penetrating Radar (GPR)

Need: **Verification of declared underground movements of Safeguarded items**
Detection of undeclared underground facilities

Techniques include:

- **Ground penetrating radar** (HF centimetres of penetration – VHF metres of penetration)
- **Acoustic sonar** (either from a sound source, a pneumatic hammer or controlled explosive)
- **Passive magnetic mapping**
- **Resistance mapping**
- **Magneto-telluric (MT), with either natural (lightning strikes) or controlled sources** (kilometres)
- **Gravity anomaly measurements**
- **Terahertz imaging** (tens of centimetres)

Remark(s): **(i) Different techniques offer different levels of ground penetration and object resolution**
(ii) The Agency has established the Application of Safeguards to Geological Repositories (ASTOR) group of experts to advise on a future integrated safeguards approach for geological sites.

Novel Technologies

Target example applications:

Verification	Neutron imaging Tuneable diode laser spectroscopy (TDLS) Magnetic resonance for flow & enrich. mon. Antineutrino detection
Complementary access & forensics	Laser spectrometry techniques (LIBS, LALIF) Optically stimulated luminescence (OSL) Solid state chemical sensors Ground penetrating radar (GPR)
Detection	**Mobile laser spectroscopy** **Mobile atmospheric gas sampling & analysis** **Energy emission detection and analysis**

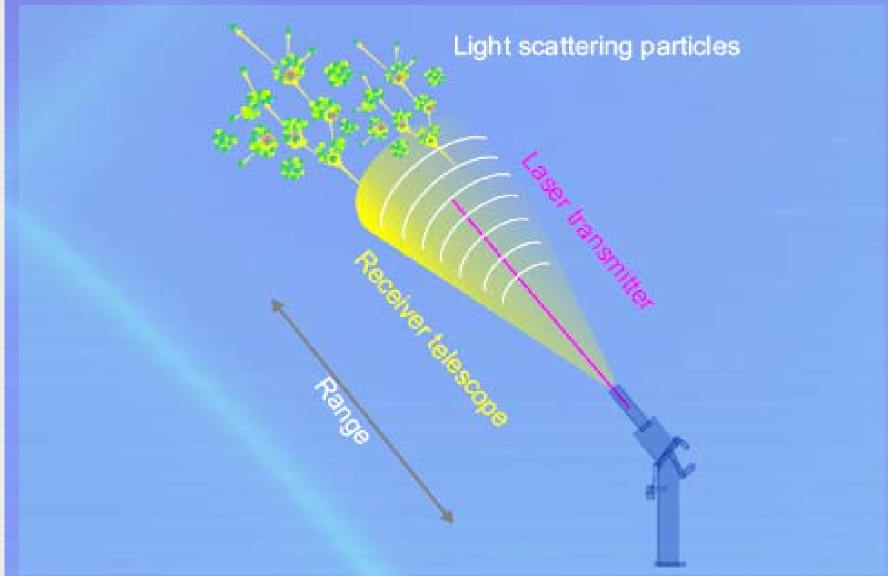
Novel Detection Technologies

Source: RF MSSP

Light detection and ranging (LIDAR)

Need: To detect undeclared nuclear facilities and activities

Detecting the presence and nature of nuclear process activities at suspected nuclear locations using light detection and ranging (LIDAR)



1 A mobile LIDAR laboratory travels to the vicinity of a suspected location.

2 A laser, tuneable to precise wavelengths, selectively stimulates specific airborne molecules that emanate as gaseous compounds from nuclear processes.

3 A light sensitive telescope scans the stimulated atmosphere, detecting the presence, or absence of the stimulated signature molecules.

4 The returned light from the atmosphere is analysed, identifying the compound type and the location of its source.

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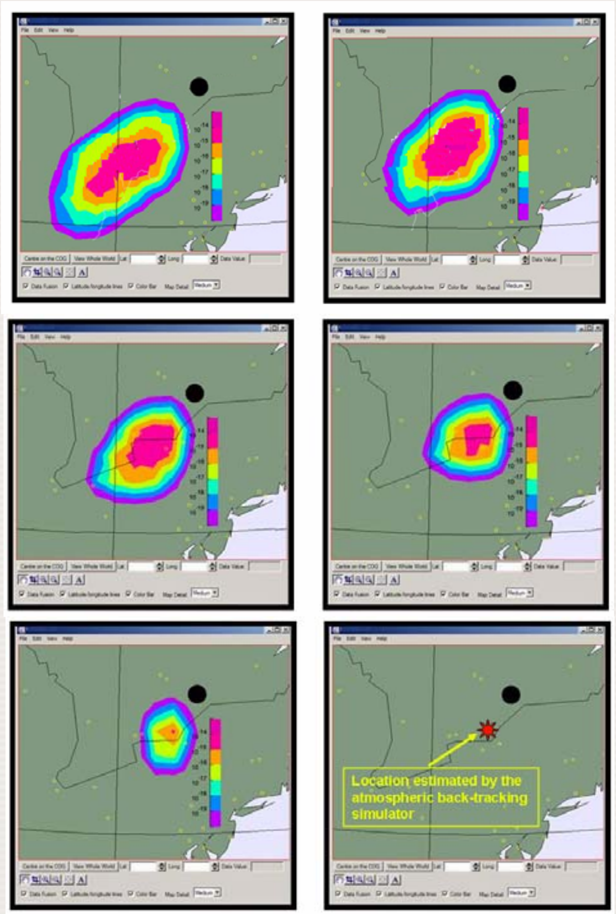
Novel Detection Technologies

Source: GER MSSP

Sampling and analysis of atmospheric gases

Need: To detect undeclared nuclear facilities and activities



Task underway to assessment the technique for safeguards applications, commencing with:

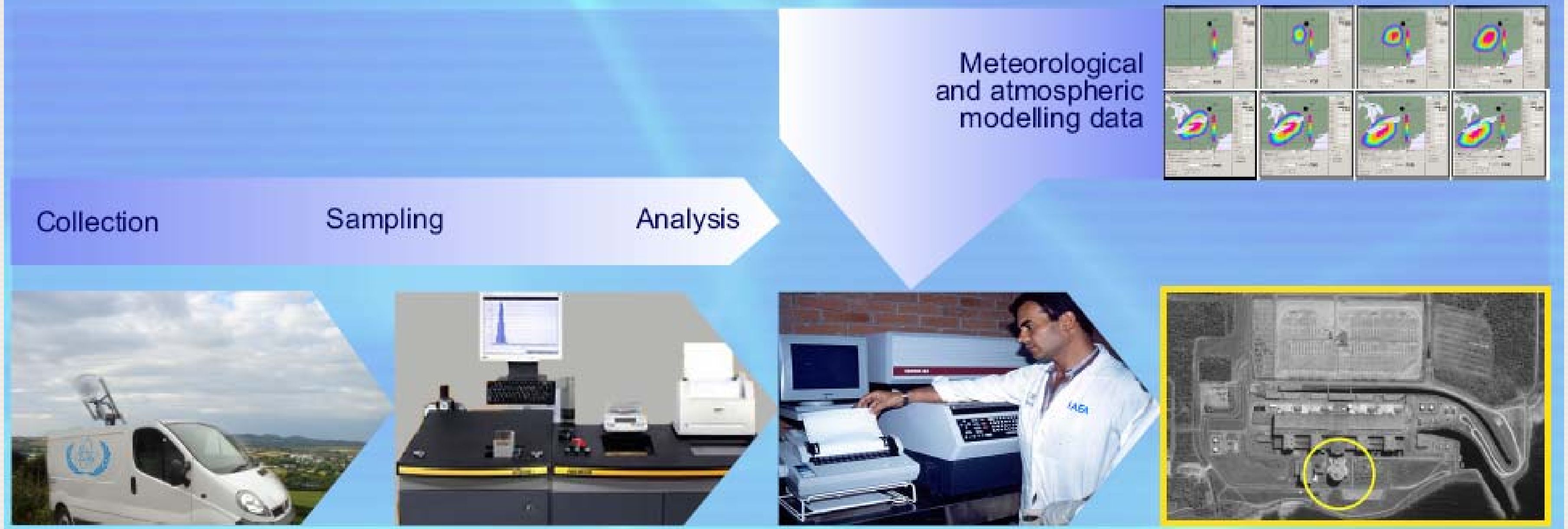
- Development of appropriate safeguards relevant scenarios
- Simulation exercises, and
- Cost-benefit analysis of the technique compared to current practices

Novel Detection Technologies

Sampling and analysis of atmospheric gases

Description:

Sampling and analysing atmospheric gasses to determine the existence and locality of a nuclear process



1 A mobile laboratory samples and concentrates atmospheric-borne pollutants. Local meteorological conditions and the GPS location are also recorded.

2 Field samples are brought to a field laboratory for preparation, analysis and measurement.

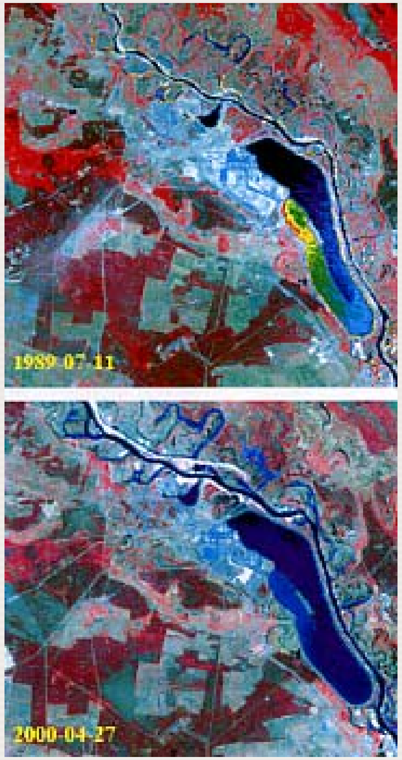
3 Measurement data is combined with meteorological data and suitable atmospheric modelling to provide an estimate of the source direction.

4 The airborne material is identified and the probable location of the source is estimated.

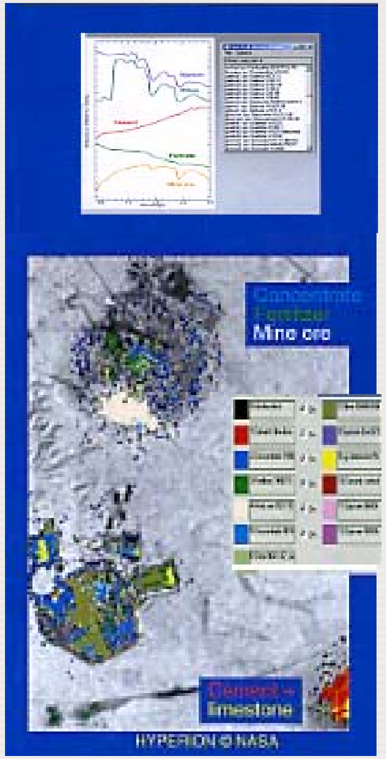
Novel Detection Technologies
Energy emission detection and analysis

Need: **To detect undeclared nuclear facilities and activities**

Visible



Infrared (with false colour)



Hyper-spectral – makes chemical identification of materials possible

Synthetic aperture radar (SAR)

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Novel Detection Technologies

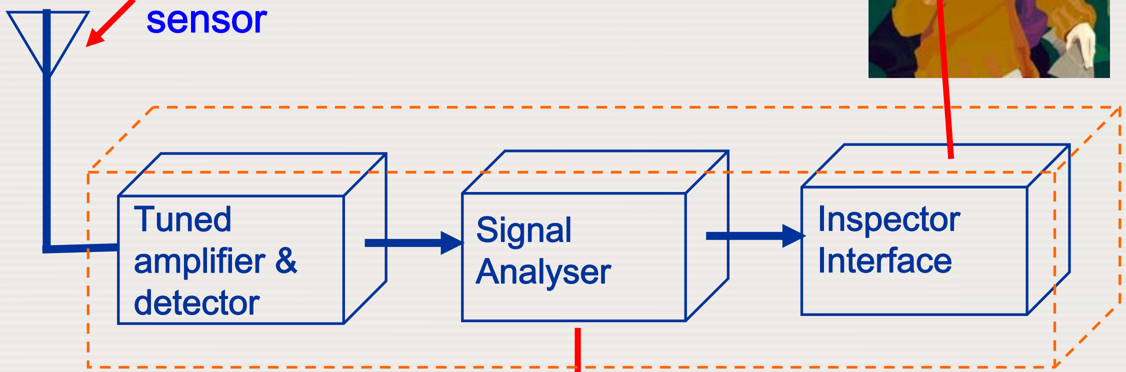
Energy emission detection and analysis

Need: **To detect undeclared nuclear facilities and activities**

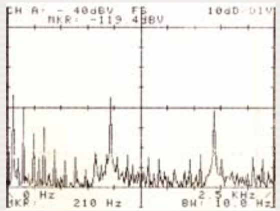
Emanations

Undeclared, or clandestine nuclear process

Appropriate electromagnetic (or acoustic) sensor



Functional block diagram of the instrument



Plant emanations and background noise

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Departmental Needs Gathering

Direct engagement with policy makers, experts and inspectors to define future technical needs

Project SGTS08
Identifying and Matching Needs and Novel Solutions

Technical Meeting on
Techniques for IAEA Verification of Enrichment Activities
April 2005

Technical Meeting on
Noble Gas Monitoring, Sampling and Analysis for Safeguards
September 2005

Workshop on
Safeguards Tools of the Future
October 2005

Workshop on
JAEA- IAEA Workshop on Advanced Safeguards Technology for the Future Nuclear Fuel Cycle
August 2006

Technical Meeting on
Application of Laser Spectrometry in IAEA Safeguards
August 2006

Workshop on
Advanced Sensors for Safeguards
April 2007

Workshop on
Inspection Needs
August 2007

R&D → Implementation

- The Novel Technologies Project commenced with 5 short to medium term (2 – 5 years) tasks
- Further longer-term tasks (5+) years are foreseen
- Future tasks will be proposed to all MSSPs
- Projects funded by MSSP and managed by NTU
- Predefined roadmap to implementation via NTU

Immediate Attention

Technology	Application	Timeframe
Laser Induced Breakdown Spectroscopy	Standoff Characterisation of Nuclear Materials	2 years
Optically Stimulated Luminescence	Determination of historical background radiation levels in a building	3 years
Mobile laser spectroscopy	Detection of target molecules in emissions from facility	3-5 years
Simulation of atmospheric gas concentrations	Estimate point of origin of release of target substance	2 years
Sampling and analysis of atmospheric gases	Detection of target molecules in atmosphere	2 years

Conclusions

- Novel Technologies Unit firmly established with ongoing portfolio of technical projects
- Further projects to be established upon completion of 'needs foundation' document
- Proposed 'cradle to grave' model for implementation of novel technologies
- Assistance greatly welcomed