Novel Technologies for IAEA Safeguards

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Abstract
This paper will introduce the International Atomic Energy Agency's (IAEA) Novel Technologies Project and it will include descriptions of some of the techniques and instruments currently under consideration for the detection of undeclared nuclear facilities, materials and activities.

The IAEA is the world's centre for cooperation in the nuclear field. It works with its Member States and multiple partners worldwide to promote safe, secure and peaceful uses of nuclear technologies. Three main pillars, or areas of work, underpin the IAEA's mission: safety and security; science and technology; and safeguards and verification. The IAEA is also the world's nuclear safeguards inspectorate with more than four decades of verification experience, conducting inspections at nuclear and related facilities in more than 140 States, most of which have undertaken not to possess nuclear weapons, pursuant to the global Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Through on-site inspection and other verification activities, IAEA inspectors work to confirm the absence of undeclared materials, facilities and activities with the overall goal of preventing the further spread of nuclear weapons.

Implementation of IAEA safeguards has evolved considerably over the past decades, reflecting changes in the nuclear industry and the international situation. The early detection of undeclared facilities, materials and activities requires new approaches, supplemented by technologies that differ significantly from those used traditionally for on-site verification. In this framework, the project *Novel Techniques and Instruments for Detection of Undeclared Nuclear Materials and Activities* was established within the Department of Safeguards to identify specific needs in this area and to initiate the necessary research, development and evaluation of techniques and instruments that will be used to support future implementation of evolving IAEA inspection and safeguards regimes.

Introduction
The timely detection of an undeclared nuclear facility, activity or material will require advanced approaches, supplemented by technologies that may differ significantly from those used by the IAEA for more "traditional" on-site verification. The IAEA Medium Term Strategy for 2006 to 2011[1] includes the enhancement of its detection capabilities through the development of new, or improved, safeguards approaches and techniques, and the acquisition of more effective verification equipment. Within this framework, the IAEA established the project *Novel Techniques and Instruments for Detection of Undeclared Nuclear Facilities, Materials and Activities* to identify specific implementation needs that may not be met by traditionally used methods and instruments, and to initiate any necessary research and development of novel techniques and instruments that could provide more effective solutions for the IAEA's implementation of additional protocols, including the conduct of complementary access[2].

Development and Implementation of Novel Safeguards Methods and Instruments
Implementation of effective and efficient safeguards has relied increasingly on the development and deployment of methods and instruments meeting specific functional and technical requirements. Accordingly, equipment development has complemented the safeguards implementation approaches

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[1] *IAEA Medium Term Strategy 2006-2011*, www.iaea.org/About/mts2006_2011.pdf.
[2] "New technologies" are defined by the Project as those for which the methodology is already understood and implemented by the Agency for safeguards applications. Examples include the next generation surveillance and sealing systems.
"Novel technologies" are defined by the Project as those for which methodology has not been applied previously to safeguards applications. Examples include laser spectrometry and spectroscopy.

over the past decades. For example, early safeguards equipment was developed for the main purpose of supporting on-site materials and activity verification at declared locations.

After the 1991 Gulf War and the discovery of a clandestine nuclear weapons programme in Iraq, safeguards approaches were enhanced to include additional methods and techniques, providing the IAEA with further tools by which it could better detect undeclared activities. These included environmental sampling, information analysis, the monitoring of sensitive technologies and satellite imagery. New technologies, such as ground penetrating radar, were also developed in support of conducting complementary access.

By their very nature, clandestine nuclear processes are undertaken at undeclared locations, or at declared locations which may be used as a "cover" for an undeclared process. The location of such activities requires appropriate equipment that can detect characteristics related to the particular activity. The Novel Technologies Project aims to broaden the range of techniques and instruments available to the IAEA, including emerging novel techniques and instruments that can assist in the detection of undeclared activities in undeclared locations (e.g. small industrial areas, universities, workshops, etc.).

Figure 1 shows a simplified nuclear fuel cycle (NFC) comprising the processes, in general form, which can lead to either material for nuclear power generation or for weaponry.

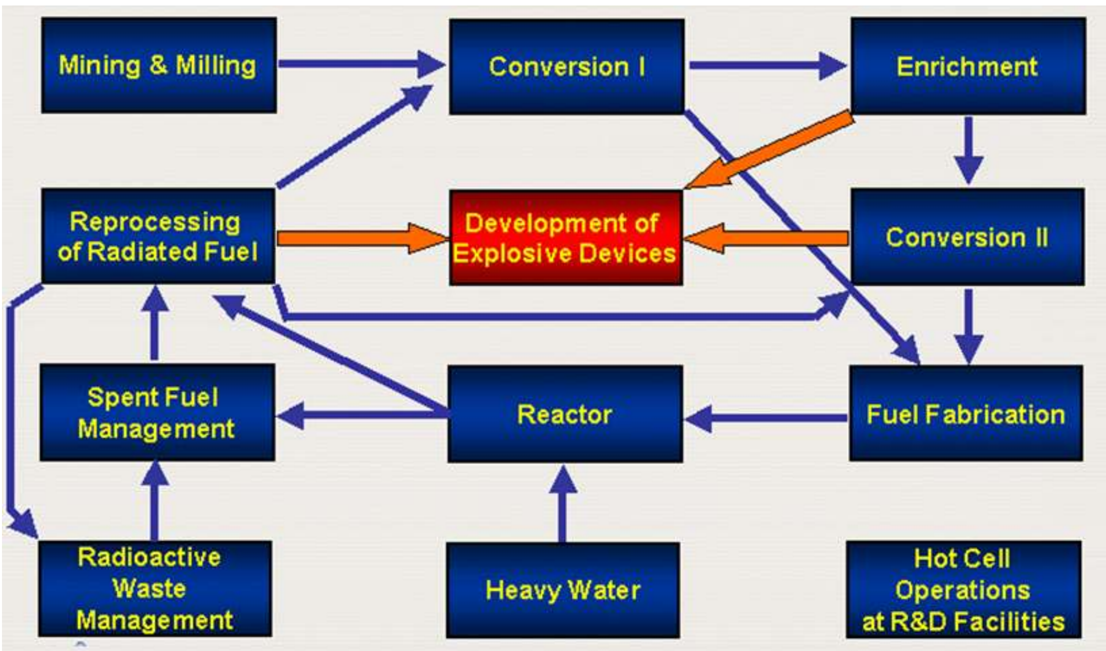


Figure 1. A simplified schematic of the nuclear fuel cycle.

Through a systematic and detailed analysis of each NFC process, it is possible to determine the existence of any safeguards-useful *indicators* and *signatures*[3], which may be strong signs of clandestine operations.

[3] "Indicators" ~ Entities that go into making the process operative. Examples include information and/or materials in the form of necessary resources, facility design data, related R&D, etc.

"Signatures" ~ Entities produced by the process when it is in operation. Examples include information, materials and/or radiant energy in the form of operational reports, produced materials, process by-products, energy emanations, etc.

The Novel Technologies Project (the Project) will review indicators and compile signatures for all critical NFC activities, identify those with the most promise for detection, particularly at a distance, and perform a gap analysis to identify suitable methodologies or instruments for safeguards applications. If it is determined that a suitable methodology or instrument does not exist, then the Project, with the support of Member States, will pursue the required development and testing that will result in a safeguards-appropriate solution. This multidisciplinary task is illustrated in Figure 2.

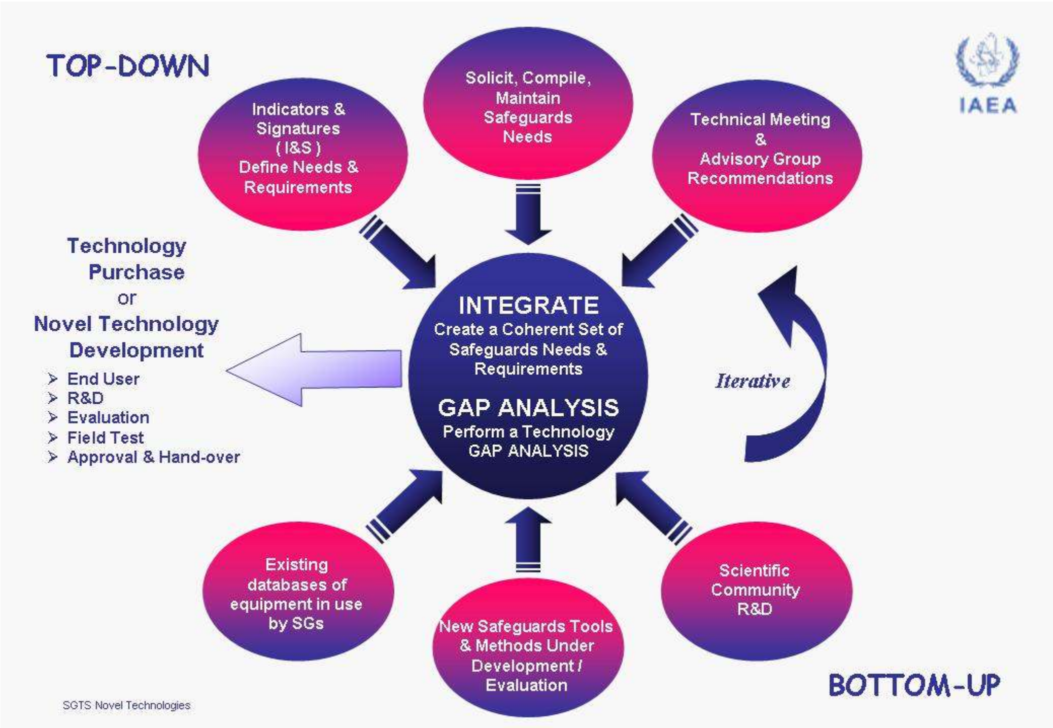


Figure 2. A systematic approach is being used to analyze technology gaps to most efficiently focus safeguards tools and method development efforts.

Project Tasks

As a precursor to the above approach, the following proposals were selected by the IAEA for further development and evaluation to meet specific needs for either on-site or away-from-site detection of undeclared activities.

Table 1. Laboratory and On-site Forensics of a Location's Past Nuclear Activities: OSL

Need	Application	Proposed Solution	Proposed Technology
To determine whether or not an undeclared location has been used previously for storing radiological material.	On-site verification Complementary access.	Measure the radiation-induced signature retained in many common building materials.	Optically stimulated luminescence (OSL)

Basic Methodology: OSL

I.

In this example, a location is suspected of being used previously for the storage of, or activities involving, radioactive materials.

***Figure 3.**: An artist's impression of a location with stored undeclared radioactive materials.*

II.

During complementary access, an IAEA inspector encounters the same location disguised to appear as an ordinary functioning office.

***Figure 4:** The same location as in Figure 1, but subsequently "disguised".*

III.

To verify the previous purpose and use of the location, the inspector collects samples of the surrounding building materials and transports them to an analytic laboratory for OSL analysis.

***Figure 5:** Collection of sample materials*

IV.

The collected samples are analyzed for residual nuclear activation by OSL, indicating the previous presence of stored nuclear materials.

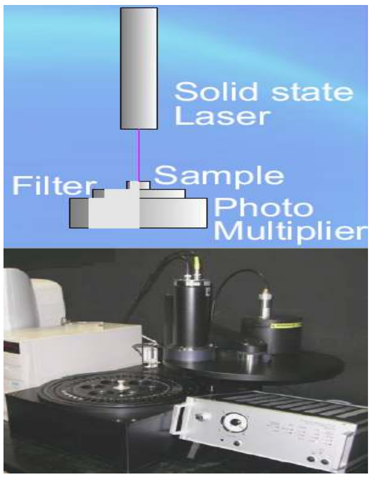


***Figure 6:** OSL Laboratory*

Table 2. On-site Forensics of Materials: LIBS

Need	Application	Proposed Solution	Proposed Technology
To determine the nature and history of materials found onsite.	On-site verification Complementary access.	Use on-site laser spectrometry to determine identify compounds, elements and isotopes	Laser-induced breakdown spectroscopy (LIBS)

Basic Methodology: LIBS

I.

A LIBS typically comprises (i) a laser system to ablate the surface of the material to be analyzed to create a micro-vapour, and (ii) a spectrometer to generate a spectroscopic profile of the micro-vapour constituent components.

The resolution of the LIBS is mostly dependent on the design of the spectrograph. It has been suggested that such instruments could be designed to provide both elemental and isotopic results.

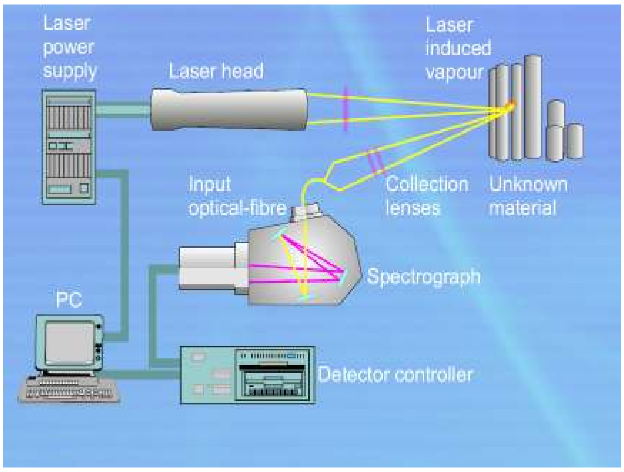


Figure 7: The basic operation of a LIBS instrument

II.

A trained IAEA inspector operates the LIBS unit to produce a spectroscopic profile from the unidentified materials found during an on-site visit. This is then compared to those in the LIBS system's library to determine the material's constituents.

Figure 8: *An artist's impression of an IAEA inspector operating a LIBS instrument*

Table 3. Near-site Sampling of Airborne Materials

Need	Application	Proposed Solution	Proposed Technology
To detect the presence and nature of nuclear fuel cycle process activities at suspected locations.	Away-from-site (stand-off) detection.	Use a mobile sampling laboratory in the vicinity of a suspected site to detect the presence of characteristic gaseous compounds, emanating from nuclear fuel cycle processes into the atmosphere.	Light detection and ranging (LIDAR)

Basic Methodology: LIDAR

LIDAR techniques are used routinely by environmental monitoring agencies to determine the presence of pollutants in the atmosphere. A laser, tunable to precise wavelengths (λ), selectively stimulates specific airborne molecules emanating as gaseous compound from the process. A light-sensitive telescopic spectroscope scans the atmosphere to detect the presence of the stimulated molecules.

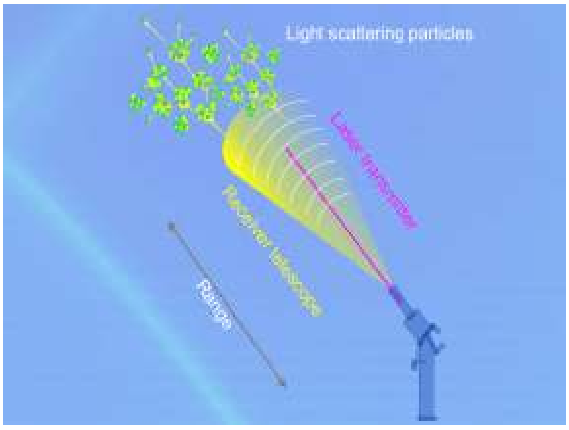


Figure 9: *The basic LIDAR method.*

In the example below, a LIDAR-equipped vehicle travels to the vicinity of the location that may be suspected of engaging in an undeclared nuclear fuel cycle process.

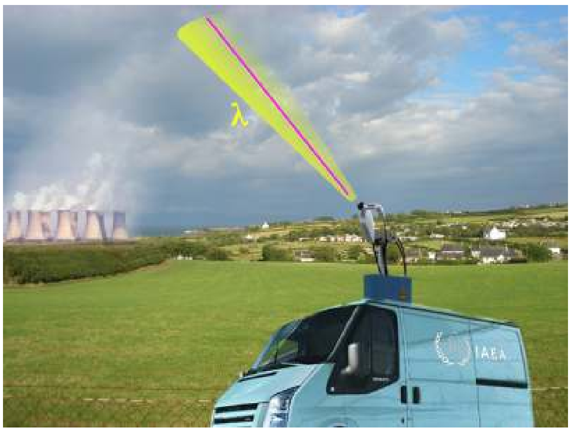


Figure 10: *An artist's impression of a mobile LIDAR unit*

Table 4. Near-site Sampling of Airborne Materials

Need	Application	Proposed Solution	Proposed Technology
To detect the presence and nature of nuclear fuel cycle process activities at suspected locations.	Away-from-site (stand-off) detection.	Use onsite to determine the nature and history of compounds and elements.	Sampling and analysis of atmospheric gases

Basic Methodology: Sampling and Analysis of Atmospheric Gases

I.

A mobile gas sampling vehicle travels around the region of interest collecting and concentrating atmospheric-borne pollutants. Local meteorological conditions and the GPS location are also recorded at each sampling location. The collected samples are transported to a laboratory for analysis.

Figure 11: *An artist's impression of a mobile on-site gas sampling laboratory.*

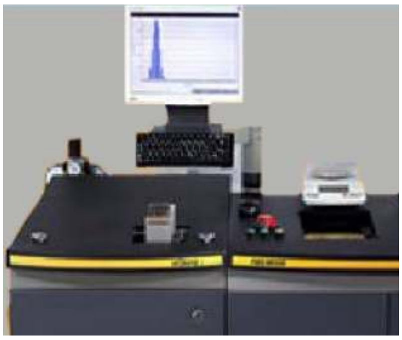


Figure 12: *Sample analysis*

II.

The field-collected sample data are combined with meteorological data and suitable atmospheric back-tracking simulator to provide an estimate of the source direction. The airborne material is identified and the probable location of the source is estimated.

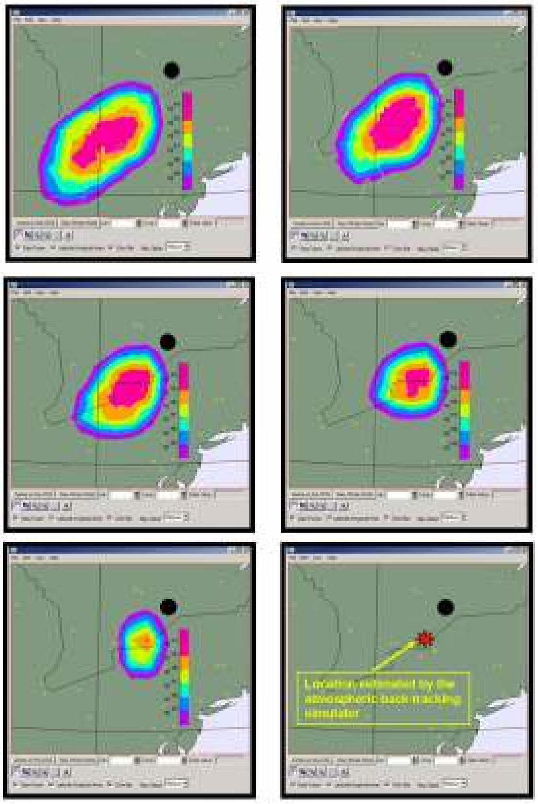
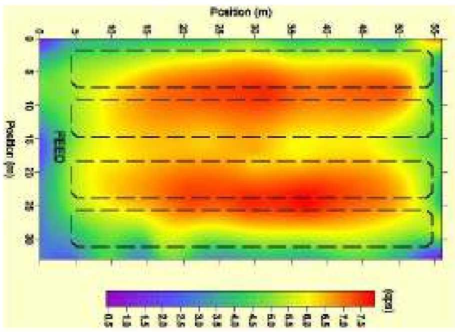


Figure 13: *An artist's impression of an atmospheric back-tracking simulator*

In parallel with the tasks outlined above, the project has also convened specialist technical meetings on techniques for the verification of enrichment activities[4], noble gas sampling and analysis[5] and laser spectrometry techniques[6]. Further specialist meetings covering novel technologies are being planned. Additionally, the project has been active with the support of Member States in establishing contacts with international R&D organizations and experts engaged in a wide range of sensor and detection technologies. Thirteen Member State Support Programmes (MSSP) have also agreed to assist the project by facilitating technical exchanges with both private and government operated R&D laboratories and by providing access to experts for short-duration tasks, attendance at technical meetings, advising on novel methods and instruments, conducting field tests and in the provision of supplementary funding.

The following representative technologies have been proposed as solutions to current and emerging Safeguards verification, complementary access, forensic and other stand-off detection needs:

Table 5. Verification of the Operation of a Gas Centrifuge Cascade

Need:
To detect the presence (or to verify the absence) of enrichment above declared levels in a declared gaseous centrifuge plant producing low enriched uranium (e.g. countering undeclared production or embedded micro-cascade scenarios) Source: Los Alamos National Laboratory (LANL)
Proposed Solution and Methodology:
Install a low-power, self-organizing network of neutron detectors above the centrifuge cascade.  *Figure 14: Artists's impression of a centrifuge cascade with individual neturon detectors mounted above* Data from each neutron sensor is collected and processed to produce a continuous indication of the relative enrichment levels throughout the cascade.  *Figure 15: The computer image of the cascade generated from the measured neturon emissions.*

[4] International Atomic Energy Agency, Technical Meeting on Techniques for IAEA Verification of Enrichment Activities, STR-349, IAEA, Vienna (2005).
[5] International Atomic Energy Agency, *Technical Meeting on Noble Gas Monitoring Sampling and Analysis for Safeguards*, IAEA, Vienna (2006).
[6] International Atomic Energy Agency, *Technical Meeting on Application of Laser Spectrometry Techniques in IAEA Safeguards*, IAEA, Vienna, in publication.

Table 6. UF_6 Enrichment and Material Flow Monitoring

Need:
Non-intrusive enrichment and flow monitoring for a gas centrifuge facility Source: LANL & Lawrence Livermore National Laboratory (LLNL)
Proposed Solution and Methodology: NMR

Measure both enrichment and material flow rate, without penetrating cascade pipe-work, using nuclear magnetic resonance (NMR) with a relatively low magnetic field.

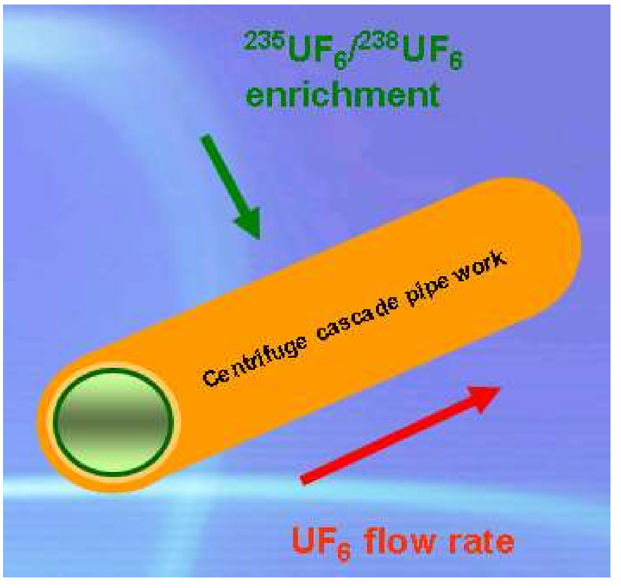


Figure 16: Schematic showing the essential functional needs for a UF_6 flow and enrichment monitor

Placement of two or more sensors on the pipe will allow both enrichment and flow-rate measurements.

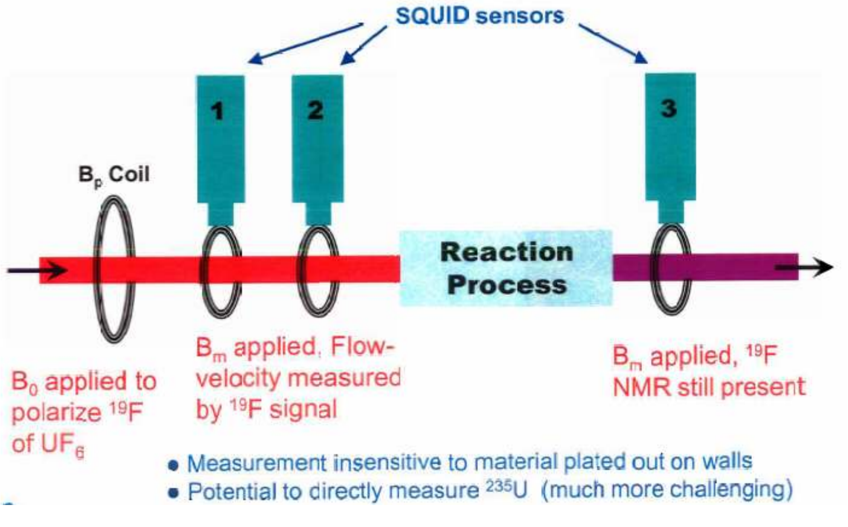


Figure 17: The proposed basic layout of a flow and enrichment monitor based on NMR.

Table 7. Verification of the Operation of Research and Power Reactors

Need:

To monitor the core operating conditions of a nuclear reactor (research and power types)
Source: LLNL and Sandia National Laboratory (SNL)

Proposed Solution and Methodology:

I.
Install an antineutrino detector in a convenient location within, or near, the reactor building.

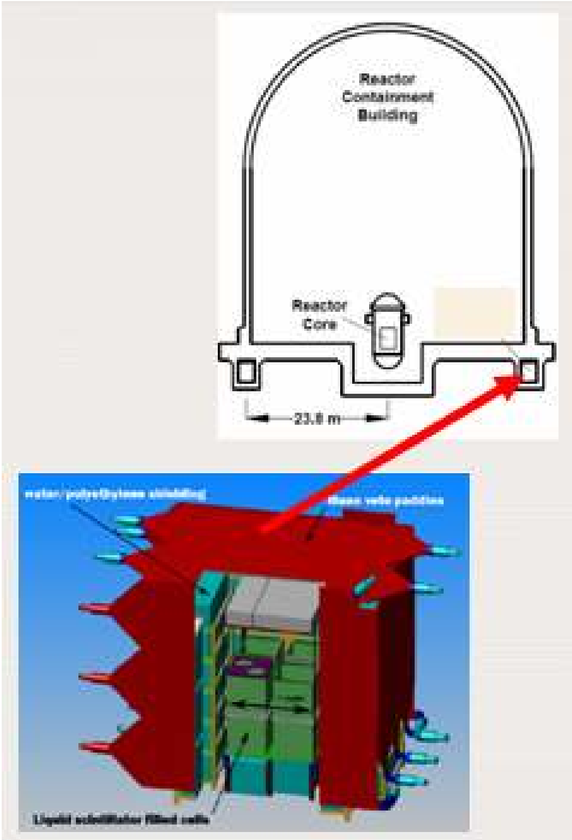


Figure 18: The experimental test set-up at the San Onofre nuclear generating station and a cutaway diagram of the LLNL/SNL antineutrino detector

II.
The operation of the reactor core and its relative power level can be monitored directly over time.

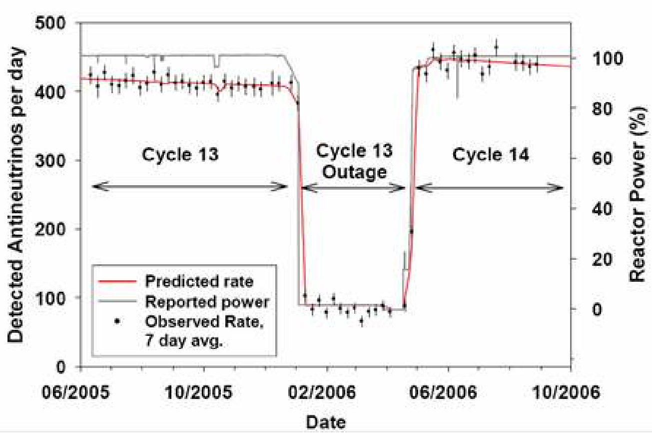


Figure 19: Comparison of the predicted antineutrino detection rate with the stations' reported power

Table 8. Verification of the Operation of a Gas Centrifuge Cascade

Need:
Uranium enrichment sensor for GCEP over time (countering the “micro-cascade” scenario) Source: Pacific Northwest National Laboratory (PNNL)

Proposed Solution and Methodology:

I.

Install many simple, robust, low-cost OSL sensors at strategic points within the cascade and pipe-work.

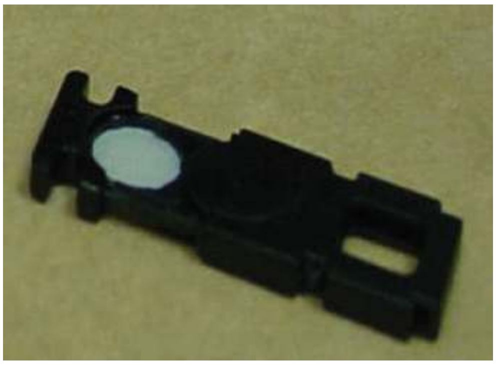


Figure 20: Magnified view of a small, passive OSL detector

II.

Exposure to radiation from within the cascade components (e.g. pipe-work) will cause the OSL-sensitive material in the tab to be stimulated .The relative level of stimulation will be proportional to the time-integrated radiation intensity.

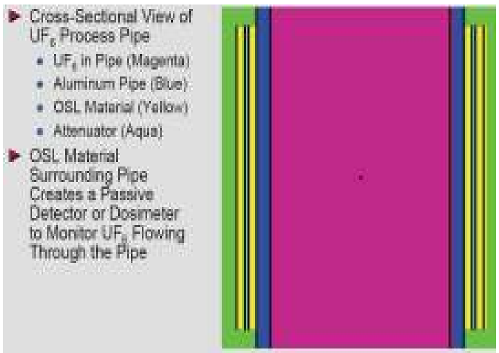


Figure 21:Cross-sectioned view of a UF_6 Process Pipe

III.

The relative exposure of each tab to the incident radiation is measured.

Figure 22: A commercial OSL detector reader

Table 9. Detection of Specific NFC Chemical Compounds

Need:
To detect specific chemical compounds associated with NFC processes Source: Sandia National Laboratory (SNL)
Proposed Solution and Methodology:
Utilizing a micro machined pre-concentrator with a hybrid of a gas chromatography channel and a quartz surface acoustic wave array (SAW) detector, the system is capable of sensitive/selective detection of gas-phase chemical analyses. It can be 'pre-tuned' to targets of interest, during fabrication, by careful selection of absorption film layer. Developed by Sandia National Laboratory, it is now a commercial product, marketed under the name µchemlab. The technique could be used to detect the presence of specific NFC chemical compounds.  *Figure 23: A prototype hand-held gas chromatograph based on SAW detector technology (Photo by Bud Pelletier for SNL)*

Table 10. Stand-off Detection and Analysis

Need:

To detect specific radiant energy from nuclear processes.

Proposed Solution and Methodology:

I.

A source of activity is capable of producing information, matter and radiant energy, which may be detectable with an appropriate method or instrument.

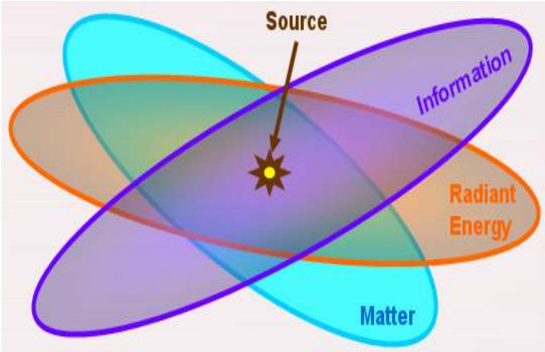


Figure 24: A representation of a point source and the entities (information, radiant energy and matter) that have the potential to be detected away from the source

II.

By further investigating other portions of the electromagnetic spectrum, it may be possible to detect and identify the location of an undeclared nuclear activity. These techniques include satellite, airborne and land-based spectroscopy, infrared and panchromatic spectrometry, and the detection of acoustic and other electromagnetic emanations.

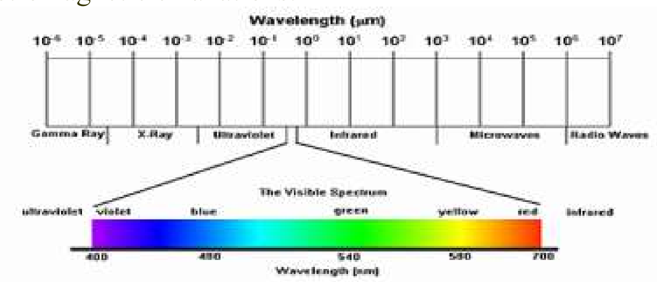


Figure 25: The Electromagnetic Spectrum

Summary

The establishment of the Novel Technologies Project has provided a mechanism for the IAEA to address the technologies required for emerging and future inspectorate needs. Moreover, it has facilitated the IAEA's access to a greatly expanded range of methods and instruments, thereby allowing safeguards planners the opportunity to develop novel verification and detection approaches for the peaceful use of nuclear energy and applications.

The project will continue to conduct surveys to identify safeguards needs that cannot be met with available techniques, broaden technical collaboration with other non-proliferation organizations and the international R&D sector and, where required, initiate further tasks that will lead to safeguards-useable methods and instruments. The basis of that will be a review and analysis of the nuclear fuel cycle processes, identifying the most safeguards-useful activity indicators [8] and emanating signatures that can "travel" from the source location and can be detected with a high level of confidence and accuracy. Indicators and signatures will be information, matter and/or energy associated with a particular nuclear fuel cycle process. Once identified, methods useful for the detection of promising indicators and signatures will be assessed by experts to determine if suitable methodology or instruments are available. Where none exist in a safeguards-useable form, the project will define appropriate technical and procedural requirements, initiating the necessary R&D and testing regimes.