# IAEA Safeguards: Challenges in Detecting and Verifying Nuclear Materials and Activities

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## Abstract

The Safeguards System of the International Atomic Energy Agency (IAEA) is designed to ensure that States use nuclear technology solely for peaceful purposes by detecting and verifying nuclear materials and activities. At present the IAEA applies safeguards activities in more than 900 nuclear facilities around the world. The variety of physical and chemical properties of nuclear materials including their storage environment and the complexity of nuclear activities requires a wide range of different verification and detection tools. Ongoing development is necessary to provide the IAEA's inspectorate with the best possible tools to perform the various safeguards activities.

New and improved technologies to enhance Safeguards verification are discussed herein and detection tools to meet the various safeguards challenges are presented.

The paper describes the efforts of the IAEA inspectorate to verify independently the inventories and flows of declared nuclear material and to confirm that existing nuclear activities are carried out as declared. Detection activities, capable of detecting possible undeclared nuclear materials and nuclear activities (such as undeclared enrichment and reprocessing) are elaborated.

The IAEA is a strong promoter of nuclear technology for peaceful purposes, which is increasingly used throughout the world, but at the same time the IAEA needs to provide assurance that nuclear material and nuclear technology is not misused to build nuclear weapons.

## 1. Introduction

The mission of the IAEA is to promote the safe and secure use of nuclear technologies for peaceful purposes throughout the world and to ensure their peaceful use through verification. The IAEA has three main instruments to maximize the contribution of nuclear technology while verifying its peaceful use: Verification (Safeguards), Safety (security, science & technology) and Technical Assistance. All three areas are interlinked, e.g. there will no public acceptance of nuclear technologies if they are not safe to use and the development and expansion of nuclear technologies will only be possible if assurance of its peaceful use can be provided.

Safeguards are applied by the IAEA to verify the correctness and completeness of declarations made by States about the exclusively peaceful use of their nuclear material and activities and thereby reducing the risk of proliferation of nuclear weapons. Nuclear weapons require nuclear material — either a significant quantity (SQ) of plutonium (~ 8 kg) or a SQ (~ 25 kg) of highly enriched uranium (HEU). Plutonium is produced during the operation of uranium-fuelled reactors. HEU could be produced in an enrichment plant which normally produces low enriched uranium

(LEU) required for fuel supply to reactors. Both products are abundant in the civil fuel cycle in quantities of hundreds of tons. The challenge of detecting the diversion of a SQ is obvious and the IAEA needs improved detection capabilities and novel tools to meet its future safeguards challenges, which include the detection of indicators of undeclared nuclear materials and activities. The IAEA's future goal is to possess new and improved equipment/technology that will address present deficiencies, have higher reliability, enhance the efficiency and effectiveness of verification activities and, ensure the security of information that can be provided in a timely manner.

## 2. Inspections

The Agency inspects over 900 locations worldwide holding various nuclear materials with different physical and chemical properties and associated storage environments. The complexity of nuclear activities requires a wide variety of tools to verify nuclear material declarations in a timely manner, including non destructive assay (NDA) equipment, remote monitoring systems, destructive analysis (DA), environmental sampling (ES) and containment and surveillance (C/S) systems.

The IAEA is not an Agency with unlimited funding and it is increasingly difficult to cope with a growing workload generated by increases in the number of nuclear facilities and in the inventory of nuclear material. In order to meet these challenges, staff resources have been stretched to their limits and the efficiency and effectiveness of the SG system is constantly screened for improvements. In addition, the discovery of clandestine nuclear programmes in several Member States required the strengthening of the SG system. The Model Additional Protocol (AP) approved in 1997 equips the IAEA with important supplementary tools which address these limitations by providing the IAEA with broader access to information and locations. Access will not be restricted to declared nuclear sites, but will extend almost anywhere, including high-tech industrial facilities, under certain conditions.

Today, the implementation of integrated safeguards (IS) — the optimum combination of all safeguards measures available to the IAEA — is advancing and it is anticipated that IS will significantly reduce the inspection effort in the field. The results of inspection activities, combined with the results of other safeguards measures (e.g. complementary access (CA) under the AP; information analysis and evaluation; satellite imagery) form the basis of the annual safeguards conclusions drawn for States. IS can only be applied after the IAEA has obtained a complete picture of the State's peaceful nuclear activities by reaching and maintaining its broader conclusion about the completeness and correctness of State's nuclear material and activities. For many cases, IS implementation involves an increased number of unannounced inspections and CA visits. Instruments for these specific types of verification activities need to be made available to inspectors at very short notice. Such equipment must be multipurpose, easy to operate and portable in order to allow the inspector to readily perform numerous tasks within the short time span of each particular verification activity, including searching for indicators of undeclared nuclear materials and activities.

New plant designs with complex operational schemes will require the development of new, design-specific safeguard systems. Possessing limited research and development capabilities, the IAEA relies mainly upon the support of its Member States, a mechanism which should also ensure the involvement of R&D organizations operating outside of the traditional safeguards community.

## 3. Verification and Detection Systems

The IAEA applies about 100 different instruments for the verification of nuclear materials. Environmental sampling (ES) has proven to be an excellent tool to determine past and present usage of nuclear materials. Its unmatched sensitivity using particle analysis is used to detect enrichment activities or reprocessing operations. However, the complexity of the analysis, the costs involved and the time lapse between sampling and actual results are limiting its routine potential. Alternative methods such as commercially available laser ablation spectrometers are being considered to reduce the increasing number of environmental samples on a case-by-case basis. Instruments using optical stimulated luminescence (OSL) will soon be commercially available and can be applied to investigate the past presence of radiation emitting substances.

Advancements in data treatment capabilities have provided additional instrument functionality, such as location stamped information and improved nuclear material identification, through the use of information organized in embedded databases. Other advancements in detector technologies (e.g. NaI, CdZnTe, $LaBr_3$ and HPGe) and signal processing hold the promise of increasing the resolution and efficiency of radiation detectors. Current high resolution gamma spectroscopy systems (HRGS) are based on low temperature cooled HPGe detectors, which sometimes limit their application in the field. Less expensive, smaller HRGS systems with reduced power consumption could be designed provided that the detectors can work at room temperature.

Miniaturization will continue to be important, facilitating the conversion of bulky equipment into smart portable equipment designed for field applications. An example of a device presently under development consists of a wireless control unit, neutron (He-3 tubes) and gamma detectors (CdZnTe) packed together in a customized lightweight body pack. The spectral capabilities of the gamma detector would identify the presence of radioisotopes while the neutron response would be indicative of nuclear materials. The design includes wireless transmission of the sensor data which would allow the inspector to perform freely other activities while the body pack continuously screens for radiation.

## 4. Detection of Undeclared Materials and Activities

Confirming the absence of indicators of undeclared nuclear materials and activities demands additional instrument capabilities above and beyond those required under the traditional ‘accountancy-based’ verification approach. For example, CA requires detection devices to search for non-traditional elements/isotopes (such as americium, neptunium, beryllium, and tritium) that could indicate the presence of a clandestine nuclear weapons programme.

The IAEA strategically sets priorities in technologies for the detection and quantification of enrichment and reprocessing activities. At present, the IAEA lacks an NDA method for detecting or locating undeclared enrichment or reprocessing activities at a distance. The application of differential absorption LIDAR (light detection and ranging) techniques to measure the on-site trace level of elemental or chemical compounds, such as volatilized solvents used during reprocessing (Tributylphosphate (TBP)), could be developed as a possible technique to confirm the absence or presence of reprocessing activities. Tunable diode laser systems have the potential to determine $^{235}U$ enrichment in $UF_6$ gas and to indicate the presence of HF gas, a by-product of enrichment activities. A portable instrument for HF gas monitoring is also being developed, designed for easy operation in airborne and ground-based mobile searches for enrichment activities.

Design information verification (DIV) is an important measure to confirm that existing facilities are used as declared by an operator or State and to detect the presence of undeclared design features and hidden facilities which could indicate undeclared nuclear activities or the diversion of nuclear material. Among several geophysical methods, ground penetrating radar (GPR) has been selected as an approved technology for the detection of hidden objects and structures. However, the challenge remains to interpret immediately and unequivocally the resulting radargrams. In most cases, additional measures are needed to reach a final conclusion.

## 5. Enrichment Plants

Safeguards at enrichment plants are a major challenge for the Department of Safeguards as these plants represent one of the most sensitive parts of the nuclear fuel cycle and as the number of enrichment plants is expected to increase significantly in coming years. Present Safeguards approaches are based on a combination of announced routine inspections providing snapshots of inventories and limited frequency unannounced access (LFUA) to the cascade areas to confirm the absence of HEU production. New approaches for safeguarding enrichment plants call for better technology for in-situ verification measurements and monitoring systems. In-line NDA needs to be developed to monitor flow and/or enrichment levels, i.e. to confirm that the plant operates as declared. Furthermore, any new approach should guard against excess production of enriched uranium from possible undeclared feed materials that could subsequently be used as feed for a much smaller, clandestine enrichment facility. The IAEA therefore needs instrumentation to quantify all materials in the various process stages, including those in vessels connected to the process, in order to strike an effective balance among feed, products and tails. This entails authentication of the various operators’ load cells (process and accountability) to derive a real-time balance of feed and withdrawal of $UF_6$.

The flow of $UF_6$ cylinders in the facility needs to be tracked with minimal inspector presence. Currently, these $UF_6$ cylinders can only be tracked manually using tag checks. Tags based on radio frequency identification (RFID) do not meet strict safeguards requirements concerning tamper resistance. The IAEA has successfully tested a laser item identification system (LIIS) that identifies individual $UF_6$ cylinders by the intrinsic spatial irregularities that are unique to each cylinder. This technique needs further development and would be coupled with video surveillance to provide a fully unattended system. The same technique would maintain continuity of knowledge (CoK) on cylinders which have been identified for verification until a quantitative assay is completed at a later stage.

Analytical tools at the enrichment plant sites are needed to partly replace the need for DA and thereby improve timeliness and reduce inspection resources. Presently DA samples are shipped from each facility to the IAEA's analytical laboratory in Seibersdorf. This is very costly and time consuming and, in some instances, air transportation regulations do not allow for nuclear material samples to be shipped. The IAEA intends to develop on-site analytical capabilities for $UF_6$ measurements using tunable diode laser spectroscopy (TDLS).

## 6. Plutonium Handling Facilities

Modern nuclear facilities are automated to decrease both personnel exposure and production costs. As a consequence of automation the direct access to nuclear material for both the operator and the IAEA inspectorate is limited. New technological standards in terms of networking and integration of unattended verification and C/S systems have been developed to cover the complete processes and storage areas of such facilities. Although such verification systems deliver data consistent with international target values, the combined measurement uncertainties in the verification of the plutonium strata might easily exceed the limits set by the safeguards goal of detecting the loss of a significant quantity. The amount of safeguards data collected for verification purposes is tremendous and the continuous presence of inspectors represents a large effort for the IAEA. Therefore the challenge remains to find adequate additional SG measures to meet safeguards goals and to cope with all safeguards activities within the limited resources available.

Future reduction in inspection efforts can only be realized by the full use of an integrated network of the various verification and monitoring systems and intelligent data evaluation packages. This requires the highest level of reliability of the systems in use and quickly available resources for repair if components of the network fail. Recently, a large reprocessing facility has commenced its active test with the necessary safeguards instrumentation in place. A new class of monitoring systems for in-process materials operating on a real-time basis is realized by a complex and sophisticated software system (I3S) integrating the different verification data with operator declarations. Furthermore, Monte Carlo simulations for the design and calibration of the monitoring systems have been extensively used and will be indispensable in the future.

## 7. Reactors

There are about 400 reactors including research reactors and critical assemblies under safeguards. Traditional approaches for a power reactor require quarterly inspections including PIVs at core loadings, strict surveillance measures on spent fuel and reactor cores and NDA verification of fresh and spent fuel on a gross defect basis. Partial defect verification may be required, depending on fuel type, upon shipment of spent fuel from the reactor side, subject to the safeguards approach applied. A passive gamma emission tomograph, currently being developed with the help of several Member States Support Programmes (MSSPs), is projected to be able to detect defects at a pin level.

The most advanced verification tools for spent fuel in wet storage are the digital Cerenkov viewing device (DCVD) and the safeguards MOX Python (SMOPY) device. SMOPY combines gross neutron counting with gamma spectroscopy to verify and distinguish irradiated MOX fuel from LEU fuel and to confirm burn up. Measurements involving the installation of underwater equipment are typically manpower-intensive and require significant inspection resources.

Under IS, the criteria for timeliness and the level of verification for spent fuel have been relaxed. The timeliness criterion for spent fuel is one year as compared to 3 months, surveillance can be limited to core opening periods and no partial defect measurements are required upon shipment. This relaxation has been used to formulate new IS approaches which result in significant savings of inspection and equipment resources.

## 8. Dry Storages for Spent Fuel

The quantitative and qualitative verification of spent fuel in wet and dry storage areas is a demanding task for the IAEA. The number of spent fuel assemblies (SFAs) is rapidly increasing and most spent fuel ponds at nuclear power plants are reaching their capacity. As a consequence, spent fuel is transferred to intermediate or long term dry storages. The IAEA spends significant inspector resources to maintain continuity of knowledge (CoK) while the spent fuel is loaded to casks and transferred to a permanent storage location where it becomes virtually inaccessible.

The development of unattended verification and monitoring systems is the only means of decreasing inspection resources. Such systems have recently been developed for CANDU reactors in order to monitor the complete process of loading, transferring and storing spent fuel in dry storage silos. The quantification of loaded bundles is performed with a VXI fuel monitor (VIFM) timer-counter system with accompanying underwater surveillance measures. Continuity of knowledge during transfer is maintained by using a mobile unit neutron detector (MUND) mounted in a waterproof enclosure fixed and sealed on the upper part of the transfer flask. The silo entry gamma monitor (SEGM) monitors the final silo loading. SEGM consists of a pair of gross gamma silicon detectors inserted at different levels into the verification tubes available for each silo, thereby providing direction sensitive verification of the silo loading.

The IAEA requires methods to demonstrate that the cask content has not changed in the event of loss of CoK or as a part of periodic routine requirements for re-verification. The limited penetration of radiation from the inner assemblies and the interference of neighbouring casks when measuring neutrons represent significant challenges when seeking to quantify directly the content of a dry storage by NDA methods, and as a result further development effort is needed. At present, the IAEA takes a neutron/gamma ‘fingerprint’ at the time of positioning of casks into the dry silo and compares it with a fingerprint taken at the time of re-verification. The maintenance and/or restoration of continuity of knowledge of a spent fuel dry storage container by a reproducible fingerprint require a systematic management of fingerprints over a long period of time. A database has been developed for the storage and evaluation of fingerprints to secure and effectively compare fingerprints while taking into account the decay and changes in the measurement hardware configuration. An assessment of the sensitivity level for the detection of the removal of spent fuel items is underway.

## 9. Waste, Hold-up and In-Process Inventories

Bulk handling facilities such as reprocessing and fuel fabrication plants often accumulate a huge number of waste containers that together contain significant amounts of nuclear material although the content of nuclear material in waste drums is usually very low and not homogeneously distributed. Representative sampling is therefore unfeasible and the IAEA needs to employ NDA methods instead.

Although several NDA methods exist to tackle the problem of hold-up accounting in bulk facilities, the related measurement uncertainties often exceed the specified goal. Commercially available germanium-based spectroscopy systems with embedded computerized numerical calibration capabilities verify nuclear materials contained in hold-up and waste. Specialized remote, often physically large, hold-up counters based on neutron coincidence techniques are being developed to quantify and monitor in real-time plutonium inventories in MOX fuel fabrication plant processes.

## 10. Illicit Trafficking

The IAEA continues to enhance and develop equipment to counter the illicit trafficking of nuclear materials, capitalizing upon existing synergies between safeguards equipment and instruments used to detect radiation at borders, terminals and other places.

Such NDA systems must provide for a quick analysis in order to cope with an often enormous throughput of goods and people. Integration of nuclear and other radioactive material monitoring systems with monitoring systems for other hazardous and sensitive materials (e.g. explosives) would minimize the intrusiveness of control measures. In order to reduce the number of follow-up control measures and to avoid possible evacuation measures, the number of false alarms should be minimized. Active detection methods for shielded nuclear materials (e.g. prompt gamma activation analysis (PGAA)) are being considered for possible development. In addition to fixed installed portal monitors, the IAEA is seeking to further improve its portable equipment to quickly identify any radioactive material, including possible radiological dispersion devices (RDD).

## 11. Disposition of Excess Nuclear Weapon Materials

The IAEA is exploring technology to verify nuclear materials declared as excess by nuclear weapons States (NWSs). The challenge is to provide verification tools to draw adequate safeguards conclusions without disclosing and knowing the characteristics of the disposed nuclear material. An attribute verification system with an information barrier for plutonium exhibiting classified characteristics is under development by two NWSs, which utilizes neutron multiplicity counting and high resolution gamma spectrometry (AVNG). The multiplicity counting will be performed with liquid scintillators while high resolution gamma spectroscopy is used for the isotopic composition. The system will provide a final result without providing raw data.

## 12. Outlook

With the renaissance of nuclear energy, States worldwide have indicated their intentions to build new nuclear power plants. The safeguarding of facilities for the fuel supply and spent fuel management associated with these reactors will be a major challenge for the IAEA within its present budgetary resources. The Director General of the IAEA, Mr. ElBaradei, stated “This [nuclear fuel-making] creates many new challenges, both for the international community and for us, because verifying enrichment facilities or reprocessing facilities is quite difficult and the so-called conversion time is very short. So we are dealing with what I call *virtual nuclear-weapon States*” (Vienna, Oct 2006). Today, nuclear technology and material have become far easier to obtain and, as more and more nuclear materials are produced, used, stored, or transported around the world, safeguards concerns and security risks will grow as a result. In order to meet future challenges, the safeguards system will need to be further strengthened to ensure its continued effectiveness and credibility. The IAEA inspectorate therefore needs the best possible tools at its disposal to perform the various safeguards activities aimed at providing assurance to the public that nuclear technologies are dedicated exclusively to peaceful purposes.

## 13. Conclusions

The IAEA operates a large diversity of equipment to verify declarations about nuclear materials and activities made by States pursuant to their safeguards agreements. Verification of nuclear materials is a cornerstone of the safeguards system. Emerging challenges in the verification and detection of nuclear material and activities demand the ongoing adaptation of existing instrumentation and the development of new equipment.

The IAEA places high priority on improving its verification techniques for enrichment plants and reprocessing plants. Additional analytical capabilities for environmental sampling and effective non-destructive assay (NDA) methods are indispensable both in support of the IAEA’s abilities to detect undeclared nuclear materials and activities and to support Member States in the detection of, and response to, illicit trafficking.