Safeguards at light-water reactors: Current practices, future directions

Advanced verification methods for LWRs are being tested as part of IAEA efforts toward more effective and efficient safeguards

by Neil Harms and Perpetua Rodriguez

Safeguards measures at the world's light-water-cooled reactors (LWRs) — the major type of nuclear power reactor in use today for the production of electricity — are well established. More than 220 LWRs and other types of power reactors presently are under IAEA safeguards in non-nuclear weapon States.*

This article addresses current IAEA safeguards practices at LWRs and also safeguards measures under consideration and development that go beyond the practices of today.

Why does the IAEA implement safeguards at nuclear power plants? How are these facilities a threat to nuclear proliferation? To answer these questions, it is important to look at the kind of nuclear materials at nuclear power plants. Excluding the use of mixed uranium-plutonium oxide (MOX) fuels for the moment, LWRs use low-enriched uranium (LEU), categorized as "indirect-use" material from the standpoint of its potential use in the manufacture of nuclear weapons. After these nuclear materials have been fueled in the reactor core, the spent fuels are categorized as "direct-use" material. Plutonium contained in spent fuel, as well as fresh MOX fuels, represent a strategic material from a safeguards standpoint. This is one of the determining factors that affects the safeguards approach and the inspection goal for a facility.

Implementation of safeguards at these facilities is covered by agreements between the State, or States, and the IAEA. To fulfill its obligations under the agreements, the IAEA carries out verification activities in order to draw its own independent safeguards conclusions. For agreements concluded under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the technical objectives of safeguards are defined in Article 28 of INFCIRC/153 (Corrected) as "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown and deterrence of such diversion by risk of early detection". Safeguards agreements under the non-NPT system are based on guidelines contained in the document INFCIRC/66 Rev. 2; it requires that safeguards be applied to nuclear materials, facilities, equipment, and non-nuclear material and to certain technological information. The manner in which the IAEA designs the safeguards activities at these facilities is referred to as the "safeguards approach".

The classical safeguards approach

The safeguards approach is based on an analysis of all technically possible diversion paths at a facility and on the requirements of the particular safeguards agreement. The approach is also designed to counter the possible undeclared production of direct-use material. It refers to the system of nuclear materials accountancy, containment, surveillance, and other measures chosen for implementation of safeguards. The following are also taken into consideration: (i) measurement methods and techniques available to the Agency; (ii) the design features of the facility; (iii) the form and

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*As of January 1996, there were 226 power reactors under IAEA safeguards in non-nuclear weapon States. Worldwide there were 437 nuclear power plants; the difference is accounted for by power reactors in nuclear-weapon States that are not under IAEA safeguards.

accessibility of the nuclear material; (iv) the possible existence of unsafeguarded nuclear activities; and (v) inspection experience.

The inspection goal

The inspection goal for a facility consists of a quantity component and a timeliness component. (*See table.*) The quantity component relates to the scope of the inspection activities necessary in order to provide assurance that there was no diversion of a significant quantity (SQ) of nuclear material over a material balance period (MBP). The timeliness component on the other hand relates to the periodic inspection activities necessary to provide assurance that no abrupt diversion has taken place. The inspection goal for each facility is regarded as attained if all the criteria relevant to the material types and categories present at the facility have been satisfied. In its implementation of safeguards, the Agency strives for full attainment of both components of the inspection goal.

Current safeguards implementation

How are IAEA safeguards being implemented at the present time? Fundamentally, the Agency's safeguards implementation is regulated by the IAEA Statute and by the safeguards agreements. Paragraph 2 of INFCIRC/153 (Corrected), the model for safeguards agreements, stipulates more specifically that safeguards will be applied "...for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices..." In the case of LWRs, the safeguards approach considers two basic tools to achieve the inspection goals:

Item accountancy. This includes item counting and identification, non-destructive measurements and examination to verify the continued integrity of the item.

Containment and surveillance (C/S) measures. These are used to complement the accountancy verification methods for safeguarding the spent fuel. Since LWR cores are usually not opened more than once per year, it is often possible to seal the reactor pressure vessel head.

The installation of a surveillance system that surveys the area where spent fuel is stored allows the Agency to detect undeclared movements of nuclear material, and potential tampering with containment and/or Agency safeguards devices.

In summary the following activities are performed to achieve IAEA inspection goals:

- ***Audit of accounting records and comparison with reports to the Agency;***
- ***Examination of operating records and reconciliation with accounting records;***
- ***Verification of fresh fuel before core loading.*** In order to detect possible diversion of fresh fuel, the verification is carried out by item counting, serial number identification, and non-destructive assay (NDA). For facilities using fresh MOX fuel, the verification activities are carried out on a monthly basis by item counting, serial number identification, and seal verification assuming that the fuel is received from an IAEA safeguarded facility. However, in the case where fresh MOX fuel is received from unsafeguarded facilities, additional NDA measurements are performed and the fuel is maintained under seal if kept in a dry store, or under surveillance if kept in a wet store. Seal verification and/or surveillance evaluation is also carried out on a monthly basis in addition to the usual accountancy verification methods.
- ***Verification of fuel in the core.*** The fuel is verified by item counting and serial number identification following refuelling and before the reactor vessel is closed. For facilities using fresh MOX fuel in the core, loading is either maintained under human or underwater surveillance. Soon after verification, C/S measures are applied to ensure that the reactor core remains unchanged.
- ***Verification of spent fuel pond.*** The spent fuel is verified after sealing the transfer canal gate or upon closure of the reactor core. In addition to evaluating the C/S measures applied,

Significant quantities of nuclear materials and timeliness goals

Category	Type	Significant Quantities	Timeliness Goals
Direct-use material	Plutonium*	8 kg plutonium	1 month
	High-enriched uranium	25 kg uranium-235	1 month (fresh) 3 months (spent)
	Plutonium in spent fuel	8 kg plutonium	3 months
	Uranium-233	8 kg uranium-233	1 month
Indirect-use material	Low-enriched uranium**	75 kg uranium-235	12 months
	Thorium	20 t thorium	12 months

*for plutonium containing less than 80% plutonium-238

**less than 20% uranium-235; includes natural and depleted uranium verification of the spent fuel by observation and evaluation of the Cerenkov glow using NDA techniques is performed.

Each year, the IAEA issues the Safeguards Implementation Report, which records the main conclusions reached, draws attention to deficiencies, and recommends corrective actions. The problems encountered include inconclusive surveillance, lack of appropriate equipment, incomplete safeguards measures, difficulties in the verification of some nuclear materials, restrictions on planning inspections, inspector designations, and some other administrative problems indirectly affecting the IAEA's goal attainment.

With the experience gained from these problems, recommended steps to minimize their occurrence have greatly improved safeguards implementation. In countries of the European Union, an agreement has been reached between the Agency and EURATOM to work on co-operative activities (referred to as the New Partnership Approach) which has resulted in a reduction of inspection effort and introduction of new surveillance systems. Equipment has been improved to cope with difficult facility conditions where traditional equipment has failed to provide conclusive verification results. Co-operation from the operators has also resulted in additional improvements for the safeguards approach of some facilities.

Programme 93+2 and future directions

Recent events have demonstrated the need for the IAEA's safeguards system to provide credible assurances not only regarding declared nuclear activities but also regarding the absence of undeclared nuclear activities. The system based on material accountancy has proved to be reliable in providing assurance about the peaceful use of declared material and declared facilities and installations. However, the system can be strengthened and made more efficient with new measures, in particular by improving the Agency's capability to detect undeclared activities in States having comprehensive safeguards agreements. The need for strengthening measures that would go beyond the scope of the existing safeguards agreements has been emphasized. This gave birth to what is called "Programme 93+2", the purpose of which is to provide the most effective overall approach to strengthen safeguards and, concurrently, to reduce the frequency of some other measures, thereby saving costs.

Remote Monitoring Systems. As a step towards the IAEA's objective of reducing inspection costs at LWRs while improving safeguards efficiency and effectiveness, a field trial using a Remote Monitoring System (RMS) has been undertaken in a semi-static storage facility in a co-operative effort between Switzerland and the Agency. The RMS currently being tested is based on an all digital approach which facilitates image and data handling (for example, information on Agency seals), transmission, processing, and storage. The communication system is independent of the monitoring system. The equipment has sufficient internal data storage and battery power, allowing the system to gather images and data in the event of loss of the network connection and/or facility power. The "state of health" data regarding system operation and its environment is provided to monitor equipment performance and malfunctions. The system provides near-real-time information, depending on how images and data acquisitions are set up. The use of RMS at an LWR facility is anticipated to be in conjunction with a reduced number of interim inspections, either announced or unannounced. An unannounced inspection would mean that the State and the operator would be informed of the Agency's intention to perform such an inspection only when the IAEA inspector arrives at the entrance to the facility.

Assuming the use of advanced technology, for example an RMS in an LWR facility, how would it affect the current safeguards implementation? At LWRs where currently three to four quarterly interim inspections are done per year, the number of inspections could be less, probably one unannounced inspection in addition to the physical inventory verification. At LWRs having fresh MOX fuel present, the current monthly interim inspections performed per year could be reduced, possibly to two to four unannounced inspections. The result — from the synergistic effect of combining routine inspections, unannounced inspections providing broad access at locations identified in the Expanded Declaration, increased co-operation with State Systems of Accounting and Control (SSAC), advanced C/S technology, and more frequent declarations by facility operators of certain operational and nuclear material transfer data — would be increased assurance regarding the exclusively peaceful use of facilities and the absence of undeclared activities.

When considering an alternative safeguards approach, it is useful to include the perspective of those parties directly affected by IAEA safeguards at LWRs, that is, facility operators and the SSAC in a particular State.

Every IAEA safeguards inspection is seen as an "interruption" to the nuclear facility operator's routine activities. How do facility operators regard safeguards inspections during a refueling outage when their time is heavily occupied with maintenance and shutdown activities? How much time is involved for a normal routine safeguards inspection? The following items could be given due consideration:

- Reduction of the number of IAEA inspections, especially during refueling and maintenance outages;
- For LWRs receiving fresh MOX fuel, possible co-ordination of IAEA verification with other State (shipper) regulatory functions to minimize handling and reduce radiation exposure to personnel;
- Implementation of improved unattended monitoring and surveillance systems to reduce inspection frequency and costs, while maintaining and improving safeguards effectiveness; these systems may transmit the information directly to the Agency for near-real-time analysis;
- Increase in the use of computerized operator records by IAEA inspectors to facilitate auditing in a timely and efficient manner;
- Reaching a practical working agreement between the SSAC and the specific Operations Division in the IAEA to utilize a manageable number of designated inspectors familiar with the specific plant layout and procedures. The intent is to avoid seeing new inspectors every time. If a "core" of designated inspectors who would most likely conduct inspections were identified at the beginning of the calendar year, the SSAC could take the necessary measures to facilitate the administrative requirements of the operators with reference to security and radiation safety and ease the bureaucratic procedures sometimes encountered during inspections; this, however, may require more freedom in scheduling inspections, or more inspectors;
- Scheduling of IAEA inspections to be performed within the day shift (e.g., 08:00 hrs to 18:00 hrs) to ensure availability of facility personnel knowledgeable about IAEA safeguards. There may be unavoidable exceptions to this, e.g., refueling activities involving loading of fresh MOX fuel into the core. Also, it is important that the shift staff is informed of IAEA equipment needs, for example, maintaining adequate lighting in areas where IAEA surveillance equipment is installed, or concerning actions to be taken in case an IAEA seal is broken.

Towards greater co-operation

The classical safeguards approach is applied to the majority of LWRs currently under IAEA safeguards around the world. It utilizes a combination of routine interim and physical inventory verification inspections. It incorporates nuclear material item accountancy, containment and surveillance, and other measures required to establish confidence that no unsafeguarded nuclear activities have taken place.

As part of IAEA efforts to devise an improved safeguards approach for light-water reactors, the IAEA is currently studying the possibility, under the mandate of Programme 93+2, of establishing a network of unattended near-real-time surveillance systems at selected LWRs within a State. The information gained from such a network would be supplemented by IAEA inspections at some reduced frequency, and would likely be unannounced. It might also be expected that the inspector, during his infrequent inspections, would need greater access to the plant site. Cost savings resulting from this new approach would, in part, depend upon the particular fuel cycle and number of facilities to be inspected.

A reformulation in the requirements for IAEA timeliness goals — through the use of advanced technology and/or through accumulating assurance regarding the absence of undeclared activities (particularly undeclared reprocessing or enrichment) — would also provide a basis for reducing costs in implementing safeguards on declared material in the natural and low-enriched uranium fuel cycles. ❐

Switzerland's Leibstadt nuclear power plant.