Safeguards at research reactors: Current practices, future directions

Some new verification measures are being introduced to improve the efficiency and the effectiveness of the Agency's safeguards

by Giancarlo Zuccaro-Labellarte and Robert Fagerholm

Approximately 180 research reactors and critical assemblies currently are under IAEA safeguards. The vast majority of the research reactors operate at relatively low power levels (10 megawatts-thermal or lower) and the critical assemblies at virtually zero power.* From a safeguards standpoint, this is important since a reactor's power level is a determining factor of its capability to produce plutonium. Along with high-enriched uranium (HEU) and uranium-233, plutonium is considered a "direct use" material which could be diverted for the production of nuclear weapons.

In this article, the IAEA's safeguards implementation at research reactors is addressed, including aspects related to diversion and clandestine production scenarios and main verification activities. Additionally addressed are new safeguards measures that are being introduced for purposes of providing assurances about the absence of undeclared nuclear materials and activities.

Safeguarding research reactors

Several types of research reactors are in operation. A very common type of research reactor is the swimming pool reactor which typically operates at power levels around or below 10 megawatts-thermal. The fuel elements normally consist of HEU (enriched to contain 20% or more of the isotope uranium-235) or low-enriched uranium (LEU, containing less than 20% uranium-235) contained in aluminum alloy plates, rods, or tubes. The reactor core is immersed in a large pool of water that provides both cooling and neutron moderation. The fuel assemblies in the core of a swimming pool reactor are normally visible and accessible for safeguards measurements.

Other types of research reactors operate at higher power levels (exceeding 10 megawatts-thermal). They need more powerful heat removal systems and are therefore normally enclosed in core vessels and equipped with coolant pumps and heat exchangers. The fuel elements in the reactor core at these installations are usually not visible or accessible for safeguards measurements.

Research reactors are widely used for scientific investigations and various applications. Neutrons produced by research reactors provide a powerful tool for studying matter on nuclear, atomic, and molecular levels. Neutrons often are used as probes by nuclear and solid state physicists, chemists, and biologists. Neutron experiments can also be performed outside the biological shield by means of installed beam tubes. Additionally, specimens can be positioned in or near research reactor cores for neutron irradiation, e.g. to produce radioactive isotopes for medical or research use.

Diversion scenarios. Under existing comprehensive safeguards agreements, the IAEA has the right and obligation to verify that no nuclear material is diverted from peaceful use to nuclear weapons or other nuclear explosive

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*A critical assembly is a research tool consisting of a configuration of nuclear material which, by means of appropriate controls, can sustain a chain reaction. As distinct from a research or power reactor, it normally has no special provision for cooling, is not shielded for high-power operation, has a core designed for great flexibility of arrangement, and uses fuel in a readily accessible form which is frequently repositioned and varied to investigate various reactor concepts.

devices. States conclude these agreements with the IAEA pursuant to their obligations under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).

For research reactors, the following diversion scenarios are considered:

Diversion of fresh or slightly irradiated fuel for clandestine chemical extraction of fissile material. This scenario — for which commonly available chemical engineering equipment would be adequate — is given particular safeguards attention at facilities where the fresh fuel contains HEU or plutonium, for which no further transmutation or enrichment would be needed for use in a nuclear explosive device. About 20 research reactors under IAEA safeguards are currently using such direct-use fissile material in amounts equal to more than one significant quantity (SQ). For safeguards purposes, one SQ is currently defined as 8 kilograms plutonium or uranium-233 or 25 kilograms of uranium-235 in HEU.

International efforts — for example, under the US Reduced Enrichment Research and Test Reactor programme — have been directed at developing the technology needed to use LEU instead of HEU fuel in research and test reactors without significant degradation in their performance for experiments, costs, or safety aspects.

Diversion of spent or extensively irradiated fuel for clandestine chemical extraction of fissile material in a reprocessing facility. This scenario is technically more demanding and time-consuming than the one mentioned above because of the high level of radioactivity from the fuel which is involved. However, it is of particular concern at about 15 research reactors under IAEA safeguards due to large accumulated quantities of spent fuel, and it is of importance at more than 10 others.

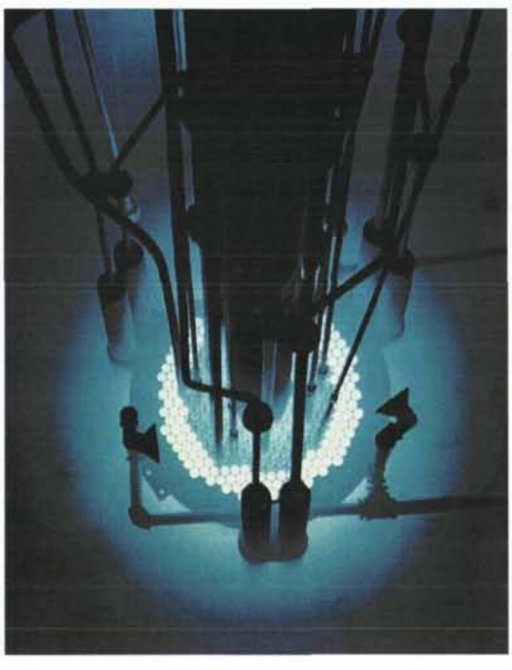
Clandestine production scenarios. The possibility exists for clandestine production of plutonium or uranium-233 through irradiation of undeclared fertile material. As techniques for using neutrons have developed, there has been an accompanying need for higher levels of neutron flux in order to carry out more complex and time-consuming experiments in a shorter time. Large research reactors have been constructed to provide these flux levels. At such reactors, production of substantial quantities of plutonium or uranium-233 through irradiation of undeclared fertile material would be technically feasible. This could be achieved, for example, by placing target materials in irradiation positions in or near the core, or by replacing reflector elements by fertile material targets. However, studies have shown that it is not possible to produce one SQ of plutonium in one year at a research reactor that operates below about 25 megawatts-thermal. The actual production capability depends on the individual reactor design and operating parameters.

The Agency's current safeguards system requires that all research reactors operating at power levels above 25 megawatts-thermal are evaluated with respect to their capability to produce at least one SQ of plutonium (or uranium-233) per year.

At present, there are about 30 thermal research reactors with power levels of 10 megawatts-thermal or higher which are subject to IAEA safeguards. About 10 of these operate at power levels exceeding 25 megawatts-thermal and are subject to additional safeguards measures with respect to the clandestine production scenarios.

Elements of "classical" IAEA safeguards

Currently, the IAEA's principal inspection activities at research reactors are an annual physical inventory verification (PIV); inspections serving timely detection purposes for fresh (unirradiated) fuel, core fuel, and spent fuel; auditing of records and reports; verification of specific types of fuel transfers; and verification activities to confirm the absence of clandestine irradiation of fertile material.



A research reactor in Japan is used for tests of fuel behaviour as part of nuclear safety studies. ***(Credit: JAERI)***

The research reactor at Bataan in Indonesia. *(Credit: Meyer/IAEA)*

At the PIV, the fresh fuel and spent fuel are verified using non-destructive assay (NDA) methods to confirm that all declared fuel is accounted for. Core fuel is verified by NDA methods or by a criticality check corroborated by other reactor data.* Interim inspections are performed at research reactors at intervals determined by the safeguards timeliness requirements for specific inventories of different material types.** If more than one SQ is present at a facility, verifications of the core fuel and spent fuel are carried out four times per calendar year at quarterly intervals, while verification of fresh fuel containing HEU and plutonium are carried out 12 times per calendar year at monthly intervals. Verifications of fresh fuel containing less than one SQ of HEU or plutonium are carried out four times per calendar year at quarterly intervals if more than one SQ of HEU or plutonium (fresh and irradiated) is present at the facility.

Transfers of fuel and experimental material containing HEU, plutonium, or uranium-233 into or out of a facility are verified either at the shipping or receiving facility if shipments are sealed by the Agency, or at both the shipping and receiving facilities if the shipment is not sealed.

To check that there has been no unrecorded production at high-power research reactors (greater than 25 megawatts-thermal) of one SQ of plutonium or uranium-233, one of the following procedures are used:

- analysis of the facility design and operations;
- containment and surveillance (C/S), among other measures (e.g. power monitoring), which confirm that the reactor is shut down or has not operated for a sufficient period;
- performance of one of the following activities: 1) the use of C/S measures to confirm that no unrecorded introduction of fertile materials or their removal after irradiation has taken place; or 2) evaluation of the fresh fuel consumption and the operator's data on spent fuel burnup to confirm that they are in conformance with declared design information and reactor operations.

Information of relevance to safeguards about the design of the research reactor is provided to the Agency by the State. It is examined and verified according to established Agency procedures and is re-examined at least once a year. When modifications or changes in design information relevant to safeguards occur, they are verified to establish the basis for adjustment of safeguards procedures, and the necessary adjustments are then implemented.

Elements of strengthened safeguards at research reactors

In June 1995, the IAEA Board of Governors endorsed the general direction for a strengthened and cost-effective safeguards system, under Part 1 of what is known as "Programme 93+2". Part 1 measures are those that can be implemented under the Agency's existing legal authority provided in comprehensive safeguards agreements.

Some measures designed to increase the efficiency and improve the effectiveness of safeguards are of a general nature. They include early provision of design information; and description of the State's nuclear fuel cycle.

Other measures are more specific to particular facilities. They include the description and status of the research and development activities, in particular related to uranium enrichment and reprocessing; environmental sampling at strategic points selected for routine inspections; unannounced routine inspections to confirm declared nuclear activities and the absence of undeclared nuclear activities; unattended monitoring and remote transmission of safeguards information.

The continuous development of new technologies also brings to light the possibility of new safeguards measurements and surveillance systems, which allow the remote operation of equipment and remote transmission of safeguards data.

*A criticality check is an inspection activity which provides evidence that a reactor has reached criticality and that a controlled nuclear reaction is sustained, i.e. the core contains at least minimal critical amounts of nuclear material.

**Safeguards timeliness is related to the time needed to convert the nuclear material from its present status to HEU or plutonium metal.

The impact of these new measures on the operators and States will depend very much on the type of nuclear facilities and the particular States or areas where these facilities are located.

An essential component in introducing the proposed measures is the increased co-operation with the States and the State System of Accounting and Control (SSAC) for nuclear material. This is needed to enable the IAEA to plan and conduct inspection activities more efficiently. The SSACs and IAEA may also carry out inspections or selected support activities jointly in order to economize resources and to make optimal use of the present system.The coordinated and efficient use of the new measures will reduce the current effort of safeguarding declared nuclear material and at the same time will enhance detection capability of possible undeclared nuclear activities and material.

As mentioned earlier, the frequency of inspections at research reactors varies from one to 12 per year, depending on the type and quantity of nuclear material present at the facility. The current inspection activities are planned in such a way as to provide assurance that the declared nuclear material remains under safeguards. It is more difficult within the present system to give assurance that the reactor has not been used to produce undeclared plutonium or uranium-233 by undeclared operations, in particular if the produced quantity of undeclared fissile material is much less than one SQ (e.g. 2 kg or less of plutonium per year).

For facilities now inspected 12 times per year, measures can be taken during these frequent inspections to check for possible undeclared operations. In other research facilities where the quantities of declared nuclear material are below one SQ, the frequency of inspections is normally once per year, or for some larger research reactors, two inspections per year. In these cases the new measures can considerably contribute to improving the Agency's capability to provide assurance regarding the absence of undeclared activities.

Measures which are presently being introduced under the IAEA's existing legal authority include:

Environmental sampling. The irradiation of targets and their subsequent dissolution in a hot cell to extract, for example, plutonium might be successfully concealed from the classical safeguards measures, particularly if the quantities produced are much less than one SQ. Where the inspections are announced and the frequency is limited to once per year, it might be possible to conceal the undeclared activity and interrupt it before the IAEA inspection is carried out. However, in any chemical process used to separate fissile material, small amounts of material would migrate to the surroundings of the area where this material is processed. Even though great care were taken to prevent losses, traces of this activity could remain and could be detected by the sophisticated and highly sensitive analytical methods used on environmental swipe samples.

The impact which these analytical techniques will have on facility operations is low, since the sampling is carried out by taking swipe samples inside or outside hot cells during regular inspections; little preparation is required by the operator.

Overview of safeguards measures and detection capabilities at research reactors

Detection Capability

	Declared nuclear material		Undeclared nuclear material/activities	
	Determination of Quantity	Timeliness	Determination of Quantity	Operation/Production
Present safeguards measures	Yes	Yes	No	Yes*
Environmental sampling	No	No	No	Yes**
Unannounced inspections	Yes	Yes	No	Yes
Remote monitoring:				
video surveillance	No	No	No	Yes
transmission of accountancy data	Yes***	Yes***	No	No
NDA, radiation monitors	Yes***	Yes***	No	Yes

*The present safeguards system is based on detecting undeclared operations to produce one SQ/year (or more) of undeclared plutonium or uranium-233.
**Environmental sampling is effective also in cases of production of much less than one SQ /year.
***In connection with unannounced inspection arrangements

Unannounced inspections. Unannounced inspections are those where the State and the operator are first informed of the Agency's intention to carry out an inspection at the time when the IAEA inspector arrives at the entrance of the site. The State's co-operation is necessary since the implementation of such inspections requires that the State grant multiple-entry visas or allow entry without visas to the inspectors. In addition, arrangements have to be made by the operator to grant access to the Agency inspector to the facility in a short time. The facility operator needs to be prepared for an unannounced inspection at any time. The benefit is that an assurance about the absence of undeclared activities at the facility at the time of the inspection implies that this has been the case with certain probability over the whole time interval since the last on-site inspection.

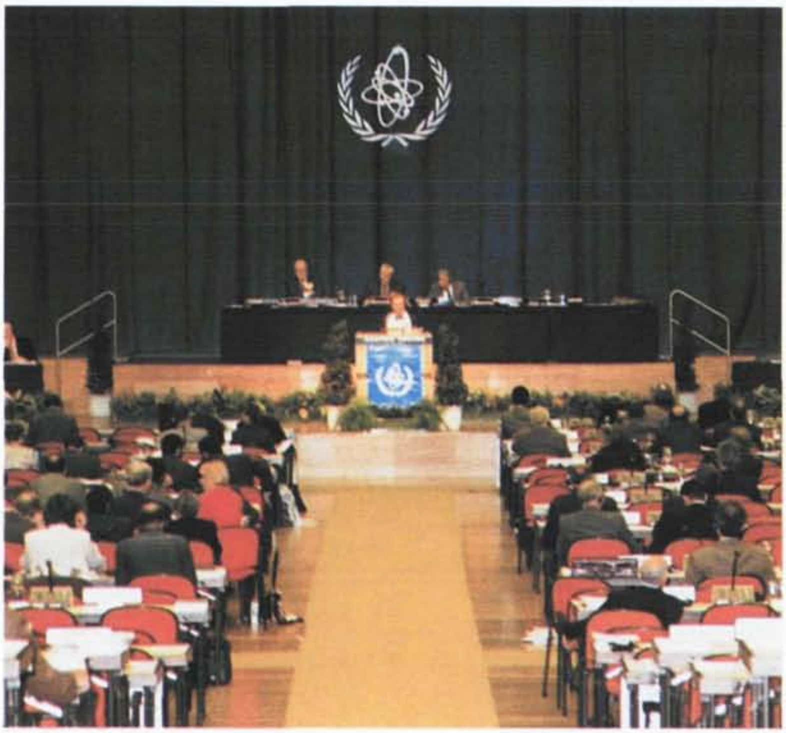
Remote monitoring. These types of systems include:

Video surveillance. The installation of cameras which can be operated remotely would allow continuous surveillance of facility operations and reduce the possibility that undeclared activities could be carried out undetected. This technique is not intrusive to the operator, since the only requirement is continuous and sufficient illumination of the area under surveillance.

Measurement and accountancy data. Remote transmission of inspection data would provide additional assurance that no undeclared activities have taken place, particularly when used in connection with unannounced inspections. The extent to which the necessary equipment can be used in a facility depends on the facility conditions and operating practices and requires the co-operation of the State, the SSAC, and the facility operator, who will be operating the equipment that provides the data for use by the IAEA.

The utilization of remote monitoring will enable a reduction in the requirement for inspectors to be physically present, with additional reductions in intrusiveness in facility operations. *(See table on previous page for a general overview of the verification capabilities provided using new safeguards measures at research reactors.)*

IAEA Member States have endorsed some new safeguards measures and are considering others. ***(Credit: Pavlicek/IAEA)***



Future co-operative efforts

Over the past years, the IAEA and its Member States have been taking steps to strengthen the effectiveness and improve the efficiency of the safeguards system. The objective is to provide assurances that a State's declared nuclear material remains in peaceful use and that no undeclared nuclear activities and material are known to exist.

The "classical" safeguards system based on the accountancy of nuclear material has proved to be reliable in providing assurances about the peaceful use of declared material and declared facilities and installations. However, the system needs to be further strengthened with respect to providing assurances about undeclared nuclear materials and activities.

Some of the new safeguards measures that have already been approved are aimed to strengthen the system and have to some extent already been introduced. They considerably improve the capability of detecting the diversion of declared nuclear material and the production of undeclared nuclear material. However, they are not capable of determining the quantity of undeclared nuclear material produced through undeclared activities. Attaining such verification objectives would require greater co-operative efforts and additional safeguards measures.

At the present time, the IAEA Board of Governors is considering further measures for strengthening the effectiveness and efficiency of safeguards. The extent to which additional measures can be implemented will depend upon the outcome of its work. ❐