Safeguarding sensitive nuclear materials: Reinforced approaches

An overview of major factors underlying the IAEA's specific approaches for safeguarding different types of sensitive nuclear materials

by T.E.Shea and K. Chitumbo

Viewed through the perspective of a State intent on the acquisition of nuclear weapons, certain nuclear materials subject to IAEA safeguards could significantly contribute to such an effort. The decision to divert safeguarded materials would require the State to weigh the strategic, programmatic, and economic benefits against the risks of detection and subsequent actions.

In that context, the "sensitivity" of specific nuclear materials reflects two principal considerations. First, in the general sense, nuclear materials closest to the requirements for nuclear-weapon manufacture are clearly more sensitive than others. Second, in terms of a specific situation, certain nuclear materials might provide important support to a State's clandestine nuclear-weapons programme, taking into account other capabilities that might be available domestically or through international arrangements.

In States that have not accepted comprehensive IAEA safeguards, there are agreements of more limited scope. These may also apply to non-nuclear materials, to specified equipment, and to nuclear or non-nuclear facilities that could be important in the context of a State's efforts to acquire nuclear weapons. In such cases, the adopted safeguards measures follow general requirements, and are adapted to the circumstances of a specific situation.

Safeguards are implemented in non-nuclear weapon States under different assumptions. Most non-nuclear weapon States have voluntarily accepted comprehensive IAEA safeguards on all nuclear materials. Absent contrary indications, those nuclear activities are normally presumed to be of a legitimate and peaceful nature. In such cases, IAEA safeguards are, in effect, confidence-building measures, wherein the Agency and the State co-operate to demonstrate the State's non-proliferation bona fides. IAEA safeguards measures are directed to detect violations of the relevant safeguards agreements, should a State be so tempted.

This article looks at the major factors taken into account in planning the implementation of IAEA safeguards, reflecting the relative sensitivity of different safeguarded nuclear materials.

Sensitive nuclear materials

Nuclear weapons contain fission-energy components fabricated with plutonium, highly enriched uranium (HEU) (uranium containing 20% or more of the isotope uranium-235), or uranium-233. Thus, the safeguards "sensitivity" of materials, equipment, or facilities subject to IAEA safeguards is established in relation to the ready availability of plutonium or HEU, and to the ability to produce and process them.

Nuclear weapons can be fabricated using plutonium containing virtually any combination of plutonium isotopes, according to advice given by nuclear-weapon States. Plutonium containing very high percentages of the isotope plutonium-239 is better suited than plutonium containing 10% or more of the isotope plutonium-240. However, even highly burned reactor-grade plutonium can be used for the manufacture of nuclear weapons capable of very substantial explosive yields. Except for plutonium created for heat-source applications containing 80% or more of the isotope plutonium-238, all plutonium is considered to be of equal "sensitivity" for purposes of IAEA safeguards in non-nuclear weapon States.

Only a small amount of HEU remains in peaceful nuclear activities, primarily in research reactor fuels. Very little uranium-233 exists.

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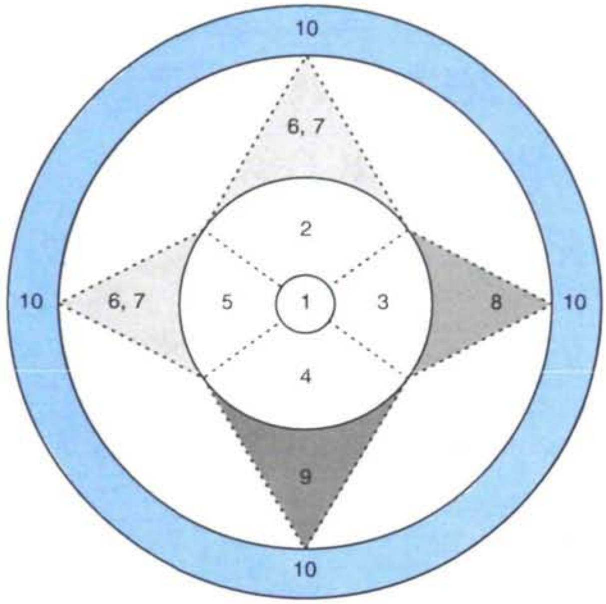

Layers of safeguards activities to cover diversion strategies

IAEA safeguards measures are based on a multi-layered combination of activities that take into account potential diversion strategies (1). These strategies could include the understatement of nuclear materials (2); the misuse of facilities and nuclear material (3); the borrowing of nuclear materials (4); and the overstatement of nuclear materials (5). To cover such specific strategies, IAEA safeguards measures include verfication (measurements) and auditing activities (6, 7); the verification of design information and special inspections (8); and the use of containment and surveillance (C/S) and special inspections (9). These measures are specific elements of overall safeguards activities (10) that are done to verify a State's physical inventory of its safeguarded nuclear programme and to evaluate the closing balances of safeguarded nuclear material within defined areas (material balance areas).

Other nuclear materials — for example, natural uranium — may be critical to the operation of an isotope production reactor or enrichment plant. The situation also could arise where safeguarded heavy water might be required for the operation of an unsafeguarded research or power reactor in a State not having a comprehensive safeguards agreement, and the reactor could be used to produce plutonium or uranium-233.

Diversion strategies

The safeguards approach implemented at a given facility is designed to counter plausible diversion strategies. The strategies and associated concealment schemes which might be used by a potential diverter include:

- *The removal of nuclear material subject to safeguards.* This could be done with or without falsified records and reports (e.g., understatements of receipts or overstatements of shipments, overstatements of discards and/or retained wastes, or overstatements of inventory declarations); with or without the substitution of falsified or partially falsified material; or with or without safeguarded material being borrowed from other facilities.
- *The misuse of safeguarded facilities.* This could be done, for example, through undeclared production of plutonium or uranium-233 in research or power reactors; configuration and production of HEU in low enrichment facilities; undeclared reprocessing or scrap recovery; or undeclared heavy-water production or scrap recovery).
- *In States not subject to comprehensive safeguards agreements, reproducing or misusing equipment that is subject to safeguards.*

Safeguards activities

Safeguards comprise a series of measures applied at specified facilities or other locations. In addition to the measures traditionally applied, the IAEA is in the process of implementing measures to strengthen the safeguards system. These include special inspections; increased emphasis on the provision of design information and its verification; expanded reporting of transactions involving specified materials and equipment; and the adoption of complementary measures such as environmental sampling. The arrangements for implementing these considerations have not been completed. These additional measures would apply first and foremost to sensitive nuclear materials subject to IAEA safeguards.

The safeguards measures applied at sensitive nuclear facilities are based on a layered combination of activities to cover the different groups of diversion strategies mentioned above. These activities include:

Examination of design information and verification of the physical inventory. These activities are done to:

- confirm a facility's appropriateness for the declared peaceful nuclear activities;

- establish that the information is complete, accurate, and consistent, and that the facility is constructed, operated, and maintained in accordance with the information provided. The provision, examination, and verification of design information begins with the conceptual design of a plant and extends over its life through decommissioning. Extensive physical verification activities are carried our during plant construction and modifications or maintenance, during cold and hot plant commissioning, and to the extent practicable, during plant operations.
- serve as the basis for the design and implementation of a safeguards approach for the facility that is intended to detect diversion or facility misuse; and
- serve as a reference basis against which comparisons will be made over the life of the facility to establish normal expectations and abnormal or anomalous conditions.

Activities to cover verification of inventory changes and timeliness requirements. These include:

- extensive use of containment and surveillance (C/S) measures at facilities in areas where items are controlled and where material is stored in bulk. In some cases, measurement systems are integrated for unattended verification.
- depending on the scale and complexity of a facility, the use of dynamic C/S systems to monitor plant operations within process areas. These systems may incorporate plant measurement systems in combination with engineering flowsheet predictions.
- compilation of operator data and verification of amounts and locations of safeguarded material flows, storage inventories, and process inventories during plant operations to permit near-real-time accountancy (NRTA) balances over separate and combined segments of the plant. (Other facility-specific arrangements are agreed, where appropriate.) The manner in which data are collected and the frequency for deriving NRTA balances depend on the scale of the plant. For new reprocessing plants, on-line data acquisition is foreseen, making use of the data acquired in the steps above, as are on-site data analysis capabilities to permit NRTA balance closings as often as on a daily basis.
- computation of material balances (an element of nuclear accountancy) for sub-campaigns at large processing plants corresponding to contiguous operations carried out for individual clients.

Verification of the physical inventory. Once per year, plant operators are required to shut down their plants, clean out the nuclear materials, and take physical inventory. The IAEA verifies the operator's declared physical inventory by appropriate non-destructive and destructive analysis according to random sampling plans. C/S measures are applied to reduce measurement requirements, or to serve as the basis for maintaining continuity of knowledge over verified information.

Evaluation of the material balance. At the end of each physical inventory verification, the material balance over a 1-year (maximum) period is evaluated and verified. In addition, cumulative material balances are computed over the life of the facility to ensure long-term stability.

Sensitive nuclear materials and facilities under comprehensive IAEA safeguards

Facility types	Sensitive nuclear materials	Number of facilities	SQ amount of nuclear materials involved
Storage	Plutonium HEU	26	3 678
Research reactors*	Plutonium HEU	102	200
Power reactors	Plutonium	141	22 381
Reprocessing	Plutonium	6	68
Fuel fabrication plants**	Plutonium HEU	15	911
Enrichment plants	Capable of producing HEU	5	

* *including critical assemblies*
** *including conversion plant*

Notes: Data are as of the end of March 1993 and pertain to non-nuclear weapon States having safeguards agreements in force pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons and Treaty of Tlatelolco (INFCIRC/153 agreements).
SQ = Significant quantity of material. 1 SQ for plutonium = 8 kilograms.
SQ for highly enriched uranium (HEU) = 25 kilograms.

Verification of initial inventory

Verification of the initial inventory is done to establish that the State's initial declaration of facilities, equipment, and materials subject to a safeguards agreement is complete and accurate.

Safeguards implementation will depend on whether or not a facility has been built or has been operated before safeguards are applied initially, or re-applied when relevant conditions recur, as may happen for plants in non-nuclear weapon States that are not bound by comprehensive safeguards agreements.

The investigations carried out prior to implementing safeguards under such circumstances resemble a form of nuclear archeology. They combine extensive examinations of plant historical operating records and analysis of trace samples from within and around a facility to confirm the operating records.

Fuel cycle considerations

As States establish more complete fuel cycles, the capabilities of their respective systems of accountancy and control (SSACs) of nuclear material normally increase. Such capabilities raise two diametrically opposed considerations in safeguards implementation. First, to some extent, the IAEA would make use of the SSAC to meet its obligations and draw independent conclusions. Second, the increased technical capabilities and control typically established in States with extensive civil nuclear programmes could be used to support sophisticated diversion concealment strategies.

Throughout most of the history of peaceful nuclear activities, an argument grounded on the utilization of energy resources has driven the notion that a State's nuclear power industry would not be complete until it had mastered all elements of the front and back ends of the "fuel cycle". This includes uranium enrichment, fuel fabrication, nuclear power reactor design and construction, spent fuel reprocessing, and plutonium fuel fabrication for recycling in light-water power reactors or for use in breeder reactors. However, owing to very low uranium prices and high costs associated with reprocessing and plutonium fuel fabrication, this situation has not materialized. Most States have, perhaps by default, elected a "once-through" option for fuelling light-water reactors, intending to store the spent fuel in geological repositories without reprocessing.

An intermediate case also has emerged: States export their spent fuel to a reprocessing complex (typically in a nuclear-weapon State) and receive in return separated plutonium or manufactured mixed oxide (MOX) fuel assemblies.

A tandem fuel cycle also is under consideration as a means to improve the economics of heavy-water reactors. In this case, the spent fuel discharged from light-water reactors is "re-canned" without reprocessing.

Each of these cases raises new possibilities and challenges to ensure that the scope and focus of safeguards remain relevant.

Sensitivity of specific situations

States with nuclear weapons programmes have chosen, with very few minor exceptions, to create separate installations specifically in support of that purpose.

In non-nuclear weapon States, as additional fuel-cycle capabilities are established, the ability to acquire nuclear weapons through diversion or facility misuse increases. First, access to inventories of separated plutonium increases as the number of facilities and the size of the inventories grow. Second, opportunities for concealing diversion increase, for example, by borrowing

Facilities under safeguards or containing safeguarded materials at the end of 1992

	Number of facilities (number of installations)			
Facility category	**INFCIRC/153 agreements**	**INFCIRC/66/ Rev. 2 agreements**	**Nuclear-weapon States**	**Total**
Power reactors	151 (182)	13 (17)	2 (2)	166 (201)
Research reactors and critical assemblies	134 (145)	22 (22)	2 (2)	158 (169)
Conversion plants	6 (7)	3 (3)	0 (0)	9 (10)
Fuel fabrication plants	33 (34)	9 (9)	1 (1)	43 (44)
Reprocessing plants	5 (5)	1 (1)	0 (0)	6 (6)
Enrichment plants	5 (5)	1 (1)	1 (1)	7 (7)
Separate storage facilities	35 (36)	6 (6)	5 (5)	46 (47)
Other facilities	54 (57)	4 (4)	0 (0)	58 (61)
Subtotals	423 (471)	59 (63)	11 (11)	493 (545)
Other locations	290 (468)	28 (32)	0 (0)	318 (500)
Non-nuclear instalations	0 (0)	3 (3)	0 (0)	3 (3)
Totals	713 (939)	90 (98)	11 (11)	814 (1048)

Notes: Data in the category for INFCIRC/153, which refers to comprehensive safeguards agreements pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons and/or Treaty of Tlatelolco, exclude locations in Iraq. The category for INFCIRC/66/Rev.2 excludes installations in nuclear-weapon States but includes installations in Taiwan, China.

among facilities, or through cumulative limitations in the sensitivity of verification activities. Thirdly, as civil activities increase, the pool of knowledgeable specialists in certain technological areas will expand, providing a support base which could facilitate weapons-related activities.

Strengthened support and transparency

In the aftermath of the Iraqi experience, where the IAEA discovered a clandestine nuclear-weapons programme, important lessons emerged for the implementation of effective safeguards. They include the need for greater transparency in nuclear operations so that peaceful nuclear activities can proceed with the confidence of the international community. This transparency can be gained to a certain extent through improvements in IAEA safeguards, but perhaps to a greater extent through conscientious actions by States to control access to sensitive materials and technology, to report transfers of material and equipment to the IAEA, and to express concerns when the actions of States appear inconsistent with normal peaceful nuclear programmes.

Various measures are being implemented to strengthen IAEA safeguards. While the specific elements of special inspections, provision and verification of design information, and expanded reporting have received special attention, one of the most significant changes is the adoption of "enhanced safeguards analysis" as a mechanism for complementing traditional verification measures. The specific elements of "enhanced safeguards analysis" are being defined, but certain directions already are evident.

First, systematic reviews of information related to the nuclear activities of States will be undertaken on a routine basis. The information will include design information and inspection data obtained in the normal course of IAEA safeguards implementation. Information from all facilities within a State, and from transaction partners in international commerce will be examined. In addition, information from other departments of the IAEA will be collated to confirm the safeguards data and to indicate inconsistencies that may suggest undeclared activities. Reviews of publications regarding the nuclear activities within a State also will be examined in a routine manner.

Information provided by Member States in conjunction with recent recommendations by the IAEA Board of Governors also will be considered in these Statewide reviews. This information includes expanded reporting of all nuclear material transfers, and transfers of other materials and items that have been specifically identified (in IAEA document INFCIRC/254).

In addition to these sources of information, it has been acknowledged that Member States of the IAEA are obligated to advise the Agency of credible information suggesting that a State may be in violation of its non-proliferation obligations. Such information will be used in conjunction with other information, as available, in determining the need for clarifications, official visits or, in appropriate cases, special inspections.

Moreover, information from the analysis of water, air, and soil samples may provide indications of undeclared enrichment or reprocessing. The technology exists to provide a significant verification capability through this means; the arrangements have not been established yet.

IAEA safeguards are in an important state of transition. The adoption of such extended capabilities into routine safeguards implementation is currently under consideration. There is a hope that such enhanced analysis capabilities not only will strengthen the Agency's verification system, but that, through their implementation in a synergistic arrangement, the costs of verification may be limited without sacrificing effectiveness. Routine inspections of facilities which process, store, and use separated plutonium and HEU currently account for approximately one-third of all IAEA inspections. Whether the enhanced analysis methods enable a reduction in the remaining two-thirds, or in inspections at these facilities, is not yet clear. ❐

As part of verification activities, the IAEA analyzes information on the status of safeguarded nuclear materials.