Reconciling IAEA Safeguards Requirements in a Treaty Banning the Production of Fissile Material for Use in Nuclear Weapons or other Nuclear Explosive Devices

Thomas E. Shea

IAEA Safeguards Agreements are in force in every state known to have nuclear activities. Three types of Safeguards Agreements have evolved, and they differ in the undertakings accepted by states and in the obligations and scope of IAEA verification activities. To some extent, the verification arrangements adopted in a treaty banning the production of fissile material for use in nuclear weapons or other nuclear explosive devices (the 'Cut-Off Treaty', in this article), will affect — and be affected by — existing control systems that also focus on the production and use of fissile materials, chief among them IAEA safeguards. In particular, differences in the scope of coverage, the verification objectives, the measures and technology applied, and the evaluation methods and reporting may arise. As negotiation of a Cut-Off Treaty proceeds, it is important that efforts to rationalize overlapping requirements and implementation assure that IAEA safeguards and the Cut-Off verification systems are mutually complementary, and that the final outcome assures that the totality of verification undertakings is effective and efficient.

IAEA safeguards are in transition and the changes coming about may complicate that rationalization. The strengthened safeguards system will improve the ability to detect undeclared production of fissile materials on the one hand, but the legal provisions and the methods to be applied will require several years for full implementation.

In May of 1997, the IAEA Board of Governors adopted a model for a protocol to extend the provisions of existing safeguards agreements to strengthen the ability of IAEA safeguards to detect the undeclared production of fissile material. As additional states complete their constitutional ratification requirements for the Additional Protocol, steps are underway to change IAEA safeguards by integrating newly provided rights for increased access to information, increased inspection access and the use of new technologies to improve the effectiveness and efficiency of safeguards, with the verification arrangements embodied in the original safeguards system. The resulting strengthened safeguards system will, in the course of the next few years, be capable of responding effectively to any plausible proliferation threat. The assurances gained concerning the absence of clandestine fissile material production facilities within states may provide a justification for reducing requirements for certain current inspection activities, with resulting cost-savings.

Thomas E. Shea is Senior Officer in the Office of the Deputy Director General of the Department of Safeguards of the IAEA, assigned to provide technical support to the Conference on Disarmament, as may be requested in relation to the negotiation of a treaty banning the production of fissile material for use in nuclear weapons or other nuclear explosives.

Fissile Material vs. Nuclear Material

The term "fissile material" is not actually used in implementing IAEA safeguards agreements. Rather, IAEA safeguards are applied to "nuclear material" — any *source* or *special fissionable material*[1] as defined in Article XX of the IAEA Statute. Special fissionable material is defined as: "plutonium-239; uranium-233; uranium enriched in the isotopes 235 or 233; any material containing any of the foregoing; and such other fissionable material as the Board of Governors shall from time to time determine." The term source material is defined in the IAEA Statute as "uranium containing the mixture of isotopes occurring in nature; uranium depleted in the isotope 235; thorium; any of the foregoing in the form of metal, alloy, chemical compound, or concentrate; any other material containing one or more of the foregoing in such concentration as the Board of Governors shall from time to time determine; and such other material as the Board of Governors shall from time to time determine."

The term "fissile material" is not actually used in implementing IAEA safeguards agreements. Rather, IAEA safeguards are applied to "nuclear material" — any source or special fissionable material as defined in Article XX of the IAEA Statute.

In IAEA safeguards, "nuclear material" is further categorized into "direct-use nuclear material" that could be used in the manufacture of nuclear weapons or other nuclear explosives without reprocessing or further enrichment, and "indirect-use nuclear material" that would require irradiation or enrichment to make it suitable for use in nuclear weapons. For the purposes of IAEA safeguards, direct-use nuclear materials are: plutonium except that containing 80% or more of the isotope plutonium-238, uranium containing 20% or more of the isotope uranium-235, and uranium-233. "Separated direct-use nuclear materials" are those direct-use nuclear materials that have been separated from fission products and thus the processing that would be required for their use in nuclear weapons is substantially less and the times required substantially shorter than if mixed with highly radioactive fission products. The definition of fissile material to be included in the Cut-Off Treaty may be close to this definition of separated direct-use nuclear material. Differences in these basic definitions could complicate the obligations as well as actions required of states and the implementation of IAEA safeguards and Cut-Off verification.

Different Types of IAEA Safeguards Agreements and Arrangements

IAEA safeguards are applied under different types of agreements and arrangements and the scope, objectives, measures, technology, evaluations and reporting employed may vary.[2]

At present, 183 states have undertaken in treaty commitments not to develop or otherwise acquire nuclear weapons or other nuclear explosives. Such states accept "Comprehensive IAEA Safeguards Agreements" (CSAs) to demonstrate their non-proliferation *bona fides*.

Four of the remaining nine states have or plan nuclear activities. Cuba has two partially completed facilities subject to IAEA safeguards. There are no known nuclear materials in Cuba. In the three remaining states with nuclear activities (India, Israel and Pakistan), IAEA safeguards are applied at specific facilities to the facilities themselves or to certain equipment, nuclear material or other material (such as heavy water).

The five remaining states with nuclear activities are nuclear-weapon states (NWS) parties to the Treaty for the Non-Proliferation of Nuclear Weapons (NPT) and all five have in force Voluntary Offer Safeguards Agreements on certain of their nuclear facilities and materials.

In addition to these different types of safeguards agreements, three additional safeguards arrangements are noteworthy.

SAFEGUARDS IN CSA STATES[3]

IAEA safeguards are said to be the cornerstone of the international non-proliferation regime, and CSAs are the cornerstone of IAEA safeguards. CSAs obligate states to submit *all* nuclear material to IAEA safeguards and obligate the IAEA to apply safeguards to *all* nuclear materials submitted by states pursuant to those CSAs. The scope of IAEA safeguards in states pledging not to develop or otherwise acquire nuclear weapons includes what is understood to be “fissile material”, together with nuclear materials other than fissile material. Under CSAs, IAEA safeguards focus on the state and proliferation-related activities that the state itself might direct or carry out if that state — with all of its available resources — were to seek to develop or otherwise acquire nuclear materials for use in a nuclear weapons programme. Thus, CSA verification activities address possibilities involving both declared nuclear activities and undeclared activities; they are intended to confirm that all nuclear materials are submitted to safeguards and remain committed to peaceful use.

Two verification objectives guide the implementation of IAEA safeguards under CSAs:

- to *detect the diversion of significant quantities of nuclear material* declared by the state from peaceful use to the manufacture of nuclear weapons or other nuclear explosives, or for any other purpose; and
- to verify the correctness and completeness of the declarations made by states, including the objective to *detect undeclared production* of fissile materials anywhere on the territory of the state or under its control.

In that CSAs are intended to provide assurance of non-proliferation, the safeguards system for CSAs is designed to alert the international community before a state could acquire its first nuclear weapon. This non-proliferation focus has led to requirements that include not only fissile materials, but the materials from which fissile materials are produced: the safeguards applied to low enriched uranium (LEU), natural and depleted uranium and thorium in CSAs provide additional opportunities for detecting actions that might be taken by a state intent on acquiring nuclear weapons or other nuclear explosives. (The only nuclear materials that are not subject to inspection in CSA states are the small amounts that are permitted to be exempted from safeguards, practicably irrecoverable nuclear materials on which safeguards have been terminated, and nuclear materials designated for non-proscribed military applications on which safeguards are not required.)[4]

Measures Related to Verification at Declared Facilities in CSAs

Over the years, the standard criteria have been adopted to guide the implementation of safeguards at declared facilities, affecting the extent and quality of information to be provided by states, design information verification activities, the safeguards approach to be applied at the facility to satisfy safeguards goals, and specific requirements related to inspection frequencies, inspection activities and the outcome of those activities. For plutonium and for uranium-233, an amount of 8kg is considered adequate for a state to produce its first nuclear weapon, taking into account process losses and the need to be conservative in the design, absent the benefit of nuclear tests. For high enriched uranium (HEU), an amount of 25kg of the isotope uranium-235 is similarly considered adequate. Depending on the form and purity of the materials, the times estimated as necessary for a state to complete the fabrication of its first nuclear weapon once these materials are available ranges from as low as seven to ten days for pure metal, to as long as three months when reprocessing is required, or one month if enrichment is required. For these materials, for LEU, natural and depleted uranium, and for thorium, the minimum time required for irradiation and reprocessing is estimated to be one year. These criteria reflect the non-proliferation objective for CSAs, establishing fixed quantity definitions to verification parameters that serve as the basis for planning and evaluating IAEA safeguards.

The structure and content of CSAs and the infrastructure for implementing safeguards may affect Cut-Off Treaty verification not only in CSAs, but may also be of interest in other states as well. Below the level of the Agreements, subsidiary arrangements are concluded as part of the legal framework under which the safeguards are implemented. Subsidiary arrangements include a General Part and a Facility Attachment for each facility identified. The General Parts of the Subsidiary Arrangements are standardized to the extent possible, and while the Facility Attachments for different types of facilities begin with “models”, substantial adaptations are often required to accommodate the specific characteristics of individual facilities. Facility Attachments relate specific obligations and inspection rights applicable at individual facilities to specific paragraphs in the Safeguards Agreement with a state.

Under CSAs, a “State system of accounting for and control of its nuclear material” (referred to as a SSAC) must be created to be responsible for implementing effective accountancy arrangements and to control imports and exports. States must make extensive declarations regarding their past, present and future nuclear activities at safeguarded facilities and report at specified periods on their nuclear material inventories and flows. When a CSA first enters into force, the initial inventory declaration is investigated closely to assure that it is complete and accurate. Subsequently, in relation to each facility a state declares, the state is required to carry out material balances annually and to report material unaccounted for on the basis of a measured physical inventory and measured inventory changes. Those state declarations are verified by the IAEA to assure that they are complete and accurate, and that declared nuclear materials are not diverted to the manufacture of nuclear weapons or other nuclear explosive devices.

Measures Related to Clandestine Fissile Material Production Under CSAs

The discovery of an extensive clandestine nuclear weapons programme in Iraq, an NPT state subject to a CSA, gave evidence to the fact that a safeguards system that concentrated on verifying declared activities was inadequate. In strengthening the safeguards system, the IAEA Board of Governors recognized that to address the possibility of clandestine operations, some provision for access had to be provided to locations anywhere within the territory of a CSA state or under its control. Similar needs were included in the verification provisions of the Chemical Weapons Convention and the Comprehensive Nuclear-Test-Ban Treaty (CTBT). While the principal focus of INFCIRC/153 is on declared facilities and nuclear materials, INFCIRC/153 includes provisions for special inspections that could be requested by the IAEA anywhere on the territory of the state. However, as became evident in the case of the Democratic People’s Republic of Korea (DPRK), the request for a special inspection has not been accepted. The Additional Protocol to the CSA, based on INFCIRC/540,[5] was created to extend the reach of INFCIRC/153 Agreements, providing the additional information, access and technology required for IAEA

The discovery of an extensive clandestine nuclear weapons programme in Iraq, an NPT state subject to a CSA, gave evidence to the fact that a safeguards system that concentrated on verifying declared activities was inadequate.

Safeguards to address all plausible means through which a state party to a CSA might proceed if it were to decide to violate its undertakings and attempt to acquire nuclear weapons.

The provisions of INFCIRC/540 allow the IAEA to require information on states' nuclear programmes including research and development, facilities that never operated or were decommissioned, and activities relating to the manufacture or import of equipment that could be used to produce or purify fissile materials. It allows for complementary access to resolve questions pertaining to activities or materials, including managed access to sensitive locations. Integrating the assurances regarding possible clandestine facilities or undeclared operations in declared facilities provided through the Additional Protocol will allow the IAEA to adapt the verification requirements at declared installations. Integrated safeguards under CSAs together with Additional Protocols are intended to use country profiles as a means to differentiate between the verification activities needed without discriminating among states.

The strengthened safeguards system will include verification activities from the basic CSA together with new verification possibilities provided by the Additional Protocol. The mechanisms for accomplishing that integration are being developed, and implementation will likely proceed in stages, addressing states with limited nuclear operations and building on experience before advancing to increasingly complex situations.

The goal is to conclude Additional Protocols in all states having made non-proliferation commitments by 2000, i.e. all CSA states. At each of the four annual meetings of the IAEA Board of Governors, a number of Additional Protocols are put forward for authorization for signing, and the total number of states is changing too rapidly to make including a table meaningful. In considering the relevance of IAEA Safeguards to Cut-Off Treaty verification in states pledging in one or more treaties not to acquire nuclear weapons, whether or not an Additional Protocol is in force should be an important consideration.

IAEA Safeguards in Other States With or Planning Nuclear Activities

IAEA safeguards implementation in Cuba, India, Israel and Pakistan are applied under Safeguards Agreements that were established as conditions for exports to those states of research or power reactors, or components thereof, or nuclear fuel or heavy water. These agreements stipulate that any fissile material created through irradiation in those reactors is also subject to safeguards, and any plant processing or using that fissile material will be subject to safeguards as long as that safeguarded fissile material is in the facility. Note that while the safeguards verification requirements at a given type of facility generally follow the requirements established in CSAs, specific differences may arise from the fact that the facility itself or equipment or material may be subject to safeguards, and the safeguards agreement may include provisions that reflect the selective nature of such safeguards agreements — especially provisions for substitution.

Of the safeguards applications in this category, the most germane to a Cut-Off Treaty might be the PREFRE Reprocessing Plant in India which is subject to IAEA safeguards when it reprocesses spent fuel that is under safeguards; plutonium recovered at PREFRE has been subject to safeguards through MOX manufacturing; and the fuel assemblies remain subject to safeguards through and following irradiation at the Tarapur Atomic Power Station boiling water reactors. The provisions of the applicable safeguards agreements allow for substitution, and in this case, plutonium not subject to safeguards was substituted for the safeguarded plutonium during MOX fuel manufacturing. When the assemblies were completed, the plutonium content was measured and the amounts contained were returned to safeguards.

Note that the Additional Protocol is applicable to all states, including states subject to safeguards agreements based upon INFCIRC/66.[6]

Safeguards Implementation in NWS Parties to the NPT

As NWS of the NPT, France, the People's Republic of China, the Russian Federation, the United Kingdom and the United States have entered into limited scope voluntary offer safeguards agreements (VOAs) modelled on CSAs. These VOA agreements place no obligation on the state in relation to the nuclear materials to be subject to safeguards and they permit the state to withdraw nuclear materials and to remove facilities from the list designated by the state which the Agency can select for the purposes of safeguards implementation. Moreover, there is no obligation on the Agency to carry out safeguards at facilities designated by the state.

The provisions of the VOAs allow many more opportunities for verification than can be implemented under the funding provided. The IAEA budget has remained at zero-growth for more than ten years now, even as additional mandatory verification activities arose in South Africa, Argentina and Brazil, and in the newly independent states of the former Soviet Union. As budget restrictions limit the activities that the Agency can carry out, safeguards implementation in these states is an early casualty. Note that when safeguards are applied at a facility in one NWS party to the NPT under a VOA, the same requirements apply as if the facility were in a CSA state.

The IAEA budget has remained at zero-growth for more than ten years now, even as additional mandatory verification activities arose in South Africa, Argentina and Brazil, and in the newly independent states of the former Soviet Union. As budget restrictions limit the activities that the Agency can carry out, safeguards implementation in these states is an early casualty.

At present, the most germane application of IAEA safeguards to a Cut-Off Treaty is at enrichment plants in China and the United Kingdom.

All nuclear facilities in France and the United Kingdom, except those dedicated to nuclear weapon programmes and naval reactor programmes are subject to Euratom safeguards under the provisions of the Treaty of Rome. Euratom is seen as a regional control authority and a partnership arrangement has evolved where both the IAEA and Euratom apply safeguards, primarily in non-nuclear-weapon states (NNWS) of the European Union. The partnership arrangement was established to eliminate unnecessary duplication of work, thereby reducing intrusion into normal plant operations and reducing the costs to the IAEA and Euratom. The arrangements are implemented in such a manner that the IAEA and Euratom are each able to derive independent conclusions, according to their respective requirements. In France and the United Kingdom, the funding provided has not been adequate to allow for the IAEA to apply safeguards except in limited situations. Euratom has gained extensive experience in applying its verification measures in both states, and Euratom's experience and existing capabilities at reprocessing plants and at enrichment plants in France may affect and be affected by verification under a Cut-Off Treaty.

Note that the Additional Protocol is applicable to all states, including NWS parties to the NPT. All five NWS of the NPT have, or will soon have, signed Additional Protocols based on INFCIRC/540; however, for the most part, the Protocols adopted by these states are intended to provide the IAEA with additional information to assist the IAEA in detecting suspicious activities in other states. These states have not adopted any obligation to cease production of fissile material and the VOAs including the Additional Protocols may not be useful to meeting obligations under the Cut-Off Treaty in relation to fissile material production in those states. However, the Protocols in NWS parties to the NPT may affect or be affected by considerations that might be included in the Cut-Off Treaty relating to exports of equipment or materials that could assist other states in efforts to acquire the capability to produce fissile material — including material or equipment specifically designed for that purpose, or dual-use equipment or material.

The Protocols in NWS parties to the NPT may affect or be affected by considerations that might be included in the Cut-Off Treaty relating to exports of equipment or materials that could assist other states in efforts to acquire the capability to produce fissile material — including material or equipment specifically designed for that purpose, or dual-use equipment or material.

Other Relevant IAEA Verification Activities

In addition to the normal range of safeguards implementation, three additional areas of verification may be relevant to the Cut-Off Treaty:

- The IAEA is carrying out extended verification measures in Iraq under the provisions of United Nations Security Council resolution 687, including unrestricted access to locations of interest and wide area environmental monitoring to detect clandestine production of fissile material. The experience gained in this extreme situation may be of benefit in considering the access provisions to be established under the Cut-Off Treaty — the rights granted and the difficulties encountered;
- The IAEA is monitoring a freeze on operations in facilities in the DPRK in relation to an Agreed Framework concluded between the United States and the DPRK, including monitoring a freeze on operations at the reprocessing plant at Nyongbyon, which is being maintained at operational stand-by. Again, the experience gained in relation to attempts to implement special inspections may be of benefit in considering provisions for extraordinary inspections under a Cut-Off Treaty; and
- The IAEA is participating with the Russian Federation and the United States in a Trilateral Initiative to develop a verification system for excess defence fissile materials in those states, including provisions for terminating verification of weapon-origin plutonium following irradiation in nuclear power reactors to specified levels. Such provisions may also be relevant if termination conditions are addressed for fissile materials subject to verification under a Cut-Off Treaty.

Safeguards Measures and Technology Related to Reprocessing and Enrichment

As the scope and verification requirements for the Cut-Off Treaty are established, the relevance of IAEA experience and existing requirements in states will enable detailed investigations to proceed for specified types of facilities and for specific facilities as appropriate. Given the negotiation mandate, it would appear that verification of reprocessing and enrichment operations will logically be required, and thus a preliminary review of IAEA experience in applying safeguards at enrichment and reprocessing plants may be useful.

Declared Reprocessing Plants

The plutonium produced in nuclear reactors is separated from the uranium, fission products and other actinides in reprocessing plants. With very few exceptions, all plutonium reprocessing plants employ the same process technology, the Purex process. (Uranium-233 is produced in a similar manner by irradiating thorium, and separated through a similar process; however, no uranium-233 reprocessing plants are subject to IAEA safeguards.) Reprocessing plants require processing of intensely radioactive materials and hence require remote processing within very substantial structures to contain the radioactivity. These characteristics, together with difficulties inherent in measuring accurately the amounts of plutonium (or uranium-233) at the starting point of the processing, make the application of safeguards complex and more expensive than any other safeguards application.

Safeguards at reprocessing plants are designed to detect misuse of the facility (undeclared reprocessing) and diversion from declared flows and inventories of plutonium and uranium. Meeting safeguards verification requirements is most difficult in large operating plants, as the IAEA safeguards goals are fixed in terms of amounts necessary for manufacturing one nuclear weapon, and as those amounts become small in relation to the total amounts of nuclear material processed, the safeguards approach must be expanded in scope and made increasingly intrusive in order to provide the required assurances that the plants are not misused and that the nuclear materials are accurately measured, declared and are not diverted. The technical problems are further complicated if the plants operated before safeguards were applied, and if the plant instrumentation is incomplete or unreliable. The safeguards literature is rich with information describing the technical means that have been developed for reprocessing plants.

The safeguards approach for a reprocessing plant will depend on a range of considerations, chief among which is its operational status. The following conditions may apply:

- continued reprocessing operation;
- operation for non-reprocessing purposes (e.g., removal of americium-241 from plutonium, waste fractionation, etc.);
- stand-by (here the verification requirements depend very much on the length of time between a notice of intent to resume operations and the actual resumption);
- decommissioning (here the safeguards approach is progressively simplified as the time and effort required to resume operations increases with the destruction, entombment or removal of key components); and
- decommissioned or abandoned. (The frequency with which periodic checks are required depends on whether the buildings remain and, if so, if they remain in use; the methods may entail periodic visits or satellite imagery analysis, depending on cost considerations.)

The cost and effort required can vary from almost no cost for decommissioned or abandoned facilities up to continuous inspection with tens of millions of dollars of verification equipment.

IAEA safeguards at reprocessing plants begin with the examination of information required of the state on relevant aspects of the design and construction of the facility, on its operation and on the nuclear material accountancy system employed. Design information reviews are made early in the consideration of the safeguards approach for a facility to determine whether the information is sufficient and self-consistent. During construction, commissioning and thereafter during normal operations, maintenance and modifications, and into decommissioning, the design information is verified through inspector observation and appropriate measurements and tests to confirm that the design and operation of the facility conforms to the information provided. In addition to these methods, environmental sampling may be applicable depending on the circumstances, as a means to detect reprocessing of plutonium with different characteristics. This safeguards measure provides the basis for determining the other elements of the safeguards approach for a given facility and the basis for applying all other safeguards measures.

For each reprocessing facility, depending on its operational status, whether it is a small, medium or large-scale plant, and facility-specific features, appropriate combinations of the following measures are combined with design information verification activities in the safeguards approach for the facility:

- application of containment and surveillance at key parts of the plant, to maintain continuity of knowledge of verified information and to track operations to determine whether or not observed operations conform to operator declarations;
- application of measurements, including measurements made by the operator for accountancy, criticality safety or process control and measurements made by the IAEA using IAEA equipment or, under suitable arrangements, using operator equipment;
- solution measurement and monitoring systems, to track the movement of solutions containing nuclear materials within the process area and to provide authenticated volume measurements of nuclear materials in solutions;
- near real-time accountancy, to detect plutonium losses within the specified monthly timeliness intervals;
- nuclear materials accountancy, involving annual material balances based upon verified physical inventories and physical inventory changes (this includes the analysis of shipper-receiver differences and material unaccounted for over successive material balance periods); and
- cumulative nuclear materials accountancy, involving total and trend analysis over the full period during which IAEA safeguards are applied at the facility.

Safeguards at reprocessing plants include the taking of samples for analysis at the IAEA Safeguards Analytical Laboratory, located in Seibersdorf, Austria. Sample preparation at the facilities includes spiking with reference materials and dilution to reduce the radioactivity of the samples to facilitate shipment and handling. Shipping such samples is expensive and requires appropriate radiation protection measures.

The verification equipment used at reprocessing plants includes standard seals and surveillance equipment, plus specialized systems:

- pneumatic measurement systems for determining the volume and density of solutions in instrumented vessels;
- secure sample containers to protect samples from tampering;
- densitometry equipment to permit IAEA verification of the concentration of plutonium in solutions before, during and following its separation and purification (K-edge densitometry for purified solutions and hybrid K-edge densitometry for solutions containing fission products and uranium); and
- in large-scale plants, on-site analytical laboratories are necessitated in view of the number of samples required and the timing for analysis.

Clandestine Reprocessing Plants

In a CSA state, any undeclared reprocessing would constitute a clear violation of the provisions of the Agreement and the Additional Protocol. Reprocessing operations normally involve the release of gaseous fission products into the atmosphere and the release of particulates, some of which are deposited at significant distances from the facility. The detection measures for detecting clandestine plants are as follows.

Enhanced Information Analysis: Under the provisions of the Additional Protocols, CSA states are required to be thorough in providing information relating to research and development concerned with reprocessing, manufacturing and importing specialized vessels for reprocessing and the construction, operation and decommissioning of any reprocessing plants, past, present and future. The IAEA analyzes the information provided and compares that information with information obtained from a range of sources, including:

- information obtained through the implementation of safeguards within the states;
- information reported to the IAEA involving transfers of nuclear materials and specified items of equipment;
- information obtained through other IAEA activities, including technical cooperation projects;
- open-source information from scientific journals and the media; and
- other information as states may provide.

Complementary Access: Under the provisions of the Additional Protocol, the IAEA has the right to request access to locations to resolve inconsistencies in information provided. The specific provisions for such access are complex and a careful analysis will be required to determine their relationship to Cut-Off Treaty requirements as negotiations proceed.

Environmental Sampling: Environmental samples may be taken under existing provisions of the Additional Protocol at locations where complementary access is provided. Additional provisions for wide-area environmental sampling are under consideration and approval by the Board of Governors is required before this feature of the Additional Protocol can be implemented.

Declared Enrichment Plants

IAEA safeguards at a uranium enrichment plant are intended to meet three objectives:

- to detect the production of HEU or excess high enrichment production if high enrichment production is declared;
- to detect excess LEU production (that might subsequently be further enriched at a clandestine plant or within a plant under safeguards, with a higher risk of detection);[7] and
- to detect diversion from the declared uranium product, feed or tails streams.

The nuclear materials accountancy measures applied to detect diversion from the declared feed, product and tails streams in an enrichment plant provide a means to assure that a plant is not being used to produce HEU, and in those cases where a low enrichment plant has been used earlier to produce HEU, this method assumes increased importance.

While essentially all reprocessing plants use a single process, nine uranium enrichment technologies have been advanced. Some of these technologies are unlikely to be exploited and some would no longer be selected because of very high electrical power requirements. While the safeguards approach for any enrichment plant will include common elements, the differences in the various process characteristics and the plants requires different safeguards methods.[8] While IAEA safeguards have been applied primarily to gaseous centrifuge plants, the IAEA has carried out investigations in relation to aerodynamic nozzle enrichment plants, gaseous diffusion plants, molecular laser enrichment (MLIS) and electromagnetic (calutron) enrichment systems. Limited studies have been carried out to consider safeguards at atomic vapour laser enrichment (AVLIS) plants, but little if any work has proceeded in relation to the remaining technologies that have yet to advance to the point of being incorporated in industrial scale plants: chemical exchange enrichment, ion exchange enrichment and plasma separation enrichment.

As in the case of reprocessing plants, design information examination and design information verification are central to the implementation of IAEA safeguards at enrichment plants. Enrichment technology is considered to be proliferation-sensitive and thus IAEA inspector access to the areas where enrichment equipment is installed is restricted by the technology holders, and inspector observation of the inside details of enrichment equipment is forbidden, as is access to critical plant operating parameters. Verification arrangements have been established within these restrictions that allow the IAEA to meet the objectives indicated.

Enrichment technology is considered to be proliferation-sensitive and thus IAEA inspector access to the areas where enrichment equipment is installed is restricted by the technology holders, and inspector observation of the inside details of enrichment equipment is forbidden, as is access to critical plant operating parameters.

Design information examination and verification provides a reference for understanding the normal steps for introducing feed and removing product and tails, and for assuring thereafter that no temporary or permanent modifications are made that would allow the plant — or any part thereof — to be used for the production of undeclared HEU. During construction, commissioning, during normal operations, maintenance and modifications, and into decommissioning, the design information is verified through inspector observation and appropriate measurements and tests to confirm that the design and operation of the facility conforms to the information provided.

Environmental sampling has proven to be an extremely potent method for determining whether or not an enrichment plant produces HEU. Clearly, if the plant is producing HEU for a non-proscribed purpose, or if a low enrichment plant was formerly used for HEU production or is near a high enrichment plant, environmental sampling may be less useful. The safeguards approach in such facilities would require greater emphasis on other aspects of the safeguards, but even in such circumstances, cluster analyses of particulates over time may provide a basis for detecting new production, as may differences in minor isotope ratios.

For a given enrichment technology, in a manner similar to that for declared reprocessing plants, the safeguards approach for an enrichment plant will depend to a great extent on the operational status of the facility. In particular, the following conditions are fundamental to establishing effective and efficient safeguards:

- operating enrichment plants:
  - — producing HEU for non-proscribed purposes (here the verification must assure that only the declared amounts of HEU are produced, and environmental sampling may be of little if any relevance);
  - — producing LEU in a plant reconfigured from earlier high enrichment production or in a

plant nearby another plant used for HEU production (here the verification activities intended to detect undeclared HEU production will be more complicated due to remaining traces of HEU, so, for example, environmental sampling may be of little relevance);

— producing LEU and never having produced HEU;

- operational standby (again, as for reprocessing plants, the verification requirements will differ depending on the advance notification interval required);
- decommissioning (the safeguards activities will be progressively simplified and the plant is dismantled; the destruction or disposition of the enrichment equipment removed should be monitored); and
- decommissioned or abandoned (here again, as for reprocessing plants, the inspection methods and frequency will depend upon the final state of the structures and periodic assurance that steps are not being taken to return a decommissioned or abandoned plant to operation will differ accordingly).

For each enrichment plant, depending on its technology, operational status, capacity and layout, the following measures are incorporated in the safeguards approach:

- measurements of the amounts of uranium and the enrichments of uranium in feed, product and tails cylinders, by means of weighing the cylinders and the use of non-destructive assay systems to measure the uranium enrichment, and sampling for analysis at the IAEA Safeguards Analytical Laboratory;
- applications of containment and surveillance on feed, product and tails cylinders, and at key parts of the plant, in particular at the uranium feed point and the product and tails removal points (integrated sealing-surveillance systems are being used at some plants that allow the facility operator to attach and remove seals as an efficient means to obtain assurance that all cylinders attached or detached from the declared feed and take-off points are verified), and at locations where instruments are installed to maintain continuity of knowledge of verified information and to track operations to determine whether or not observed operations conform to operator declarations;
- determinations that uranium in the process piping contains less than 20% of the isotope uranium-235, through continuous enrichment monitors or specialized measurement systems used in conjunction with limited-frequency unannounced inspections inside the cascade areas of some centrifuge plants;
- in other centrifuge plants, in-line instruments will be introduced for measuring the actual enrichment of the uranium in uranium hexafluoride gas in the feed, product and tails lines, and mass flow meters on the product flow line;
- in some facilities, use of limited frequency unannounced access inspections into the cascade hall to detect plant modifications that might signal high enrichment operations;
- in some facilities, monitoring of the separative work produced between successive inspections and comparison of those amounts with operator declarations and supportive inspection data;
- nuclear materials accountancy, involving annual material balances based upon verified physical inventories and physical inventory changes (this includes the analysis of shipper-receiver differences and material unaccounted for over successive material balance periods); and

- cumulative nuclear materials accountancy, involving total and trend analysis over the full period during which IAEA safeguards are applied at the facility.

Clandestine Enrichment Plants

The methods used to detect undeclared enrichment plants are essentially as for undeclared reprocessing. Enrichment operations normally result in the release of aerosols — especially at locations where connections to the process piping are made, but also through the plant ventilation system. These aerosols may not travel very far, and thus environmental sampling is likely to be effective close by such facilities.

The difficulty in finding emissions from clandestine enrichment plants is further compounded by advances in enrichment technology that greatly reduce the size of plants and reduce the electrical power requirements.

Enhanced Information Analysis: States are required to be thorough in providing information relating to research and development linked to enrichment, manufacturing and importing enrichment equipment and specialized materials (carbon fibre vessels and maraging steel, for example) and the construction, operation and decommissioning of any enrichment plants, past, present and future. As for reprocessing, the IAEA analyzes the information provided and compares that information with information obtained from the sources identified above in relation to reprocessing.

Complementary Access: As above, for reprocessing.

Environmental Sampling: As for reprocessing, environmental samples may be taken under the provisions of the Additional Protocol at locations where complementary access is provided. Additional provisions for wide-area environmental sampling are under consideration, and approval by the Board of Governors is required before this feature of the Additional Protocol can be implemented, but the detection of enrichment at points distant from plants is less likely.

Evaluations and Reporting of IAEA Safeguards Findings

Many other fundamental features of IAEA safeguards may be relevant to verification of a Cut-Off Treaty, including the following.

Autonomy of Agency

The Director General of the IAEA is empowered to bring to the Board of Governors suspicions of violations of the provisions of safeguards agreements, and the IAEA is empowered to bring to the United Nations Security Council situations which suggest that safeguards agreements may have been violated. The Director General is authorized to receive any information that may bear on a given situation, but the Director General is responsible for determining whether, how and when to act on such information.

Confidentiality

IAEA safeguards are carried out under conditions that require the Agency to protect the confidentiality of information relating to facility design and operation, inspection findings and evaluations, especially those at the level of the state.

Statements

Statements summarizing the activities carried out during each inspection are provided to the state shortly after each inspection, and a summary statement with conclusions regarding the outcome of inspections is provided annually. These statements are also "safeguards confidential".

Consultations

In determining the most efficient means to meet safeguards objectives, consultations are held in a cooperative framework. When anomalies and discrepancies are detected in the course of inspections or subsequent evaluations, consultations are held to find prompt and effective means for their resolution.

Special Inspections

The Director General is empowered to request a Special Inspection in a CSA state, based upon unresolved questions that suggest that a state may be in violation of its CSA provisions. The provisions of the Additional Protocols for complementary access are intended to improve the ability to resolve significant questions in the light of experience.

Safeguards Implementation Report

Each April, the IAEA Secretariat prepares a report to the Board of Governors summarizing all verification activities carried out and the conclusions derived therefrom. (Problem matters are brought to the attention of the Board as they arise.)

Concluding Remarks

IAEA safeguards began in the 1960s and have continued to evolve, without pause, as new verification responsibilities were assigned, as peaceful nuclear operations increased in size and complexity and as international relations posed new challenges. At present, 220 IAEA inspectors carry out approximately 11,000 days of inspection work each year, using 110 different verification systems that have been developed under sixteen ongoing IAEA Member State Support Programmes. The legal, technical and administrative arrangements adopted in different states and in different facilities respond to obligations mandated through Safeguards Agreements. In a wide range of areas, consideration of the existing safeguards arrangements will ensure that Cut-Off Treaty verification and IAEA safeguards are implemented in ways that provide the maximum value at the minimum cost.

Notes

1. "Fissionable" nuclei will fission when struck by fast neutrons having appreciable kinetic energy, while "fissile" nuclei will fission when struck by fast or slow neutrons with any amount of kinetic energy, including neutrons with essentially no kinetic energy. "Fissile" nuclei are therefore "fissionable", but only some "fissionable" nuclei are "fissile". Uranium-233, uranium-235, plutonium-239 and plutonium-241 are "fissile" nuclei; uranium-238, plutonium-238, 240 and 242, neptunium-237, americium-241 and 242(m) are examples of "fissionable" nuclei that are not "fissile".
2. Details on the status of Safeguards Agreements are published in IAEA Annual Reports and are available on the IAEA web site: http://www.iaea.org/worldatom/.
3. All CSAs are based upon INFCIRC/153, "The Structure and Content of Agreements between the Agency and States in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons." INFCIRC/153 is available at the web site noted above.
4. Note that no state has ever exercised the provision allowed in CSAs to designate nuclear materials for non-proscribed military applications that employ the fission characteristics of nuclear materials. States have exempted safeguards on depleted and natural uranium for use in ceramics, for example, and as a catalyst in petrochemical processes, and on depleted uranium metal for use as ballast material in aircraft and boats and in military applications involving armor-piercing projectiles. The provisions for excluding nuclear material from safeguards for non-proscribed military activities are set forth in paragraph 14 of INFCIRC/153.
5. INFCIRC/540, Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards. INFCIRC/540 is available at the web site given in note 2.
6. INFCIRC/66/Rev.2: The Agency's Safeguards System (1965) as provisionally extended in 1966 and 1968. INFCIRC/66 is available at the web site identified in note 2.
7. Note that more than 80% of the separative work required to produce uranium containing concentrations of uranium-235 of 90% or more is spent in raising the enrichment from natural levels (0.71% uranium-235) to approximately 4% enriched. A much smaller top-end facility would be needed to increase the enrichment from 4% to high enrichment levels than if the facility were to start with natural uranium.
8. The IAEA has no experience in relation to plutonium enrichment processes, only one of which has been suggested (AVLIS).