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The Safeguards at Reprocessing Plants under a Fissile Material (Cutoff) Treaty

Shirley Johnson

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About the IPFM

The International Panel on Fissile Materials (IPFM) was founded in January 2006. It is an independent group of arms-control and nonproliferation experts from both nuclear weapon and non-nuclear weapon states.

The mission of the IPFM is to analyze the technical basis for practical and achievable policy initiatives to secure, consolidate, and reduce stockpiles of highly enriched uranium and plutonium. These fissile materials are the key ingredients in nuclear weapons, and their control is critical to nuclear weapons disarmament, to halting the proliferation of nuclear weapons, and to ensuring that terrorists do not acquire nuclear weapons. IPFM research and reports are shared with international organizations, national governments and nongovernmental groups.

The Panel is co-chaired by R. Rajaraman of Jawaharlal Nehru University, India, and Professor Frank von Hippel of Princeton University. The founding members of the Panel include nuclear experts from sixteen countries: Brazil, China, France, Germany, India, Japan, Mexico, the Netherlands, Norway, Pakistan, Russia, South Africa, South Korea, Sweden, the United Kingdom and the United States.

Princeton University's Program on Science and Global Security provides administrative and research support for IPFM.

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Overview

A Fissile Material Cutoff Treaty would, at the least, ban the production of new fissile material for weapons. The most costly verification challenge would be to apply safeguards to reprocessing plants in the eight states having nuclear weapons (the five NPT nuclear weapon states, Israel, India, and Pakistan). The purpose would be the same as NPT safeguards at the corresponding facilities in non-weapon states: to verify that no newly separated fissile material (primarily plutonium and highly enriched uranium) is diverted to weapon use.[1] This could be very costly. Although there are only two operating reprocessing plants in the non-weapon states, Japan's Tokai and Rokkasho facilities, these two plants alone account for 20 percent of the total international safeguards inspection effort performed by the International Atomic Energy Agency (IAEA).[2]

A 1996 Brookhaven National Laboratory study estimated that two thirds of the routine inspection effort devoted by the IAEA to verifying an FMCT in the nuclear weapon states would be focused on reprocessing plants.[3] The Brookhaven study estimated that there were 52 reprocessing installations, large and small, civilian and military, existing in various operating or shutdown modes in states having nuclear weapons. Although the total number of installations is fewer today, it is clear that safeguarding reprocessing plants under an FMCT will be challenging. This paper explores how the safeguarding could be done cost-effectively. It is assumed that the safeguarding will be done by the IAEA. The comprehensive safeguards approach developed by the IAEA for the Rokkasho Reprocessing Plant is taken as the point of departure.

In non-weapon states, safeguards are applied according to IAEA Safeguards Criteria[4] that specify the activities considered necessary by the IAEA to provide a reasonable probability of detecting the diversion of a significant quantity of nuclear material from under safeguards. The safeguards are designed to detect a diversion of one significant quantity (SQ) of nuclear material removed either abruptly or in a protracted manner. The IAEA defines an SQ as the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. For plutonium, one SQ is defined to be 8 kg.[5] The time requirement for detection of an abrupt diversion of one SQ of plutonium is within one month and, for protracted diversion, it is one year.[6]

The definition of a reprocessing facility will need to be clarified in the relevant FMCT safeguards agreement. Currently, the IAEA defines a reprocessing facility to be any installation that has the capability to separate nuclear material from fission products, regardless of the throughput, inventory or operational status. This includes hot-cell facilities with separation capabilities. A more practical criterion for including facilities as reprocessing facilities under the FMCT could be that an installation must have the capability to separate and purify at least one significant quantity of fissile material per year.

The 15 largest operating reprocessing plants are shown in Table 1. Under an FMCT, many of the plants built to produce plutonium for weapons would be decommissioned. Some could continue in operation, however, for civilian purposes and some could be used for military purposes that would not be banned by an FMCT, for example, reprocessing fuel from naval-propulsion and tritium-production reactors.

Facility	**Type**	**Operational Status**	**Operating Capacity (**tHM/yr)
France			
UP2	Civilian	Operating	1000
UP3	Civilian	Operating	1000
India			
Trombay	Military	Operating	50
Tarapur	Dual	Operating	100
Kalpakkam	Dual	Operating	100
Israel			
Dimona	Military	Operating	40-100
Pakistan			
Nilore	Military	Operating	10-20
Russia			
RT-1	Dual	Operating	400
RT-2	Civilian	Construction suspended, 1989	800
Seversk	Dual	Operating	6000
Zheleznogorsk	Dual	Operating	3500
U. K.			
B205	Civilian	Operating	1000
THORP	Civilian	Operating	1200
U. S. A.			
PUREX	Military	Shut-down	7400
SRP	Converted	Special Operations	15

Table 1. Major reprocessing plants outside the NPT non-weapon states, their status and their operating capacities. Capacities are defined in terms of the operating or licensed maximum annual throughput of metric tons of "heavy metal" (uranium and plutonium) in the material being reprocessed (tHM/yr). Design capacity is sometimes much larger than the typical operational throughput.[7]

The reprocessing plants to be safeguarded under an FMCT may be grouped into the following categories:

- Operating civilian plants,
- Operating plants reprocessing fuel from military reactors sometimes exclusively and sometimes in combination with civilian-reactor fuel,
- Shut-down or closed-down plants, and
- New civilian plants, not yet operating.

The large plants that have been operating without international safeguards prior to the FMCT will pose the greatest challenge. Unlike Rokkasho, provisions for safeguards will not have been designed into the plants nor the constructed designs verified by the IAEA during construction and before the plants went into operation. It would be extremely expensive for the IAEA to attempt to retrofit an operating plant with safeguards measurement and monitoring systems similar to those installed in the Rokkasho Plant. Where independent measurement and monitoring systems cannot be installed at reasonable cost for verification of operator measurements, the IAEA may have to accept a lower probability of detection of a diversion.

The following sections of this paper describe the general approach to reprocessing-plant safeguards that has been developed by the IAEA and a modified approach that could be adapted to already-operating plants in weapon states. We include a brief discussion of safeguards at mixed-oxide (uranium-plutonium, MOX) plants. Subsequent sections describe more briefly safeguards approaches for military plants, new operating plants constructed after an FMCT comes into force, and shut-down or closed-down facilities.

FMCT Safeguards at an Operating Reprocessing Plant

A safeguards approach for reprocessing plants must address primarily two types of attempted diversion scenarios under which the operator either:

1) Reprocesses undeclared nuclear material, bypassing the accountancy measurement points; or
2) Removes plutonium at a low rate that cannot be detected with confidence, due to measurement uncertainties.[8]

Although almost all reprocessing plants use the PUREX process, their design and operating modes vary considerably. These plant characteristics and the operator's nuclear material accountancy systems must be considered when designing a safeguards approach for a specific facility. The arrangements necessary to implement the IAEA safeguards approach at a specific facility are described in the Facility Attachment to the national safeguards agreement.[9]

The next section provides a technical description of the activities and accountancy measurements within a reprocessing plant. This is followed by a discussion of the proposed FMCT Safeguards Approach.

Material Balance Areas and accountancy measurements. Using the Rokkasho Reprocessing Plant as an example, Figure 1 shows an accountancy structure having five Material Balance Areas (MBAs).[10]

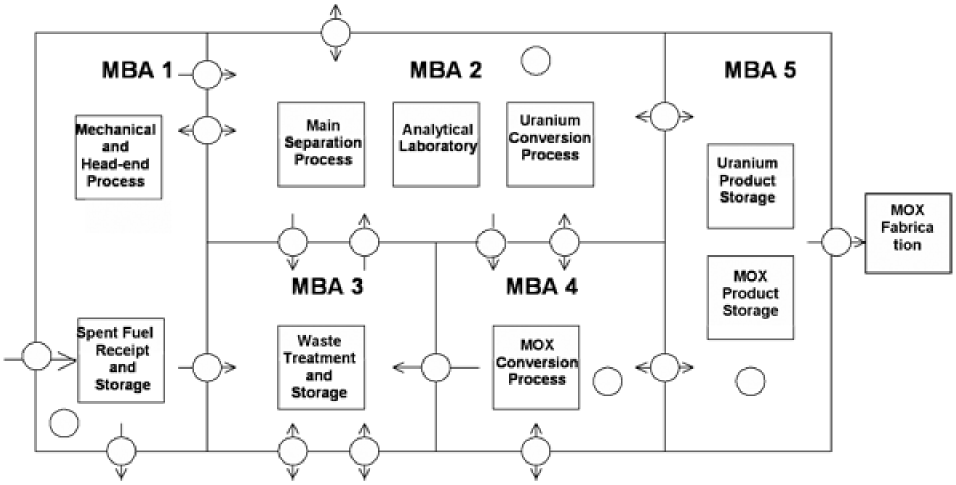

Figure 1. Accountancy Structure for the Rokkasho Reprocessing Plant. The circles indicate Flow Key Measurement Points for verification of Inventory Changes. Those with arrows indicate FKMPs across MBA boundaries and those without arrows for those calculated within an MBA, such as nuclear material loss and gain. The boxes represent Inventory Key Measurement Points within the MBAs, which are established for the verification of inventory declarations and timeliness.

MBA 1 – *Cask Receipt and Storage, Spent Fuel Unloading and Storage, and Head-End Process.* Irradiated fuel assemblies are received in casks from a reactor or away-from-reactor storage facility and stored in one or more ponds at the reprocessing facility (see, for example, Figure 2).

There are currently no accurate measurement methods available to verify the plutonium content in the spent fuel. The uncertainties of the reactor-operator calculations of plutonium content can be 3 to 10 percent, and sometimes even larger.

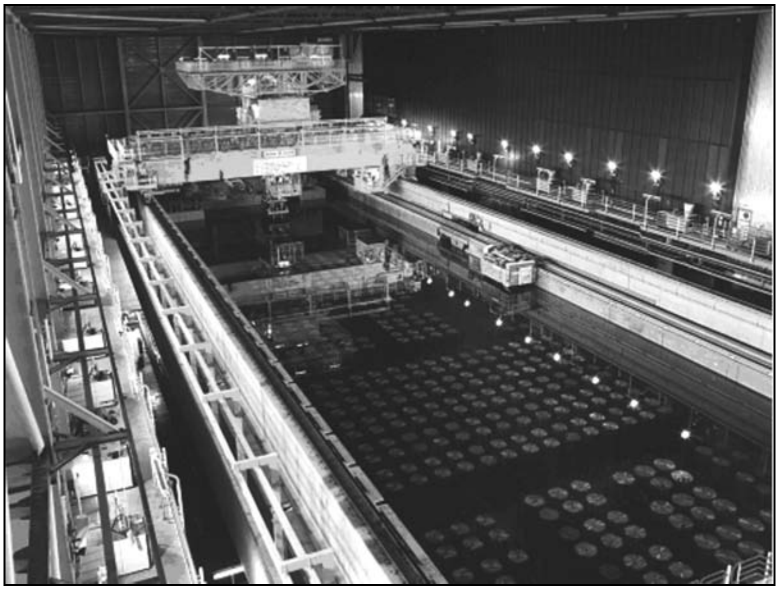

Figure 2. Spent-fuel storage pool at the U.K. Thermal Oxide Reprocessing Plant (THORP). *Source: World Nuclear Association.*[11]

The fuel assemblies are later transferred from the storage pool(s) into the head-end process of the plant where they are chopped or sheared into small pieces for dissolution in boiling nitric acid. Most plants use a batch process for dissolution, but some modern plants, such as those in France, use a continuous-feed dissolver.

Accountancy measurements are made in a well-calibrated Input Accountability Tank. Measurements of the volume of the clarified dissolver solution and its concentration of plutonium provide the first good measurements (0.3 to 1.0 percent uncertainty) of the plutonium content in the spent fuel entering the reprocessing plant. The solution is then transferred in measured batches to the main separation process in MBA2.

Undissolved structural parts of the spent fuel assemblies, including fuel-rod-cladding “hulls” and assembly end pieces, are collected into drums. The highly radioactive solid waste and additional liquid wastes are transferred to a waste treatment and storage area (MBA3).

It is critical to assure that the dissolver solution being measured comes from the declared spent fuel and that none of the dissolver solution bypasses the Input Accountability Tank. Surveillance and radiation monitoring systems are used to track the spent fuel into the dissolver vessel, and solution-monitoring systems track the dissolver solution to the Input Accountability Tank.[12]

MBA 2 – *Main Separation Process*. The measured batches of dissolver solution received from MBA1 are processed in a first extraction cycle. There the plutonium and uranium are separated from the fission products in an organic solvent mixed into the acid. Uranium and plutonium are then separated from each other and their solutions transferred to their purification cycles. Depending on the methods used, measurements of the purified plutonium in solution have an expected uncertainty of between 0.2 and 0.8 percent.

In the Rokkasho Reprocessing Plant, the separated uranium is purified, concentrated and approximately 99% of the uranyl nitrate is then transferred to a conversion process – all within MBA2. After conversion to UO_3, it is transferred to a product-storage area in MBA5. The remaining uranyl nitrate is routed directly to the uranium-plutonium mixed-oxide (MOX) powder-production process in MBA4.

Although the uncertainties of the main flow measurements into and out of MBA2 are relatively small, if the process hold-up inventory is large, it could provide an opportunity to divert material that would not be detected until after the yearly clean-out and Physical Inventory Verification is conducted. Continuous monitoring of selected process flows within MBA2, using installed solution monitoring systems, provides continuity of knowledge and confirmation of the declared operational status.

MBA 3 – *Waste Treatment and Storage*. Highly radioactive liquid waste, containing undissolved particles from the head-end process, concentrated fission products, and medium activity liquid waste are received in the waste-treatment area. They are further concentrated by evaporation and may be mixed together prior to being introduced to a vitrification process in which they are mixed into molten glass. After accountancy measurements have been completed for consideration of termination of safeguards, canisters of solidified vitrified waste are transferred to a long-term storage area.

At the Rokkasho Reprocessing Plant, the uranium and plutonium present in drums containing leached hulls and end pieces received from the Head-End (MBA1) are measured or estimated for accountancy purposes. Only when waste has been treated to make the nuclear material “practically irretrievable”—for example by vitrification or mixing with cement—can it be considered for termination of safeguards. Following accountancy measurements, wastes that have not been made practically irretrievable are stored at the MBA as “retained waste.”

The total quantity of plutonium going into waste in a reprocessing plant is typically less that 0.5 percent of the total throughput, with concentrations in the milligram per liter (parts per million) range. Due to the low concentrations and inhomogeneities, the measurement uncertainty, using current technology, is 5 to 25 percent.

MBA 4 – *Mixed-oxide (MOX) Conversion Process.* The process of producing uranium-plutonium mixed-oxide powder at the Rokkasho Reprocessing Plant starts with the mixing of uranyl and plutonium-nitrate solutions. The resulting mixture is dried and calcined to produce oxide powder that is then milled to a uniform particle size. Processes used in other countries convert the uranium and plutonium solutions to oxide powders separately prior to mixing.

Prior to canning, the powder lots are sampled and the filled cans are weighed for nuclear-material-accountancy purposes. The cans are then packed into storage canisters and transferred to the product-storage area in MBA5.

Although the samples of the oxide product can be measured in a laboratory with uncertainties of about 0.2 percent, non-destructive analysis (NDA) using neutron and gamma radiation counters is more likely to be used on the storage containers for safeguards verification. The enhanced NDA system developed for the Rokkasho Reprocessing Plant has reduced the measurement uncertainties to less than 0.8%. Such measurements can be performed using an unattended measurement system.

The in-process inventory in the plutonium conversion line can be quite large. As a result, a significant diversion might not be detected until the annual clean-out and the physical inventory verification. Some form of continuous solution monitoring in the feed vessels and radiation monitoring[13] along the conversion lines is therefore needed to assure that the process is operating as declared.

MBA 5 – *MOX and Uranium Product Storage*. In the Rokkasho Reprocessing Plant, canisters of uranium-oxide product are received for storage from the Conversion Process in MBA2 and canisters of MOX product are received from the MOX conversion process in MBA4.

Since this MBA is a storage area containing previously verified containers of product material, there need be no new measurements. The integrity of the measurements performed in MBA4 is maintained by surveillance and radiation monitoring systems to detect movements of containers and materials within and out of the facility. In other plants, containers used for long-term storage could be sealed with tamper-indicating seals.

MBA X – *MOX-Fuel Fabrication*. At Rokkasho, the JMOX fuel fabrication facility will be physically connected to the MOX conversion building. Although it could be considered as an additional MBA to the Pu recycle process, at Rokkasho it will be a separate facility. If located on another site, as in France, it would normally be considered a separate facility. In the latter situation, continuity of knowledge would need to be maintained on the MOX powder during shipping—usually by sealing the containers—in order to avoid the requirement of re-measurement upon receipt in the fabrication plant.

At a MOX-fuel fabrication plant, MOX powder is blended with uranium oxide to the desired Pu/U ratio and introduced to the pelletizing process. The pellets are then loaded into fuel rods that are combined into fuel assemblies (see Figure 3). Storage areas are required between the various processes and for the final MOX fuel assemblies prior to shipment to the receiving reactors. Storage areas are also provided for MOX-containing scrap material from the process.

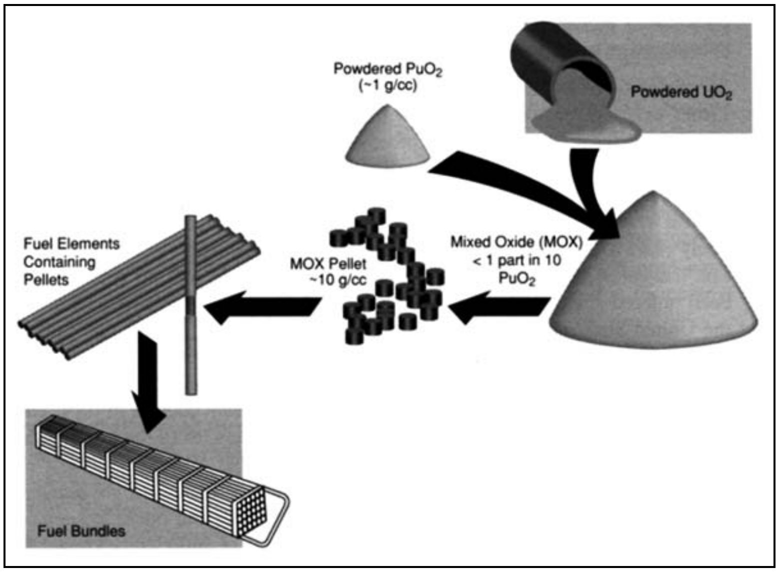

Figure 3. Stages of MOX fuel fabrication. Because the dangers of radiation doses to the lungs and bones from inhaled plutonium oxide, the production of MOX fuel has to be done inside glove boxes until the end caps are welded onto the fuel rods and the outsides of the rods are cleaned.[14]

Because there can be large inventories stored in a MOX plant, they can contribute significantly to the over-all material-balance evaluation during the yearly physical inventory verification.

The uncertainty associated with the measurement of plutonium in the fabricated MOX fuel assemblies is quite high—approximately 10 percent.[15] Because of this high uncertainty, it is important to monitor the flow of material through the process with containment and surveillance devices and radiation monitoring systems.[16]

Safeguards Approach. At already-operating reprocessing plants in the weapon states, meeting the current IAEA Safeguards Criteria would be very costly and perhaps impossible. With some reduced confidence in meeting the IAEA timeliness requirements, newer verification and monitoring tools and methods could be used to drastically reduce the verification costs relative to those for Rokkasho with only a relatively modest increase in measurement uncertainties. Specifically, the proposed Safeguards Approach for FMCT verification at already operating reprocessing plants includes the following changes:[17]

- *Short-Notice Random Inspections (SNRI) instead of continuous inspector presence at reprocessing plants.*[18] SNRIs at a frequency of six to eight per year would replace the current NPT monthly inventory verification inspections to meet timeliness requirements. Although some intervals between inspections would be longer than one month, a delay in the detection of a diversion would appear to be much less serious in a weapon state than in a non-weapon state. As will be shown below, eliminating the need for continuous inspector presence would greatly reduce costs.

  The operators of a reprocessing plant would be required to provide advance declarations of operational schedules and continuous, timely declarations of materials flows and inventories**.** These declarations would offset the reduced presence of IAEA inspectors and provide the basis for inspection activities during an SNRI.[19] This would also result in more transparent facility operations. Of course, while inspection efforts and costs would be reduced for the IAEA, more of a burden would be placed on the operators and their State authorities.

  The installation of continuous solution and radiation monitoring systems and Containment/Surveillance (C/S) measures would give additional confidence by providing continuity of knowledge of material flows and movements, and of the operational status of the reprocessing plant between the SNRIs.

  Inspection activities at other strategic points during the SNRIs could provide added assurance that the facility is being operated as declared. These could include random, very short notice checks of expected or declared operating parameters in control rooms and a low level of random sampling of material in process.[20]

- *A random number of measurements during the SNRIs would replace the 100% verification of major inventory changes in the MBAs.* The use of unattended measurement systems and continuous monitoring would compensate for the reduced verification level.

- *Focus primarily on establishing materials balances for plutonium and highly enriched uranium.*[21] Less effort than under NPT safeguards in non-weapon states would be devoted to verifying inventories of low-enriched, natural, and depleted uranium.[22] This would be compatible with most other proposals for verification of an FMCT in that they do not include monitoring of these materials at other facilities.

- *Verify waste transfers only in cases of large discrepancies between operator declarations* and declared and verified design and operational production values. If the design values are on the order of 0.5 percent of the plant throughput—i.e., the same order as the measurement uncertainties—this would not increase overall uncertainties that much.

The following procedures and equipment would be the same as the current approach for NPT verification at the Rokkasho Reprocessing Plant:

- *Physical Inventory Verification once a year after the facility has been cleaned out and the operator has provided an inventory declaration.* Statistical evaluations of the operator's declaration and verification results would indicate whether significant quantities of nuclear material were ”unaccounted for.” Simultaneous inspections would be carried out at any other facilities in the state having the same type of nuclear material to assure that no “borrowing” between facilities was taking place.

- *Periodic verification of selected design information to confirm that no safeguards relevant changes have been made and that the facility design remained as declared by the operator*.

- A *large and dedicated Data Collection and Evaluation System to manage the volume of data and information resulting from operator declarations, surveillance and monitoring systems, and inspector on-site measurements*. [23] This system would collect data from inspector-controlled unattended measurement and monitoring systems and automatically perform preliminary evaluations based on the operator declarations or on expected or design values. The results, including alerts of possible discrepancies, could then be transmitted remotely to the IAEA.

This proposed simplified FMCT Safeguards Approach for operating reprocessing plants would yield an overall uncertainty for the annual material balance for the entire facility of about one percent – only marginally larger than the corresponding uncertainties for the NPT safeguards.[24] This excludes the larger uncertainties in both the NPT and FMCT safeguards approaches associated with the estimates of the amount of plutonium originally in the spent fuel and in measurements of the plutonium in fresh MOX fuel. These are dealt with by containment and surveillance to assure that no significant amount of plutonium is diverted between the dissolver and Input Accountability Tank or in the MOX fuel fabrication process. For a large facility like the Rokkasho Reprocessing Plant, which has an annual throughput of 800 tons of spent fuel containing about one percent plutonium (about 8,000 kg), a one-percent uncertainty translates into an overall measurement uncertainty of 80 kilograms plutonium – ten significant quantities. For this reason, the IAEA requires added assurance by additional measures. Many of these could be carried out during short-notice random inspections.

The following measures, for example, might be undertaken:

Random sampling of the process and waste streams, including ratios of plutonium and uranium with the minor transuranics, curium, americium and neptunium helps provide assurance that there had not been any change in operating parameters declared by the operator. Random measurements of the amount of plutonium in the newly filled plutonium oxide containers are also carried out non-destructively through analysis of the emitted gamma and neutron radiation. Finally, the declared in-process inventory of the conversion and any MOX fuel-fabrication lines can be verified.

The use of containment and surveillance could detect attempts to send undeclared batches of spent fuel through the plant. Random, short-notice measurements of plutonium in dissolver solutions in MBA1, in plutonium nitrate in MBA2, and in oxide in MBA4 would deter any abrupt large-scale diversion. Measurements at a few key points would make it more difficult to hide slow but sustained diversions of plutonium.

For any operating facility, the in-process hold-up of plutonium would be significant. The various verification measures taken during the short-notice inspections therefore would have to be confirmed by the annual Physical Inventory Verification, when the facility is completely cleaned out.

Table 2 compares the effects of the Adapted Safeguards Approach with the Safeguards Approach being implemented at Rokkasho. A more detailed list of inspection activities that would need to be carried out in order to implement the proposed Adapted Safeguards Approach for operating facilities under an FMCT is provided in the Appendix. The associated measurement uncertainties are expressed as percent Relative Standard Deviation (RSD) at 1 sigma. They represent best approximations based on International Target Values[25], experience in other facilities,[26] and expected results at the Rokkasho Reprocessing Plant.

Material for Verification	**Safeguards Criteria for Non-Weapon States**		**Interim Adapted Safeguards Criteria for Weapon States**	
	Inspection Activities	**%RSD**	**Inspection Activities**	**%RSD**
Inventory Changes	Continuous verification	Solution=0.8 Oxide=0.8	Unattended, remote monitoring & SNRI	Solution=1.0 Oxide=1.0
Interim Inventory Verification	Monthly for Pu timeliness. NRTA evaluations.	Solution=0.8 Oxide=7 Fuel=7	6-8 SNRI of one week duration.	Solution=0.9 Oxide=10 Fuel=10
Other Strategic Points	Flow within the MBA for confirmation of the operational status	NA	Flow within the MBA for confirmation of the operational status	NA
Physical Inventory Verification	Process cleanout once per year.	Solution=0.6 Oxide=1.1 Oxide/Scrap=4	Process cleanout once per year inspections.	Solution=0.8 Oxide=1.5 Oxide/Scrap=4

Table 2. Overview of Inspection Activities

Equipment and inspection costs. The cost of the proposed FMCT Safeguards Approach for a large operating reprocessing plant would be significantly less than estimated in the 1996 Brookhaven Report and far less than cost of NPT safeguards at the Rokkasho Reprocessing Plant.

Equipment and software costs. Purchase of initial hardware and software would cost about $15 million (to be paid by the IAEA), or about one fifth the cost incurred for the Rokkasho Reprocessing Plant. Some of this cost could be shared by the host state and/or operator if an acceptable 'joint use' of specific systems could be arranged. Installation and maintenance (to be paid by the host state) would cost perhaps $5 million.[27] Maintenance and replacement over the first ten years would average about $1 million per year (to be shared by the IAEA and the state).

These estimates are based on experience at Rokkasho and other facilities. Costs for the proposed FMCT safeguards system are reduced by the elimination of a number of very expensive waste-measurement systems. Some savings have been assumed for the measurement/monitoring and data handling systems because much of the R&D and design work carried out for the Rokkasho plant could be adapted for other reprocessing plants.[28] A final cost saving, compared to Rokkasho, would be that a full-capability on-site laboratory[29] would not be included. Unattended measurement systems and inspector operated equipment would be implemented to the extent possible. A few samples would be sent to the IAEA.

Inspection costs. Table 3 summarizes the projected routine inspection effort required to implement the FMCT Safeguards Approach for an operating reprocessing plant. Although larger teams are required for the Short Notice Random Inspections, the elimination of the requirement of continuous inspector presence reduces the Person Days of Inspection (PDI) and therefore the inspection effort to about one fifth or less that of the NPT safeguards at the Rokkasho Reprocessing Plant.[30]

Inspection or Visit	Visits per Year	Inspection Days	Number of Inspectors	Person Days
Short Notice Random Inspection	8	5	3	120 PDI
Physical Inventory Inspection	1	10	5	50 PDI
Other Activities				30 PDI
TOTAL	**9**	**15**	**8**	**200 PDI**
COST	**200 PDI X $2000/PDI/year = $400,000/year**			

Table 3. Annual Inspection Effort in person-days of inspection (PDI) and cost.

Plants Reprocessing Fuel from Military Reactors

Of the 13 reprocessing plants currently operating in nuclear weapon states listed in Table 1, seven are labeled as military or dual purpose. Of these:

- The reprocessing plants at Seversk and Zheleznogorsk in Russia are to be shut down.[31]

- India's three reprocessing plants will either revert to civilian status when that country joins the FMCT or shut down; and

- Israel's reprocessing plant would be expected to shut down when that country joins the FMCT.

This leaves Russia's RT-1 reprocessing plant at the Mayak complex in the Urals. It treats spent LEU fuel from first-generation VVER-440 light-water power reactors, and spent HEU-fuels from the BN-600 demonstration breeder reactor, research reactors, naval reactors and the isotope-production reactors that produce tritium for Russia's nuclear weapons.[32] No other weapon state currently reprocesses its naval or tritium-production reactor fuel.[33] There may therefore be sensitivities at the RT-1 plant about foreign inspectors becoming aware of naval-reactor fuel design or perhaps about the power levels at which the tritium-production reactors are operating.[34]

Russia might want to conceal from IAEA inspectors the design and perhaps enrichment of the spent naval fuel. The quantities and isotopics of the fuel coming from different types of reactors could be concealed, however, by not revealing exactly which fuel is being reprocessed at a particular time and mixing fuel from different types of reactors in the same dissolution batch.[35]

Future Reprocessing Facilities

Under an FMCT, any new reprocessing plants built in nuclear weapon states should be subject to the same safeguards criteria as new plants in non-nuclear weapon states. Lessons learned from the Rokkasho plant have shown the importance of designing safeguards features into new facilities that will reduce the inspection effort and improve the quality of safeguards. Modernizing the safeguards approach for future reprocessing facilities could yield a great reduction of inspection effort and costs along with enhanced operational transparency. This would involve:

- Design features to make the plants more safeguards friendly;[36]
- An integrated state-level approach including all fuel-cycle facilities;
- Short-notice random inspections as an alternative to permanently-stationed inspectors;
- Remote monitoring capabilities for timely review at IAEA headquarters;
- Some on-site analytical capabilities for timely results;
- Continuous monitoring of major material flows and frequent (possibly daily), random sampling and measurement of in-process material. This could possibly be achieved using unattended, on-line measurement systems;
- Short-notice access to operating records to provide higher assurance of no tampering;
- Establishing expected ratios of selected isotopes and elements in wastes in order to better identify their source and confirm process operating parameters;
- Implementation of Flow Sheet Verification to confirm that neptunium, curium, and possibly americium follow their expected routes through the reprocessing plant, as declared by the operator; and
- Specialized inspectors.

Safeguards Approach for Shutdown or Closed-Down Facilities

A shutdown facility is one that contains nuclear materials and could be restarted. A closed-down facility has been cleaned out but has not yet begun decommissioning. In non-weapon states, facilities that have been either shutdown or closed-down continue to be categorized as facilities, irrespective of inventory, and remain under IAEA safeguards. Inspection and design verification activities are conducted for the purpose of assuring that no new nuclear material has been introduced, that the current inventory (if any) remains as declared and that operations of the facility have not been restarted[37]. This approach would also apply under the FMCT.

The Safeguards Approach in this case would be based on the concept of monitoring selected facility operations combined with short-notice random inspections (SNRI). This would require that the operator provide to the IAEA operational schedules and activities in advance or in near-real time. Operator declarations [38] would need to be reported within an agreed time for the specific operations being monitored. This could be done using the standard electronic IAEA Mailbox System.[39] The short notice random but infrequent inspections would be performed to collect and review monitoring data and to check containment/surveillance (C/S) systems. Operator declarations received by the IAEA would be used as reference data and for planning inspections. Notice time to the State of a pending SNRI would be determined by the travel requirements to the site and restrictions within the State. For such inspections, multiple-entry visas should be issued to IAEA inspectors for a period of one year.

A combination of some of the following monitoring and inspection activities could be implemented according to the specific facility situation and design:

- *Satellite or aerial monitoring* could possibly detect arrival of spent fuel or other externally visible manifestation of unusual activities at a facility.

- *With improved technology, motion and/or radiations sensors* could possibly be used as monitors or as activation systems for cameras to detect and record the receipt of fuel or crane movements.

- *Monitoring and/or sealing of the spent fuel transfer channel to the head-end mechanical cells.* A combination of gamma and neutron sensors, along with video surveillance, would detect any movement of spent fuel to the mechanical cells for chopping and feed to the dissolvers. In some cases the channel could be rendered inoperable by applying tamper-indicating seals.

- *Sealing or monitoring of the shear mechanism controls*. In some facilities the control system for the shearing machine can be rendered inoperable by applying tamper indicating seals. Surveillance of the control area along with acoustical monitoring could also provide added assurance that shearing is not taking place.

- *Monitoring solution flows* within selected locations (tanks) could confirm that there are no undeclared operations. Declared operations such as cleanout or system testing could take place and be monitored. An unattended and authenticated Solution Measurement and Monitoring System (SMMS), which shares the pressure signals from the operator's tank level sensors, could provide a continuous record of solution volumes and densities within selected tanks. The use of Solution Monitoring Software (SMS) would assist the inspector in interpreting the collected data and could provide some confidence that the data was true and correct.

- *Monitoring of the plutonium conversion and/or fuel fabrication lines*. The installation of radiation sensors, such as He^3 neutron detectors, at selected locations on the process lines, could detect the increased presence of neutron emitting material and the direction of movement. Data could be collected locally in an unattended mode or transmitted to a data collection and evaluation system.

- *Monitoring the use and/or storage of essential reagents*, such as Tributyl phosphate. Feed valves might be immobilized with tamper-indicating seals or external flow sensors could be attached to the feed lines.

- *Monitoring or periodic checking for the gaseous fission product Kr-85* could reveal undeclared fuel dissolution activities. During inspections, the operator's Kr-85 gas monitors should be checked, particularly on the safety panels. External environmental monitoring for Kr-85 gaseous effluents could be used if there are no other operating reprocessing plants in the vicinity[40].

The cost of implementing safeguards at a shutdown or closed-down facility would vary depending on the complexity and accessibility of the plant, the presence or absence of nuclear material, its current use and activity, and its geographical location. The use of only two of the above options would normally be sufficient, however, to provide assurance of a facility's non-operating status. The use of remote monitoring systems would dramatically reduce the need for physical presence of inspectors on-site, except for equipment maintenance and discrepancy resolution. Overall, the safeguards burden would be low.

Conclusion

Modern safeguards approaches would make possible verification of the FMCT at operating reprocessing plants. This could be done at a confidence level comparable to what is achieved by the IAEA today at Japan’s Rokkasho facility with only a modest increase in the expected time for detecting a significant diversion of plutonium. By replacing the permanent on-site inspectors and laboratory with short-notice random inspections and other measures, the costs could be greatly reduced relative to the Rokkasho NPT safeguards system.

Plants (currently only one) that reprocess naval and other military-reactor fuel may require certain special arrangements to allow effective safeguarding, while allowing the owning states to protect fuel quantity and design information that they may consider sensitive national-security information.

For any new reprocessing plant constructed after an FMCT comes into force, the safeguards approach should be the same as that used in the non-nuclear states under the NPT, but modernized to reduce inspection effort.

Verification of shut-down and closed-down plants could be done largely through a combination of remote monitoring, seals and short-notice random inspections. The safeguards burden would not be high.

Endnotes

[1] It is assumed that the Yongbyon reprocessing plant in the Democratic People's Republic of Korea will have been fully decommissioned before an FMCT comes into force.

[2] The IAEA spent $92 million directly on safeguards in 2006. Including a 35-percent overhead for its share of Information and Support Services and Policy and General Management would bring the total to $124 million; *IAEA Annual Report 2006,* International Atomic Energy Agency, Vienna, 2007, Table A1.

[3] D. Dougherty, A. Fainberg, J. Sanborn, J. Allentuck, and C. Sun, *Routine Inspection Effort Required for Verification of a Nuclear Material Production Cutoff Convention,* Brookhaven National Laboratory, Report BNL-63744, SSN-96-14, 1996, www.ipfmlibrary.org/bnl96.pdf.

[4] *IAEA Safeguards Criteria,* Issued 1 January 2004.

[5] *IAEA Safeguards Glossary,* 2001 edition, Table II, p. 23.

[6] *IAEA Safeguards Criteria, op. cit.*

[7] *Global Fissile Materials Report 2006,* International Panel on Fissile Materials, Princeton, NJ, www.ipfmlibrary.org/gfmr06.pdf, Table 3.3, corrected.

[8] Ralph G. Gutmacher, *Measurement Uncertainty Estimates for Reprocessing Facilities*, Los Alamos National Laboratory, LA-11839-MS (ISPO-315), October 1990; and *International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Materials*, IAEA STR-327, 2001.

[9] Tariq Rauf, IAEA, "A Cutoff of Production of Weapons Usable Fissionable Material: Considerations, Requirements and IAEA Capabilities," Conference on Disarmament, Geneva, 24 August 2006, www.ipfmlibrary.org/rau06.pdf.

[10] S. Johnson and A. Islam, "Current IAEA Approach to Implementation of Safeguards in Reprocessing Plants", *Proceedings of the Fourth International Conference on Facility Operations—Safeguards Interface*, October 1991; S. J. Johnson, R. Abedin-Zadeh, C. Pearsall, et al, "Development of the Safeguards Approach for the Rokkasho Reprocessing Plant," IAEA Symposium on International Safeguards, Vienna, Austria, 1997.

[11] www.world-nuclear.org/education/graphics/storpondthorp.gif, 5 June 2008.

[12] M. Ehinger, B. Chesnay, C. Creusot, J. Damico, et al., "Solution Monitoring Applications for the Rokkasho Reprocessing Plant", 7th International Conference on Facility Operations-Safeguards Interface, Charleston, SC, 2004.

[13] K. Whitehouse, E. Carr, D. Sim, G. Morris, and K. Tolk, "PIMS for Safeguards Measurements at Rokkasho Reprocessing Plant", 7th International Conference on Facility Operations-Safeguards Interface, Charleston, SC, 2004.

[14] www.ieer.org/sdafiles/vol_5/5-4/c-fold.html, 7 June 2008.

[15] Development work is currently underway to improve on this measurement in support of the construction of the JMOX Fabrication Plant in Japan.

[16] Y. Abushady, "Short Notice Random Inspection (SNRI) Regime at a Uranium Fuel Fabrication Plant in Spain", IAEA Symposium on International Safeguards, Vienna, 16-19 October 2006, *op cit*; and T. Ishikawa, "Implementation of SNRI and Borrowing Inspection in Japan", IAEA Symposium on International Safeguards, Vienna, 16–19 October 2006.

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[17] Thomas Shea et al., “Safeguarding Reprocessing Plants: Principles, Past Experience, Current Practice and Future Trends,” *Journal of the Institute of Nuclear Materials Management,* Vol. 21, Issue 4, 1993; Fred Franssen, Shirley Johnson, and Thomas Shea, “Planning for Design Information Verification at the Rokkasho Reprocessing Plant”, 35th Annual INMM Meeting, July 1994; J. G. M. Goncalves, V. Sequeira, B. Chesnay, C. Creusot, et al., “Verification of Plant Design: Instruments and Methods”, 44th Annual INMM Meeting, Phoenix, AZ, 2003; and B. Chesnay, C. Creusot, S. Johnson, et al., “Innovative Approaches to DIE/DIV Activities at the RRP”, 7th International Conference on Facility Operations-Safeguards Interface, Charleston, SC, 2004.

[18] Y. Abushady, “Short Notice Random Inspection (SNRI) Regime at a Uranium Fuel Fabrication Plant in Spain,” IAEA Symposium on International Safeguards, Vienna, 16–19 October 2006; and T. Ishikawa, “Implementation of SNRI and Borrowing Inspection in Japan”, IAEA Symposium on International Safeguards, Vienna, 16–19 October 2006.

[19] J. Wuester, B. Chesnay, G. Gerrein, et al., “Automating the Operator Interface—Operator Declarations at RRP,” 7th International Conference on Facility Operations-Safeguards Interface, Charleston, SC, 2004.

[20] The samples could be subject to on-site measurements using non-destructive techniques for nuclear material content, ratios of selected isotopes or characteristics of process chemicals. A very small number of samples could be periodically sent for destructive analyses at the IAEA Safeguards Analytical Laboratory in Austria.

[21] Although most civilian reprocess plants recover plutonium from low-enriched-uranium spent fuel, some military reprocessing plants recover HEU as well from naval, production and research-reactor fuel.

[22] Some verification of uranium would be required, however, because verification of the Pu/U ratios at selected points within the process is essential to understanding the operations of the facility.

[23] J. Wuester et al., *op. cit*.

[24] Ralph G. Gutmacher, “Measurement Uncertainty Estimates for Reprocessing Facilities,” Los Alamos National Laboratory, LA-11839-MS (ISPO-315), October 1990.

[25] IAEA STR-327. International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Materials (April 2001).

[26] Ralph G. Gutmacher, “Measurement Uncertainty Estimates for Reprocessing Facilities,” Las Alamos National Laboratory, LA-11839-MS (ISPO-315), October 1990.

[27] Installation costs are very dependent on the state.

[28] The data collection and evaluation system would still remain a major expense, however – more than half the initial investment by the IAEA.

[29] G. Duhamel, E. Kuhn, P. Zahradnik-Gueizelar, Y. Kuno, et al, “Establishing the Joint IAEA/JSGO/NMCC Safeguards On Site Laboratory for the Rokkasho Reprocessing Plant: a major challenge for managing the interfaces,” 7th International Conference on Facility Operations-Safeguards Interface, Charleston, SC, 2004.

[30] Our estimates do not take into account the effort required for the initial setting up and testing of safeguards equipment and procedures. Also, the travel time required to implement short-notice random inspections (SNRIs) in some States may affect the number of required PDIs per inspection. The $2000/PDI used in Table 2 is an incremental number. Dividing the total IAEA Safeguards budget by the number of PDIs per year would yield a number closer to $10,000/PDI.

[31] Two associated plutonium-production reactors in Seversk shut down in the summer of 2008 and the Zheleznogorsk reactor is to shut down in 2011, U.S. Department of Energy, *Fiscal Year 2009 Budget Request, Vol. 1, National Nuclear Security Administration,* February 2008, p. 509.

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[32] Reportedly, the RT-1 plant has three separate spent-fuel dissolution lines for: 1) Low-enriched (3-4% enriched) uranium from Russia's first-generation VVER-440 light-water reactors; 2) Medium (17–26 percent) enriched uranium fuel from Russia's BN-600 demonstration breeder reactor; and 3) Ninety-percent-enriched uranium fuel from two isotope-production reactors at Mayak and from naval and research reactor fuels with a variety enrichments. For RT-1 reprocessing lines, T. B. Cochran, R. S. Norris and O. A. Bukharin, *Making the Russian Bomb: From Stalin to Yeltsin,* Westview, 1995, p. 84; and Anatoli Diakov, personal communication, 15 April 2008. For BN-600 fuel enrichment, O. M. Saraev, "Operating experience with Beloyarsk fast reactor BN600 [Nuclear Power Plant], *Technical committee meeting on unusual occurrences during LMFR operation,* IAEA-TECDOC—1180, 1998, p. 103. For enrichment of Russian isotope-reactor fuel, Oleg Bukharin, "The Size and Quality of Uranium Inventories in Russia," *Science & Global Security 6* (1996), p. 59. For enrichment of Russian naval-reactor fuel, Chunyan Ma and Frank von Hippel, "Ending the production of highly enriched uranium for naval reactors," *The Nonproliferation Review 8* (2001), p. 86. Russia's research reactors are fueled primarily by 90-percent or 36-percent enriched uranium, *Nuclear Research Reactors of the World,* International Atomic Energy Agency, Vienna, 200.

[33] France, the United Kingdom and the United States all store their spent naval-reactor fuel, Ashot Sarkisov and Alain Tournyol du Clos (eds.), *Scientific and Technical Issues in the Management of Spent Fuel of Decommissioned Nuclear Submarines,* NATO Science Series, Vol. 215, Springer, 2006. The United States produces its tritium in power reactors. France has been producing its tritium in its *Celestin* production reactors whose spent fuel is currently stored but may eventually be reprocessed at La Hague, Mycle Schneider, personal communication of information obtained from AREVA, 21 May 2008. The United Kingdom shut down its Chapel Cross power reactors, which also produced its tritium in 2004. It is not known what arrangements the United Kingdom has made for its future tritium supply. One possible source is the United States.

[34] The production for use in nuclear weapons of tritium, an isotope with a half-life of 12.3 years, would not be banned by the FMCT because tritium is not a fissile material.

[35] There might be limits on the flexibility for mixing different types of fuel, depending on their dissolution characteristics.

[36] Permanently installed vessel calibration systems for convenience and reproducibility; remote viewing capabilities into strategic cells for design verification; improved mixing, sampling and calibration capabilities in accountancy vessels; improved transparency and authentication for sampling systems; installation of accountancy systems that allow operators to declare inventories for any location in the facility at any time in order to accommodate short-notice or no-notice inspections; minimization of recycling of plutonium solutions and powders and improved transparency of the recycling that does occur (such recycling can create uncertainty for the interpretation of plutonium flow measurements and provides an opportunity for the same material to be declared more than once); well-defined waste handling and treatment areas to simplify accountancy and tracing of waste sources; independent measurement and monitoring systems for the inspectors, whenever possible and reasonable; and easier access to safeguards-relevant operating information.

[37] Thomas Shea, et al, "Safeguarding Reprocessing Plants: Principles, Past Experience, Current Practice and Future Trends," *Journal of the Institute of Nuclear Materials Management*, Vol. 21, Issue 4, 1993.

[38] J. Wuester, B. Chesnay, G. Gerrein, et al, "Automating the Operator Interface – Operator Declarations at RRP", 7th International Conference on Facility Operations-Safeguards Interface, Charleston, SC, 2004.

[39] Y. Abushady, "Short Notice Random Inspection (SNRI) Regime at a Uranium Fuel Fabrication Plant in Spain", IAEA Symposium on International Safeguards, Vienna, 16-19 October 2006; and T. Ishikawa, "Implementation of SNRI and Borrowing Inspection in Japan", IAEA Symposium on International Safeguards, Vienna, 16-19 October 2006.

[40] See e.g. "Detection of Clandestine Fissile Material Production," chapter 9 in *Global Fissile Material Report 2007.*

Appendix: Comparison of Safeguards Approaches

The table below compares the current safeguards approach used in the NPT non-weapon states with the “Adapted Interim Approach” suggested here for the reprocessing plants that are already built and operating in the other states to whose facilities safeguards would be applied as a result of the FMCT.

The shaded inspection activities would have the greatest impact on measurement uncertainties and detection capabilities.

	Safeguards Approach for NPT Non-Weapon States		**Interim Adapted Approach for Other States**	
Measurements	**Inspection Activities**	**%RSD**	**Inspection Activities**	**%RSD**
Inventory Changes	**Continuous verification**	**Sol=0.8** **Oxide=0.8**	**Unattended, remote monitoring & SNRI**	**Sol=1.0** **Oxide=1.0**
Spent Fuel Receipt	C/S measures. NDA for gross defects.	NA	C/S measures. NDA for gross defects.	NA
Dissolver Solution Transfers	100% sampling & HKED & IDMS with volume determination.	IDMS=0.2 HKED=0.7 Vol=0.2	Sampling & HKED during IIV. SMMS for volume and CoK.	Pu=0.7 U=0.6 Vol=0.5
Pu Solution Transfers	100% sampling & HKED & DA with volume determination.	HKED=0.6 DA=0.2 Vol=0.2	Sampling and HKED during IIV. SMMS for volume and CoK.	Pu=0.6 Vol=0.5
Pu Ox. Transfers	Random sampling & DA, or NDA and weighing.	DA=0.2 NDA=0.8 Wt=?	Random NDA and weighing during IIV.	NDA=0.8 Wt=?
MOX Shipment	Random sampling & DA, or NDA and weighing.	DA=.2 NDA=.8 Wt=?	NDA and weighing during IIV, as available.	NDA=1.1 Wt=?
MOX Fuel Shipments	NDA during SNRI	NDA=7	NDA during SNRI	NDA=10
All U Shipments	Sampling, DA and volume or weight.	UNH=1.2 UOx=?	No verification	NA
Recycle material	Sampling, DA and volume determination.	DA=3 Vol=1	Periodic sampling for DA at SAL, during IIV.	DA=3
Measured Discard	Vitrified HALW by NDA	NDA=10	Less than design values.	NA
To Retained Waste	Hulls by NDA. HALW by sampling, DA and volume determination.	NDA=10 DA=3 vol=1	Less than design values.	NA

	Safeguards Approach for NPT Non-Weapon States		Interim Adapted Approach for Other States	
Measurements	**Inspection Activities**	**%RSD**	**Inspection Activities**	**%RSD**
Interim Inventory Verification	**Monthly for Pu timeliness.** **NRTA evaluations.**	**Solu=0.8** **Oxide=7** **Fuel=7**	**6-8 Short Notice Random Inspections for 1 week duration.**	**Solu=0.9** **Oxide=10** **Fuel=10**
Spent Fuel	C/S evaluation	NA	C/S evaluation	NA
In-process U/Pu Solution.	Random sampling for HKED with SMMS for volume and CoK.	U/Pu=0.7 vol=0.3	Random sampling for HKED and volume, where available.	U/Pu=0.7 vol=0.5
In-process Pu Solution	Random sampling for HKED with SMMS for volume and CoK.	Pu=0.6 Vol=0.3	Random sampling for HKED and volume, where available.	Pu=0.6 Vol=0.5
In-process PuOx or MOX	In-situ NDA with monitoring for CoK.	NDA=7	In-situ NDA with monitoring for CoK.	Pu=10
Pu or MOX Product	C/S evaluation.	NA	C/S evaluation.	NA
MOX Fuel	NDA and item counting during SNRI	7	NDA and item counting	10
Facility Design	Design information examination and verification.	NA	Design information examination and verification.	NA
Other Strategic Points	**Flow within the MBA for confirmation of the operational status**	**NA**	**Flow within the MBA for confirmation of the operational status**	**NA**
Spent Fuel to Head-end	Radiation monitoring and surveillance.	NA	Radiation monitoring and surveillance.	NA
Complete Dissolution	In-tank density, temp. and time from SMMS.	NA	In-tank density, temp. and time from SMMS.	NA
In-process Solution Flows	Flow-rates, densities and volumes from SMMS.	NA	Limited flow-rates, densities and volumes from SMMS.	NA
Recycle material	Sampling for DA and volume determination.		Monitoring of OPDs for unusual transfers.	
Feed to Conversion	Random sampling for HKED and SMMS.		Monitoring with SMMS.	
Feed to Fabrication	Monitoring with NDA.		Monitoring with NDA.	
Flow Sheet Verification for Np	Periodic HKED or HRGS to confirm U:Pu:Np-237.		Periodic HKED or HRGS to confirm U:Pu:Np-237.	
Operating Conditions	Random checks of selected operating records.		Random checks of selected operating records.	

	Safeguards Approach for NPT Non-Weapon States		**Interim Adapted Approach for Other States**	
Measurements	**Inspection Activities**	**%RSD**	**Inspection Activities**	**%RSD**
Physical Inventory Verification	**Process cleanout once per year, including borrowing inspections.**	**Solu=0.6 Oxide=1.1 Oxide Scrap=4**	**Process cleanout once per year, including borrowing inspection.**	**Solu=0.8 Oxide=1.5 Oxide Scrap=4**
Spent Fuel in pond	C/S measures. Item Counting.	NA	C/S measures. Item Counting.	NA
In-process U/Pu Solution.	Random sampling for HKED and volume determination.	U/Pu=0.7 Vol=0.3	Random sampling for HKED and volume, if possible.	U/Pu=0.7 Vol=0.5
In-process U Solution	Random sampling for HKED and volume determination.	HKED=0.6 Vol=0.3	Random sampling for HKED and isotopics. No volume.	HKED=0.6
In-process Pu Solution	Random sampling for HKED and volume determination.	HKED=0.6 Vol=0.2	Random sampling for HKED and volume when possible.	HKED=0.6 Vol=0.5
In-process Pu Oxide	NDA to confirm cleanout.	NA	NDA to confirm cleanout.	NA
In-process U Oxide	NDA to confirm cleanout.	NA	NDA to confirm cleanout.	NA
Pu or MOX Product	Evaluation of C/S. Random samples for DA.	Solu=0.2 Ox=1.1	Evaluation of C/S.	NA
Waste	Random samples for DA and volume.	DA=3 Vol=1	Evaluate against design values.	NA
SRD Evaluation	Statistical evaluation.		Statistical evaluation.	
MUF Evaluation	Statistical evaluation		Statistical evaluation	

Glossary

NOTE: The following Glossary includes IAEA safeguards terminology[1] and as well as terminology specific to reprocessing safeguards.

Alternative Nuclear Material (ANM): Fissionable materials defined as Np, Cm and Am. While not defined under the IAEA Statute as source material or special fissionable material, information on separated ANM is collected by the IAEA under voluntary arrangements with relevant States.

Borrowing: Borrowing nuclear material from other facilities in the State to replace diverted nuclear material for the duration of an IAEA inspection.

Campaign: A timely connected series of reprocessing operation of materials which is characterized by a unique relationship such as origin or customer ownership.

Clean Out: The combination of run down, flush out, drain out and rinsing which is carried out before long term shut down between campaigns and at PIT.

Closed-down Phase (CP or CD): The closed-down phase of a facility (or part thereof) will begin when routine operations have been stopped and nuclear material has been removed to the extent possible, but the facility (or part thereof) has not been decommissioned for safeguards purposes. During this phase the facility may be either in a State of Preservation or in a State of Decommissioning:

> **State of Preservation (CP):** The facility will be in a State of Preservation when it is closed-down, as defined above, but decommissioning activities have not begun.
> **State of Decommissioning (CD):** The facility will be in a State of Decommissioning when it is closed-down, as defined above, and the Agency has been informed of the decision to begin decommissioning. Decommissioning activities for safeguards purposes will include the removal or rendering inoperable of the Essential.

Construction Phase (UC): The Construction Phase of a facility (or part thereof) will begin with the preparation of the site for construction and will continue until the new constructed is ready for commissioning. This phase includes the manufacturing and assembling of the components, the erection of civil works and structures, the installation of components and equipment and the performance of associated functional tests.

Commissioning Phase (CM): The Commissioning Phase of a new facility (or part thereof) will begin after completion of construction and before the new construction is considered to be functional. During this phase, systems and equipment will undergo extensive acceptance testing by the operator to ensure that the facility functions as designed. System and equipment operation will be tested in accordance with design assumptions and performance criteria. This phase may include the use of nuclear material for testing.

Continuity of Knowledge (C-o-K): The requirement that knowledge must be continuously maintained on nuclear material or equipment as to its location, flow, integrity, etc.

Cut off Time (C-o-T): That point in time for a flowing bulk facility, such as a reprocessing plant, that a material balance is struck and declared. The CoT is usually optimized so that as much material as possible is in locations that can be measured.

C/S: **C**ontainment and **S**urveillance

Destructive Analysis (DA): Determination of nuclear material content and, if required, of the isotopic composition of chemical elements present in the sample. Destructive analysis normally involves destruction of the physical form of the sample. In the context of IAEA safeguards, determination of the nuclear material content of an item sampled usually involves:

(a) Measurement of the mass of the sample;
(b) The taking of a representative sample;
(c) Sample conditioning (if necessary) prior to shipment to the Safeguards Analytical Laboratory for analysis;
(d) Processing of the sample to the chemical state required for the analysis (e.g. dissolution in nitric acid);
(e) Determination of the concentration of the nuclear material (U, Pu, Th) present in the sample (i.e. elemental analysis);
(f) Determination of the isotopic abundance ratios of U or Pu isotopes (i.e. isotopic analysis).

Decommissioned for Safeguards Purposes (DE): The facility (or part thereof) will be considered as Decommissioned for Safeguards Purposes when the structures, systems and equipment essential for its operations have been verified by the Agency as removed or rendered inoperable so that the facility can no longer be used to store, handle, process or utilize nuclear material.

Design Information (DI): "information concerning nuclear material subject to safeguards under the agreement and the features of facilities relevant to safeguarding such material". Design information includes the facility description; the form, quantity, location and flow of nuclear material being used; facility layout and containment features; and procedures for nuclear material accountancy and control. This information is used by the IAEA to design the facility safeguards approach, to determine material balance areas and select key measurement points and other strategic points, to develop the design information verification plan and to establish the essential equipment list. Design information for existing facilities should be provided by the State as soon as possible after the decision has been taken to put the facility under safeguards; in the case of new facilities, such information is to be provided by the State as early as possible before nuclear material is introduced into the new facility. Further, the State is to provide preliminary information on any new nuclear facility as soon as the decision is taken to construct, or to authorize the construction of, the facility, and to provide further information on the safeguards relevant features of facility design early in the stages of project definition, preliminary design, construction and commissioning. Facility design information is to be provided for any safeguards relevant changes in operating conditions throughout the facility life cycle. Design information is submitted to the IAEA by the State using the IAEA design information questionnaire (DIQ).

Design Information Examination (DIE): Activities carried out by the IAEA to determine that the State has provided all relevant descriptive and technical information needed, inter alia, to design a safeguards approach for a specific facility. These activities are also carried out to confirm that the information is consistent and complete.

Design Information Verification (DIV): Activities carried out by the IAEA at a facility to verify the correctness and completeness of the design information provided by the State. Initial DIV activities are performed on a newly built facility, or facilities or parts of facilities that are coming under safeguards for the first time, to confirm that the as-built facility is as declared. Periodic DIV activities are performed on existing facilities to confirm the continued validity of the design information and of the safeguards approach. The IAEA's authority for performing a DIV is a continuing right throughout all phases of a facility's life cycle until the facility has been decommissioned for safeguards purposes.

Diversion:

Diversion into MUF - A concealment method in which an amount of declared material M is removed from a material balance area and the accounting records are adjusted to account for the amount M removed. Because the operator's accounting records reflect the removal of M, there is no falsification of these records. This diversion strategy causes an imbalance in the MUF equation, and the diversion amount M shows up as part of a non-zero MUF. The diverter assumes that the uncertainty of MUF (δMUF) would be large enough to hide the removal. This type of diversion may be detected through observation of an unexpectedly large value of MUF. However, if δMUF is large because measurement quality is poor or because there are large quantities of material accounted for improperly, then the diversion of M can be concealed.

Diversion into SRD - A concealment method similar to diversion into MUF but involving the transfer of nuclear material between safeguarded material balance areas. Diversion can be detected by statistical evaluation of the shipper/receiver difference.

Diversion into D - A concealment method in which the diverter removes an amount of declared material M but does nothing to the operator's accounting records to hide the diversion. The accounting records are therefore now false (and have thus been falsified). The diversion causes a discrepancy (i.e. defect) between the material declared to be present and the material actually present. The only way to detect the diversion is for the inspector to measure the container(s) from which M was removed and to compare the measured value with the operator's declared value. The scheme is referred to as diversion into D because it can be detected through observation of an unexpectedly large value of the D statistic. Diversion into D can be concealed if measurement quality is poor and the variance of D (δD) is large.

Design Information Questionnaire (DIQ): A standardized form to be used by the State to provide the IAEA with detailed design information on a specific facility which is relevant to the establishment of a safeguards approach and preparation of the Facility Attachments for that facility.

Drain Out: Liquid remaining in vessels after run-down is removed from the bottom of the vessels. Sampling is no longer possible and Solution Monitoring systems do not operate. Drain out is not carried out in the solution process area of JR4C.

Euratom Treaty (Treaty Establishing the European Atomic Energy Community): The Treaty entered into force in January 1958. The States party are: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom. In accordance with Article 77 of Chapter VII of the Treaty, the European Commission will satisfy itself that, in the territories of Member States: (a) ores, source materials and special fissile materials are not diverted from their intended uses as declared by the users; and (b) the provisions relating to supply and any particular safeguarding obligations assumed by the Community under an agreement concluded with a third State or an international organization are complied with.

Facility: “a reactor, a critical facility, a conversion plant, a fabrication plant, a reprocessing plant, an isotope separation plant or a separate storage installation [irrespective of inventory]; or any location where nuclear material in amounts greater than one effective kilogram is customarily used”.

FKMP: See Key Measurement Point below

Flow Sheet Verification (FSV): activities which aim to confirm that the ^{237}Np follows the expected routes through a reprocessing plant in accordance with the flow-sheet declared by the operator. The declared flow-sheet is confirmed during the Initial DIV activities. The FSV activities during the Operating Phase may include: sampling and analysis for Np at selected locations within the process; checking of process parameters during random visits to Other Strategic Points (OSP); and DIV activities.

Flush Out: After stopping the supply of process solution, nitric acid is continuously fed to the equipment to “push” out the nuclear material.

FP: **F**ission **P**roducts

HALW: **H**igh **A**ctive **L**iquid **W**aste

HASW: **H**igh **A**ctive **S**olid **W**aste

H/E: **H**ead/**E**nd

Hybrid K-Edge (**HKED):** A technique used for measuring the U or Pu concentration in mixed solutions by combining X-ray fluorescence and K-edge densitometry. This is done by determining the ratio of photon transmissions at energies that closely bracket the K-electron absorption edge of the U or Pu. Can also be used to determine Np in the presence of fission products.

HM: **H**eavy **M**etal

Input Accountability Tank (IAT): The well calibrated and instrumented vessel selected as the FKMP for the measurement of dissolver solution to be transferred from the head-end of a reprocessing facility to the main process.

Inspection Goals: are performance targets, as specified in the IAEA Safeguards Criteria, for verification activities at individual facilities and for verification activities coordinated across the State. The inspection goal for a facility consists of a quantity component and a timeliness component. The quantity component relates to the scope of the inspection activities that should be carried out in order to be able to draw a conclusion that there has been no diversion of 1 SQ or more of nuclear material over a material balance period and that there has been no undeclared production or separation of direct-use material. The timeliness component relates to the periodic activities necessary to conclude that there has been no abrupt diversion during a calendar year.

International Target Values (ITV): Target values for random and systematic measurement uncertainty components for destructive analysis (DA) and non-destructive assay (NDA) measurements performed on nuclear material. The values are expressed as per cent relative standard deviations, and are values for uncertainties associated with a single determination result. The currently used set of values (ITV 2000) was published as [STR-327: International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Material, 2000, Safeguards Technical Report].

IIT: **I**nterim **I**nventory **T**aking

Interim Inventory Verification (IIV): An inspection activity that does not coincide with the ending date of a material balance period and does not necessarily have to include all nuclear material present in the material balance area. Under [153], verification is made for purposes of timely detection or, for example, for re-establishment of the inventory of nuclear material within an area covered by surveillance after a failure of surveillance.

Inventory Change (IC): "an increase or decrease, in terms of batches, of nuclear material in a material balance area". Such a change shall involve one of the following:

(a) Increases: import, domestic receipt, nuclear production, accidental gain, retransfer from retained waste and deexemption of nuclear material from IAEA safeguards;

(b) Decreases: export, domestic shipment, nuclear loss, other loss, measured discard, transfer to retained waste, exemption of nuclear material from IAEA safeguards, and termination of IAEA safeguards on nuclear material transferred to non-nuclear use.

IPI: **I**n-**P**rocess **I**nventory

Key **M**easurement **P**oint **(KMP):** "a location where nuclear material appears in such a form that it may be measured to determine material flow or inventory. 'Key measurement points' thus include, but are not limited to, the inputs and outputs (including measured discards) and storages in material balance areas".

Flow Key Measurement Points (FKMP): Those KMPs where flow (inventory changes) are measured or determined at MBA boundaries and reported to the IAEA.
Inventory Key Measurement Points (IKMP): Those KMPs where inventory is measured or determined within an MBA and reported to the IAEA.

LASCAR (LArge SCAle Reprocessing): a multinational forum (1988-1992), with the overall objective to assist the IAEA through provision of information and expert advice in the development of effective and efficient safeguards for large scale reprocessing plants.

LALW: **L**ow **A**ctive **L**iquid **W**aste

LASW: **L**ow **A**ctive **S**olid **W**aste

LEU: **L**ow **E**nriched **U**ranium

Mailbox System: used for timely or near-real time reporting by the operator of agreed facility operations. Reporting of encrypted data is made to a non-retrievable electronic 'mailbox' by the operator within a specific reporting time. The data is then retrieved by the IAEA and used for timely evaluations and inspection planning.

A fully auditable mailbox system to support short notice inspections must incorporate the following essential features:

- Non-repudiation – the operator cannot deny having posted a declaration;
- Trusted date and time stamp;
- Uniqueness – only one OPD is to be posted in each time period;
- Unalterable – neither the operator nor anyone else can change OPDs (see below) once they have been posted without leaving a full, effective and informative audit trail;
- Secure – the declaration process cannot compromise the security of the Agency's or the operator's computer systems;
- Counterfeit proof – only the operator's authorized staff can post declarations;
- Acknowledgement – the operator should get a signed, time-stamped receipt from the Agency for each declaration posted.

Maintenance and Modification Phase (MM): The Maintenance and/or Modification Phase may involve all or part of the facility. It may also coincide with other phases, such as the

Operating Phase or the Shut-down Phase. Any safeguards relevant change in the design or operation of systems or equipment, as specified in the General Part of the Subsidiary Arrangements will require an Initial DIE/DIV.

Material Balance Areas (MBA): "an area in or outside of a facility such that:

> (a) The quantity of nuclear material in each transfer into or out of each 'material balance area' can be determined; and
> (b) The physical inventory of nuclear material in each 'material balance area' can be determined when necessary, in accordance with specified procedures, in order that the material balance for Agency safeguards purposes can be established".

In establishing such material balance areas the IAEA uses the following criteria:

> (i) The size of the material balance area should be related to the accuracy with which the material balance can be established;
> (ii) In determining the material balance area advantage should be taken of any opportunity to use containment and surveillance to help ensure the completeness of flow measurements and thereby simplify the application of safeguards and concentrate measurement efforts at key measurement points;
> (iii) A number of material balance areas in use at a facility or at distinct sites may be combined into one material balance area to be used for Agency accounting purposes when the Agency determines that this is consistent with its verification requirements; and
> (iv) If the State so requests, a special material balance area around a process step involving commercially sensitive information may be established".

Material Balance Period (MBP): the time between two consecutive physical inventory takings (PITs) as reflected in the State's material balance report.

MOX: **M**ixed **Ox**ides of Plutonium (PuO_2) and Uranium (UO_2)

MUF: **M**aterial **U**naccounted **F**or is calculated for a material balance area (MBA) over a material balance period using the material balance equation, commonly written as:
MUF = (PB + X – Y) – PE where
PB is the beginning physical inventory,
X is the sum of increases to inventory,
Y is the sum of decreases from inventory,
PE is the ending physical inventory.
Because book inventory is the algebraic sum of PB, X and Y, MUF can be described as the difference between the book inventory and the physical inventory. For item MBAs, MUF should be zero, and a non-zero MUF is an indication of a problem (e.g. accounting mistakes) which should be investigated. For bulk handling MBAs, a non-zero MUF is expected because of measurement uncertainty and the nature of processing. The operator's measurement uncertainties associated with each of the four material balance components are combined with the material quantities to determine the uncertainty of the material balance σMUF.

Near Real Time Accountancy (NRTA): A form of nuclear material accountancy for bulk handling material balance areas in which itemized inventory and inventory change data are maintained by the facility operator and made available to the IAEA on a near real time basis so that inventory verification can be carried out and material balances can be closed more frequently than, for example, at the time of an annual physical inventory taking by the facility operator. When the in-process inventory cannot be determined by measurement, NRTA requires that an estimate, including its uncertainty, be made of the inventory in each equipment item, on the basis of adequately documented techniques. NRTA evaluation software performs statistical analyses on a sequential set of operator and IAEA data over a defined period of time.

Non-Destructive Assay (NDA): A measurement of the nuclear material content or of the element or isotopic concentration of an item without producing significant physical or chemical changes in the item.

Nuclear Material (NM): Any source material or special fissionable material (U, Pu, Th).

On Site Laboratory (OSL): A laboratory for safeguards analytical measurements which is built on the same site as the facility being safeguarded. The laboratory may be jointed used by the IAEA and the State.

Operating Phase (OP): The Operating Phase (routine operations) of a facility (or part thereof) begins after commissioning is completed and when nuclear material has been introduced to the main facility, or support facility such that it may function for its declared purpose.

Operator Declaration (OPD): Operating and accounting records and reports, and any other agreed information, needed for conducting inspections at a specific facility and which are provided in electronic form in advance or in near real time.

Other Strategic Points (OSP): “a location selected during examination of design information where, under normal conditions and when combined with the information from all ‘strategic points’ taken together, the information necessary and sufficient for the implementation of safeguards measures is obtained and verified; a ‘strategic point’ may include any location where key measurements related to material balance accountancy are made and where containment and surveillance measures are executed” . Activities at OSPs are also referred to as verification of “flow within the MBA”.

OSP-C/S: for installation of containment and surveillance devices.
OSP-M: for installation of monitoring systems.
OSP-OS: for confirmation of the operational status of the facility.

Output Accountability Tank (OAT): The well calibrated and instrumented vessel selected as the FKMP for the measurement of plutonium to be transferred from the main process area of a reprocessing facility to the next MBA which may be storage or a conversion process.

Physical Inventory Listing (PIL): A report provided by the State to the IAEA in connection with a physical inventory taking by the operator, "listing all batches separately and specifying material identification and batch data for each batch". Such listings are to be attached to each material balance report even where there was no nuclear material in the material balance area at the time of the ending physical inventory taking.

Physical Inventory Taking (PIT): **Physical inventory -** "the sum of all the measured or derived estimates of batch quantities of nuclear material on hand at a given time within a material balance area, obtained in accordance with specified procedures". The physical inventory is determined by the facility operator as a result of a physical inventory taking and is reported to the IAEA in the physical inventory listing. The physical inventory is verified by the IAEA during a physical inventory verification inspection. The ending physical inventory for a material balance period is also the beginning physical inventory for the next material balance period.

Physical Inventory Verification (PIV): An inspection activity that follows closely, or coincides with, the physical inventory taking by the operator and closes the material balance period. The basis for a PIV is the list of inventory items prepared by the operator. The data are correlated with the physical inventory listing reports submitted by the State to the IAEA.

Pre-Construction Phase (PC): The Pre-construction Phase for a facility (or part thereof) begins as soon as the decision is taken to construct or to authorize its construction. This phase includes the planning, design and engineering activities that precede the actual construction.

Remote Monitoring (RM): A technique whereby safeguards data collected by unattended C/S, monitoring and measurement systems are transmitted off-site via communication networks (to IAEA Headquarters, a regional office or another IAEA location) for review and evaluation. The system's internal recording capability is used for backup purposes. Remote monitoring may provide better utilization of equipment, better planning of inspections and a reduction in the inspection effort needed to meet verification requirements. These systems transmit data ranging from equipment state of health data to verification data. The use of redundancy is particularly applicable for unattended C/S and monitoring devices. For data sent over unsecured transmission lines, authentication and encryption are required.

Rinsing: Acid (or alkaline) washing of vessels.

Run-down: All vessels are reduced to the minimum operational level (heel) and material is fed forward through the system. Run-down applies only in the Head End process area.

Safeguards Analytical Laboratory (SAL): IAEA safeguards laboratory located at Seibersdorf outside of Vienna, Austria.

Safeguards Approach: A set of safeguards measures chosen for the implementation of safeguards in a given situation in order to meet the applicable safeguards objectives. The safeguards approach takes into account the specific features of the safeguards agreement (or agreements) and, where applicable, whether the IAEA has drawn a conclusion of the absence of undeclared nuclear material and activities in the State. Safeguards approaches are developed for each facility under safeguards. In addition, safeguards approaches may be developed for generic facility types and, mainly under integrated safeguards, for the State as a whole.

Safeguards Criteria: As currently defined, the set of nuclear material verification activities considered by the IAEA as necessary for fulfilling its responsibilities under safeguards agreements. The Criteria are established for each facility type and location outside facilities (LOF), and specify the scope, the normal frequency and the extent of the verification activities required to meet the quantity and the timeliness components of the inspection goal at facilities and LOFs. In addition, the Criteria specify verification activities to be carried out in a co-ordinated manner across a State. The Criteria are used both for planning the implementation of verification activities and for evaluating the results.

Shipper-Receiver Difference (SRD): "the difference between the quantity of nuclear material in a batch as stated by the shipping material balance area *[reactor]* and as measured at the receiving material balance area *[preprocessing plant]*".

Short Notice Random Inspections (SNRI): An inspection performed both on short notice and randomly. SNRIs are part of a safeguards approach developed for low enriched uranium and MOX fuel fabrication plants subject to safeguards, in order to provide improved coverage of domestic transfers of nuclear material. SNRIs may also be used at other facility types where the safeguards approach calls for unpredictably scheduled short notice inspections.

Shut-down Phase (XS): The Shut-down Phase of a facility (or part thereof) involves the interruption of routine operations of the facility (or part thereof) for a period of time exceeding three months. During this phase, the facility (or part thereof) will contain nuclear material and could be restarted (i.e. return to the Operating Phase), should the State/Operator choose to do so.

Significant Quantity (SQ): A Significant Quantity is the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. Significant quantities take into account unavoidable losses due to conversion and manufacturing processes and should not be confused with critical masses. Significant quantities are used in establishing the quantity component of the IAEA inspection goal. Significant quantity values currently in use are given in Table A.1.

Material	SQ
Direct use nuclear material	
Pu(a)	8 kg Pu
233U	8 kg 233U
HEU (235U ≥ 20%)	25 kg 235U
Indirect use nuclear material	
U (235U < 20%)(b)	75 kg 235U (or 10 t natural U or 20 t depleted U)
Th	20 t Th

Table A.1. Significant Quantities

Notes:

(a) For Pu containing less than 80% 238Pu.

(b) Including low enriched, natural and depleted uranium.

Simultaneous Inspections: Inspections performed by IAEA inspectors simultaneously or within a short period of time at two or more facilities in a State in order to detect possible diversions arranged in collusion between facilities by, for example, the temporary transfer (‘borrowing’) of nuclear material between facilities so that the same material would be verified twice by the IAEA, once in each of the two facilities inspected. The facilities may be of the same type (e.g. light water reactors (LWRs) using fuel assemblies of the same kind), or they may be linked in the same nuclear fuel cycle (e.g. LWRs, fuel fabrication and reprocessing plants, and spent fuel storage areas).

Solution Measurement & Monitoring System (SMMS): An in-tank measurement system used for the determination of solution level, volume and density. The technology is based on the bubbling of a controlled stream of gas through dip tubes installed at various depths within the solution and in the vapor space above the solution. The solution measurement data is obtained by determining the differential pressure between dip tubes and a specified time and applying a tank calibration equation. Monitoring data is obtained by the continuous collection of the in-tank measurements and plotting them on a display. Electromanometers are used to measure and collect the data and Solution Monitoring Software (see below) is used to calculate, evaluate and display this information.

> **Independent SMMS -** uses IAEA owned and controlled high accuracy, independent and authenticated pressure measurement devices. It is usually installed on the most important process vessels. The instruments are connected directly to the pneumatic dip tube measurement lines of the vessels. Other features can also be Pressure transmitters can also be the measurement the absolute pressure in the vapor space of the concentrators, or the use of pneumatic bubbler transmitters to evaluate the air-flow in the pneumatic bubbling system. The system normally uses RUSKA measurement devices, PLC’s for instrument interface, and PC’s for data collection, evaluation of state-of health information and data buffering, and

authenticated data transmission if a central data collection and evaluation system is available.

Authenticated SMMS: uses mainly industrial pressure measurement devices on less important process vessels. These can be pressure or temperature sensors, as well as neutron detectors mounted on the extractors in the main process. The signal is split from the operator pressure transducers and collected locally or transmitted to a central data collection and evaluation system. SMS (see below) is used as part of the authentication of the system.

Solution Monitoring Software (SMS): is software that is used routinely by inspectors and includes configuration, pre-processing and evaluation functions to be applied to SMMS (see above) data. It automatically analyses the data from the sensors (pressure, temperature, (and neutron detectors if installed). It detects events in a series of data, compares with a reference signature and raises alarms in case of differences (auto-correlation). It also calculates the volume transferred at the FKMPs, and correlates the information between sender and receiver vessels (cross-correlation). It provides the inspector with a high level Graphical User Interface, for configuration, parameterization or evaluation.

Standard deviation (σ): The positive square root of the variance. The standard deviation is expressed in the same units as the mean value for the population or probability distribution. The **relative standard deviation**, or coefficient of variation, is defined as $\delta = \sigma/\mu$, where μ is the mean of the population or distribution.

Tributylphosphate (TBP): an organic solvent used in the PUREX process to separate fission products, uranium and plutonium. The organic phase is emulsified with the nitric acid aqueous phase and then separated, usually employing a mixer-settler or a counter-current pulse column.

Unattended Monitoring (UM): A special mode of application of non-destructive assay or C/S measures, or a combination of these, that operates for extended periods without inspector intervention. The use of unattended safeguards instruments has long been a part of IAEA safeguards. Optical surveillance used to monitor an area for safeguards relevant activities over extended periods is unattended. Unattended radiation detection sensors are used to monitor the flow of nuclear material in a facility process area. For unattended monitoring, certain criteria must be met, including measures to ensure data authentication and encryption. Solution measurement systems can also be used for monitoring with process.

About the Author

Shirley Johnson is an independent nuclear consultant, retired from the IAEA in 2007. For the last 6 years of her 25 years at the IAEA she was Head of the JNFL Project and oversaw the development, installation and implementation of safeguards for the Rokkasho Reprocessing Plant in Japan.

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