**Joint Study of
Improved Safeguards Methodology
Using No-Notice Randomized Inspection
at JNC's Pu Handling Facilities**

April 2000

Ming-Shih Lu and Jonathan B. Sanborn

**Brookhaven National Laboratory
and the
Japan Nuclear Cycle Development Institute**

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1 INTRODUCTION

After the Iraq war, the International Atomic Energy Agency (IAEA) 93+2 Program was developed to strengthen and improve the cost-effectiveness of the existing safeguards system. In particular, the Program aims to enhance the IAEA ability to detect undeclared nuclear activities and materials. The IAEA 93+2 Program includes:

- A: Increased access to information and its effective use
- B: Increased physical access
- C: Optimum use of the existing system.

The measures considered are divided in two parts: measures in Part 1 are those, which may be implemented within the existing IAEA authority; Part 2 measures require complementary legal authority, in the form of an additional Protocol, INFCIRC/540. A description of the status of its implementation can be found in "Implementation of the Additional Protocol" (Cooley, 1999).

In particular, increased physical access includes access beyond locations requiring additional authorities derived from the INFCIRC/540 and no-notice randomized inspections. No-notice randomized inspections could enhance the inspection effectiveness and efficiency by increasing the coverage of the material involved, providing better confirmation of the operational status of the facilities and higher degree of confidence that no undeclared activities or materials existed at the facilities - including the detection of possible measures to conceal diversions.

A review of literature on both the theoretical models of randomized inspections as well as field trials in the U.S., Sweden and Canada was conducted for this study; and the result is included in Appendix 1 of this Report. More recently, short-notice, randomized inspections have been implemented for the first time by the IAEA at low enriched uranium fabrication plant in Japan (Ishikawa 1999). The procedures used at JNF include the installation of and daily declaration to a mailbox computer, advance general

declarations of shipments and receipts, and the establishment of a mechanism for transfer of data from the facility to the inspectors.

Section 2 of this report describes the operation, with emphasis on safeguards activities, at plutonium handling facilities in Japan Nuclear Cycle Development Institute, including Tokai Reprocessing Plant (TRP), Plutonium Conversion and Development Facility (PCDF), Plutonium Fuel Production Facility (PFPP), and Joyo and Monju fast breeder reactors. The IAEA inspection activities for various material types at each flow and inventory key measurement points (KMPs) have also been organized in tables at the end of each sub-section for each facility.

Finally, in Section 3, four schemes of randomized inspections are suggested:

- 1: Facility Approach, randomized inspection at scheduled monthly opportunities,
- 2: Facility Approach, randomized inspection at any time,
- 3: Facility Approach, randomized inspection at any time, including INFCIRC/540 activities and access.
- 4: State-Level Approach, randomized inspection at any time, including INFCIRC/540 activities and access.

In all the schemes suggested, about 50% of the interim inspections may be omitted, although the inspections, when carried out probabilistically, will be more intensive. The IAEA could achieve the same timeliness and detection probability goals as required in regular, non-randomized inspections. In addition, the IAEA safeguards system would be strengthened due to the enhanced ability to detect undeclared nuclear materials or activities. For ease of comparison, also included in this Section is a summary of the current IAEA Safeguards Criteria relevant to the interim inspections for timeliness for each facility and a brief summary of the IAEA interim inspection activities. Details, including a description of theoretical basis for the randomized inspections are

given for the Tokai Reprocessing Plant, while only a summarized version is given for the remainders of the facilities.

2 DESCRIPTION OF FACILITY OPERATION AND SAFEGUARDS ACTIVITIES

2.1 Tokai Reprocessing Plant (TRP)

The TRP operation is based on chop and leach and PUREX processes and is designed to process 0.7 t spent fuel per day, with about 90 t annual processing capacity, taking into consideration the time necessary for clean up, maintenance, physical inventory taking, safeguards and safety inspections. The plant has been in operation since 1977 and has processed a total of 935.9 t of spent fuel from light water reactor (LWR) and Advanced Thermal Reactor Fugen up to March 1997.

As shown in Figure 2-1, the TRP is divided into three material balance areas (MBAs): spent fuel storage area (JR1A) including chop and leach, chemical processing area (JR2A), and product storage area (JR3A); with 9 flow key measurement points (KMPs) and 8 inventory KMPs. A near-real-time materials accountancy system is being used at TRP (Kashimura, 1994). The safeguards activities for TRP are summarized in Table 2-1 and Table 2-2 and are briefly described below.

Since the spent fuel is shipped to the TRP in casks without seals, they are item counted, and verified with improved Cerenkov viewing device (ICVD) with 50% detection probability for gross defects by the IAEA inspectors when the casks are unloaded into the spent fuel pool. The identification of spent fuel assemblies is verified with an under-water surveillance camera. As illustrated in Figure 2-2, the fuel unloading pool, storage pool, and fuel transfer pool are covered with IAEA surveillance cameras, including MIVSs, Minolta cameras and an under-water video system covering the route between the fuel transfer pool and the mechanical processing cell (MPC). The IAEA inspectors observe the transfers of spent fuels into the MPC. During the annual physical inventory verification (PIV) and the 11 monthly interim inventory verifications (IIVs), the containment and surveillance (C/S) systems are evaluated. If C/S is inconclusive,

spent fuels are item counted and verified with 50% detection probability during PIV;
20% detection probability during IIVs, as described in the IAEA Safeguards Criteria.

JR1A : Spent Fuel Assembly and Dissolved Solution

JR2A : U and Pu Nitrate Solution

JR3A : UO_3 Powder and Pu Nitrate Solution

Figure 2-1. Material Balance Areas and Key Measurement Points for TRP

Table 2-1 Typical Inspector's Activities for Material Accountancy in TRP: Flow KMP

KMP Code	Strata	Way of Verification	Detection Probability	C/S Measures	Timing of Verification
1	Irradiated fuel assembly	Item counting, ID check and NDA (Gross) by ICVD	Random Medium (RM)	Video cameras (MIVSs)	At receipt of fuel assembly Monthly for MIVS Service
2	Dissolved fuel solution	Volume: Digital manometer Concentration: Sample is treated in operator's lab., then shipped inspector's lab. for analysis.	All	Not Available (NA)	At receipt of solution in input accountability tank
	(to OTL) Chopped fuel	Weight: Balance	Not Specified (NS)	NA	NS
	(to OTL) Dissolved solution	Volume: Level indicator Concentration: From accountability data of same input batch.	NS	NA	NS
3	Leached hulls	Estimation: 0.1(%) to input amount	All	MIVSs	Monthly
4	Rework solution	Volume: Level indicator Concentration: U: Photospectrometry Pu:□ counting	NS	NA	NS
5	Discharged liquid waste to sea	Volume: □ Level indicator Concentration:□ counting	NS (RH?)	NA	NS
	Retained waste	Volume: □ Level indicator Concentration: □ Various chemical analysis	NS (RH?)	NA	NS
	HAW solution to the TVF (retransfer from retained waste)	Volume: □ Dip tube manometer Concentration: □ spectrometry	Random High (RH)	NA	At transfer of HAW to TVF

Table 2-1. Typical Inspector's Activities for Material Accountancy in TRP: Flow KMP

KMP Code	Strata	Way of Verification	Detection Probability	C/S Measures	Timing of Verification
5 (con'd)	Vitrified product	HAW volume: Dip tube manometer HAW concentration: Estimation at each vessel based on analysis data at receiving tank. (Analytical method is γ spectrometry.)	RM	MIVS	At transfer vitrified waste to storage pit
6	(From outside facility) Small quantity of various materials.		NS	None	NS
7	UO ₃ powder product	Weight: Balance Concentration: Titration, mass spectrometry	None	None	NS
	Plutonium nitrate solution product	Volume: Digital manometer Concentration: Coulometry, mass spectrometry	All	None	At transfer of γ plutonium nitrate γ solution to storage tank
8	(to outside facility) γ UO ₃ powder product γ	Item counting, PMCG (NDA)	RH	None	At transfer of UO ₃ powder product to outside facility
	Plutonium nitrate solution to the PCDF	Receiver's data	All	None	At transfer of plutonium nitrate solution to PCDF
9	Uranyl nitrate solution to PCDF γ	Receiver's data	NS	None	NS
	Small quantity of various materials to outside facility	Weight: Balance etc	NS	None	NS

Table 2-1. Typical Inspector's Activities for Material Accountancy in TRP: Flow KMP

KMP Code	Strata	Way of Verification	Detection Probability	C/S Measures	Timing of Verification
5 (con'd)	Vitrified product	HAW volume: Dip tube manometer HAW concentration: Estimation at each vessel based on analysis data at receiving tank. (Analytical method is $\square$ spectrometry.)	RM	MIVS	At transfer vitrified waste to storage pit
6	(From outside facility) Small quantity of various materials.		NS	None	NS
7	UO ₃ powder product	Weight: Balance Concentration: Titration, mass spectrometry	None	None	NS
	Plutonium nitrate solution product	Volume: Digital manometer Concentration: Coulometry, mass spectrometry	All	None	At transfer of $\square$ plutonium nitrate $\square$ solution to storage tank
8	(to outside facility) $\square$ UO ₃ powder product $\square$	Item counting, PMCG (NDA)	RH	None	At transfer of UO ₃ powder product to outside facility
	Plutonium nitrate solution to the PCDF	Receiver's data	All	None	At transfer of plutonium nitrate solution to PCDF
9	Uranyl nitrate solution to PCDF $\square$	Receiver's data	NS	None	NS
	Small quantity of various materials to outside facility	Weight: Balance etc	NS	None	NS

Table 2-2. Typical Inspector's Activities for Material Accounting in TRP: Inventory KMP

KMP Code	Strata	Way of Verification	Detection Probability	C/S Measures	Timing of Verification
A	Irradiated fuel assembly	Item counting, ID check and NDA (Gross) by ICVD, C/S	Random Medium (RM)	Video cameras (MIVSs)	PIV
B	Nitrate solution	Volume: Manometer Concentration: Coulometry	Random High (RH)	NA	PIV
C	Small quantities of nuclear materials	Weight: Balance, etc Volume: Measuring cylinder, etc.	RH	NA	PIV
D	Nitrate solution	Weighing and Volume measurement and various chemical analysis	RH	NA	PIV
E	Nitrate solution	Volume: Dip tube manometer Concentration: Various chemical analysis	RH	NA	PIV
F	UO ₃ Product	Item counting and NDA by PMCG	RH	NA	PIV
G	Pu Nitrate solution.	Volume: Dip tube manometer Concentration: Titration	RH	None	PIV
H	HAW solution in TVF	Volume: Dip tube manometer Concentration: spectrometry	RM	MIVS	PIV

Figure 2-2. Surveillance Camera in Spent Fuel Receipt and Storage Area for TRP

At the MPC, the fuel assemblies are checked for identification and gamma radiation and then sheared; the process is under IAEA observation. The chopped end pieces from the fuel assemblies are checked (via gamma measurement) before disposal. The sheared pieces of the fuel rods then enter the dissolver tank, from which the leached hulls (with estimated 0.1% of the nuclear materials) are checked by the IAEA cameras before disposal.

The dissolver tank solutions are then clarified before entering a buffer tank and then transferred into the input accountancy tank, where the nuclear accountancy values are established via volume and concentration measurements, and the liquid samples are taken for chemical analysis. The IAEA follows the flow of dissolver tank solution by observing the strip charts as the buffer tank fills and empties. During IIVs, the inventory in the head-end processing area before the input accountancy tank is confirmed by comparing the strip charts with surveillance records. The IAEA inspectors observe sample taking and preparation. The samples are treated using a U/Pu spike, diluted, and then sent to Seibersdorf Laboratory in Austria. At present, the inspector does not maintain good control of the samples, which is sent unsealed by pneumatic transfer. However, Sandia National Laboratory has developed a tamper resistant "rabbit" for this purpose and it is being implemented. Duplicate samples are taken for the TRP as well as the Japanese government inspection agency. The IAEA checks tank volume calibration once a year. The IAEA shares the same electromanometer with the facility, but has independent recording devices and data analysis software, and the IAEA equipment is stored in a sealed cabinet to protect against tampering.

The input accountancy tank solution is then further separated into Pu stream and U stream through two extraction cycles and then purified. The uranium solution is denitrated into UO_3 and shipped off-site. The Pu nitrate solution is concentrated and transferred to the output accountancy tank and then into plutonium storage tank in the product storage MBA. The high activity liquid wastes are transferred to Tokai Vitrification Facility (TVF) for vitrification and final disposal. TVF is considered as part of the chemical processing MBA of TRP for safeguards purposes.

For the annual PIV, all the tanks in the chemical processing area are cleaned out, thus the nuclear inventory therein is minimal. During interim inventory verification (IIV) for timeliness, liquid volumes in the 7 buffer tanks in the chemical processing area are measured via level indicator and chemical analysis of samples taken from each tank. In addition, as required by the IAEA, the nuclear material content in each individual contactor, small pots and columns are estimated via engineering approximate equations as a function of the nuclear concentrations in nearby tanks. The approximation was developed based on regression analysis of past operating data, using bi-difference from known quantities and engineering judgment. The IAEA uses the same approximation to estimate the nuclear content of each volume. During each IIV, the contents in the evaporators are drained to the output accountancy tanks. Typical holdup inventory in the contactors, pipes, columns and pumps during an IIV is about 2 kg Pu. Throughout the entire process MBA, the Pu inventory is about 20 kg during normal operation.

The product plutonium nitrate solutions then enter the output accountancy tanks before entering the Pu storage tanks in the third MBA, product storage area. Such transfers are measured completely (100%) via volume measurements and sampling for chemical analysis. If the content in the Pu storage tanks has been changed since the previous inspection, the content is first estimated by the operator based on the previous accountancy value for the storage tank and the flows from the Pu output accountancy tanks. During the inspection, the volume is measured and samples are taken for chemical analysis. When the chemical analysis report is available, around one week later, the accountancy value for the Pu storage tank is established accordingly.

Recently, a solution monitoring system similar to the tank monitoring system (TAMS) in PCDF has been implemented to enhance safeguards effectiveness at TRP. The system monitors the liquid level, density and temperatures of the input and output accountancy tanks and four out of the seven Pu nitrate product storage tanks. (Densities for three of the product storage tanks are not available.) The additional system could provide effective monitoring for all the flows at TRP.

The Pu nitrate solution in the product storage tanks are then transferred via underground piping to a nearby conversion facility, Plutonium Conversion Development Facility (PCDF). The transfers are measured 100% at the receiving end, with volume measurement and sampling for chemical analysis. At the PCDF, camera surveillance is used to monitor a valve position indicating if transfers occurred when a simultaneous PIV between TRP and PCDF cannot be carried out, and the timings of the transfers are inferred from the surveillance tapes. The shipments occurred about 11 times per year.

In 1994, the person-days of inspection (PDI) used for the TRP by the IAEA is 625 (about 720 PDIs for 1996), and the facility operator effort on safeguards is 7627 person-days. In 1993, when the TRP was shutdown, the IAEA still used 360 PDIs to safeguard the facility.

2.2 Plutonium Conversion and Development Facility (PCDF)

PCDF is unique in that the uranium and plutonium nitrate solutions are co-converted into mixed oxide (MOX) powder via a microwave heating method. The design capacity is to produce 10 kg MOX powder per day. Since 1983, PCDF has converted 707 kg of Pu for Fugen Advanced Thermal Reactor (ATR), 709 kg for Joyo Fast Breeder Reactor (FBR) and around 3600 kg for Monju FBR.

For safeguards purposes, the facility is divided into two MBAs, one for the conversion process (JR1B) and the other for the powder storage (JR2B); with 8 flow KMPs and three inventory KMPs, as shown in Figure 2-3. The measurement activities at all the KMPs for flow verification and during the PIV and IIVs are listed in Table 2-3.

Plutonium nitrate solution is received from TRP about 11 times per year, with 55 kg Pu per receipt, or annually 600 kg Pu. The receipts are monitored continuously by an unattended inspector's tank monitoring system (TAMS), measuring volume, density and temperature. Similar to TRP, the tank volume calibration is carried out once a year with the IAEA. 100% of the receipts are sampled for chemical analysis to determine

plutonium concentration and isotopics. Before the chemical analysis result is available (typically one week after sampling), provisional estimates based on the Pu product tanks are used. The accountancy values based on chemical analysis for the receipts are used as the basis of for accountancy throughout the process.

At the processing MBA, the uranium and plutonium nitrate solutions are mixed, denitrated, calcined via microwave heating, milled and then stored in 5 kg (Pu) cans for intermediate storage. The process is operated in batches at a rate of 2 kg of Pu+U per batch, 5 batches per day. The powders are blended to achieve the specified elemental and isotopic composition and stored in canisters (5.7 kg Pu per canister) in the powder storage MBA. During IIV, the holdup in glove boxes and blender is between 7 and 12 kg Pu and is estimated by the operator via bi-difference and measured by the IAEA with Holdup Blender Assay System (HBAS) via neutron coincidence counting, using operator declared isotopics. The accountancy values for the material in intermediate storage (up to 40 kg Pu) are determined via weighing after calibration with inspectors weight, with occasional sampling for chemical analysis. For the MOX products, provisional estimates based on weighing and estimated Pu/U ratio are entered into the computer system daily, and then adjusted as chemical analysis results become available about one week later. The solid wastes are stored in drums and measured with operator's waste drum assay system (WDAS) via neutron coincidence counting, with operator declared isotopics before sealing, and confirmed via gamma measurement after sealing.

The canisters for shipment are measured continuously in unattended mode by the IAEA with plutonium canister assay system (PCAS) via neutron coincidence counting. The PCAS also includes a camera to record the identification of the canister and the timing of the measurement. In addition, the product storage area is under camera surveillance (MIVS). The operator's isotopics are used by the IAEA, with occasional checking via HRGS or sampling for chemical analysis. The operator's accountancy values for the product powder are based on electronic balances and the accountancy values established earlier at the receipt, with periodic sampling for chemical analysis. The product MOX powder is shipped to PFPF in canisters with 5.7 kg Pu capacity about 20

canisters per month, 5 to 6 shipment per year. Each year, in addition to a PIV, IAEA conducts 11 interim inventory verifications (IIV) for timeliness purpose at PCDF. The annual inspection effort by the IAEA is about 180 PDIs for PCDF.

Figure 2-3. Material Balance Areas and Key Measurement Points for PCDF

Table 2-3 Typical Inspector's Activities for Material Accountancy in PCDF

1. Flow KMPs

1.1 Input (Plutonium Nitrate)

Volume, density, and temperature measurement of plutonium nitrate solution at the input accountability tank (P11V11) is carried out in unattended mode by the Tank Monitoring System (TAMS). Measurement of plutonium concentration and isotopic composition is carried out by DA. TAMS data is reviewed during the inspection for DA.

1.2 Output (MOX Powder)

Measurement is carried out in unattended mode by the combination of remote-NDA (PCAS) and MIVS. The data is reviewed during monthly inspection.

2. Inventory KMPs

2.1 PIT

PIV is carried out once a year.

IKMP	Stratum	Description	Detector	Defect	Probability
A	SOP	Pu nitrate	TAMS & DA	Bias	High ($\beta=0.1$)
	SOM	Pu-U nitrate	TAMS & DA	Bias	High ($\beta=0.1$)
	MO1	MOX powder	EBAL & DA	Bias	High ($\beta=0.1$)
	SCF	Scrap	EBAL & INVS	Partial	High ($\beta=0.1$)
	SD1	Holdup in P13-P16	HBAS	Gross	High ($\beta=0.1$)
	MO1-B	MOX powder in P17	HBAS	Gross	High ($\beta=0.1$)
	WA1	Sludge	PMCN	Gross	High ($\beta=0.1$)
	WA1-D	Waste Drum	WDAS	Partial	High ($\beta=0.1$)
	WA1-VD	Waste Drum (under Seal)	MOLE	Gross	Med. ($\beta=0.5$)
	WA1-VC	Waste Container (under Seal)	MOLE	Gross	Med. ($\beta=0.5$)
B	SM1	Laboratory and R&D	EBAL & INVS	Partial	High ($\beta=0.1$)
C	MO1S	MOX canister (under C/S)	PCAS#0	Partial	Remeas. ($\beta=0.9$)
	SCFS	Scrap canister (under C/S)	PCAS#0	Partial	Remeas. ($\beta=0.9$)

Heel strata (SOP-H, SOM-H, MO1-H, and so on) are omitted.

Table 2-4. IIV for Timeliness Purpose

IIV is carried out once a month.

IKMP	Stratum	Description	Detector	Defect	Probability
A	SOP	Pu nitrate	TAMS & INVS	Partial	Med. ($\beta=0.5$)
	SOM	Pu-U nitrate	TAMS & INVS	Partial	Med. ($\beta=0.5$)
	MO1	MOX powder	EBAL & INVS	Partial	Med. ($\beta=0.5$)
	SCF	Scrap	EBAL & INVS	Partial	Med. ($\beta=0.5$)
	SD1	Holdup in P13-P16	HBAS	Gross	Med. ($\beta=0.5$)
	MO1-B	MOX powder in P17	HBAS	Gross	Med. ($\beta=0.5$)
	WA1	Sludge	PMCN	Gross	Med. ($\beta=0.5$)
	WA1-D	Waste Drum	WDAS	Partial	Med. ($\beta=0.5$)
	WA1-VD	Waste Drum (under Seal)	Seal replace		Low ($\beta=0.8$)
	WA1-VC	Waste Container (under Seal)	Seal replace		Low ($\beta=0.8$)
B	SM1	Laboratory and R&D	EBAL & INVS	Partial	Med. ($\beta=0.5$)
C	MO1S	MOX canister (under C/S)	C/S review		
	SCFS	Scrap canister (under C/S)	C/S review		

Heel strata (SOP-H, SOM-H, MO1-H, and so on) are omitted.

2.3 Plutonium Fuel Production Facility (PFPP)

PFPP receives MOX powder, plutonium oxide powder, and uranium oxide powder and fabricates them into fuel assemblies. All operations in the facility are remotely controlled and the process areas as well as the feed and product storage areas are not usually accessible. The powders received are rebottled, blended, granulated, and pressed into pellets. The pellets are then sintered to ceramic quality with densities between 10 g/cc and 11 g/cc. The sintered pellets are ground to specified geometrical dimensions, sampled for chemical analysis, and inspected for geometrical dimensions and appearance. The rejected pellets, grinder sludge, etc. are fed to scrap recovery as much as possible. The pellets that pass the inspection are loaded into the fuel pins, which are then welded with end plugs. The welded fuel pins are then scanned by gamma counting and inspected for geometrical dimensions and appearance, and then fabricated into fuel assemblies. The facility is designed to produce 5 ton MOX fuel assemblies per year for Monju and Joyo FBRs and has been in operation since 1987, produced 11 tons of MOX fuel assemblies in total. A nearby facility, Plutonium Fuel Fabrication Facility (PFFF) has an annual production capacity of 10 ton MOX for ATR fuel, and has produced in total 132 ton MOX assemblies for ATR, 5 ton for Joyo FBR, and 12 ton for a critical assembly.

For safeguards purposes, the facility is considered as one MBA with 6 flow KMPs and 8 inventory KMPs, as shown in Figure 2-4. An on-line real-time material accounting system is used. In addition, an extensive advanced containment and surveillance system (ACS) and a set of unattended and attended NDA devices distributed throughout the facility are combined to serve as basis for near-real-time accountancy (NRTA) for the IAEA safeguards. Recent safeguards implementation at PFPP has been described in Nakano, 1997 and Takahashi, 1994.

Mixed oxide and PuO_2 powders received at PFPP are measured by the IAEA with an unattended, continuous operating plutonium canister assay system (PCAS) based on neutron coincidence counting. The neutron coincidence measurement triggers ACS

surveillance cameras to achieve complete, unattended measurement of the receipts. In addition, the ACS monitors the feed storage area. For the items received from PCDF, the shipper's accountancy values are used. For receipt foreign, the powders are sampled for chemical analysis and the shipper/receiver differences reported.

Since the fabrication processes are performed in glove boxes, the process materials entering and leaving each glove box are weighed; the measured weights serve as the basis of accountancy values for the process material. For the operator, the accountancy values for the pellets, fuel pins and fuel assemblies are calculated based on the accountancy values for powders established in the receiving area as described in the previous paragraph, together with weight measurement throughout the fabrication process. Care has to be taken since the PuO_2 powder is hygroscopic. An automated accounting system (AAS) is used to keep track of all the materials in process. Material accounting data for all the materials throughout the process, including weights, identification numbers for the containers, locations... etc. are entered into the computer system automatically. Additionally, some of the powders and pellets are sampled for chemical analysis for quality control as well as accountancy.

At the end of each day, process material are removed from the glove boxes as much as possible and transferred into the intermediate storage. For the operator, the holdups in the glove boxes are determined by bi-difference between the material entering and leaving each glove box. The glove boxes are cleaned out thoroughly once per year. Waste are stored in drums and assayed with Waste Drum Assay System (WDAS) based on passive neutron coincidence counting.

The following NDA devices are used:

- MAGB - material accountancy glove box,
- SBAS - super glove box assay system,
- FPAS - fuel pin assay system,
- FAAS - fuel assembly assay system,
- INVS - inventory sample neutron and gamma assay.

All of the systems mentioned above are based on passive neutron coincidence counting (INVS includes in addition Ge HRGS) for the measurement of various materials throughout the facility. Thus, including PCAS for the MOX powder receipt, and WDAS for waste, the NDA systems provide complete coverage of all materials in the facility. In particular, the product fuel assemblies are measured unattended with FAAS under the ACS surveillance such that the identities, locations, and nuclear content of the fuel assemblies are stored in the computer continuously.

In summary, as described in Takahashi, 1994, the safeguards system for the PFPF is composed of:

- AAS: Advanced accountancy system, which controls all transfers of materials in the facility and is an on-line real time material accounting system that can produce a declaration of nuclear material within the facility by using the data acquired upon material transfer.

- ACS: Advanced containment and surveillance systems, which were specially designed for and installed in the feed and product storage areas with prototype authentication equipment taking both storage configurations into account, and are applied so that independent surveillance can reduce the sampling rate for remeasurement of nuclear material at interim inspections and physical inventory verification. The ACS includes CCTV systems with various switches and sensors including gamma detectors and crane monitor systems to monitor movement of input Pu canisters and product fuel assemblies.

- RNDA: Remote controlled non-destructive assay systems, which consist of NDA systems for storage areas and for the process area, based on a high level neutron coincidence counting technique, accommodated for automated transfer operation, and usable in a continuous, unattended mode.

-AAVS: Advanced accountancy verification system, which involves the software to do near real-time accountancy (NRTA) for the purpose of continuous and statistical oversight of nuclear material within the facility.

Each year, in addition to a PIV, IAEA conducts 11 interim inventory verifications (IIV) for timeliness purpose at PFPF. The inspector's activities for material accountancy verifications are described in Tables 2-5 and 2-6. Since NRTA is in effect, the detection probability used for sampling during the IIVs is 20% for most of the materials. Before each IIV, the glove boxes go through a minor cleanup in order to facilitate IAEA inspection measurement for the hold ups. The cleaned up materials are weighed and stored in intermediate storage. During PIV, the detection probability goal is 90% for most materials in process, 20% for feeds and 10% for products since the feeds and PCAS and FAAS cover products under continuous surveillance with unattended NDA. Each year, the inspection effort for PFPF is around 250 PDIs.

INVENTORY KMPs:

- A: Pu STORAGE & TEMPORARY FEED STORAGE (ON SHIPPER'S DATA)
- B: Pu STORAGE (ON RECEIVER'S DATA)
- C: FEED MATERIAL HANDLING PROCESS
- D: SPECIFIED POWDER & PELLET HANDLING
- E: FUEL PIN FABRICATION & ASSEMBLING
- F: ANALYTICAL LABORATORY
- G: WASTE STORAGE AREA
- H: FUEL ASSEMBLY STORAGE

FLOW KMPs:

- 1: RECEIPT & SHIPMENT OF PuO_2 OR MOX POWDER, AND SRD
- 2: SHIPMENT & RECEIPT OF FUEL ASSEMBLIES
- 3: RECEIPT & SHIPMENT OF UO_2 POWDER AND PELLET IN THE FACILITY
- 4: RECEIPT & SHIPMENT OF NUCLEAR MATERIAL (EXCEPT FEED MATERIAL)
- 5: TRANSFER TO OR RETRANSFER FROM RETAINED WASTE; RECEIPT AND SHIPMENT OF WASTE AND BAG-OUT MATERIAL; ACCIDENTAL LOSS/GAIN
- 6: NUCLEAR LOSS; REBATCHING; CATEGORY CHANGE

Figure 2-4 Structure of MBA and KMP for PFPF

Table 2-5 Typical Inspector's Activities for Material Accountancy

1. Flow KMPs

Measurement of input and output to/from the facility is carried out in unattended mode by the combination of remote/NDA and Advanced-C/S. The data of Measurement is reviewed during inventory verification for timeliness purpose on a monthly basis.

2. Inventory KMPs (PIV)

PIV is carried out once a year.

KMP	STRA	DESCRIPTION	DETECTOR	DEFECT	DETE. PROBA. (β value)
B	MO	MOX powder	PCAS#	Partial	0.8*
	PDP	Pu O2 powder	PCAS#	Partial	0.8*
	SCF	Clean Scrap	PCAS#	Partial	0.8*
	SDF	Dirty Scrap	PCAS#	Partial	0.8*
A	PDP	Pu O2 powder	PCAS#	Partial	0.9**
C&D	PMC	Process Material (calculated)	MAGB# #	Partial	0.1
	PMM	Process Material (measured)	MAGB# #	Partial	0.1
	PDP	Pu O2 powder	MAGB#	Partial	0.1
	SDF	Dirty Scrap	MAGB# #	Partial	0.1
	SCF	Clean Scrap	MAGB# #	Partial	0.1
	SG	Hold-up	SBAS# #	Partial	0.1
E	FRF	Fuel pin	FPAS	Partial	0.1
G	WA	Waste	WDAS	Partial	0.1
H	FFF	Fuel Assemblies	FAAS	Partial	0.9**
	OT	Other material	INVS	Partial	0.1

* Remeasurement with β value 0.8 is required for the purpose of authentication of AC/S.

** Remeasurement with β value 0.9 is required according to inspection criteria.

Table 2-6 Inventory Verification for Timeliness Purpose

Inventory verification is carried out on monthly basis

KMP	STRA	DESCRIPTION	DETECTOR	DEFECT	DETE. PROBA. (β value)
B	MO	MOX powder	PCAS#	Partial	0.8*
	PDP	Pu O2 powder	PCAS#	Partial	0.8*
	SCF	Clean Scrap	PCAS#	Partial	0.8*
	SDF	Dirty Scrap	PCAS#	Partial	0.8*
A	PDP	Pu O2 powder	PCAS#	Partial	0.95**
C&D	PMC	Process Material (calculated)	MAGB# #	Partial	0.8**
	PMM	Process Material (measured)	MAGB# #	Partial	0.8**
	PDP	Pu O2 powder	MAGB#	Partial	0.8**
	SDF	Dirty Scrap	MAGB# #	Partial	0.8**
	SCF	Clean Scrap	MAGB# #	Partial	0.8**
	SG	Hold-up	SBAS# #	Partial	G.B (constant)***
E	FRF	Fuel pin	FPAS	Partial	0.8**
G	WA	Waste	WDAS	Partial	0.5
H	FFF	Fuel Assemblies	FAAS	Partial	No Measurement
	OT	Other material	INVS	Partial	0.8**

*Remeasurement with β value 0.8 is required for the purpose of authentication of AC/S.

** value is decreased from 0.8 to 0.5 when NRTA is failed.

***Special arrangement

2.4 Monju and Joyo FBRs

2.4.1 Monju FBR

Monju is a prototype FBR at 710 MWt. The reactor uses around 15% and 21% fissile Pu fuels with depleted uranium as blanket. Monju reactor consists of 198 core fuel assemblies and 172 radial blanket assemblies, each fuel assembly weighs about 200 kg. The reactor is refueled twice a year, each time replacing one forth of blanket assemblies. Currently the reactor is in maintenance.

The fresh fuel handling route and the relevant safeguards equipment are shown in Figure 2-5. Typical inspectors' activities for material accountancy are listed in Table 2-7. The fresh fuel assemblies are received in sealed (with VACOSS) casks from PFPF. The seals are removed under CCTV camera that continues to provide surveillance for the loading of receipts into the fresh fuel storage rack. The seals are verified with 50% detection probability during PIV, 20% during IIV. The fresh fuel storage is also covered under IAEA camera surveillance in the room above ground. However, it is possible to access the fresh fuel underground, where although the access is sealed, the fresh fuel is not considered by the IAEA to have dual C/S system. The fresh fuels are then transferred into a sodium storage tank using an underground transporter before they are loaded into the reactor core. The inventory in the sodium storage tank and reactor core cannot be verified directly and is thus covered by an elaborate containment/surveillance system with continuous, unattended NDA system, as described below (Usami, 1995).

There are three sets of NDA equipment covering the entire fuel transfer route:

ENGM- entrance gate monitor at fresh fuel storage (coincidence counting)

EVRM- radiation monitor for ex-vessel transfer machine

EXGM- exit gate monitor under water in the channel to spent fuel port

All of the NDA equipment above and the fuel transfer routes are covered under camera surveillance. The ENGM monitors the fuel as they leave the fresh fuel storage

via an entrance gate into the under-floor transporter. It is based on neutron coincidence counting and can distinguish between fresh MOX fuels from blanket assemblies and other core elements, e.g., control rods. The fuel assemblies are moved via an ex-vessel transfer machine (EVTM) into an ex-vessel sodium storage tank (EVST) for temporary storage. An ex-vessel transfer machine radiation monitor system, EVRM, is mounted on ex-vessel transfer machine and monitors the fuel transfers between the core and the sodium storage tank. It is based on total neutron counting and NaI gross gamma measurement and can distinguish fresh from irradiated fuel assemblies.

After irradiation for five cycles, the irradiated fuels are then transferred via ex-vessel transfer machine into the sodium storage tank. The spent fuel assemblies are canned and then transferred under water into the spent fuel pool. The EXGM system monitors under water the flows of irradiated fuels entering and leaving the spent fuel pool; it includes a ^{10}B neutron counter and two ionization chambers for gamma detection and can determine the direction of fuel movement. The spent fuel pool is covered with MUX surveillance, similar to spent fuel pools at light water reactors. The inventory in the spent fuel pool can be verified with ICVD when necessary. The spent fuel handling route and the relevant safeguards equipment are shown in Figure 2-6.

To improve the safeguards effectiveness, two additional neutron detectors serving as C/S devices will be installed later this year near the EVST and above the reactor core so that the fresh fuels will be safeguarded by a dual C/S system.

In addition to an annual PIV, there are 11 IIVs per year for timeliness purposes (for fresh MOX). During the IIVs, the C/S systems are evaluated and fresh fuels are identified and item counted. Core fuel and spent fuel are verified by examination of C/S and the recorded NDA data for fuel transfers. In 1996, IAEA used 43 PDIs for safeguards at Monju.

Figure 2-5. Fresh Fuel Handling Route and Safeguards Equipment

Figure 2-6. Spent Fuel Handling Route and Safeguards Equipment

Table 2-7 Typical Inspector's Activities for Material Accountancy in FBR

1. Flow KMPs

1.1 Receipt

Receipt of fresh fuels from PFPF – VACOSS Seal check

1.2 Shipment

Shipment to FMF and RETF – Appropriate measures(seals/observation by inspectors)

2. Inventory KMPs

2.1 Interim inventory verification I I V

IIV is carried out once a month.

KMP	STRA	DESCRIPTION	DETECTOR	DEFECT	DETE. PROBA.
A	MOX fresh fuel -under single C/S		Item counting VACOSS Seal MUX	--- --- ---	--- Low ($\beta=0.8$) Low ($\beta=0.8$)
B	MOX fresh fuel, Spent fuel (Difficult to access area)		MUX, ENGM, EVRM, EXGM	---	
C	MOX fresh fuel (in core) (Difficult to access area)		MIVS, ENGM, EVRM, EXGM	---	
D	Spent fuel (under single C/S based on surveillance)		MUX	---	

2.1 Physical inventory verification I I V

PIV is carried out once a year.

KMP	STRA	DESCRIPTION	DETECTOR	DEFECT	DETE. PROBA.
A	MOX fresh fuel -under single C/S		Item counting VACOSS Seal ENGM	--- --- ---	--- Med. ($\beta=0.5$) Low ($\beta=0.9$)
	-under dual C/S (to be applied)		VACOSS Seal MUX	--- ---	Med. ($\beta=0.5$) Med. ($\beta=0.5$)
	Fresh blanket fuel		Item counting ENGM	--- Gross	--- Med. ($\beta=0.5$)
B	MOX fresh fuel, Spent fuel (Difficult to access area)		MUX, ENGM, EVRM, EXGM	---	See Safeguards Criteria
C	MOX fresh fuel (in core) (Difficult to access area)		MIVS, ENGM, EVRM, EXGM	---	See Safeguards Criteria
D	Spent fuel (under single C/S based on surveillance)		Item counting MUX	---	---

2.4.2 Joyo FBR

Joyo is an experimental FBR at 100 MWt. The reactor uses around 15% and 20% fissile Pu fuels with reflectors in the peripheral instead of blankets. Joyo reactor consists of 67 core fuel assemblies. The reactor would be operated at full power for 75 days, refueled by replacing one sixth of the core, which takes about 30 days. The cycle would be repeated three more times, when an extensive maintenance/refueling taking six months to a year would be required. After that, the reactor would resume full power operation and the cycle repeats. A fuel assembly would reside in the core in average about two years.

The fuel handling procedures and safeguards measures are largely the same as those at Monju. The differences will be highlighted below. At Joyo, the fresh fuel assemblies are received in sealed cask with Type E seals from PFPF.

At Joyo, a cask car is used to transfer fresh and irradiated fuel outside of the reactor hall, and an ex-vessel transfer machine (EVTM) is used to transfer the fuel assemblies inside the reactor hall. (At Monju, an equipment hatch can be opened to allow the EVTMMoves in and out of the reactor hall during refueling.) At Joyo, the fresh fuel is transported via the cask car from fresh fuel storage pit to the boundary at the reactor hall, lowered into a transfer rotor tank via a transfer rotor, rotated so that the fuel assembly is inside the reactor hall and then picked up and transferred via the EVTMM into the peripheral of the core where there are 30 locations for storage. The fresh fuel would be stored there for one cycle (75 days) and then put into the core for six cycles. The spent fuel is removed in exactly the same route in reverse, except that they are store in the peripheral of the core for two cycles before they are moved into spent fuel storage pond. The inventory in the reactor core and its 30 peripheral storage locations cannot be verified directly and is thus covered by an elaborate containment/surveillance system with continuos, unattended NDA system, as described below (Hashimoto, 1994).

The monitors on the cask car (CCRM) include ^3He neutron detector and NaI gamma detector and they can distinguish fuels from other materials (e.g., irradiated reflectors and control rods) and can also distinguish spent fuel from fresh fuel. The ENGM, EXGM and EVRM systems described earlier are also used here.

In addition to an annual PIV, there are 11 IIVs per year for timeliness purposes (for fresh MOX). During IIVs, the C/S systems are evaluated and fresh fuels are identified and item counted. Core fuel and spent fuel are verified by examination of C/S and the recorded NDA data for fuel transfers four times per year. Since the surveillance for the spent fuel pool cannot determine the number of fuel assemblies shipped, and that the IAEA chose not to verify the spent fuel transfers, the spent fuel inventory in the pool is verified with improved Cerenkov viewing device with 20% detection probability when transfers occurred during the period; 50% for PIV.

To improve the safeguards effectiveness, an additional neutron detector serving as a C/S device will be installed later this year above the reactor core so that the fresh fuels will be safeguarded by a dual C/S system.

3 NO-NOTICE RANDOMIZED INSPECTIONS

In this section, four schemes of randomized inspections for each facility will be developed. Brief descriptions of theoretical models of randomized inspection, in particular, illustration of how they can be used to reach the same detection probability goals as required in regular inspections are described later in this sub-section. Requirements for their implementations for the operators and inspectors are provided for Tokai Reprocessing Plants. The relevant current IAEA Safeguards Criteria for each facility are also organized in tables for easier understanding of the current safeguards requirements.

The randomized inspections are developed so that the existing safeguards objectives can be accomplished in a more cost effective manner. About 50% of the interim inspections may be omitted, although the inspections when carried out probabilistically will be more intensive. If, in addition, remote monitoring is used, the actual inspections can be further reduced.

3.1 Randomized Inspections at Scheduled Opportunities

In the basic scheme, an inspection has two stages:

- (i) randomizing the decision as to whether or not an actual inspection is to be carried out with a probability p , followed by enhanced inspection activities to achieve a higher detection probability than that necessary in a non-randomized inspection.

The non-detection probability for such a randomized inspection is:

$$\beta = 1 - p + p\beta'_{actual}$$

where $1 - \beta'_{\text{actual}}$ is the detection probability that must be achieved when an actual inspection is implemented. Thus, at any scheduled timeliness inspection opportunity, the detection probability goal $1 - \beta_{\text{goal}}$ as required by the IAEA Safeguards Criteria can be achieved if the inspection probability p is not smaller than the detection probability goal $1 - \beta_{\text{goal}}$ and that the actual detection probability $1 - \beta'_{\text{actual}}$ is not smaller than $(1 - \beta_{\text{goal}})/p$.

In this way, the number of inspections would be reduced while the same timeliness and detection probability goals can be achieved as in regular inspections. For example, if $p=0.6$ is used, in average, there will be $11 * 0.6 = 6.6$ interim inspections per year, instead of 11.

3.2 Randomized Inspections at Any Time

The basic model of randomized inspection described above can be generalized so that the inspections may occur at any time. Inspections carried out according to the model will also satisfy both the timeliness and detection probability goals. In addition, the inspection effectiveness is enhanced since inspections may commence at any time, not only at scheduled opportunities, thus strengthening the Agency's ability to detect undeclared material or activities.

A possible way to expand the coverage of the current inspection regime while achieving the same timeliness and detection probability goals is to include the intermediate inspection opportunities at t_i $i=1,2,3,...,N-1$, before t_N , when a timeliness period arrives, such that:

$$\prod_{i=1}^k \beta_i \leq \beta_{\text{goal}}$$

where $k \leq N$.

The basic model of randomized inspections described earlier can then be applied to these intermediate inspection opportunities. Let the probability for carrying out the i -

th actual intermediate inspection be p_i , and the detection probability in the actual inspection be $1-s_i'$. The detection probability goal requirement becomes:

$$(1-p_i) + p_i s_i' \leq \beta_i$$

This condition must be satisfied at each t_i . As described in the previous Section, this can be satisfied if

$$p_i \geq 1 - \beta_i \text{ and } 1 - s_i' \geq \frac{1 - \beta_i}{p_i}. \text{ In this way, inspections may occur at any time}$$

while reaching the same timeliness and detection probability goals.

An example will be used to illustrate the principle. Assume that 50% detection probability on a monthly basis is the goal. If an inspection may occur any day, the non-detection probability on a daily basis can be set to (0.5) to the (1/30) power, or 0.977. Thus, one can use $0.025 > 0.023 (=1-0.977)$ as the probability for inspection to occur each day. When an inspection is to occur probabilistically, the detection probability for the inspection must be increased to $0.023/0.025=0.92$. In this way, the actual number of inspections may be decreased, but the same detection probability goal is achieved all the time. Inspection would be more effective since attempt to conceal a diversion would more likely be detected if inspection is not scheduled.

3.3 Tokai Reprocessing Plant (TRP)

3.3.1 IAEA 1991-1995 Safeguards Criteria for IIV

The IAEA Safeguards Criteria for interim inspections at a reprocessing plant are summarized in the table below. The timeliness Criteria is one month for Pu product and in-process Pu, and three months for spent fuel. Thus, there are 11 monthly interim inspections per year at TRP (plus one physical inventory verification). Details of the inspection requirements are described in the IAEA Safeguards Criteria.

Pu Product	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G+P
S C/S	Y		Y		
V C/S		20%			
D C/S	Y	20%			

In Process Pu: per DDG-SG approved procedures, e.g., via NRTA.

Waste	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G
S C/S	Y		Y		
V C/S		20%			
D C/S	Y	20%			

Spent Fuel	Surv.	Seal	IC	DP	Defect Tests
No C/S		Y	20%	G	
S C/S	Y				
If transfers w/o IC		+	Y	20%	G
V C/S		20%			
D C/S	Y, or	20%			
If transfers w/o IC,		+20%			

[Notations: Surv.=surveillance, IC=item counting, DP=detection probability goal, G=gross defect test, P=partial defect test, C/S=containment/surveillance, S=surveillance with camera or video, V=seal, D C/S= dual C/S, Y=yes, DDG-SG= Deputy Director General-Safeguards Department, w/o=without]

3.3.2 Current Interim Inspections Activities at TRP

The current interim inspection activities for various types of materials at TRP are summarized below:

- 1) Spent Fuel - Review of C/S records from cameras; the surveillance record is also compared with the operator's declaration on movement in the spent fuel storage area.
- 2) For the spent fuel in the head end process area before input accountancy tank including spent fuel transfer pool, mechanical treatment cell, dissolvers and buffer tanks, the declarations are based on the reactor operators values. Inspectors also check flow of the spent fuel batches from the dissolvers to the input accountancy tank.
- 3) The buffer tanks inventories in the processing area from the input accountancy tank to Pu output accountancy tank are measured via tank volume measurement and chemical analysis, with 50% detection probability at one or two tanks for bias defect tests based on operator's provisional declaration.
- 4) The inventories in contactors, small pots and columns in the processing area are estimated via engineering equations based on physical parameters at nearby tanks.
- 5) The Pu solution in the Pu evaporators is drained nominally into the output accountancy tanks to minimize unmeasurable inventory in the processing area.
- 6) The Pu solution in the Pu product storage tanks are estimated by the operators and then measured (via tank volume measurement and chemical analysis) when selected for verification with 50% detection probability based on operator's provisional declaration for partial and bias defect tests. However, all Pu solutions in the Pu storage tanks are measured if operator cannot provide the provisional declaration based on volume measurement and chemical analysis.
- 7) For hulls in hulls drums, camera surveillance records and neutron measurement data obtained from an unattended monitoring system are reviewed. The surveillance record is also compared with the operator's declaration on movement in the vitrified waste transfer cell.

- 8) For vitrified high level liquid waste (HALW), camera surveillance record and data from unattended monitoring system based on neutron measurement are reviewed. The surveillance record is also compared with the operator's declaration on movement in the vitrified waste transfer cell.

3.3.3 Randomized Inspections and State-Level Approaches:

To achieve a more cost efficient and strengthened safeguards system, four schemes of randomized inspections will be analyzed:

- 1: Facility Approach, randomized inspection at scheduled monthly opportunities,
- 2: Facility Approach, randomized inspection at any time,
- 3: Facility Approach, randomized inspection at any time, including INFCIRC/540 activities and access.
- 4: State-Level Approach, randomized inspection at any time, including INFCIRC/540 activities and access.

In all the schemes, about 50% of the interim inspections may be omitted, although the inspections, when carried out probabilistically, will be more intensive. The IAEA could achieve the same timeliness and detection probability goals as required in regular, non-randomized inspections. In addition, the IAEA safeguards system would be strengthened due to the enhanced ability to detect undeclared nuclear materials or activities.

3.3.3.1 *Randomized Inspection – Facility Approach, Based on Traditional Inspection Practice at Specified Monthly Date*

Assumptions and Requirements

A fundamental requirement is the timely (prior to the scheduled monthly inspection dates) provision of information to the IAEA (say, via a mailbox or sent electronically, with proper authentication and encryption, to the IAEA Office in Japan) including:

facility operation, and maintenance schedules
schedules and characteristics of shipments and receipts,
information for the material in process and storage and,
other information as agreed between the IAEA and the facility.

[In this basic randomization approach, the information provided should be the same as that necessary for the facility under regular inspections, i.e., accountancy information only. The additional information listed above would enhance the transparency of facility operation.]

Designated IAEA inspectors should be allowed to access Japan and the facilities with multiple entry visas. Facility operators should be ready for inspection and assist IAEA inspectors as necessary. SSAC should also be notified as soon as the inspectors arrive at the facility so that they may witness or assist the inspection.

Implementation Procedure

- 1) Facility operator prepares as usual under traditional inspection approach. After inspectors' arrival, operator provides them with general ledgers, source documents, list of inventory items on disks and operating records including operator's measurement data for examination.

- 2) IAEA decides on a monthly basis with probability p if an actual inspection will be implemented. The inspection probability p should be not less than 50%, the detection probability goal for Pu product. (For example, $p=0.6$)
- 3) If an actual inspection is necessary (by random selection), verify the materials as described in Section 3.3.2 above except that the detection probability must be increased to the goal specified in the Criteria for each material divided by p , the probability used to determine if an actual inspection is necessary. (With $p=0.6$, the corresponding detection probability in actual inspection is $0.5/0.6=0.83$.) In addition, inspectors check the consistency between the information just received on-site and the information received (in the mailbox) prior to the inspection.

Comments

The basic randomization approach is the easiest to implement and could allow the IAEA to save up to half actual interim inspections while achieving the same timeliness and detection probability goals as required under the current Safeguards Criteria. However, the other three randomization approaches would in addition enhance the safeguards effectiveness and should also be considered.

3.3.3.2 *Randomized Inspection - Facility Approach. Based on Traditional Inspection Practice But Allows An Inspection To Occur At Any Time*

Assumptions and Requirements

A fundamental requirement for randomized inspections at any time is the provision of information in advance (say, on quarterly basis) on facility operation and maintenance schedules, schedules and characteristics of shipments and receipts, and other information as agreed between the IAEA and the facility. More detailed declarations on the material/operation, including update of the advance information provided earlier, may be declared (say, to a mailbox) on a more frequent basis, e.g., weekly.

Facility should be ready to declare inventories and accept inspections at any time. Since a computerized, near-real-time accountancy database is available, declaration of inventory on demand should not be difficult. Inventories in the buffer tanks, contactors, small pots, and columns in the process area are treated in the same manner as in regular inspections.

Designated IAEA inspectors should be allowed to access Japan and the facility with multiple entry visas on a random basis. Facility must also be flexible in accepting and assisting inspection at unscheduled times to meet the Agency requirement. Inspectors should be allowed immediate (say, within 30 minutes after arrival at gate) access inside the facility to observe facility activities and to set up additional surveillance; other inspection activities may begin after a mutually agreed time, say, in two hours.

SSAC should also be notified as soon as the inspectors arrive at the facility and may assist or witness the inspections.

Implementation Procedures

- 1) Assuming that an inspection may occur at any day in a month. IAEA decides a set of β_i , $i=1$ to 30, such that their products is not greater than the detection probability goal, 50%. An example is to set them equally to $(0.5)^{(1/30)}=0.977$. (Thus $1-\beta_i=0.023$)
- 2) IAEA decides if an inspection will occur on the i -th day with probability p_i , p_i should be at least $1-\beta_i$. (for example, $p_i=0.025$) If an actual inspection is necessary, verify the materials as described in Section 3.3.3.1 for the traditional non-randomized inspection. An actual inspection may be omitted probabilistically.
- 3) After inspectors' arrival, facility operator provides them with general ledgers, source documents, list of inventory items on disks and operating records including operator's measurement data for examination. Inspectors check the consistency

between the information just received and the information received prior to the inspection.

- 4) Given an actual inspection, the detection probability must be increased to $(1 - \beta_i)/p_i$. (for example, $0.023/0.025=0.92$) In addition, inspectors check the consistency between the information just received on-site and the information received (in the mailbox) prior to the inspection.

Comments

- 1) The randomized inspection that could occur at any time would be more effective since concealment for a diversion would be more difficult. For example, processing of undeclared material or diversion of Pu in between previously scheduled inspection dates may be detected when inspections could occur any time.
- 2) The inspectors are quite free to set β_i 's, as long as their product satisfies the timeliness detection goal. Thus, when it is inconvenient for the Agency to carry out inspections at certain times, inspectors may set the corresponding β_i to 1. (Of course, inspector should not notify the operator in advance for such decisions.) Alternatively, inspectors may set some β_i to a lower value, for example, in order to carry out an interim inspection for timeliness in conjunction with flow verification. In this way, a dynamic timeliness goal could be achieved all the time: any diversion could be detected within a timeliness period with the detection probability as required in the Criteria.
- 3) Another advantage is that unannounced inspections would enhance the Agency's ability to verify the absence of undeclared material or activities.
- 4) The facility operation would become more transparent to the IAEA via advanced declarations. This would contribute to confidence building between the facility and the IAEA. It would also help the Agency to plan for more effective and efficient inspections.

3.3.3.3 Randomized Inspections at Any Time with INFCIRC/540 Strengthened Safeguards System- Facility Approach

IAEA is in the process of implementing strengthened safeguards system, as described in INFCIRC/540. Although irrelevant to randomization of inspections, IAEA may wish to carry out some INFCIRC/540 activities in conjunction with any inspection. Thus, in addition to the activities described in Section 3.3.3.2, IAEA may:

- 1) use remote monitoring to transmit surveillance records (or other information), authenticated and encrypted appropriately, to the IAEA Office,
- 2) verify the correctness and completeness of information provided, and
- 3) verify the absence of undeclared activities or materials.

Activities for 2) and 3) above relevant to INFCIRC/540 should be carried out as they become necessary, but should not be implemented mechanistically.

Assumptions and requirements, and Implementation procedures relevant to the randomization approach are the same as that described earlier. Additional declarations as required under INFCIRC/540, and Part 1 Measures must also be provided.

It should also be pointed out that SSAC may carry out some C/S activities as described in the Annex J of the Criteria in a manner that could allow the IAEA to reach its independent conclusions. If so, some credits for the C/S should be acknowledged; that would contribute to possible reduction in inspection effort.

Facility operators may develop procedures for managed access to protect proliferation sensitive or commercially sensitive information, or proprietary information, or to meet safety or physical protection requirement for access beyond strategic points at the facility.

3.3.3.4 Randomized Inspections with INFCIRC/540 Strengthened Safeguards System in a State-Level Approach

In a State-Level approach, all Pu handling facilities – beginning with spent fuel in the reprocessing plant, followed by Pu conversion plant, Pu fuel fabrication plant and ending at reactors using Pu fuel are considered as in the same Zone. Flow verifications among these facilities in the same zone become unnecessary. (This will be a significant saving for both the IAEA and JNC.) Instead, inventories at all facilities in the zone are verified simultaneously. With traditional inspections, this may be impossible for practical reasons. With randomized inspections, inventory declarations are made in advance and inspections at some facilities may be omitted while at others, inspection activities enhanced. Furthermore, additional containment/surveillance measures could be used at facilities selected for inspections to detect possible concealment by borrowing if simultaneous inspections remain difficult due to lack of inspectors available.

IAEA should develop a comprehensive understanding of nuclear activities in each state as a whole. This includes assessment of all information received, including that provided by the State under INFCIRC/540, under INFCIRC/153 (including that under Part 1 Measures for a strengthened and cost-effective safeguards system), that obtained by inspectors during inspection (and via remote monitoring), as well as information collected from open sources or that provided by other states. The Agency should evaluate the completeness and correctness of information regarding nuclear and nuclear related material, facilities, equipment, as well as research and development activities in the state as a whole. Based on the information review, IAEA may plan its inspection activities more effectively.

Assumptions and requirements, and Implementation procedures for the facilities relevant to the randomization approach are the same as that described in section 3.3.3.2, except that they will be applied to all facilities in the same zone – including reprocessing plant, conversion and fabrication plant, and reactors using reprocessed Pu.

For the IAEA, randomization may be applied at two (or more) levels in a nested manner: all facilities in the same zone as a whole, and then each facility (or further down to strata level) individually. IAEA would first decide probabilistically if there will be any inspection at all. If no, no inspection will be necessary at any facility. If so, decide which facilities will need inspections probabilistically. This should be executed in such a way that the timeliness goals can be achieved for all materials. (For example, by using the same book ending date for all facilities in the same zone.) The procedures described in Section 3.3.3.2 can be used here as well, except that the product of the two probabilities (inspection or not and which facility) would be used as the probability of inspection, p_i , in Section 3.3.3.2.

Comments:

In this approach, the emphasis is material accountancy for the state as a whole, instead of at each facility. Focus of the safeguards is the detection of diversion from the State as a whole, instead of from each facility or MBA. Diversion with concealment by borrowing could evade detection in traditional safeguards based on facility approach, if the inventories at different facilities are not taken simultaneously. Zone approach with simultaneous inspections could detect such concealment, but it is difficult to implement due to the lack of inspection resources. Randomized inspections, with advance declaration, would allow more flexible allocation of inspection resources since not all facilities must be actually inspected. Containment/surveillance measures may additionally used to detect possible borrowing scenarios, if necessary. Significant savings could be realized since flow verifications among these facilities become unnecessary.

Summary for Randomized inspections at TRP:

In summary, four schemes of randomized inspections have been proposed:

- 1: Facility Approach, randomized inspection at scheduled monthly opportunities,
- 2: Facility Approach, randomized inspection at any time,
- 3: Facility Approach, randomized inspection at any time, including INFCIRC/540 activities and access.
- 4: State-Level Approach, randomized inspection at any time, including INFCIRC/540 activities and access.

In all the schemes, up to 50% of the interim inspections may be omitted, although the inspections, when carried out probabilistically, will be more intensive. The IAEA would still be able to achieve the same timeliness and detection probability goals as required in regular, non-randomized inspections. In addition, with the last three schemes, the Agency would enhance its ability to detect undeclared nuclear material or activities since inspections may occur at any time. In particular, when the last scheme is used, the verification for flows within and in-between JNC Pu facilities become unnecessary and the Agency can enhance its ability in verifying the completeness and correctness of all information for the State as a whole.

3.4 Plutonium Conversion and Development facility (PCDF)

3.4.1 IAEA 1991-1995 Safeguards Criteria for IIV

The IAEA Safeguards Criteria for interim inspections at a MOX fabrication plant are summarized in the table below. The timeliness Criteria is one month for Pu product and in-process Pu, and three months for spent fuel. Thus, there are 11 monthly interim inspections per year at PCDF (plus one physical inventory verification). Details of the inspection requirements are described in the IAEA Safeguards Criteria.

MOX powder	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G+P
S C/S	Y		Y		
V C/S		20%			
D C/S	Y	20%			

In Process Pu- per DDG-SG approved procedures, e.g., via NRTA, or:

	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G+P
S C/S	Y		Y		
V C/S		20%			

Waste	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G+P
S C/S	Y		Y		
V C/S		20%			
D C/S	Y	20%			

3.4.2 IIV Activities at PCDF

As described earlier in Section 2, provisional values for accountancy are entered into the computer databases for PCDF at the end of each day. When the results of the chemical analysis for the materials involved become available (typically a week after sampling), the provisional values are adjusted accordingly. Thus, for randomized IIVs, the computer databases is available for inspections.

Details of the IIV activities are summarized in Table 2-4 in Section 2. In particular, the IAEA determines the holdup based on the Holdup Blender Assay System (HBAS). Waste drums are assayed via Waste Drum Assay System (WDAS). It is noted

that the actual detection probabilities used by the IAEA at PCDF, 90%, is higher than that required by the Safeguards Criteria.

3.4.3 Randomized Inspections at PCDF

The four randomization approaches described for TRP could be adapted readily from the PCDF. Note that the computerized database is readily available since they are entered at the end of each day. Furthermore, all the plutonium shipments are surveyed in unattended mode via PCAS, which would further simplify the randomized inspections.

3.5 Plutonium Fuel Production Facility (PFPF)

3.5.1 IAEA 1991-1995 Safeguards Criteria for IIV

The Criteria relevant to interim inventory verification for PFPF are listed below:

MOX powder	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G+P
S C/S	Y		Y		
V C/S		20%			
D C/S	Y	20%			

In Process Pu- per DDG-SG approved procedures, e.g., via NRTA, or:

	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G+P
S C/S	Y		Y		
V C/S		20%			

Waste	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G
S C/S	Y		Y		
V C/S		20%			
D C/S	Y	20%			

Fuel rods/assemblies	Surv.	Seal	IC	DP	Defect Tests
No C/S			ID	50%	G
S C/S	Y		Y		
V C/S		20%			
D C/S	Y	20%			

3.5.2 IIV Activities at PFPF

All operations in PFPF are remotely-controlled and the process areas as well as the feed and product storage areas are not usually accessible. An on-line real-time material accounting system is used as the basis for near-real-time accountancy and an extensive advanced containment and surveillance system plus a set of unattended/attended NDA devices distributed throughout the facility are integrated for the IAEA safeguards.

Details of the IIV activities are summarized in Table 2-6 in Section 2. It is noted that due to the application of NRTA, the detection probabilities used for most of the materials are 20%, with the exception of 50% for the waste assayed via WDAS.

3.5.3 Randomized Inspections at PFPF

The randomization approaches described for TRP could be adapted readily at the PFPF. In fact, randomization would be even easier to implement at the PFPF since:

- all flows are measured continuously in unattended mode by the IAEA,

- an extensive advanced containment and surveillance system is used to cover the feed and products areas,
- a real time advanced accountancy system is used to control all transfers in the facility which can also produce real time accountancy information, and
- a near-real-time accountancy system is used to provide continuous statistical oversight of nuclear material in the facility.
- an extensive system of unattended/attended NDA devices are installed to measure various kinds of materials throughout the facility.

3.6 Joyo and Monju Fast Breeder Reactors

3.6.1 IAEA 1991-1995 Safeguards Criteria for IIV

Spent Fuel	Surv.	Seal	IC	DP	Defect Tests
No C/S				50%	G
S C/S	Y		Y		
If transfers w/o IC		+	Y	20%	G
V C/S		20%			
D C/S	Y, o	20%			
If transfers w/o IC		+20%			
MOX fuel assemblies	Surv.	Seal	IC	DP	Defect Tests
No C/S			ID	50%	G
S C/S	Y		Y		
V C/S		20%			
D C/S	Y	20%			

Core fuel: C/S (Fuel Flow Monitors) evaluation

3.6.2 IIV Activities at FBRs

For Monju, since the MOX fuel assemblies are sealed with VACOSS seal at the fabrication plant, they are item counted verified with 20% detection probability at the IIVs. (Type E seals are used for Joyo reactor fuels.) Core fuel is verified with evaluation of the Fuel Flow Monitors described earlier. When there were spent fuel movements in the spent fuel pool, the IAEA would verify the spent fuel with improved Cerenkov viewing device with 20% detection probability.

3.6.3 Randomized Inspections at FBRS

Note that all the fresh and spent fuel transfers in the facility are monitored with extensive NDA equipment and are under camera surveillance. Furthermore, the facility is an item facility, and the preparation of facility accountancy reports on demand for all four schemes of randomized inspections should not be difficult. It is further noted that a remote monitoring system has been tested at Monju reactor; which would allow further reduction of inspection effort.

4 REFERENCES

- Cooley 1999: J. Cooley and K. Murakami, IAEA, "Implementation of the Additional Protocol," Proceedings of the 21st ESARDA Symposium on Safeguards and Nuclear Material management, ESARDA 29, p. 63, 1999.
- Ishikawa 1999: T. Ishikawa and K. Suzuki, Japan Nuclear Fuel Co. (JNF) "Implementation of SNRI at an LEU Fabrication Plant," Proceedings of the 40th INMM Annual Meeting, 1999)
- Kashimura, 1994: T. Kashimura, E. Omori, K. Kikuchi and H. Shimizu, TRP/JNC, "Near Real Time Materials Accountancy Development at the Tokai Reprocessing Plant," IAEA-SM-333/56, IAEA Safeguards Symposium 1994.
- Nakano, 1997: H. Nakano, M. Akiba, H. Kobayashi and S. Takahashi, JNC, "The Development and Experience of Safeguards at the Plutonium Fuel Production Facility," JNMM, February 1997.
- Takahashi, 1994: S. Takahashi, T. Ohtani and H. Ohshima, JNC, "Experience in Safeguards Implementation at the Plutonium Fuel Production Facility," IAEA-SM-333/43, IAEA Safeguards Symposium, 1994.
- Hashimoto 1994: Y. Hashimoto, R. Arlt, G. Saringer, J. Janov, J. Halbig and S. Klosterbuer, "Development of Plutonium Fuel Flow Monitors for the Experimental Fast Reactor JOYO," IAEA-SM-333/51, IAEA Safeguards Symposium, 1994.
- Usami, 1995: S. Usami, T. Deshimaru, and K. Tomura, Monju/JNC, "Safeguards in Prototype Fast Breeder Reactor Monju," Proceedings 1995 International Conference on Facility Operations-Safeguards Interface, p.66.

APPENDIX 1

A Review of Existing Model of No-Notice Randomized Inspection And Their Potential Application to Model Pu Handling Facilities

Summary

Literature regarding two "alternative" safeguards concepts - randomization and zones - is reviewed. The concepts were introduced in the early 1980's to address the need to make safeguards more efficient in the light of the increasing number of facilities under safeguards and a fixed IAEA inspection budget. The paper discusses literature broadly relating these approaches to IAEA needs and objectives, reports from IAEA consultants meetings, reports of field trials, and other technical papers. The review suggests that the approaches have been extensively considered on a theoretical and practical level, and that the safeguards community endorses them on a conceptual level as potentially valid ways of achieving safeguards objectives. Actual utilization of the ideas in safeguards practice has to proceed on a case-by-case basis, but progress is being made.

1. Introduction

The purpose of this paper is to review the literature on randomization approaches and zone approaches to safeguards. These two topics are technically distinct, but address a similar issue and are often considered in combination or as alternatives; the 1991 consultants meeting described below, for example, treated the two topics together. The next section briefly discusses what these approaches are, and why they have been considered; section 3 describes four broad discussion papers that motivate the more technical discussions; section 4 discusses IAEA consultants meetings on the topic; section 5 discusses trials in five locations; section 6 considers a number of technical papers; and section 7 provides conclusions.

2. Background

Briefly stated, the issue addressed by alternative safeguards approaches is that constraints on IAEA inspection resources conflict with the increase in facilities and

materials under safeguards, if safeguards are required to be (1) based fundamentally on facilities or MBAs and (2) required to be non-discriminatory in implementation at this level. While paragraph 81 of INFCIRC/153 allows for safeguards implementation to depend on the nature of the fuel cycle and the SSAC, such a dependence is not really consistent with technical safeguards requirements as reflected, for example in the 91 - 95 criteria.

One way, in theory, to address the technical problem of maintaining some level of effectiveness in terms of a capability of detecting diversion, while reducing inspection effort, is to use a strategy of doing inspection activities on a randomly selected basis rather than all the time on a fixed schedule. This broadly defined strategy is called "randomization." Because in most cases the essential element necessary for an effectively random approach is a short-notice or unannounced inspection, the term "short notice random inspection" (SNRI) is often used.

Another approach to the resource problem is to enlarge MBAs to cover multiple facilities, obviating the need for certain flow verification measurements between MBAs or facilities; this is sometimes called a "zone approach." Combinations of these strategies are also possible.

The following brief chronology summarizes the history of the development of these safeguards concepts.

- 1983 The Hexapartite Safeguards Project (HSP). The HSP endorsed a "limited frequency unannounced access" strategy, a randomized inspection approach to detect undeclared HEU production.
- 1983 - 87 Canadian zone approach trial. This was reported in 1987; implementation of the zone approach continued.
- 1984 Initial IAEA consultants meeting on application of safeguards to multiple facility fuel cycles.
- 1987 American Nuclear Society meeting; Fuel Cycle Safeguards are considered in one session.

- 1988 General Electric SNRI Trial (USA)
- 1989 Korean Zone Trial
- 1990 NPT Review Conference. The Conference urged continued improvement in the efficiency and effectiveness of safeguards and that "this process be maintained *inter alia* by utilizing new cost effective technologies and methodologies. It invites the IAEA to consider studying new safeguards approaches, including, for example, randomized inspections." (Reference 1)
- 1991 The "91 - 95" criteria endorse (1) the concept of zone approaches with simultaneous PIVs and (2) randomized inspections to confirm the absence of borrowing and for the purpose of flow verification at fabrication facilities.
- 1991 Second Consultants Meeting on application of safeguards to multiple facility fuel cycles.
- 1993 Westinghouse SNRI trial
- 1993 - 97 The IAEA considers short notice inspections as an element of the "93+2" programme. The IAEA concluded that unannounced (no-notice) inspections at strategic points at declared facilities (in states with comprehensive safeguards agreements) was within its existing legal authority. The Additional Protocol allows for inspections at any place on a site in conjunction with design information visits or ad hoc or routine inspections based on a two-hour notice.
- 1996 Swedish SNRI trial

3. General papers on alternative safeguards approaches

The following four papers address, in general terms, the basic problem of IAEA resource constraints and the relevance of alternative approaches to safeguards.

Gruemm (1984)

Gruemm's article (Reference 2) considers potential ideas for improving the efficiency of the safeguards function, in light of IAEA resource constraints. He points out that the IAEA's approach to "non discriminatory" safeguards is to provide equal treatment for each facility of a certain type, and to verify the complete material balance of each type of MBA in an equivalent manner. He suggests that significant savings could result from abandoning the assumption that states harbor clandestine facilities, but concludes that it is improbable that such a drastic change in safeguards philosophy would find support. An alternative possibility is that of a randomized approach to similar facilities in a state; random selection of reactors for inspection, for example. Gruemm concludes that savings may be possible, but that study is need to determine any potential cost in terms of effectiveness

Higgenbotham, Gupta, DeMontmollin (1985)

The authors (Reference 3) suggest that, although INFCIRC/153 safeguards is technically based on individual facilities and material balance areas, the goals of detecting diversion should be considered at the state level. They suggest a zone approach to safeguards in which facilities in a state are grouped into three large MBAs corresponding essentially to LEU, spent fuel, and direct-use material. Savings could result from not verifying flows within these MBAs. Furthermore, effort for the new MBAs could be allocated according to the sensitivity of the material in each of them. Thus, safeguards for the LEU zone could consist of an annual PIV alone. They also suggest that the zone approach would benefit from and improved and more timely information and reporting system, and that the resulting information for flow patterns between facilities could provide useful information not available on an individual facility basis.

Petit (1987)

Petit (Reference 4, 5) states that growth of Agency inspection resources is unlikely to keep pace with the growth in nuclear facilities and materials, suggesting that IAEA efficiency will have to double in terms of the amount of material safeguarded per

inspection man-day. He concludes that there is no hope to solve this problem with the approach of uniform application of routine inspection to all similar facilities. He rejects the zone approach mentioned in the previous paragraph because of the impracticality of simultaneous inspections at multiple facilities. He suggests that activities performed at individual facilities be subject essentially to random selection.

Ek (1992).

Ek reports (Reference 6) on SAGSI discussions in the late 80s and early 90s on the topic of whether alternative safeguards; in particular the DDG asked SAGSI "... to re-examine how Agency safeguards are implemented in order to advise on ways to reduce costs while meeting new requirements and maintaining effectiveness." SAGSI reported that one way to do this might be fuller use of the state's SSACs, but that the IAEA could not delegate its responsibilities or its ability to arrive at independent conclusions. Other alternative safeguards principles identified by SAGSI were "transparency" and "openness." These principles translated operationally into increased information in the form of declarations, and increased access by inspectors. Ek states that further analysis and field tests are necessary to determine how such principles can be used in practice to increase effectiveness and efficiency. He notes that such a field test is planned in Sweden (see below; this test is essentially a test of broadened declarations and short-notice inspection).

Moussalli (1996).

Moussalli states (Reference 7) that a significant reduction of the safeguards costs could result whenever short notice random inspections are implemented even if the current safeguards implementation regime is maintained.

4. Consultant's Meetings

1984 Consultants Meeting

The IAEA held an initial consultants meeting on "The Application of Safeguards to Multiple Facility Fuel Cycles" in 1984. (Reference 8) The purpose of the meeting was to

"advise the Agency on investigations to be conducted on means whereby the characteristics of the fuel cycle of a state and entirety of the information available to the Agency concerning the fuel cycle might be more fully taken into account in the planning, implementation and evaluation of safeguard in order to improve the effectiveness and efficiency of safeguards." The meeting supported further testing of the concepts of random selection of facilities and inspection activities, and further investigation of the zone approach. It did not recommend further investigation of conditioning safeguards criteria or diversion assumptions on the nature of the fuel cycle.

1991 Consultants Meeting.

The main purpose of the 1991 meeting was to review progress made on the two concepts endorsed by the previous meeting, i.e., and the zone and randomization concepts. (Reference 9,10) The working group on the zone approach provided fairly definite and positive conclusions, endorsing the soundness of the basic technical concept of the zone approach, and recommended that the reduced intrusiveness of inspections connected with the zone approach should be recognized. It stated that the zone approach seemed most promising for the natural and LEU fuel cycles, and less promising for plutonium handling facilities. The conclusions of the working group on randomization were somewhat more equivocal, in part because the questions posed to them were framed largely in terms of random selection of facilities for inspection, as opposed to more sophisticated applications of randomization. The technical basis for randomized activities was endorsed, but a number practical problems (confidentiality in inspection planning, impact on inspector's morale, etc.) and presentational issues (e.g., how to report on goal attainment for a facility that was not selected as part of a randomized scheme) were also noted.

5. Field Trials

Canadian Zone Approach Trial.

The IAEA reported in 1987 on a four-year trial, which implemented a zone approach for unirradiated uranium fuel, starting at the conversion plant, and ending at the reactor.

(Reference 11) The trial involved four bulk facilities and a large number of reactors. It was noted that flow verification between these facilities would require between 250 and 1000 inspection man-days per year. Furthermore, borrowing was considered a very credible diversion scenario, and a zone approach with simultaneous inventories could address this problem as well. The logistics of arranging for simultaneous or near-simultaneous PIVs posed a number of practical problems, but these were largely overcome. Certain temporary "bridging measures" were developed for cases where inventories could not be scheduled precisely together. One element of these measures was the use of unannounced inspections. Thus, effectively simultaneous inventories were conducted for four years. The report attributes 8 extra inspection days per year to the requirements of the simultaneous PIVs, a small number in comparison to the alternative of flow verification.

General Electric SNRI Trial.

The General Electric LEU fuel fabrication facility in the U.S. was the site of a trial of the short-notice-random-inspection (SNRI) concept in 1989 - 1990. (Reference 12) The automated material accounting system, and large flows of material into and out of the facility made the GE plant an appropriate test bed. The objective of the trial was to verify the flows of material into and out of the facility, based on a randomized schedule of facility visits. The inspectors, however, were not able to measure full fuel assemblies, but did measure rods, and "...trace[d] the rods (to the extent possible) as the assemblies were constructed..." The inspectors also measured UF₆ flows into the facility and powder and pellets shipped from the facility. The randomized schedule was based on the concept that the materials in the flow strata would be held for a fixed "residence time" during which they would have declared values and were potentially available for inspection. The randomized inspection schedule was constructed so that, in theory, every element of a flow stratum had a non-zero chance of being inspected. Inspections were conducted on two hours notice; this involved the resolution of a number of practical problems. However, the report concluded that the "Agency has not implemented all the conditions for complete use of SNRIs" so that was "thus unable to reach its goal to verify 100% of

the flows." One of the problems evidently referred to here is the lack of implementation of a "mailbox" declaration, corrected in the Westinghouse trial.

The Westinghouse SNRI Trial

A trial very similar to that at GE was held at the Westinghouse LEU fuel fabrication plant in the US in 1993. (Reference 13) As in the GE trial, the objective was flow verification by random selection of inspection times. The procedures included a carefully implemented "mailbox declaration" whereby the facility declared values for items both by fax to the IAEA, and to a tamper-indicating computer on site. Thus values for items subject to verification were declared before the operator knew if an inspection was to occur. The strata included in the trial were UF₆ cylinders and assemblies; these items were tested for gross and partial defects by NDA. Eight inspections were carried out on a random basis over a period of about six months. Largely successful, the trial had encountered one problem with respect to the residence times of the items in the strata to be verified: a small percentage of the items were not subject to verification because the time between their creation or arrival at a declared value and their shipment or consumption by the process was too short.

The ABB Atom SNRI Trial.

A third trial of the SNRI concept for LEU fuel fabrication was held in Sweden in 1995- 96 at the ABB Atom AB facility. (Reference 14) There were significant differences between the Swedish trial and the two previous trials: (1) almost all material in the facility (not just flow strata) was available for verification (however, scrap and waste were not considered); (2) the facility was able to make *advanced* declarations on a weekly basis for the coming week; (3) the verification measurements were predominantly based on sampling and destructive analysis; (4) the method of stratification for verification purposes was based on the concept of a "project" or a fixed batch of material for a given customer. This approach meant that the problems relating to "residence time" experienced in the two previous trials did not exist. On the other hand, it appears that the approach of verifying by "project" led to some difficulties (although it is not clear that these difficulties were inescapable): first, there was the possibility of substitution of

material from one project to another, and second, the report states that resource constraints did not allow adequate detection probability for defects. The inspectorate was able to gain access to the process within 30 minutes. The report concluded very optimistically that the approach is cost-effective, strengthens safeguards, and is favored by the facility operator.

Korean LEU Zone Trial.

During 1989, a zone approach was implemented for one LEU fabrication plant and the eight reactors supplied by that plant. (Reference 15) The implementation of the simultaneous inventory was considerably eased by the fact that only two of the reactors had inventories of fresh fuel. The authors conclude that the inspection effort for the fuel fabrication facility was effectively halved by the use of the zone approach.

6. Technical studies

This section presents a review of a number of largely technical papers on the zone and randomization approaches.

Fishbone and Higgenbotham (1987) reported extensive studies of zone and zone-like approaches. (References 16,17,18,19) There are a number of variants of the zone approach that can be conceived, and these authors in a paper, which considered facility-oriented safeguards, a partial-zone approach, a full zone approach, and two types of randomization, analyze these. In the basic form of the zone approach, verification of interfacility, intra-zone nuclear material flows are eliminated, and PIVs are performed simultaneously for all facilities within the zone. Material in transit at the time of the PIV must also be adequately verified. In an analysis of a fuel cycle consisting of one conversion plant, three fabrication plants, and 21 LWRs, the authors found a reduction of about 30% in inspection effort.

The first formal adoption of a randomized inspection scheme occurred in the context of the Hexapartite Safeguards Project (HSP). A paper by Menzel (1983) (Reference 20) summarizes the conclusions of the HSP, which negotiated a safeguards approach to centrifuge enrichment facilities. An important element of that approach is the use of

randomized unannounced visits to the cascade hall for the purpose of detecting undeclared HEU production. The average frequency of such visits would depend upon the nature of each facility and how much time would be required to modify the cascade to produce significant quantities of HEU. The average frequency for inspector access to the cascade is given as 4 to 12 times per year.

Flow verification for centrifuge enrichment plants was the subject of a paper by Gordon and Sanborn. (Reference 21) This paper suggests a randomized scheme for verification of the flow of feed and product cylinders. The scheme introduced the mailbox/residence time concept, whereby cylinders would be held for possible inspection for an agreed period after a nuclear material value was irrevocably declared to a "mailbox." A fixed schedule of potential inspection dates is determined which allows each cylinder to be subject to possible inspection, and the inspectorate randomly chooses actual inspections from among those dates. A later paper by Murphey, Emeigh and Lessler (1991) (Reference 22) carefully reviews the conditions for statistical validity of an SNRI inspection plan. In particular, they review the conditions for validity of the detection probability in the Sanborn paper, pointing out that in practical circumstances these conditions - such as short residence times - may not be achieved (this has in fact turned out to be the case in the field trials). The paper also points out the need to consider diversion strategies such as substitution. Fishbone, et. al. (1991) (Reference 23) describes the mailbox concept for nuclear material transfers, conditions for the validity of mailbox declarations, and practical conditions necessary for implementation of the concept. Lu, Teichmann and Lu (Reference 24) studied the problem of achieving a valid detection probability for flow verification in spite of practical problems such as short residence times. This study is based on very realistic residence-time data, and shows the trade-offs between the residence-time distribution, expected number of inspections, and detection probability, for a number of possible inspection strategies.

Randomized strategies can also be applied to inventory verification. The question here is what level of object (e.g., facilities, MBAs, strata, items) should be the object of randomization, and how such randomization could be performed. Canty, Stein, and Avenhaus (1987) (Reference 25) consider randomized strategies in which facilities (or

facility PIVs) are randomly selected for verification, using a game-theory model. The models parameters are (1) the effort to verify a facility (2) the probability of detecting a diversion, if the facility diverts and the inspector inspects that facility (3) the total inspection effort available. This model attempts to capture the whole fuel cycle at once and is hence not detailed (the effort spent on a facility cannot be altered to change the detection probability, for example, and there is no time dimension to the model). The mathematical results of the game theory analysis are complicated, and not easily summarized. The example the authors provide suggests a radical departure from Agency practice. Markin (Reference 26) considered a number of methods of randomly selecting inspection activities, and assessed their capabilities in terms of "statistical effectiveness" (improved detection probability with fixed inspection resources) and "safeguards effectiveness" (conformity to the SIR criteria). It is pointed out that in many cases the criteria are structured so that improvement in one may violate the other. The paper concludes that randomly selecting strata (or facilities) to be verified, instead of verifying all strata (or facilities) has the potential of increasing statistical effectiveness, while randomly assigning inspection effort when verifying all strata (or facilities) does not. This is true when there is a fixed overhead inspection effort cost associated with gaining access to a stratum (e.g., instrument calibration) or facility (e.g., travel time).

Mathematical models of randomized inspection timing, and how such inspections could fulfill timeliness goals, have been studied. Canty and Avenhaus (1991) (Reference 27) consider a game-theoretic model of randomized inspection timing at a facility such as a reactor spent fuel pool. For example, an inspector randomly chooses on which 4 of the 12 inspection opportunities (the beginning of each month) he will inspect. It is assumed that if material has been diverted, detection will occur with high probability. The authors choose "average time to detection" as the objective of the game (as opposed to probability of timely detection). They show that a randomized inspection strategy can achieve shorter average detection times than a fixed periodic inspection. The randomization is achieved by assigning probabilities to each set of potential inspection schedules (e.g., inspections on month 2, 5, 7 and 9 might be given a probability of 0.1). However, Sanborn (1992) (Reference 28) looked at the same scenario and arrived at a substantially different conclusion by making a slightly different assumption. It is shown

that for a wide class of possible inspector strategies, the inspector cannot achieve a better average detection time than that of simple periodic inspection. The assumption in the Canty paper (and abandoned in the Sanborn paper) is that the adversary has to choose his time to divert before the year starts. When "probability of timely detection" is the criterion, then the optimal inspection strategy is to divide the year into intervals corresponding to the timeliness criterion (e.g., three months for spent fuel) and to assign a fixed probability to inspections at the end of each period.

Finally, two papers by Lu and Teichmann (1991) (Reference 29) and Lu (1993) (Reference 30) provide a mathematical model of the interaction between the randomized inspection plan (either selecting inspection opportunities or selecting strata to be verified) and the probabilities of detection of diversion for the individual inspection opportunities or strata. It is pointed out that a given overall goal for probability of timely detection can be fulfilled in a number of ways, either by a fixed schedule of inspections at relatively low probability of detection per inspection, or using a randomized schedule of inspections at a higher probability. The former is suggested by IAEA criteria, while the latter will tend to involve less effort given the overhead necessary for performing an inspection.

7. Conclusion

While non-random, facility-oriented safeguards are posed in INFCIRC/153 as the basis for full-scope safeguards, the theory and practice of safeguards seems to be evolving in the direction of the ideas considered in this paper. The zone approach for natural uranium has been successfully implemented in Canada, and the principle of randomized inspections were endorsed by the 1990 NPT Review Conference and incorporated into the 93+2 Programme and Protocol. The IAEA has considered zone approaches and randomization schemes in two consultants meetings. A substantial body of technical literature exists on these topics. The issue no longer seems to be whether these methods are legitimate, but whether they can be applied in specific circumstances in such a way as maintain or improve safeguards effectiveness and efficiency.

Implementation of these methods to realistic situations for plutonium facilities seems to be one of the questions that have not been covered by the literature.

References

1. Fourth Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, NPT/CONF.IV/MC.II/1, para. 7.
2. Gruemm, H., "Safeguarding the Fuel Cycle: Methodologies," IAEA Bulletin, Vol. 26, No. 3, p. 20 (1984)
3. Higginbotham, W. A., Gupta, D., and DeMontmollin, J. M., "Concept for Fuel-Cycle Based Safeguards," Nuc. Mat. Manage. XIV (Annual Mtg Issue) p.554 (1985)
4. Petit, A., "The Fuel Cycle Oriented Approach," Proc. Third International Conference on Facility Operations Safeguards Interface, American Nuc. Soc. p. 449 (1987)
5. Petit, A., "Imprevisibilité et Inspections Inopinées dans les Garanties Internationales," IAEA-SM-293/8, Nuclear Safeguards Technology, Nov. 1986, International Atomic Energy Agency.
6. Ek, P., "Independent Verification in Light of an Alternative Safeguards Approach," IAEA-SM-333/184, Symposium Proceedings of 'International Nuclear Safeguards 1994: Vision For the Future,' International Atomic Energy Agency (1994). Also of interest is Ek, P., "IAEA Safeguards A Possible Alternative Approach," Unpublished Discussion Paper, 1992
7. Moussalli, G., "Measures for Strengthening SG" paper presented at INMM Japan Chapter Meeting, Tokyo, October, 1996.
8. Report of the Consultant's Meeting on the Application of Safeguards to Multiple Facility Fuel Cycles," STR-189, April 1985, International Atomic Energy Agency.
9. "Application of Safeguards to Multiple Facility Fuel Cycles", STR-270, May 1991, International Atomic Energy Agency.

10. "Report of the Second Consultants Meeting on the Application of Safeguards to Multiple Facility Fuel Cycles", STR-275, September 1991, International Atomic Energy Agency.
11. Healy, G. J., "Zone Approach to Canadian Fuel Cycle Safeguards Concepts and Experience," Proc. Third International Conference on Facility Operations Safeguards Interface, American Nuc. Soc. p. 473 (1987)
12. Eberhard, C., and Kessler, J. C., "Short Notice Random Inspections: Resource Constraints and Effective Safeguards," Nuc. Mat. Manage. XIX (Annual Mtg Issue) p.23 (1990)
13. Fishbone, L., Moussalli, G., Hosoya, M., Ikonomou, P., and Naegele, G., Scott, P., and Fager, J., "Field Test of Short-Notice Random Inspections for Inventory-Change Verification at a Low Enriched Uranium Fuel Fabrication Plant," STR-302, International Atomic Energy Agency (1995)
14. V. Bytchkov, M. Hosoy, W. D. Sellinschegg, A. Touzov, G. af Ekenstam, J. Gustafsson, and R. Aquino, " Field Trial of No-Notice Inspection Scheme at ABB ATOM LEU Fuel Fabrication Plant in Sweden," SKI Report 96:72, December 1996
15. Kim., S. Y., Seo, O. S., Ferraris, M., and Gyntakis, E., "First Attempt of the Zone Approach for Safeguarding the Low Enrichment Uranium Fuel Cycle," Nuc. Mat. Manage. XIX (Annual Mtg Issue) p.106 (1990)
16. Fishbone, L.G., and Higginbotham, W. A., 1987, " Zone Approaches to International Safeguards of a Nuclear Fuel Cycle." Nuc. Mat. Manage. XV (Annual Mtg Issue) p. 35.
17. Fishbone, L.G., and Higginbotham, W. A., 1986, "A Study of a Zone Approach to IAEA Safeguards: the Low Enriched Uranium Zone of a Light Water Reactor Fuel Cycle." ISPO- 196 (BNL-38584) Brookhaven National Laboratory, Upton, NY, USA.

18. Fishbone, L. G., and Teichmann, T. 1991 "Analysis of the Zone Approach for Plutonium Facilities', ISPO-324 (TSO-90-14), Brookhaven National Laboratory, Upton, NY, USA.
19. Fishbone, L.G., and Higginbotham, W. A., "A Framework for Fuel Cycle Approaches to IAEA Safeguards," Nuclear Safeguards Technology, Nov. 1986, International Atomic Energy Agency.
20. Menzel, J., "Safeguards Approach for Gas Centrifuge Type Enrichment Plants," Nuc. Mat. Manage. XII no. 4, p. 30. (Winter 1983)
21. Gordon, D. and Sanborn, J. "An Approach to IAEA Material Balance Verifications with Intermittant Inspection at the Portsmouth Gas Centrifuge Enrichment Plant," BNL 51782, Brookhaven National Laboratory (1984)
22. Murphey, W., Emeigh, C., and Lessler, L., "Some Remarks Relating to Short Notice Random Inspection (SNRI)," Nuc. Mat. Manage. XX (Annual Mtg Issue) p. 103. (1991)
23. Fishbone, L., Moussalli, G., Hosoya, M., Ikonomou, P., and Wredberg, L., "The 'Mailbox' for Randomized Safeguards Inspections," Proc. 13th Annual ESARDA Symposium, p. 83 (1991)
24. Lu, M.S., Teichmann, T., and Lu, F., "Detection Probabilities for Random Inspections in Variable Flow Situations," ISPO-364 (SSN-93-33), Brookhaven National Laboratory (1993)
25. Canty, M. J., , Stein, G., and Avenhaus, R., "Detection Probabilities in Fuel Cycle Oriented Safeguards: the Reduced Frequency Unannounced Verification Model," Proc. Third International Conference on Facility Operations Safeguards Interface, American Nuc. Soc. p. 460 (1987)
26. Markin, J.T., "Randomization of Inspections," ISPO-295, N-4/88-641 Los Alamos National Laboratory, 1988

27. Canty, M. J., and Avenhaus, R., "Optimal Randomization Strategies Timely Verification, Proc. 13th Annual Symposium on Safeguards and Nuclear Materials Management, ESARDA 24, p 39 (1991)
28. Sanborn, J. "An Examination of Randomized Inspection Schedules with Respect to Two Detection Criteria," Nuc. Mat. Manage., Vol. XX, no. 4, p. 12 (1992)
29. Lu, M. S., and Teichmann, T., "A Scheme for Randomized Inspections," Nuc. Mat. Manage. XIX # 1, p. 35 (1991)
30. Lu, M.S., "Randomized Unannounced Inspections at Any Time," Proc. 15th Annual Symposium on Safeguards and Nuclear Materials Management, ESARDA 26, p 143 (1993)