INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS

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SESSION 8: FACILITY SAFEGUARDS AT AN LEU FUEL FABRICATION FACILITY IN JAPAN

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I. INTRODUCTION

In order to understand the problems of safeguarding LEU fuel fabrication facilities in comparison with fuel cycle facilities, let us list nuclear fuel cycle facilities widely encountered in safeguards in the order of safeguardability:

- Research reactors and critical assemblies
- Power reactors
- Spent fuel storage facilities
- LEU fuel fabrication facilities
- Enrichment facilities
- MOX fuel fabrication facilities
- Fuel reprocessing facilities

Economical production of nuclear energy depends on an appropriate fuel cycle in each country. It is generally acceptable for many countries to utilize fuel cycle facilities up to and including LEU fuel fabrication. However, it may be controversial to make a national decision to construct spent fuel reprocessing plants and enrichment plants to meet purely economical objectives without other political implications.

Since the LEU fuel fabrication facilities are distributed over many countries (roughly speaking, one fuel fabrication facility for 5 to 10 nuclear power plants), accumulated inspection efforts allocated for all LEU fuel fabrication facilities need about the same amount of effort allocated for all power plants. As a consequence, about 20% of the total inspection effort is actually allocated for the LEU fuel fabrication facilities. Considering the nature of bulk handling facilities and their population, the LEU fabrication facility is one of the major concerns in safeguards both for the State and the IAEA.

In contrast with the item-dominated facilities, the "material unaccounted for" (*MUF*) interpreted from measurements of nuclear material, quantities and qualities, plays an important role for verification of nuclear material at the bulk handling facilities. It should be emphasized that the type of measurements needed for safeguards are also necessary for process and quality control of plants.

Since the LEU fuel fabrication facility is categorized as a bulk handling facility, safeguards concepts applied to the bulk handling facility are of course, important. But we should not overlook that many discrete items containing nuclear material are also located on the site of such a facility, for example, thousands of UO_2 powder containers, thousands of fuel pins and hundreds of fuel bundles. Therefore, safeguards techniques for itemized facilities are also important for full implementation of safeguards at the LEU fuel fabrication facility.

As indicated by the title of this session, let us discuss the SSAC at a bulk handling facility focussing on the current practice of the SSAC at a BWR type LEU fuel fabrication facility owned and operated by the Japan Nuclear Fuel Company "JNF."

The lecture considers the following items in sequence;

- Requirements of the SSAC at the LEU fuel fabrication facility.
- An example of the facility MC&A at LEU fuel fabrication facility.
- Resources and staffing.
- Problems encountered and lesson learned.

II. REQUIREMENT OF SSAC AT LEU FUEL FABRICATION FACILITY

It is well known that a Safeguards Agreement conforming to INFCIRC/153 is required to provide that the State shall establish and maintain a system of accounting for and control of all nuclear materials subject to safeguards.

A. Relation between the IAEA Safeguards and SSAC

The relation between the IAEA safeguards and the SSAC can be interpreted in Provisions 7 and 31 of INFCIRC/153 as;

- The SSAC shall be applied in such a manner as to enable the IAEA to verify findings of the SSAC. The IAEA's verification shall include, inter alia, independent measurements and observations conducted by the IAEA.
- The IAEA, in carrying out its verification activities, shall make full use of the SSAC and shall avoid unnecessary duplication of the SSAC activities.

In this context, the SSAC shall be established and maintained in such a way to harmonize efficiently with the IAEA verification activities.

B. Technical Elements of SSAC

The elements of the SSAC shall accommodate the following items (recommended by IAEA/SG/INF/2;1980).

1. Organizational and Functional Elements at the Level of State.

- Authority and Responsibility.
- Laws and Regulations.
- SSAC Information System.
- Establishment of Requirements of SSAC.
- Ensuring Compliance.
- Technical Support.

<u>2. Organization and Operation at the Level of Facility.</u>

- Initial Information of SSAC.
- Establishment and Operation of Facility MC&A.

Since the general features of these elements are covered in other sessions of this course, I will skip procedural matters and proceed to focus on technical elements which are important for implementing the SSAC at an LEU fuel fabrication facility. These elements are:

- MC&A at facility level.
- State inspection.
- Records and reports.

In the following section, we will discuss the rather general requirements of these technical elements at the bulk handling facility, focussing on the LEU fuel fabrication facility. And then, practice and experiences obtained at the JNF fuel fabrication facility will be mentioned.

<u>C. Requirements for MC&A at an LEU Fuel Fabrication Facility</u>

For safeguards, material accounting should be interpreted as the activities carried out in a timely manner to establish the quality and quantity of nuclear material present within a defined environment and the change in the quantity and quality of nuclear material taking place within defined periods of time. Essential elements of this are material measurements, evaluation of measurement data and record keeping. Although their objectives are different, these activities not only are necessary for safeguards purposes, but also are of vital importance for process and quality control in the plant. It is important to establish a well-defined facility MC&A system which can accommodate the dual purpose of safeguards and quality control in the plant.

Next, I am going to discuss some of the important requirements for facility MC&A at an LEU fuel fabrication facility.

In Japan, Article 61-8 of the "Law for Regulation of Nuclear Source Materials, Nuclear Fuel Materials and Nuclear Reactors" (hereinafter referred to as the Law) describes that a facility operator is responsible for establishing the MC&A, conforming to the Regulatory Order Part 50 of Prime Minister's Office.

The Regulatory Order Part 50 is formulated conforming to all international commitments concluded not only on the Safeguards Agreement with the IAEA, but also on any Bilateral Agreements with the United States, Canada, Australia, UK and France.

Requirements at the facility level set forth in the Regulatory Order Part 50 are given below, together with comments dealing with specific features of the LEU fuel fabrication facility.

<u>Requirement 1</u>: The facility operator shall establish the organizational unit responsible for MC&A at the facility level.

<u>Comment</u>: At LEU fuel fabrication facilities, MC&A activity is necessary not only for safeguards but also for quality control process control and plant safety purposes. Compatibility among Organizational units responsible for safeguards purposes and the

other facility objectives is important to achieve cost effectiveness of safeguards implementation.

Requirement 2: The facility operator shall establish and maintain MBA and KMP structures.

Comment: The size of the material balance area (MBA) should be related to the accuracy with which the material balance can be established, and be designed to localize loses, if any occur, within a facility. Looking at existing LEU fuel fabrication facilities under the IAEA safeguards, we can see variety of one, two and three MBA facilities depending on different interpretation of KMP's.

Requirement 3: The facility operator shall define batch data used as a unit for accounting purpose at KMP's.

Comment: A batch is a portion of nuclear material handled as a unit for accounting purposes and for which the composition and quantity are defined by a single set of specifications or measurements.

In addition, compatibility with bilateral agreements, material of a given form from a single supplier country should be regarded as a single batch. Examples of batches at the LEU fuel fabrication facilities are:

- Several drums of UO_2 powder with the same specification and supplier country,
- One fuel assembly.

Requirement 4: The facility operator shall provide for a measurement system for determination of the quantities of nuclear material received, shipped and discarded as well as produced or lost due to nuclear transmutation or accidents.

Comment: It is intrinsic to a bulk handling facility that compositions and quantities of nuclear material in a batch are measurements either by analytical or non-destructive measurement. In this context, the measurement system plays an important role in the MC&A system.

Requirement 5: The facility operator shall establish procedures for the physical inventory verification "PIV".

Comment: The frequency of PIV depends on throughput and enrichment of uranium of the LEU fuel fabrication facility. Roughly speaking, the cut-off point for choosing one or two PIV/year would appear to be 300 ton U throughput. A facility shutdown and clean-out of plant process unit as far as practicable are necessary for conducting the PIV. Normally the PIV is therefore carried out at the end of production campaign of the plant.

Requirement 6: The facility operator shall establish procedures for evaluation of precision and accuracy of measurements and the estimation of measurement uncertainty.

Comment: For bulk handling facilities, quantitative indications of possible missing material are expressed in terms of the MUF which is dependent on measurement uncertainties.

Requirement 7: The facility operator shall establish a system of records and reports for each MBA conforming to the Regulatory Order Part 50.

D. State Inspection

Compliance of the facility operator with the requirements of the SSAC must be assured by inspection conducted by State's inspectors. As mentioned already, the MC&A depends to great extent on activities of facility. In this context, the State activities are focussed on inspections activities.

1. Degree of Assurance. There are two alternative State inspection modes; Level I and Level II, depending on different degrees of assurance required. Briefly, Level I activity includes only examination and observation of the operator's measurements and records to assure facility compliance with the SSAC. Level II activity includes not only the Level I Activity but also independent measurements conducted by the State inspector.

A group of States, the European Atomic Energy Community (EURATOM), has decided to conduct Level II activity by using EURATOM inspectors. Japan has also decided to conduct Level II activity by using State inspectors. It was a great challenge for a single State to establish and maintain an independent measurement capability by State inspectors; it is still a significant challenge.

2. State Inspection. In Japan, Article 68 of the Law describes, inter alia, that:

- The Prime Minister may cause state inspectors to enter the nuclear facilities so as to inspect records, documents and other necessary items, ask questions of a responsible person of the facility, and take samples of nuclear material in the minimum amount requested for measurements.
- The IAEA inspectors and persons designated by the governments of countries supplying nuclear material to Japan, with the accompaniment of officials appointed by the Prime Minister, may, within limits specified by Agreements, enter into the nuclear facilities so as to inspect records, documents and other necessary items and take samples of nuclear materials in the minimum of amount required for measurements.
- The Prime Minister may cause state inspectors to install seals or relevant surveillance/monitor devices to detect unathorized movement of nuclear materials under safeguards.
- The IAEA inspector accompanies with officials appointed by the Prime Minister, may also, within limits specified by Agreements install seals or relevant surveillance/ monitor devices to detect unauthorized movements of nuclear material under safeguards.

3. Inspection Goal. There has been no agreed-upon consensus on goal values for use in the SSAC yet. Some investigations have been made for clarifying the relationship between those goals used by the IAEA and the SSAC. General trends found in these investigations suggested that the detection goal used in the SSAC will be approximately 30% smaller than that used in the IAEA.

4. Escort and Facility Operation for Inspection. In Japan the Safeguards Agreement was concluded between the Japanese Government and the IAEA. Strictly speaking, the facility operator is the third party to the Agreement. Facility operators are responsible for conforming not only to the domestic law and regulations of the SSAC but also to other laws and regulations concerning plant safety, radiation exposure control, etc. In this context, there is a certain constraint for conducting inspections;

- Neither the State inspector nor the IAEA inspector can operate any parts of the facility. Facility operation can be done only by operator personnel upon request of the State Inspectorate.
- Agency inspectors should be accompanied by State inspectors, provided that the IAEA inspectors are not thereby delayed or otherwise impeded in the exercise of their functions.
- Both State inspectors and IAEA inspectors must be escorted by facility operator personnel during inspection of a facility.

5. Coordination of Inspection Plan. A facility is inspected by two different authorities, namely, the IAEA and the State. Since both the State and IAEA inspections include independent measurements, an appropriate coordination of inspection plan between the IAEA and the State is very important to minimize the burden of inspection on the operator.

III. AN EXAMPLE OF FACILITY MC&A AT LEU FUEL FABRICATION FACILITY (THE JNF) FUEL FABRICATION PLANT IN JAPAN)

A. Outline of Facility

The JNF fuel fabrication facility is a typical LEU, BWR fuel fabrication facility. Conversion from UF_6 to UO_2 is not made at this facility; therefore, the input material to the facility is UO_2 powder. The maximum enrichment handled by this facility is 4%. The production capacity is now 570 tons of uranium/ year.

This facility consists of six major manufacturing processes as shown in Fig. 1, and nuclear material flow in the facility is represented in the following sequences;

1. Green Powder Receiving. UO_2 powder contained in a five gallon transport container enters into a buffer storage located in a warehouse. The UO_2 powder produced in the same lot by a conversion plant is counted as the same batch for accounting purposes. One batch consists of approximately twenty transport containers of UO_2 powder.

2. Weighing and Sampling of Green Powder Received. After the gross weight measurement of the five gallon transport container at the ceramic area of the facility, UO_2 powder is transferred from the transport container into a five gallon bucket belonging to the facility. At the same time, one sample for each batch is taken and sent to the analytical laboratory located at

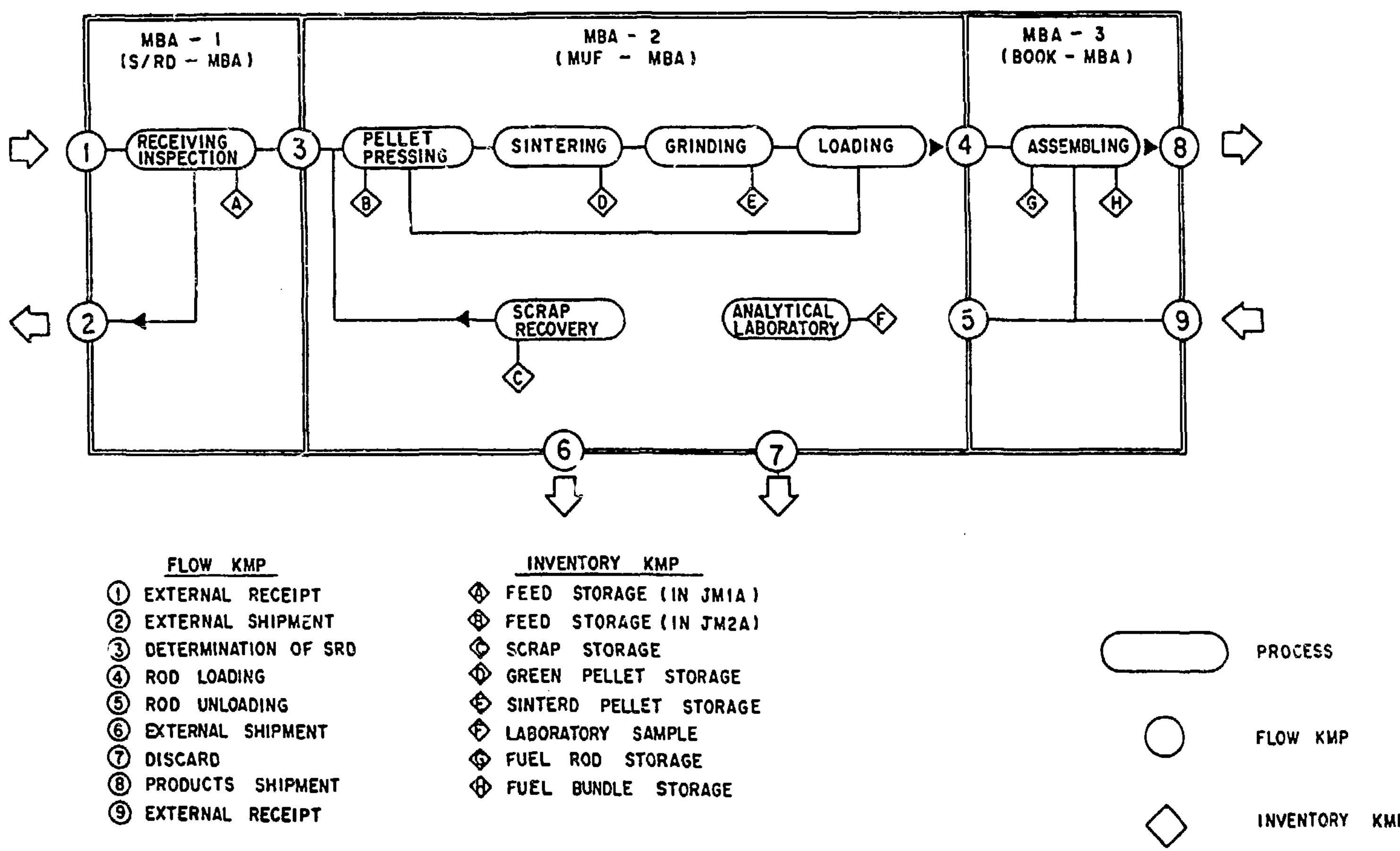


Figure 1. Material Flow and MBA/KMP

a corner of the ceramic process area for measurements of uranium content and enrichment. The tare weight of the transport container is measured in a random sampling basis in order to confirm reliability of the shipper's data. After fixing the shipper/receiver difference, the UO_2 contained in the bucket is sent to the temporary storage located at the ceramic area.

3. Powder Treatment. The UO_2 powder is blended to adjust grain size in a cell if necessary. After this process, the batch process vessel is limited to be less than about 30 kg by Safety Regulations.

4. Pelletizing. The UO_2 powder is pressed mechanically to produce green pellets by a pelletizing machine. The UO_2 powder is fed to the machine in one bucket increments. The green pellets are put on a boat and placed in a temporary storage area.

5. Sintering. The green pellets are sintered in high temperature furnaces.

6. Grinding. Sintered pellets are ground by a wet grinder to size specification.

7. Drying. Pellets ground by wet grinder are dried in elevated temperature furnaces.

8. Pellet Examination. Visual examination is c ried out to eliminate pellets with cracks, and finished pellets are stored in trays.

9. Rod Loading. Columns of finished sintered pellets are weighed and loaded into fuel rods, and then plugged by welding.

10. Fuel Rod Inspection. Finished fuel rods are examined according to quality control guidelines of the facility. The examination includes non-destructive assay of fuel enrichment for each fuel rod.

11. Bundle Assembling. Finished fuel rods are transferred to the assembling area near the ceramic process area of the facility. Then, the rods are assembled into a bundles and temporarily stored on hangers.

12. Shipping. Bundle assemblies are packaged in shipping containers and temporarily stored at a shipping yard.

13. Waste. Bulk handling facilities usually generate not only solid waste but liquid waste as well. The solid waste generated from the JNF fuel fabrication facility consists mainly of contaminated filters, gloves, papers, plastics and clothes. These contaminated materials are put into drum cans and stored on the facility site. One drum contains up to 15 g of ^{235}U. The total amount of solid waste is about 0.1% of throughput at the JNF fuel fabrication facility.

Liquid waste is mainly washing water used for decontamination and involves material in minor quantities of approximately 1 g per month.

14. Scrap Recovery. Scrap material consists mainly of grinder slag, defective sintered pellets, etc. This recoverable scrap is converted to U_3O_8 dissolved and processed through scrap recovery (which produces green powder), and is recycled. The scrap recycle rate at the JNF facility is about 7% of throughput.

B. Policy on the Design of the Accountability System

The design objectives of the facility's accountability system may be broadly divided into the following two aspects. One is to have the accountability system contribute to the nuclear material inventory control, material balance determination, manufacturing process control, quality control, safety control, physical protection, and other managerial operations of the facility. The other is to have this system satisfy the regulatory requirements of national and international safeguards. The above two aspects regarding the function of the accountability system are interdependent, and the system must be so designed that information necessary for the managerial operation and for the regulatory requirements is readily available for both. Figure 2 shows an example of the conceptual design of the accountability system.

C. Material Balance Area

In accordance with national and international safeguards requirements, the low enriched uranium fuel fabrication facility in Japan is required to establish three MBA's for accounting and controlling of the materials in the facility. As shown in Figure 1, the JNF facility is divided into three MBA's; (1) Shipper/Receiver Difference MBA, (1) a MUF MBA in which MUF will be generated and (3) Item MBA in which all materials will be accounted for by the measured values in the preceding MBA.

From the safeguards point of view, the MBA can be defined as a functional area and not as a specific area separated by any physical barrier or building structure.

- MBA-1 Shipper/Receiver Difference Area. This MBA includes all the nuclear material that is kept on shipper's data.
- MBA-2 This MBA includes the fuel fabrication process up to pellet loading, the chemical laboratory and storage of intermediate materials.
- MBA-3 This MBA includes the fuel bundle assembling process and storage of fuel rods and products kept on the basis of the facility's own measurements that were performed previously at the MBA-2.

D. Key measurement Point

Strategic points that serve as key measurement points are to be established for determination of material flow and inventory. At the JNF facility there are nine KMPs for determination of material flow at the boundary of MBAs which relate to inventory changes of the MBAs and eight KMPs to determine the inventory of each stratum which is classified by chemical and physical configuration of the material. (Refer to Fig. 1.)

Flow KMPs (1-9) and INVENTORY KMPs (A-H)

- KMP-1 Receipt of external nuclear material into MBA-1.
- KMP-2 Shipment from MBA-1 to a destination outside the facility.

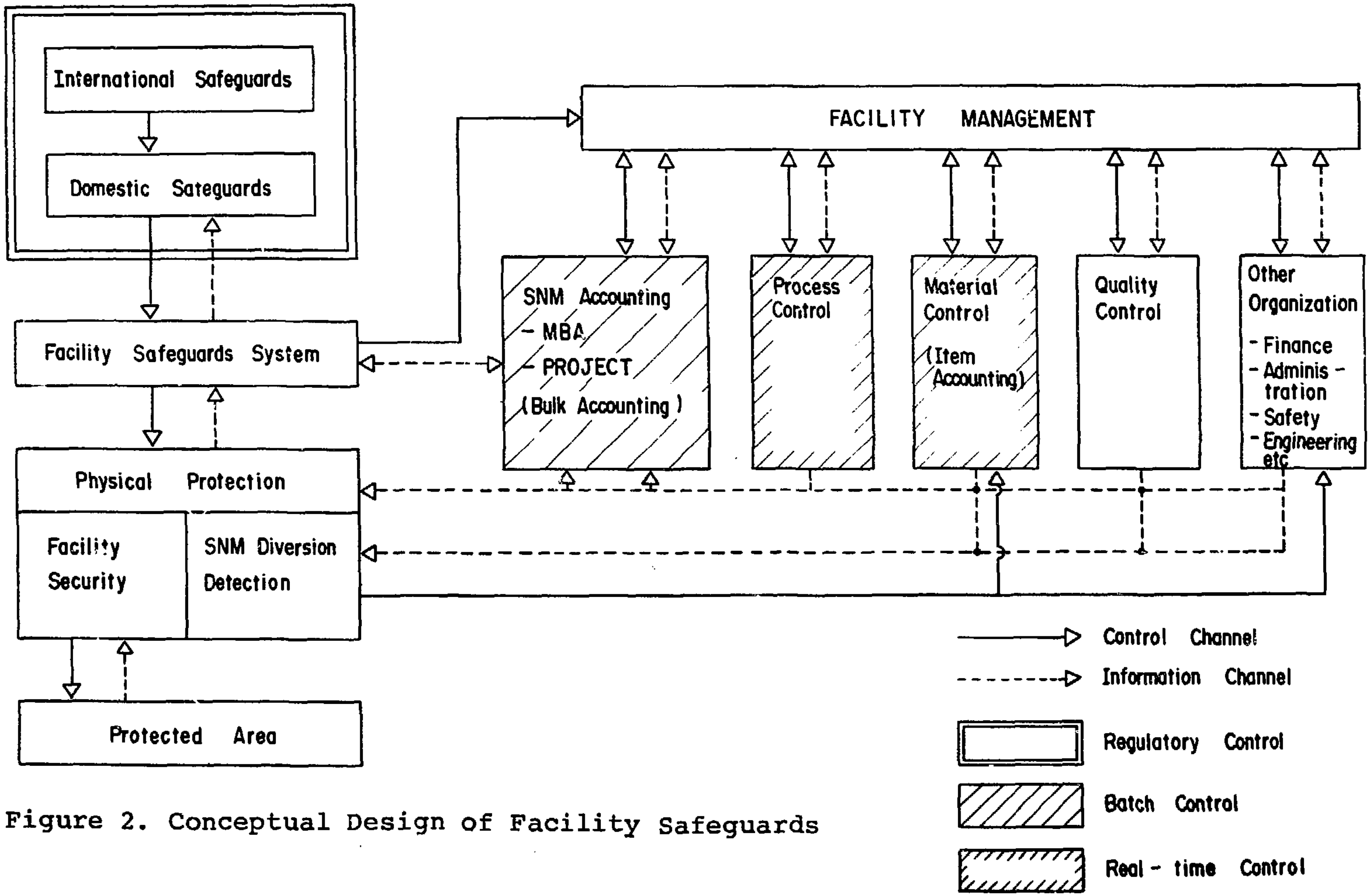


Figure 2. Conceptual Design of Facility Safeguards

- KMP-3 Shipment of nuclear material from MBA-1 to MBA-2 and determination of S/R Differences. This KMP also is used for receipt of nuclear material at MBA-2 from MBA-1.
- KMP-4 Shipment of loaded fuel rods from MBA-2 to MBA-3.
- KMP-5 Reshipment of loaded fuel rods from MBA-3 to MBA-2.
- KMP-6 Shipment of various materials from MBA-2.
- KMP-7 Measured discard and retained waste.
- KMP-8 Shipment of final products from MBA-3 to outside of the facility.
- KMP-9 External receipt.
- KMP-A Storage of feed material kept based on shipper's data.
- KMP-B Storage of feed material kept on the basis of facility's measurement.
- KMP-C Storage of recoverable scrap.
- KMP-D Storage of green pellets.
- KMP-E Storage of sintered pellets.
- KMP-F Storage of various analytical samples.
- KMP-G Storage of fuel rods.
- KMP-H Storage of fuel bundles.

E. Material Balance Accounting

The material balance accounting for each MBA shall be accomplished by determining changes in material inventory with such methods as item counting, weighing, volume measurement, sampling and analysis at the KMP's and by accounting through computerized data processing system. This system consists of four sub-systems as described below.

1. Feed Material and Scrap Control System (FASCS). This system is designed for maintenance of inventory control, as well as for calculation and statistical evaluation of shipper/receiver differences for both feed material and recoverable scrap material. This system also provides an itemized listing for the purpose of taking the physical inventory.

2. Bundle Assembling Control System (BACS). This system is designed to control the accountability information regarding the fuel rod and fuel bundle. The calculation of uranium and isotopic weight for each fuel bundle and preparation of the shipping document for the product are also made through this system. The system can provide an itemized list of fuel rods and fuel bundles for taking the physical inventory.

3. Safeguards Information System (SIS). This system is programmed to generate various regulatory reports such as the ICR, PIL, and MBR as needed.

4. Project Accountability System (PAS). This system is intended to control and maintain material balance accounting for specific project material. The system is to provide project material accountability reports for the project and maintain perpetual inventory for the project material.

The Data Transaction Diagram of this material balance accounting system is shown in Fig. 3.

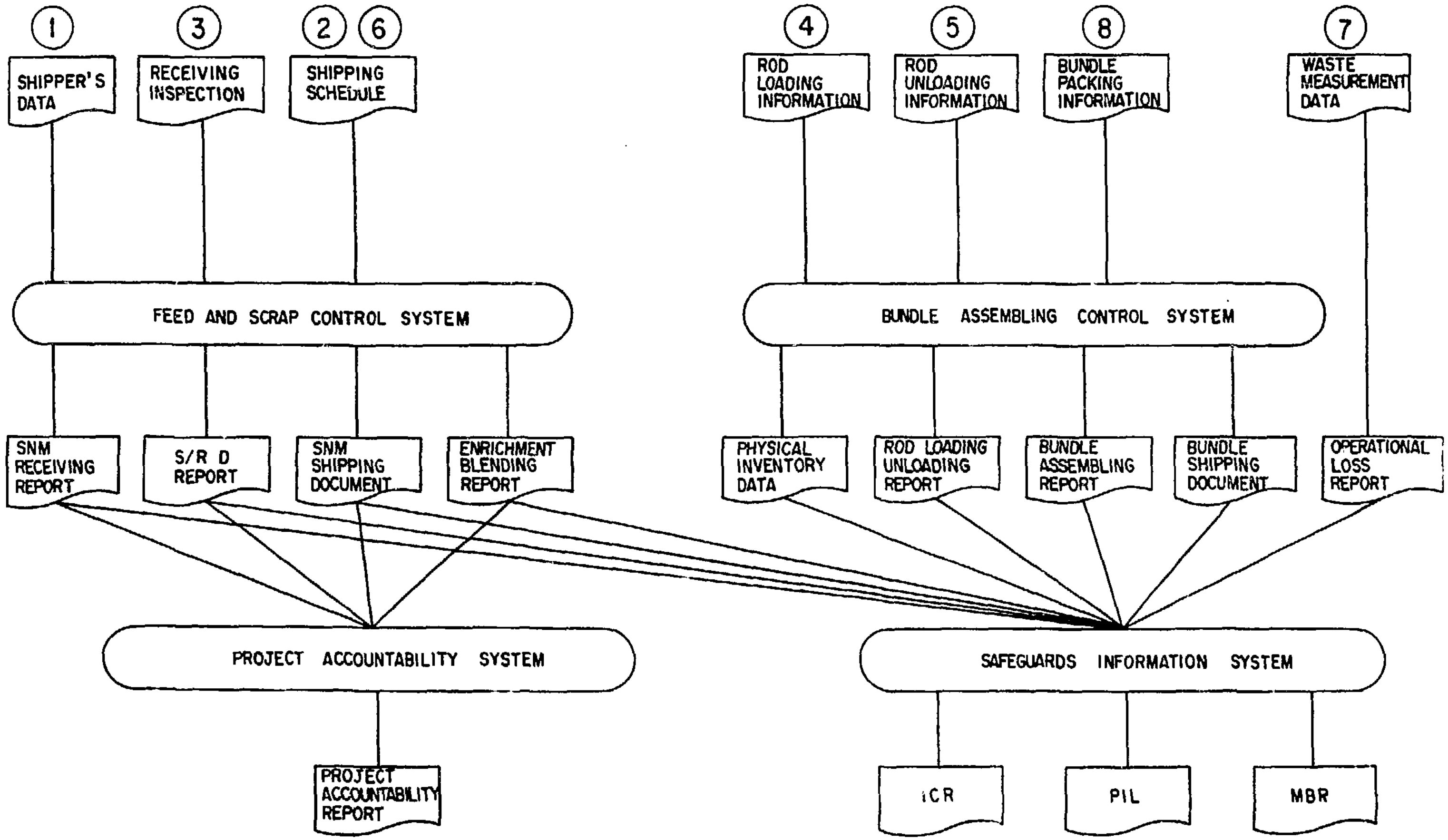


Figure 3. JNF's SNM Accountability System
Data Transaction Diagram

○ : KEY MEASUREMENT POINT

F. Measurment System

Various measurement methods for determination of nuclear materials for each of the flow and inventory key measurement points are established in consideration of chemical and physical characteristics of the nuclear materials. The material descriptions and measurement methods are summarized in Table I.

1. Measurement Methods.

a. Mass Measurements. Weight measurements at KMPs are performed with electronic scales with digital display of the weight value. The range of these scales is from 10 kg to 50 kg with divisions ranging from 1 g to 20 g. The scale is selected depending upon the weight of the items to be weighed.

b. Analytical Measurements.

Percent Uranium

- Dichromate Titration - This type of determination is based on the techniques devised by Davies and Gray which allow the determination of uranium in dilute nitrate and in the presence of large quantities of impurities.
- Gravimetric Determination of Uranium - This technique is used for relatively pure uranium compounds and is based on oxidation of the sample to U_3O_8. The final value is then corrected for non-volatile impurities.

Enrichment

- Gamma Spectrometry - This technique is used for determination of the percent of Uranium-235. Samples are converted into relatively pure U_3O_8 to make their geometry constant.

Impurities

- Trace metallic impurities are determined using a standard emission spectrographic technique.

Nuclear Poison (GD_2O_3)

- Nuclear poison as an additive in fuel is determined using an energy-dispersive X-Ray fluorescence technique.
- Alpha Counting is employed for measurement of uranium in atmospheric discharge and effluent discharged to the sewer.
- Passive Gamma Counting (SAM-II) is employed for counting containers of waste and used filters which are stored as retained waste.

2. Measurement Control Program.

a. Weight Measurement Control. All scales at KMPs are checked daily for zero setting and calibrations with standard weights. In addition, the scales are checked and calibrated once per month with the first class standard weights by personnel who are qualified by the government to perform the meaurements. The standard weights are inspected by the Inspection Institute of Weights and Measures.

b. Analytical Measurement Control. Uranium content measurement; Analytical reagents for measurement are qualified with the national standard. Analytical balances are calibrated once every six months.

Measurement/Analysis at Each KMP

KMP	Description of Nuclear Fuel Material				Type of Measurement	Method of Measurement/Analysis or Equipment
	Type	Chemical Form	Physical Form	Subject		
1	Feed material	UO_2	Powder	BU-Type shipping container	Item count	
1	Retained waste	Various	Various	Drum, Filter, etc.	Item count	
1	Nuclear fuel material other than feed material	UO_2 U_3O_8	Powder Pellet Sludge Others	Shipping containe and others	Item count	
2		Same as KMP-1 above				
3	Feed material	UO_2	Powder	5 Gal. can	Weight U-w/o U235-w/o	Scale Oxidation method Enrichment analyzer-γmeasurement
3	Nuclear fuel material Other than feed material	UO_2 U_3O_8	Powder Pellet Sludge Others	5 Gal. can 2.5 Gal. can Others	Weight U-w/o U235-w/o	Scale (exclude less than 10g-U235) Oxidation or titlation method Enrichment analyzer-γmeasurement
4	Fuel rod	UO_2	Pellet	Fuel rod	Weight U-w/o U-235-w/o	Scale Oxidation method Enrichment analyzer- measurement
5	Fuel rod	Same as KMP-4 above				
6	Nuclear fuel material other than fuel rod and fuel bundle	UO_2 U_3O_8 UO_4	Powder Pellet Sludge Others	5 Gal. can 2.5 Gal. can Others	Weight U-w/o U235-w/o	Scale (Except less than 10g-U235) Oxidation or titlation method Enrichment analyzer-γmeasurement
7	Exhaust loss	-----	-----	-----	U-Concentration	γScintilation counter
7	Sewage loss	-----	-----	-----	U-Concentration	γScintilation counter
7	Retained waste	UO_2 U_3O_8 UO_4	Powder Others	50 ℓ or 200 ℓ drum Used filter	U235-quantity	measurement by SAM-II

TABLE I (1/2)

Measurement/Analysis at Each KMP

KMP	Description of Nuclear Fuel Material				Type of Measurement	Method of Measurement/Analysis or Equipment
	Type	Chemical Form	Physical Form	Subject		
8	Fuel rod or fuel bundle	UO_2	Pellet	Fuel rod	Weight U-weight U_{235}-weight	Measured value at KMP-4 above
9	Fuel rod or fuel bundle	Same as KMP-8 above				
A	Feed material (by shipper's data)	UO_2	Powder	BU-Type shipping container	Item count	
B	Feed material (by JNF's data)	UO_2	Powder	5 Gal. can	Weight U-w/o U_{235}-w/o	By transfer card Measured value at KMP-3 above
C	Scrap	UO_2 U_3O_8 UO_4	Powder Pellet Sludge	5 Gal. can or 2.5 Gal. can	Weight U-w/o U_{235}-w/o	By transfer card Oxidation or titlation method Enrichment analyzer-γ measurement
D	Green pellet	UO_2	Pellet	Metal pellet boat	Same as KMP-C above	
E	Sintered pellet	UO_2	Pellet	Metal boat or tray	Same as KMP-C above	
F	Various lab. sample	UO_2 U_3O_8 UO_4	Various	Various	Weight U-w/o U-235-w/o	By record Average U-w/o Average enrichment or actual measured value
G	Fuel rod	UO_2	Pellet	Fuel rod	Item count	
H	Fuel bundle	UO_2	Pellet	Fuel bundle	Item count	

TABLE I (2/2)

Enrichment measurement; Gamma spectrometry equipment is calibrated with the national standards. The equipment is calibrated at the beginning of each shift. The working standards are analyzed after every eleven samples. If the average of three such readings is out of control limits, the equipment is recalibrated.

c. Nondestructive Measurement Control. Calibration standards of this nature are not available from either national or international sources. The calibration is performed once every month with a known standard gamma source that is prepared by the facility.

3. Laboratory Correlation Program. As a part of the measurement control program, this facility has participated in the Safeguards Analytical Laboratory Evaluation (SALE) Program. Also various laboratory correlation programs are being conducted between related facilities.

G. Physical Inventory Verification

The purpose of taking a physical inventory is to determine the quantities of nuclear materials on hand at a given time within a material balance area and to derive the differences between the book inventory and physical inventory that are called Book Physical Inventory Differences (BPID) or Materials Unaccounted For (MUF). The MUF is a very important figure both for plant management and for safeguards because the MUF gives a useful indication of the effectiveness of the facility's nuclear materials accountability system. It is also useful to indicate no significant loss of nuclear material and no diversion of nuclear material.

In order to meet the safeguards requirements, the physical inventory must be taken twice a year. The inventory verification frequency can be reduced when the annual throughput is less than 300 tons of uranium and when the safeguards authority has continued assurance that the plant material balance is closed with limits of error of MUF of not more than 0.3% relative.

The requirements further demand that the physical inventory verification must be conducted under the complete shutdown status of the process; and all material movement which might change the inventory balance of each MBA must be ceased after the book inventory cut-off for the inventory verification. In addition to this complete physical inventory verification, interim inventory will be taken upon completion of each fuel fabrication project to determine the material balance for the project accounting.

The physical Inventory Verification consists of four major procedures, as follows:

1. Equipment Clean Out and In-process Inventory Determination. All process equipment and systems containing nuclear material are thoroughly cleaned to minimize hidden inventory and equipment hold-up. However, in the case of the equipment or a system that cannot be disassembled for technical or economic reasons, the equipment hold-up will be estimated by means of appropriate NDA equipment or past experience.

2. Inventory Item Count. This portion of the inventory will involve item identification and accounting for all nuclear materials. With respect to discrete items visually located, their item identification number, project number, enrichment, material type, and gross, tare and net weights will be recorded.

3. Weight Verification. In order to test the gross weight assigned to inventory items, randomly selected containers are reweighed, and if only systematic bias is detected throughout this examination, the tag weight will be corrected.

4. Analytical Verification. A statistically based sampling plan is developed for various types of recoverable scrap to reconfirm the applicability of the standard uranium contents for each type of recoverable scrap.

The standard sequence of events for physical inventory is shown in Fig. 4.

H. Records and Reports

Records and reports for accountability and safeguards purposes can be categorized as follows;

1. Accounting Records. Four major types of accounting records are maintained by the facility;

a. For Inventory Changes. Record all external shipments and receipts, material transferred between MBAs within the facility, measured discards, retained waste, accidental loss or gain, and all information concerning changes in the MBA inventory.

b. For Physical Inventory Verification. Record all information used for determination of ending physical inventory, including sampling and analytical results, weight verification data, etc.

c. Adjustment and Correction. Record any shipper/receiver differences and MUFs as adjustment and corrections due to detection of errors in previous records or due to more precise later measurements, and corrections for measurement bias.

d. Changes in Batch Identities. Where a batch identification is changed, its previous batch identification and new batch identification must be recorded with traceability.

2. Operating Records. At least 6 types of operating records are to be maintained in accordance with regulations;

a. Rod Loading Operation. All accountancy data relevant to determination of the uranium and isotope weight for each fuel rod are recorded.

b. Bundle Assembling Operation. All the relevant data for the fuel rods assembled into each fuel bundle and the uranium and isotope weight for each fuel bundle are recorded.

c. Removal of Seal or Equipment. Whenever a facility operator removes a seal which has been installed by a safeguards official for any safeguards purpose, the date, seal identification number and the reason for removal are recorded.

d. Enrichment Blending Operation. Whenever enrichment blending is performed, accountancy data on the original materials used for blending including the name of the country or origin and on the material created by the enrichment blending are recorded.

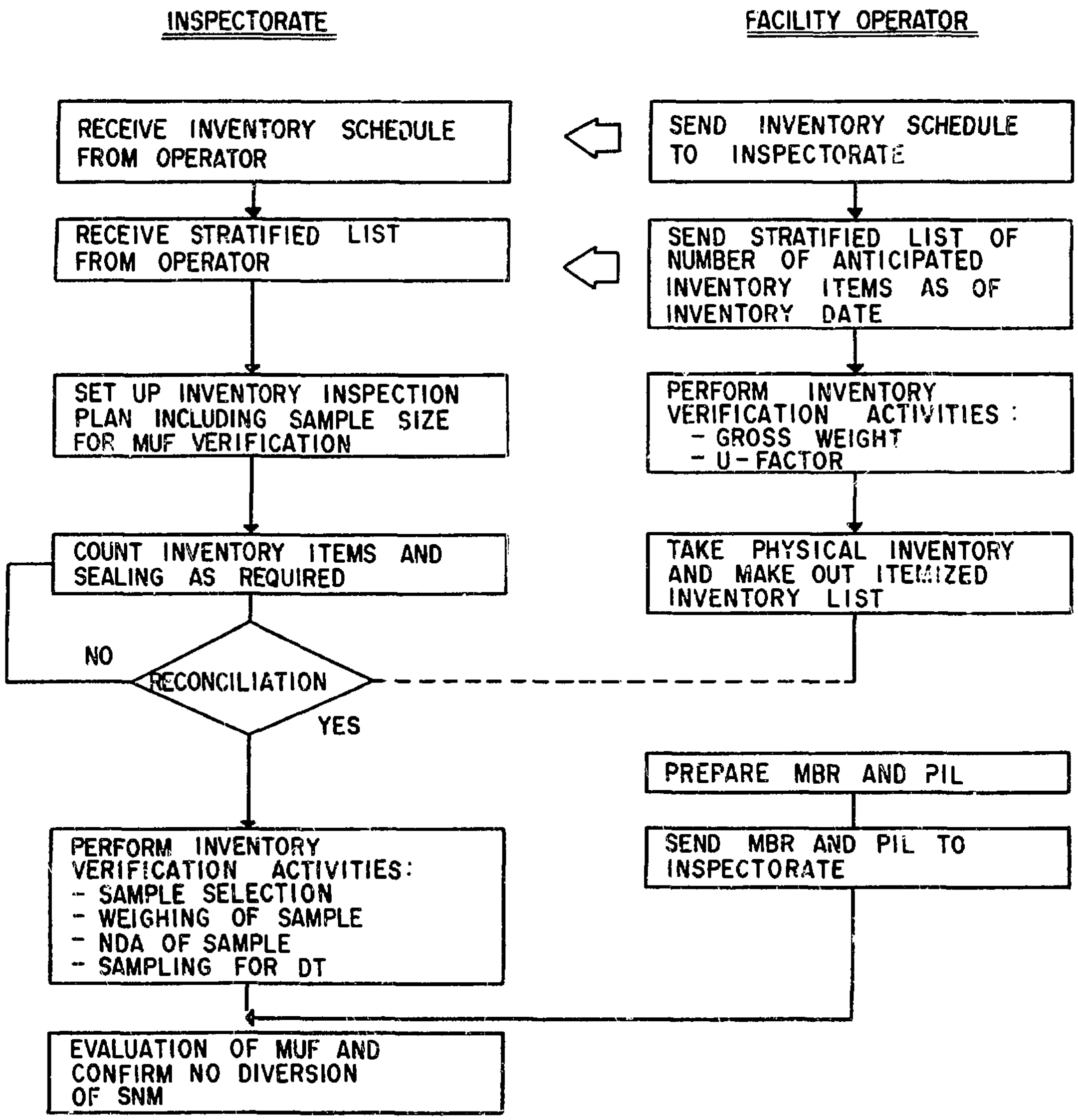


Figure 4. Standard Sequence of Events for Physical Inventory

e. Accident that Results in Loss or Gain. For accidental losses or gains of nuclear material, information relevant to the accident including date, cause and features of the accident, and estimated or known amount of nuclear material which as been lost or gained are recorded.

f. Measurement Control. With respect to measurement equipments and instruments, all relevant data for the facility measurement control program used for determination of random and systematic errors in each inventory change are recorded.

3. Regulatory Reports. Regulatory reports are required by the Regulatory Order Part 50 in connection with the Safeguards Agreements. The specific requirements on reports are stipulated in the Regulatory Order Part 50 in connection with code 10 of the Subsidiary Arrangements and Facility Attachment. These reports are;

a. Inventory Change Report (ICR). This report is used to report all inventory changes of MBA's including changes of batch identification and those due to blending, adjustment and corrections. The report must be submitted to the government office within 15 days after the end of the month in which the inventory changes occur.

b. Material Balance Report (MBR). This report is used to report the material balance of each MBA for the period between two physical inventory verifications. The report must be prepared for each type of nuclear material for which the facility keeps a separate account and submitted to the government office within 15 days after the completion of the verification.

c. Physical Inventory Listing (PIL). This report shall be attached to each MBR. All accountancy data for each batch of physical inventory must be entered.

d. Concise Note. This note shall be attached to ICR, MBR, and PIL to explain any unusual inventory changes or corrections to their previous reports respectively.

e. Special Report. This report must be prepared whenever any operational losses exceed the allowable limits or any other circumstance which might affect the safeguards concerns.

4. Project Accountability Report. This report is required to be in accordance with the fuel fabrication commercial contract. The report is prepared upon completion of each fuel fabrication project to determine project material balance accounting and to assure operational losses have not exceeded the allowance which is stipulated in the contract.

IV. SAFEGUARDS INSPECTION OF THE FACILITY

The scope and frequency of inspections are stipulated in the Article 68 of the "Law", the Regulatory Order Part 50 and the Facility Attachment of the Safeguards Agreement.

The inspection mode is categorized as monthly flow verification and the physical inventory verification. The frequency of the inventory verification, which was once a year until 1980, is now twice a year due to increase of throughput.

Inspection Schedule is decided by the State Inspectorate taking into consideration the plant operation schedule, which is submitted to the State Inspectorate six months in advance. The IAEA inspection usually takes place concurrently with the State inspection.

A. Flow Verification

The scope of flow verification activities are summarized below:

- Examination of records on verification for self-consistency and consistency with the reports which were previously submitted to the safeguards authorities. This includes source data examination.
- Item identification, counting and measurement.
- Calibration of measurement equipment used for accountability.
- Verification of the quality of the facility's measurements
- Taking representative analytical samples.
- Flow verification of nuclear material at flow KMPs.
- Application, examination, removal and renewal of seals.
- Servicing and review of surveillance equipment.

B. Inventory Verification

Normally, three days of plant shutdown are required for inventory verification activities carried out by the State inspectors and the Agency's inspectors. The detailed facility inventory verification plan shall be submitted to the State Inspectorate, a minimum of 30 days prior to the date of verification and the Stratified List approximately one week prior to the date. It is very important to discuss at this stage the details of the operator's inventory verification and the inspector's verification plan in order to eliminate potential problems that might surface at the time of inventory verification.

This discussion shall cover the availability of operator's man-power to assist inspector's measurements, appropriate location for setting of inspector's measurement equipment, background of gamma rays in the measurement area, the facility's power supply voltage fluctuation which may affect the inspector's instruments, etc. (Refer to Fig. 4.)

The scope of inventory verification activities which are stipulated in the Facility Attachment is as follows:

- Verification of the operator's physical inventory taking for completeness and accuracy.
- Weighing of containers with nuclear material on the basis of a random sampling plan.
- Taking measurement samples.
- Identification and counting of fuel assemblies and the use of NDA techniques.
- Use of in-line NDA systems.
- Application, examination, removal and renewal of seals.
- Servicing and review of surveillance equipment.

The inspector's sampling plan for inventory measurement will be established for two types of measurement methods. One is an instrumental method for quick detection of medium size to gross discrepancies of individual items with a high degree of certainty. The other is a more accurate measurement capable of detecting small discrepancies. These two methods are referred to as the attribute method and the variable method, respectively. For reference purposes the actual number of samples taken at the 1983 physical inventory at JNF facility is shown in Table II.

One physical inventory verification requires about six State inspectors for four days and a 200 man-day manpower commitment by the operator.

V. STAFFING AND RESOURCES

The facility MC&A for safeguards was first implemented in 1978 conforming to the "Law" as amended. Before that time, material accounting and control activities were conducted for process, quality and safety control purposes. Therefore, the major activities newly introduced for implementing the MC&A are mostly associated with the PIV, the routine inspection and compilation of regulatory records and reports of the MC&A in a timely manner.

A. MC&A Organization and Staffing

The manager of nuclear Material Management Section administered by the Director of Quality Assurance Department of the JNF is responsible for implementing the facility MC&A.

The Quality Assurance Department consists of five sections: Engineering, Inspection, Laboratory, Audit and Nuclear Material Management. The number of employees allocated to the Division is about 10% of the total employees at the facility. This Divi sion is responsible for all aspects of plant process and product quality control including the MC&A for Safeguards.

Four staff members have been allocated to the Nuclear Material Management Section as a full-time assignment for engaging in the facility and plant quality assurance activities. Their duties include planning the facility MC&A implementation, collecting and recording relevant data obtained by the other sections in the Department, evaluating these data for safeguards viewpoints, preparing regulatory reports of MC&A, necessary administrative arrangement for inspection etc. Besides routine activities mentioned above, about two man-days of operator time is used for making administrative arrangements and escorting the State and IAEA inspectors who enter the plant for monthly inspections.

About 200 man-days of operator manpower are necessary to conduct each PIV. Most staff members of the Quality Assurance Division are involved actively in the PIV when it occurs.

TABLE II An Example of PIV Sample Size at Each Strata

MBA	KMP	Strata	Inventory in Kg of U	No. of Item	Verification Sample		
					Weight	NDA	Sample Taking
JM1A	A	Feed Green Powder	60,000	2,700 Cans	20	75	20
JM2A	B	Feed Green Powder	70,000	3,500 Cans	30	70	30
JM2A	C	Recoverable Scrap	23,000	1,800 Cans	9	18	9
JM2A	D	Green Pellet	1,800	309 boats	9	9	6
JM2A	E	Sintered Pellet	40,000	6,800 Trays	50	50	20
JM2A	F	Lab. Sample	150	-	-	-	-
JM3A	G	Fuel Rod	54,000	20,000 rods	-	56	-
JM3A	H	Fuel Bundle	160,000	915 bundles	-	-	-

B. Resources

The resources needed at the facility level for implementing the MC&A are categorized into two parts; initial investments and operating cost.

1. Initial Investment. Since most of the equipment and devices utilized by the MC&A system have been built for process and quality control purposes, there is only a small amount of other equipment exclusively devoted to safeguards. Examples are a solid waste drum monitoring equipment and computer software for compiling the MC&A records and reports. The total expenditure used for them is estimated to be about ¥20,000,000 (1US$=¥250).

2. Operating Cost. Routine operating costs are given in terms of man-years of effort, since the cost of salaries, fringe benefits and other relevant administrative cost can vary over wide range. The commitment allocated for the MC&A at the JNF is four man-years of qualified staff members.

3. PIV Cost. The estimated cost burden to the operator involved in a PIV that requires plant shut-down can vary over wide range depending on assumptions used. One example indicates the cost burden to the operator is approximately ¥70,000,000, when the loss associated with plant shut-down is taken into account.

In any case, the PIV requires considerable cost burden to the operator.

4. Total Safeguards Cost. Estimation of the total safeguards cost burden of operator is also a difficult problem, but on an average, about 0.2% of the fuel bundle cost seems to be a reasonable estimation obtained from our experiences.

VI. PROBLEMS ENCOUNTERED AND LESSONS LEARNED

Specific technical lessons learned in implementing the SSAC for the LEU fuel fabrication facility in Japan are discussed in this section.

A. Technical issues

1. Operator MC&A for Medium Size LEU Fuel Fabrication Facility. The JNF facility MC&A satisfies the current regulatory requirements in both national and international safeguards, conforming to the IAEA Agreement and other Bilateral Agreements. This is partly due to quality control and safety control requirements other than the safeguards requirement in Japan which are, in many cases, more strict than the MC&A requirements.

However, it should be noted that this is a conclusion for a medium scale fabrication facility like the JNF facility. In the future, as required by increased plant throughput, the MC&A system needs to be improved or modified by introduction of new measurement techniques, use of computerized material control system, etc., focusing on maintenance of safeguards effectiveness while optimizing the use of limited safeguards resources.

2. Itemized fuel in a Bulk handling Facility. Whereas the fuel fabrication facility is categorized as a bulk handling facility, many itemized fuel materials are located inside the facility: for example, feed green powder, fuel rods, fuel bundles, etc. As shown in Table II, in June 1983, there were about 35,000 items in the facility. Therefore, we should not forget that considerable effort is necessary for itemized fuel MC&A in the fuel fabrication facility, and improved verification methods for itemized fuel at the fuel fabrication facility are still needed.

3. Utilization of the Operator's Equipment/Devices. In order to minimize intrusiveness to the operator and effective use of limited resources, it is important to explore a concept to utilize operator's equipment and devices for inspection. For effective implementation of safeguards in the future, this will be increasingly important because automation is the current trend of modern plants. On many occasions, the inspector will have difficulty accessing all nuclear material in the plants. One typical example can be seen at a fully automated green powder bucket warehouse in which there is no space for the inspector to gain access to inspect green powder buckets visually.

4. Relation between Safeguards Inspection and Safety Inspection. Whereas the Japanese public is accepting nuclear power as one of the major national energy sources, the public is particularly sensitive to assurances of the safety of nuclear plants, due to the unfortunate experience of once suffering from a nuclear explosion.

Considering this particular public feeling, to some extent emotional, the Japanese safety licensing authority applies very strict inspection criteria for inspecting fuel rods and bundles.

As a consequence, the facility operator is reluctant to accept any procedures that might damage fuel pins or bundles, even if its possibility is very slight and expected damages are very minor, such as a slight scratch.

Although safeguards are of vital importance, long tradition and practice in safety regulation are not easily altered. We are trying to harmonize safety and safeguards inspection practices, but it takes a time.

5. Comments on Future Large Fabrication Facility. In order to implement effective safeguards for future large scale fuel fabrication facilities, consensus on facility MC&A design criteria is needed prior to design and construction of the plant. The criteria should include, inter alia, the following considerations:

- Trends of international policy against nuclear proliferation and the associated safeguards requirements,
- Allowable allocation of resources for operator, state and IAEA,
- Harmonization among safeguards, safety and operator's production control requirements.
- Policy on utilization of operator's equipment/devices for inspection.

B. Effective, Reliable, Non-Intrusive Safeguards and Training

In my lecture at the SSAC training course last year, I illustrated a problem in safeguards by using an interpretation of the rock garden in Kyoto Japan which formerly provided the Zen meditator with a place for meditation. To carry this thought one step further, I would like to try to interpret the state of Zen meditation a bit more scientifically in order to illustrate effective, reliable and nonintrusive safeguards and training. Let me first describe brain waves in very general terms. Since brain waves are being emitted from the brains of all of us, I hope what I am going to discuss will be of interest to you.

Brain waves are fluctuations of electrical potential in the brain, as shown in Fig. 5. These can be measured by the electroencephalograph or "EEG". Phenomenologically, brain waves are classified into four different types: delta, theta, alpha, and beta waves. Delta waves, characterized by an amplitude of about 100 microvolts with a frequency of 0.3 to 4 Hertz, appear in deep sleep. Theta waves, characterized by an amplitude of about 70 microvolts with a frequency of 4 to 8 Hertz, appear in moderate sleep. Beta waves, characterized by an amplitude of about 30 microvolts with a frequency higher than 13 Hertz, appear during ordinary mental activity. Alpha waves, characterized by an amplitude of about 50 microvolts with a frequency of 8 to 13 Hertz appear to be related to an altered state of consciousness, or sleeping-wakefulness continuum.

It is interesting to note that steady alpha waves appear when people are sitting calmly <u>with their eyes closed</u>, and disappear when the eyes are opened. Many scientists have investigated the behavior of alpha waves in connection with human intellectual activity, emotional tension, and anxiety. For many years, psychological and neurophysiological studies on altered states of consciousness have focussed on understanding the relation between brain mechanisms and consciousness in general.

The practice of Zen meditation is said to emancipate man from the dualistic bondage of subjectivity and objectivity of mind and body. Recent advances in electronics now make it possible to investigate the state of meditation in a more scientific way. Using brain wave analysis, Drs. T. Hirai, N. Takemura, S. Tazawa et al. at Tokyo University have been investigating mental and physical states that occur during Zen meditation.

Now, I would like to discuss some pictures of brain wave topographs obtained by Dr. T. Hirai et al. Figure 6 shows electrodes for measuring brain waves attached to the head of a priest engaging in Zen meditation. Figure 7 (A) shows a typical brain wave topograph of an ordinary person engaging in ordinary mental activity. Figure 7 (B) shows a topograph of a well trained meditator engaging in meditation <u>with his eyes open</u>. Figure 7 (C) shows a topograph of an ordinary person sitting calmly <u>with his eyes closed</u>. These topographs in Fig. 7 have been slightly simplified by the investigators to illustrate clearly the main results and significance of their complex measurements.

The very interesting findings obtained by Dr. Hirai et al. using measured brain wave analysis of Zen meditation are as follows:

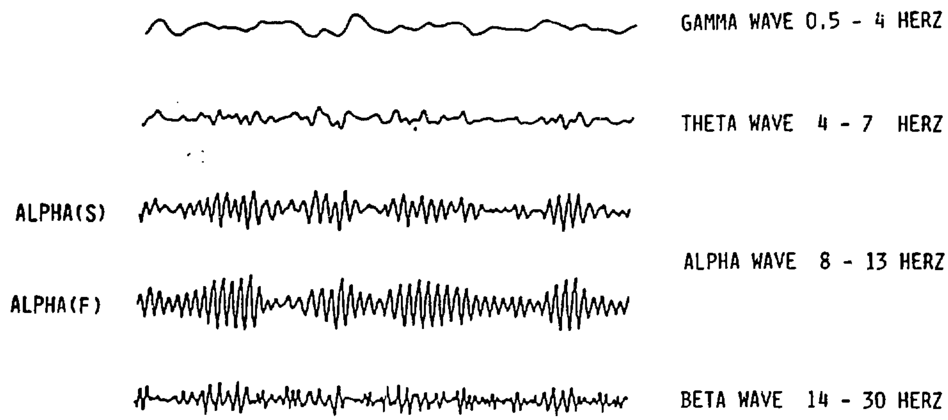
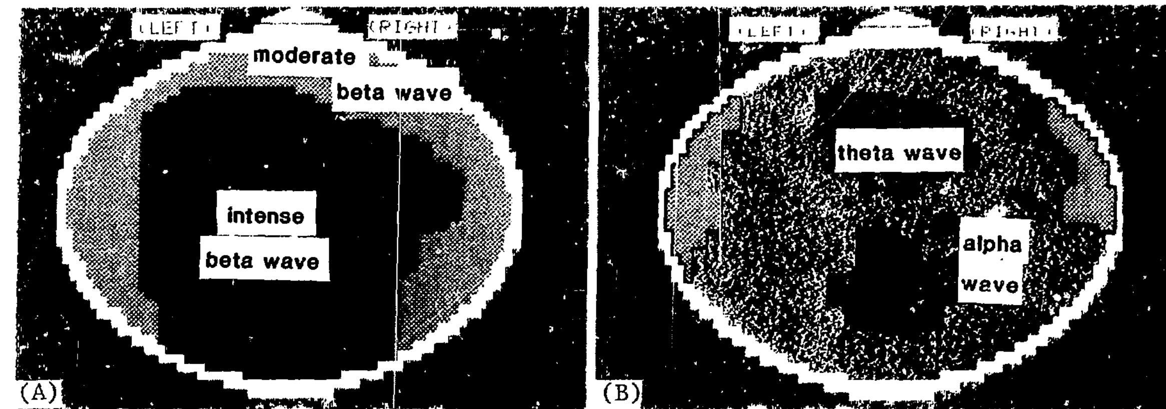


Fig. 5. Brain Wave Characteristics

Fig. 6. Electrodes attached to head of meditator for brain wave measurements.



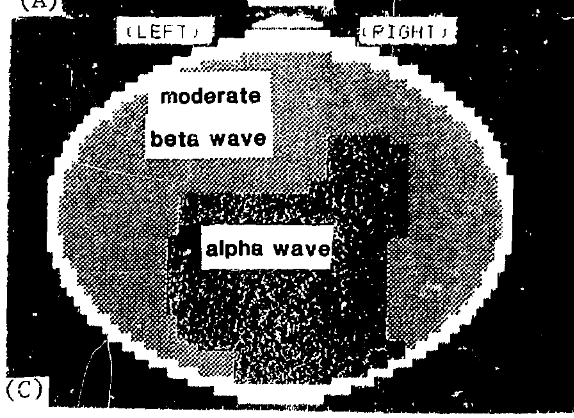


Fig. 7 Topographs show a cross-section of brain wave patterns for (A) ordinary mental activity (B) meditation with eyes open and (C) an ordinary person with eyes closed.

- A well trained meditator has <u>his eyes open</u> and is concentrating his attention inward. <u>Although his eyes are open</u>, the alpha and theta waves are conspicuous. This result had not been expected, because alpha waves are not observed from the brain of an ordinary person whose <u>eyes are open</u>.
- Although brain waves emitted during Zen meditation are similar to the brain waves of ordinary people asleep, an audio stimulus experiment performed in connection with brain wave analysis (Fig. 8) proved that Zen meditation is not merely a state of sleep. During Zen meditation the well trained meditator is <u>relaxed as when sleeping but ready to accept and to respond positively to any stimulus that may reach him</u>. This means that the alpha and theta parts of the brain in Fig. 7 (B) change to intense beta immediately after stimulus. This response will not be seen in ordinary people asleep.
- The behavior of alpha waves emitted by the brain of a well trained meditator engaging in Zen meditation is different from the behavior of the alpha wave emitted by a person who is sitting <u>with his eyes closed</u>. As shown in Fig. 8, although an ordinary person <u>with his eyes closed</u> becomes so accustomed to the periodic clicking

sound that he gradually fails to react to it, a Zen meditator reacts unfailingly to each click, no matter how many times it is repeated.

All of these findings show that the particular state of a person engaging in Zen meditation is characterized as follows:

- The state is similar to sleep; which is analogous to being non-intrusive to another person,
- but the state is different from usual sleep; the subject has his eyes open and is ready to accept and to respond positively to stimuli; this is analogous to a high degree of effectiveness,
- the subject responds reliably to each stimulus without any accustomed trends no matter how many times it is repeated; this is analogous to a high degree of reliability.

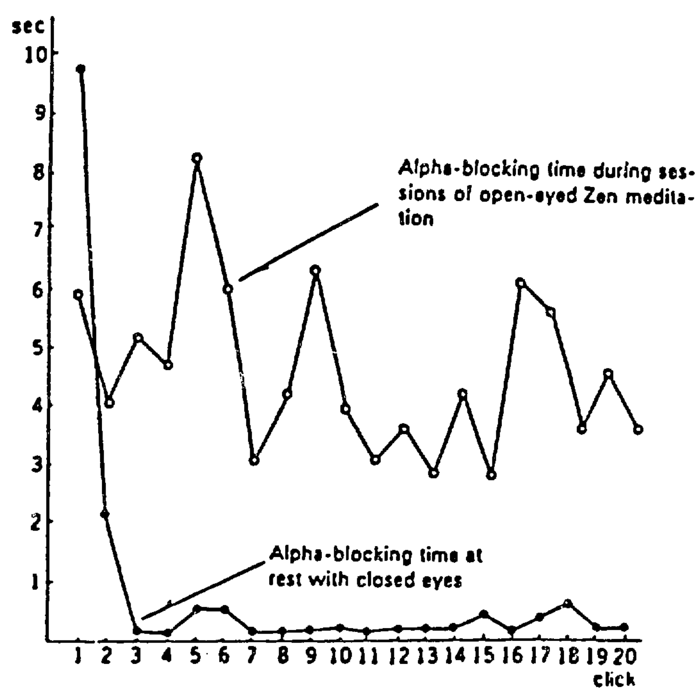


Fig. 8. Response to Click Stimulus (the alpha wave blocking time) for an ordinary person at rest with closed eyes and a well-trained meditator at meditation with open eyes. (Dr. T. Hirai: Zen and Mind, 1978)

These characteristics are all very important factors for the effective implementation of safeguards.

Although the safeguards issue is related to the safety issue, there is a substantial difference between the underlying nature of these two issues. Safety hazards are due to unknown phenomena, mechanical problems, or human errors; but safeguards hazards are always accompanied by intentional human behavior. In this context, although technology is an important element of safeguards, we should not overlook the correlation between technology and human nature for effective implementation of safeguards. Sometimes, the study of human nature provides valuable insight and intuition for solving difficult technical issues in the safeguards field. Brain wave analysis is now being used for diagnostics of brain diseases and for therapy of neuropsychological diseases, as well as for "brain washing". Current brain science is remarkable. Brain waves can tell whether or not you are falling in love, but please do not worry -- it is still impossible to tell <u>whom</u> you are loving.

Safeguards, for the purpose of nuclear non-proliferation, involves so many complicated factors (philosophical, political, technical and economic) that its implementation is still far from being fully solved. I am convinced that a solution of this difficult problem can be found. I have just shown an example that three essential factors (effectiveness, reliability and non-intrusiveness) which are considered to be difficult to satisfy at the same time, do (in fact) exist in the state of Zen meditation. But, it should be stressed that this state of meditation can be <u>accomplished only through intensive training</u> in order to concentrate one's attention inward.

Using this analogy and interpretation, I would like to close my lecture by emphasizing that the training of persons who are engaged in planning and implementing safeguards is of vital importance if we are to accomplish our common goal of effective safeguards in all types of nuclear facilities.