The Present Status of IAEA Safeguards on Nuclear Fuel Cycle Facilities

INTRODUCTION

The purpose of this paper is to examine the present approach of the International Atomic Energy Agency (IAEA) to safeguarding various types of facilities in the nuclear fuel cycle. It addresses the objectives and criteria of safeguards as they are used for the IAEA inspection planning as well as the specific safeguards techniques which are utilized by the Agency. Part I is general and includes an overview of safeguards as well as a discussion of procedures applicable to most if not all IAEA safeguarded facilities. Part II is broken down into specific facility types and focusses on the particular safeguards measures applied to them. Safeguards have reached different degrees of development for different types of facilities, in part because the Agency's experience in safeguarding certain types is considerably greater than for other types. For example, the Agency has extensive experience in safeguarding thermal power reactors, particularly light-water reactors. The Agency has very limited experience safeguarding fast breeder reactors (although safeguards are now being applied to several fast breeder reactors and support facilities). In the case of bulk handling facilities, the Agency has considerable experience safeguarding certain types of facilities — namely, conversion plants and fabrication plants. However, the Agency has limited experience applying safeguards to reprocessing plants and no experience safeguarding enrichment plants since such facilities have only just begun to come under safeguards. For certain types of facilities, such as enrichment and large reprocessing plants, definitive procedures have not been developed but the broad outlines of an expected Agency safeguards approach have emerged and these are discussed in this paper.

In light of the previous discussion, it almost goes without saying that Agency safeguards described herein are not static, but are continuously evolving. This evolution results not only from the fact that larger and more complex facilities have been coming under safeguards. Changes are also continually being introduced based on practical experience and research and development aimed at improving safeguards efficiency, reducing intrusiveness into plant operations, minimizing operator and inspector radiation exposure, and reducing subjective evaluations in determining the effectiveness of safeguards. To these ends, the technical support programmes of various countries are playing an important role.

Finally, it should be emphasized that this paper is not intended to evaluate the effectiveness of Agency safeguards or to highlight problem areas. It is simply aimed at providing a picture of what safeguards are or are planned to be at various stages of the fuel cycle.

PART I – GENERAL

Authority for Agency Safeguards

Article III.5 of the IAEA Statute authorizes the Agency:

"To establish and administer safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities, and information made available by the Agency or at its request or under its supervision or control are not used in such a way as to further any military purpose; and to apply safeguards, at the request of the parties, to any bilateral or multilateral arrangement, or at the request of a State, to any of that State's activities in the field of atomic energy."

States agree to accept safeguards either through "project agreements" for the supply of specific materials, equipment and facilities made available by or through the IAEA, "safeguards transfer agreements" in which States transfer to the IAEA their safeguards responsibilities set forth in their co-operation agreements, "unilateral submissions" by a State to IAEA safeguards of certain facilities, nuclear material or all the State's nuclear activities, or agreements pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).

The IAEA safeguards system is laid down in two IAEA documents, INFCIRC/66/Rev.2 and INFCIRC/153. The first document forms the basis for project agreements, transfer agreements and unilateral submission agreements under which equipment, facilities, nuclear material, and/or other material and information are subject to safeguards. The second document forms the basis for all agreements with non-nuclear weapon (NNW) States party to the NPT, under which all nuclear material in all peaceful nuclear activities of a State is subject to safeguards. INFCIRC/153 defines the objective of safeguards and, in addition, obliges the IAEA to formulate, based on certain of its verification activities, technical conclusions drawn in respect of the material unaccounted for, with regard to each material balance area. INFCIRC/66/Rev.2 does not include the required specifics of a conclusion, but the Agency is obliged by the Statute to make a determination of compliance and, when it is determined that non-compliance has occurred, to report to the Board of Governors. INFCIRC/66/Rev.2 provides the IAEA with means to draw, in respect to nuclear material, the same kind of conclusion as required by INFCIRC/153. The IAEA has to judge in each particular situation whether the application of its nuclear material verification procedures permits it to fulfill the responsibility of safeguarding equipment, facilities, non-nuclear material or items derived from technological information.

Objectives and Criteria

The basic undertaking by the State in NPT safeguards agreements is to "accept safeguards, in accordance with the terms of the Agreement, on all source or special fissionable material in all peaceful nuclear activities within the territory of the State, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices".

The objectives of safeguards are further defined in these agreements to be the "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear

Table 1. Threshold Amounts and Quantities of Safeguards Significance

A. Threshold Amounts

Material	Threshold Amount (TA)	TA applies to:
Pu (^{239}Pu $>$ 95%)	8 kg	Total element
^{233}U	8 kg	Total isotope
U (^{235}U $>$ 90–95%)	25 kg	^{235}U

B. Quantities of Safeguards Significance

	Material	Quantity of Safeguards Significance (SQ)	SQ applies to:
"direct-use" material	Pu	8 kg	Total element
	^{233}U	8 kg	Total isotope
	U (^{235}U $\geqslant$ 20%	25 kg	^{235}U
	Plus rules for mixtures where appropriate		
"indirect-use" material	U (^{235}U $<$ 20%)*	75 kg	^{235}U
	Th	20 t	Total element
	Plus rules for mixtures where appropriate		

* Including natural and depleted uranium.

activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection". The inclusion of the expression "for purposes unknown" is very important for the practical application of safeguards for it means that the IAEA does not have to attempt to determine the use to which diverted material is put and, in particular, does not have to determine whether nuclear material is diverted for "the manufacture of nuclear weapons or of other nuclear explosive devices".

The notions "timely detection" and "significant quantities" have been quantified in the course of the implementation of safeguards agreements. Moreover, the essential effectiveness parameters "significant quantity" and "detection time" have been discussed by the Standing Advisory Group on Safeguards Implementation (SAGSI), which has confirmed on a preliminary basis values used by the Secretariat for significant quantities. Table 1 indicates these values and also shows their relationship to "threshold amounts". A "threshold amount" of nuclear material is defined as the approximate quantity of special fissionable material needed for a nuclear explosive device. A "significant quantity" of nuclear material, or a "quantity of safeguards significance", is understood to be the approximate quantity of nuclear material with respect to which — taking into account any conversion process involved — the possibility of manufacturing a nuclear explosive device cannot be excluded.

Timeliness of detection is also an essential notion for the Agency's safeguards system and must be considered carefully in the evaluation of effectiveness. The Agency's safeguards system embodies the assumption that a diversion of a significant quantity of nuclear material, be it on the basis of an abrupt or protracted diversion strategy, must be detected on a timely basis. The Agency establishes in each particular situation the frequency and timing with which it must draw a conclusion as to whether there has been no diversion, as well as the quantity of material to which the conclusion refers, the probability of detection and the probability of a false alarm. The Secretariat has developed criteria for timeliness and used them on a trial basis whenever a particular type of facility has become subject to safeguards for the first time. With regard to the precise verification of all components of the material balance which must be followed by an investigation of material unaccounted for and by a judgement as to its causes, timeliness results primarily from the frequency of physical inventory-taking. However, in cases where the frequency of physical inventory taking and verification required to assure timeliness would seriously hamper the plant operation, timeliness must be assured by a high frequency of activities aimed at assessing the quantities of nuclear material in the plant.

The timeliness criteria were recently discussed at two meetings of SAGSI, which has made the provisional recommendation to the Director General that "detection time" be used as a parameter for timeliness and that it should correspond in order of magnitude to the "conversion time", all the qualifications attaching to the definition of these two notions being borne in mind. Generally, "conversion time" is defined as the minimum time required to convert different forms of nuclear material to the metallic components of a nuclear explosive device and "detection time" is defined as the maximum time which may elapse between a diversion and its detection by Agency safeguards. The conversion times estimated by SAGSI for different material categories are given in Table 2.

Pending the acquisition of additional practical experience and further discussions within SAGSI and other advisory groups, the Secretariat is continuing to use the values in question as guidelines.

In addition to these general guidelines for timeliness and significant quantities, the IAEA must strive for a safeguards system which has a certain probability of meeting these goals. The degree of probability with which these goals are to be met must itself be defined. Neither INFCIRC/66/Rev.2 nor INFCIRC/153 specifically mentions the concept of degree of certitude of detection, but the IAEA has interpreted these documents as implicitly embodying this concept. The *a priori* probability of detection which is sought is usually 90% or higher and is most often 95%.

Specific quantitative objectives for particular facilities are discussed in Part II.

Table 2. Estimated Material Conversion Times

Material classification	Beginning material form	End process form	Estimated conversion time
1	Pu, HEU*, or ^{233}U metal	Finished plutonium or uranium metal components	Order of days (7–10)
2	PuO_2, $Pu(NO_3)_4$ or other pure compounds. HEU or ^{233}U oxide or other pure compounds. MOX or other non-irradiated pure mixtures of Pu or U $[(^{233}U + ^{235}U) > 20\%]$. Pu, HEU and/or ^{233}U in scrap or other miscellaneous impure compounds	Finished plutonium or uranium metal components	Order of weeks** (1–3)
3	Pu, HEU or ^{233}U in irradiated fuels***	Finished plutonium or uranium metal components	Order of months (1–3)
4	U containing $< 20\%$ ^{235}U and ^{233}U; thorium		Order of one year

* Uranium enriched to 20% or more in the isotope ^{235}U.

** While no single factor is completely responsible for the indicated range of 1–3 weeks for conversion of these plutonium and uranium compounds, the pure compounds will tend to be at the lower end of the range and the mixtures and scrap at the higher end.

*** Irradiation level is chosen on a case-by-case basis.

Basic Concepts and Procedures

The basic approach of the IAEA to achieving the aforementioned safeguards objectives is a verification process consisting of three main aspects:

(1) The examination of the information provided by the State in:

- Design information;
- Accounting reports;
- Special reports;
- Amplification and clarification of reports; and
- Advance notification of international transfers.

(2) The collection of information by the IAEA in:

- Inspections for verification of design information;
- *Ad hoc* and routine inspections; and
- Special inspections.

(3) The evaluation of the information provided by the State and collected in inspections for the purpose of determining the completeness, accuracy and validity of the information provided by the State.

Basic concepts for achieving the objectives of Agency safeguards, while minimizing interference with the operation of facilities are, *inter alia:*

- Effective monitoring of the flow of source and special fissionable material by the use of instruments and other techniques at certain strategic points;
- The periodic closing of material balances by the taking of physical inventories and their verifications; and
- Independent verification by the Agency of the entire accounting for nuclear material subject to safeguards using chemical analysis and non-destructive measurements.

With respect to the last point, the basic principle in the IAEA safeguards system lies with a comparison between the information provided by the inspected party and the independent verification and observations performed by the Agency. The fact that potential diverters could be States, as well as facility operators, individuals or groups of individuals, makes it necessary that information supplied by the State be independently verified.

Both documents, INFCIRC/66/Rev.2 and INFCIRC/153, require that the State make available information to the Agency. Specifically, they require the State to:

- Provide the IAEA with information concerning facility design features and other information relevant to safeguards;
- Maintain records for each facility or material balance area; and
- Provide the IAEA with reports in respect of nuclear material based on the records kept.

The existence of a domestic accountancy and control system is a prerequisite to the application of efficient international safeguards but cannot replace the latter. The Agency takes due account of the technical effectiveness of the State's system in performing its verification. Agreements of the INFCIRC/153 type require that "the State shall establish and maintain a system of accounting for and control of all nuclear material subject to safeguards. . .". They prescribe, *inter alia*, that the system shall be based on a structure of material balance areas and shall provide for establishment of a measurement system, a records and reports system, procedures for taking a physical inventory, and provisions to ensure that the accounting procedures and other arrangements are being operated correctly. INFCIRC/66/Rev.2 does not refer explicitly to a State's system of accounting for and control of nuclear material or to all of the above elements of such a system, but it does prescribe the accounting and operating records to be kept by the State and the accounting and operating reports to be submitted by the State to the IAEA.

Agency verification is accomplished by two basic means:

- material accountancy
- containment and surveillance.

Nuclear material accountancy is currently the fundamental IAEA safeguards mechanism, while containment and surveillance serve as important complementary measures. Material accountancy refers to a collection of measurements and other determinations which enable the State and the Agency, in verifying the State's findings, to maintain a current picture of the location and movement of nuclear material into and out of material balance areas (MBAs).

A material balance area is an area where all material entering or leaving is measureable and where an inventory of the material can be determined when necessary. The establishment of material balance areas is done in consultation between the State and the Agency and their designation is included in Subsidiary Arrangements, which describe the "fine structure" of the agreement. Measurements are made at strategic points, called "key measurement points" (KMP), which are locations where essential information on flow and inventory can be gathered and verified and at which nuclear material appears in such a form as to lend itself to such measurement.

Accountancy, in the IAEA system, consists of the initial determination of physical inventory for a facility or material balance area; the perpetuation of a book inventory based on the original determination and subsequent measured inventory changes; verification and updating of the book inventory and periodic physical inventory measurements and verification; and the submission of reports to the IAEA by the State. Based on these reports, the Agency maintains a set of accounts parallel to that of the State, and these are subject to verification and comparison with the records kept at the facility. For facilities having nuclear material in unsealed bulk form, because of the measurement uncertainties, there is usually some difference between the book inventory and the physical inventory. There may also be discrepancies for other reasons, e.g., failure to measure parts of the inventory or an unmeasured loss of material or diversion. The difference between book inventory and physical inventory is the "material unaccounted for", abbreviated to "MUF". As a variable derived from measurements, MUF is, like the measurements themselves, subject to uncertainties. Thus, MUF may be a tool for judging the possibility of diversion.

A containment measure is one that takes advantage of existing structural characteristics, such as containers, tanks or pipes, to establish the physical integrity of an area or item by preventing the undetected movement of nuclear material or equipment. Such measures involve the application of tamper-indicating seals or surveillance devices to ensure that any change in the inventory of that container will be detected. Such devices would not be applied to areas or structures through which material would pass as a matter of routine plant activity. If any containment measure may have been, or may have to be, breached, the Agency must be notified by the fastest means available. For example, if there is evidence that a seal has been broken or compromised in any way, immediate notification is usually required.

Surveillance refers to both human and instrumental observation aimed at indicating the movement of nuclear material. Surveillance may involve, for example, mounting cameras or other devices at strategic points to monitor containment measures or observe inventory changes. Personnel may fulfill similar assignments by manning key observation points continuously or periodically. If human surveillance by the IAEA is applied directly, the inspection access constraints as reflected in the decisions reached in the Subsidiary Arrangements negotiated with the State would of course have to be observed.

Agency containment and surveillance techniques are carefully designed and implemented to avoid imposing any additional physical restriction on the movement of or access to material; but they have to provide to the IAEA information as to whether such movement or access occurred while inspectors were not present, in order to preserve the integrity of prior measurements of nuclear material by the IAEA and to provide the IAEA with knowledge of material flows at important points in a fuel cycle.

The key to verification by the Agency is the right to conduct onsite facility inspections. The IAEA conducts three types of inspections: *ad hoc*, routine, and special as noted above. The majority of the inspection effort is expended on the routine inspections. The safeguards agreement specifies the maximum intensity and frequency of routine inspections. A portion of routine inspections may be of an unannounced character.

The purpose of routine inspections is to verify that the information contained in the reports submitted by the State is consistent with its accounting and operating records, to verify the location, identity, quantity and composition of safeguarded materials and to verify information on the cause of shipper/receiver differences, book inventory uncertainties, and MUF. *Ad hoc* inspections are made to verify design information, initial reports and changes since the initial report and to verify the material involved in international transfers. Special inspections are made to verify information in special reports or to collect additional information when the IAEA considers information provided by the State or obtained through routine inspections to be inadequate for the Agency to fulfill its responsibilities.

IAEA inspection activities include: examining pertinent records; making independent measurements on safeguarded nuclear material using IAEA equipment and also State's or operator's equipment, verifying its proper functioning, calibration and procedures; obtaining samples and ensuring their proper collection, treatment, handling and shipping; using and servicing IAEA surveillance equipment; and affixing, inspecting and removing IAEA seals.

The IAEA makes "every effort to ensure optimum cost-effectiveness and, in order to ensure it, should use, among other means, the concentration of verification procedures in those stages in the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear weapons or other nuclear explosive devices could readily be made, and minimization of verification procedures in respect of other nuclear material on condition that this does not hamper the IAEA in applying safeguards". Therefore, the statements on material unaccounted for and its limits of accuracy must not necessarily be based on equally intensive verification activities in all types of facilities or for all types of nuclear material. These activities must, however, in all cases enable the IAEA to satisfy the objective of safeguards, i.e., the timely detection of diversion of significant quantities of nuclear material. In structuring its verification system, the IAEA takes into account not only whether material can be readily made into nuclear weapons or explosives but also the relationship between various parts of the nuclear fuel cycle. For example, although low enriched uranium cannot be directly fabricated into nuclear weapons, its value as a starting point for the production of plutonium or for further enrichment cannot be overlooked.

To achieve optimum cost-effectiveness while ensuring the capability to detect diversion, the IAEA's verification system involves two different approaches, depending upon the type of nuclear facility. For facilities in which nuclear material is produced or upgraded, such as enrichment facilities and certain power reactors and the larger research reactors, and for chemical reprocessing facilities where the material produced in reactors is separated from the other components of the irradiated fuel, the verification of all flows is of critical importance. In other types of facilities, the primary inspection activity is inventory verification.

The conclusion of the IAEA's verification activities is formulated in a "statement, in respect of each material balance area, of the amount of material unaccounted for over a specific period, giving the limits of accuracy of the amounts stated". It is important that the technical conclusion of the IAEA's verification activities includes an estimate of the operator's combined measurement uncertainties and the operator's MUF adjusted for any differences between the IAEA's and the operator's measurements. This technical conclusion gives an indication of the accuracy of the IAEA's measurements and of the degree of agreement between the operator's measurements and those of the IAEA.

The findings of routine inspections performed under NPT safeguards agreements are reported to the State concerned in the form of a statement. After the taking of the physical inventory, a second additional type of statement is sent to the State containing the conclusions drawn from the verification activities performed by the inspector. This statement shows whether the material subject to safeguards has been satisfactorily accounted for during the period between physical inventory takings. If the Agency is not satisfied with results obtained during inspections, further investigation is called for and the State is requested to examine the causes of any inadequacy and undertake the steps necessary to remedy the situation. Statements made to the States with regard to safeguards applied pursuant to INFCIRC/66/Rev.2 agreements merely report whether the IAEA has or has not detected deviations from the terms of the agreement.

Diversion Strategies

Many diversion strategies which safeguards attempt to counter are common for several, if not all, types of nuclear facilities. For example, the diverter may allow the diverted quantity to be included in MUF. This might or might not be accompanied by an over-statement of the true measurement uncertainty of MUF. He may also attempt to prevent its appearance in MUF by the falsification of flow or inventory data. For example, he may seek to use any of the following concealment techniques:

(a) understate receipts
(b) overstate shipments or declare non-existing ones
(c) overstate discards, or
(d) overstate the physical inventory.

The optimum diversion strategy is a combination of diversion into MUF and falsification of flow or inventory data. Diversion strategies as related to specific types of facilities are discussed in the appropriate sections of Part II, but most concealment techniques would fit into the general categories listed above.

PART II – SAFEGUARDS APPROACHES TO SPECIFIC FACILITY TYPES

REACTORS

There are some general features common to most power reactors currently under safeguards. In practically all cases reactor fuel takes the form of discrete, identifiable items (elements/assemblies). Information on the nuclear material contained in these items is generated by measurements at the fuel fabrication facility and by calculation of nuclear material loss (i.e. depletion through burn-up) and production (transmutation of fertile materials to fissile materials) at the reactor. Therefore, it is possible to determine nuclear material quantities in irradiated fuel on the basis of data generated at fuel fabrication facilities, taking into consideration material loss and production, and to validate such determination through counting and identification of items, provided that their physical integrity can be relied upon.

Reactor facilities are usually considered as one material balance area with a minimum of three inventory locations as follows:

- One or more fresh fuel storage areas.
- One or more reactor core units.
- One or more spent fuel storage areas.

These inventory locations constitute inventory key measurement points. Normally the only key measurement points for flows are those which reflect the receipt of fresh fuel and the shipment of spent fuel.

There are two basic diversion threats for reactors:

- The removal of one or more discrete elements or assemblies, with or without the substitution of falsified or partially falsified assemblies; and
- The use of safeguarded fuel for the irradiation of undeclared fertile materials (and consequent production of plutonium or U-233).

More specific threats deriving from these two general possibilities are discussed below with respect to particular reactor types.

LIGHT-WATER REACTORS

Features of Relevance to Safeguards

Of all the types of nuclear facilities to which the IAEA applies safeguards, the light-water reactor (LWR) appears to present the fewest problems. LWR fuel is relatively large in size and involves a relatively small number of fuel elements in both the core and storage ponds. The fresh fuel, containing low enrichment uranium, is expensive to fabricate and the tight fuel specifications at the fabrication plant mean that the amount and enrichment of the uranium in the fuel are known within the narrowest limits of any point in the fuel cycle. The enrichment of the fuel typically varies between 1.5 and 4% U-235. The fuel is usually in the form of UO_2 pellets which are sealed in cylindrical tubes. The rods are arranged in matrix-type fuel assemblies.

In LWRs, assuming that the fresh fuel contains no plutonium, the spent fuel with its produced plutonium is of higher strategic value than the fresh fuel. For this reason, a greater amount of safeguards effort is devoted to the spent fuel. In a typical facility most of the produced plutonium is located in the spent fuel pond with the remainder in the core. Most of the enriched uranium is located in the core with a slightly smaller amount in the spent fuel pond and a still smaller amount in the fresh fuel store.

A typical LWR runs on a twelve to eighteen month fuelling cycle. At the end of that period there is a shutdown for refuelling and maintenance which lasts approximately six weeks. About one-third of the fuel is discharged and replaced during each shutdown. The remaining fuel is generally repositioned for the next operational cycle. The fresh fuel normally arrives at the site two to three months before the shutdown begins. Normal management practice calls for keeping irradiated fuel in the cooling pond from six months to a year before shipment to a reprocessing plant. However, at many facilities spent fuel is currently being kept in a pond for longer periods than originally expected. A typical pond can hold one and a half times the amount of fuel contained in the core.

Diversion Possibilities

The following example of diversion possibilities, concealment methods and corresponding safeguards measures are relevant in the case of LWRs:

Diversion possibilities	Concealment methods	Safeguards measures
Removal of fuel elements from the fresh fuel store	Substitution with dummies	Application of seals NDA measurements
Removal of fuel elements from the core	Substitution with dummies	Seals Optical surveillance
Irradiation of undeclared fuel elements in the core	Undeclared shutdowns	Seals Optical surveillance
Removal of fuel elements from the spent fuel pond	Substitution with dummies	Optical surveillance NDA measurements
Removal of fuel elements from consignment when or after they leave the facility	Substitution with dummies in consignment. Understating of number of elements shipped and substitution with dummies in the spent fuel pond	Sealing of shipping container before shipment and verification of content at recipient facility

Detection Target

The detection target for light-water reactors is the absence of one or more spent fuel assemblies within two to three months and the absence of one or more fresh fuel assemblies within one year. Safeguards techniques applied to declared fuel in the core would automatically detect the introduction of undeclared fuel into it within the same time limits, and therefore no separate detection target is adopted for this type of diversion.

Safeguards Approach

The two basic tools of LWR safeguards are item accounting plus identification and containment and surveillance. The use of item accounting means that the inspector is concerned with the number of fuel assemblies rather than with quantities of nuclear material, although this concept must be tempered by the fact that in many LWR fuel designs it is possible to remove the individual fuel pins from the fuel assemblies. Containment and surveillance measures are generally used for control of the (irradiated) fuel. Because LWR cores are normally not opened more than once per year it is often possible to seal the pressure vessel heads. LWR fuel assemblies are large and a container with the requisite shielding for transporting them after irradiation is quite massive and slow moving and should be readily detected by an optical surveillance system. Removal of irradiated fuel without shielding is not considered a credible possibility.

The Agency has normally been carrying out in the range of 4 to 8 inspections per year at LWRs with an average of about 6 per facility. Generally the Agency effort at each LWR would normally involve 10–15 man-days per year.

The specific safeguarding activities and the purpose of each are as follows:

- **Audit of Accounting Records and Comparison with Reports to the Agency:** As in the case of all facilities with safeguarded material the accounting records are audited to ensure that they are formally correct (i.e. internally consistent and arithmetically correct). They are also checked to verify that the information contained in them is complete and consistent with the information contained in the reports submitted to the IAEA. This activity is meant to establish confidence in the book inventory stated by the facility, i.e., the amount of material to be accounted for. "Reports" include, for example, Inventory Change Reports, Material Balance Reports and Physical Inventory Listings;

- **Examination of Operating Records and Comparison with Accounting Records:** Operating records are audited in the same fashion as accounting records and are used to establish the distribution of fuel assemblies within the facility. This provides an additional check concerning core inventory changes. For example, a strip chart record which shows the reactor operating continuously throughout an inspection period would tend to substantiate a statement that no core inventory change had occurred. Present Agency policy is to have the plutonium content of the spent fuel reported to the IAEA at the time of final discharge from the reactor, although in some cases reporting is at the time of shipment from the facility.

- **Verification of Fresh Fuel Prior to Core Loading:** The purpose of this activity is to substantiate that there has been no fresh fuel diversion. Further, it provides substantiation of the operator's statement concerning the fuel to be loaded into the core. Physical verification includes a count of the total number of assemblies in storage and a comparison of serial numbers on the assemblies with independent data on assemblies which should be present;

- **Core Verification:** This is done by item counting or identification and counting of the fuel assemblies in the reactor core following refuelling and before the reactor vessel is closed. Following this, containment and/or surveillance methods are applied to show that the reactor vessel remains closed. These methods include using seals (e.g. on the missile shield), or using a fixed-interval surveillance device with the interval between exposures less than the time required to open the reactor vessel. Inasmuch as sealing is not feasible during refuelling, it is necessary to keep the fuel in the core under surveillance and cameras may be employed with an interval between exposures less than the time estimated for removal of fuel. Just after refuelling has taken place and before the core is closed, a physical inventory is taken of the reactor core by the operator and verified by the inspector, and upon closure seals are again attached and/or optical surveillance re-established.

The safeguarding of spent fuel in LWRs is accomplished to the degree possible through the use of optical surveillance equipment, either photographic or video, which should show that no heavy shielded containers have been used for transporting the fuel. In the event of camera failure or late installation of cameras, item counting and non-destructive assay of a random sample of the spent fuel are used as a means to re-establish or establish the inventory.

ON-LOAD FUELLED POWER REACTORS

Features of Relevance to Safeguards

Magnox and Candu type reactors and certain other power reactors are refuelled continually without reactor shutdown and this feature makes necessary safeguards measures more complex than for LWRs. This description covers mainly existing measures and not new measures that are being developed for Candu-type reactors but that are not yet implemented. Spent fuel is removed and fresh fuel added by means of remotely controlled refuelling machines. Spent fuel then is transferred by chute to the spent fuel storage area where storage is in baskets or "skips". Storage may or may not be in such a way as to facilitate fuel element counting; in particular the baskets often are stacked in close-packed three-dimensional arrays. Reprocessing schedules vary; irradiated fuel is in some cases regularly shipped away from the plant, while in other cases it is retained in storage for long periods of time.

All on-load fuelled power reactors under Agency safeguards are fuelled primarily with natural uranium. Therefore, the spent fuel containing produced plutonium has a higher strategic value than the fresh fuel. For this reason the present safeguards measures for on-load fuelled power reactors are largely directed to the task of verifying the irradiated fuel discharged from reactors. It involves at this time, in addition to containment and surveillance measures, mainly "item accounting" and, in a growing number of cases, verification that the discharged items are irradiated fuel bundles. The inspector visually counts the number of fuel bundles, elements or assemblies, and in some cases makes qualitative measurements of nuclear material. Non-destructive assay is usually only applied on special occasions such as fuel transfer or shipments, i.e. when the irradiated fuel has to be moved by the operator for his own purposes.

Some on-load fuelled power reactors under safeguards contain low enriched and/or depleted uranium fuel as well as natural uranium fuel. At least one reactor contains mixed-oxide fuel. Some on-load fuelled power reactors are equipped with low or high enriched booster rods, which help to maintain the criticality of the reactor in case of significant plant power changes. Some reactors have cobalt rods, which are part of the reactor physics design, but are not fuel and are removed from the reactor and handled separately from the fuel.

Other relevant features common to all on-load fuelled power reactors, in addition to the high frequency of refuelling, are the large number of relatively small fuel bundles in the inventory and the inaccessibility of the core for verification purposes during operation.

Diversion Possibilities

The following examples of diversion possibilities, concealment methods and corresponding safeguards measures are relevant in the case of on-load fuelled power reactors:

Diversion possibilities	**Concealment methods**	**Safeguards measures**
Removal of fuel elements from the fresh fuel store	Substitution with dummies	Simple and complex NDA techniques are possible for inventory verification
Irradiation of undeclared fuel elements	Falsification of records	Establish spent fuel inventories as completely as possible
Removal of irradiated fuel from core and spent fuel pond	Temporary borrowing from other facilities Falsification of records	Surveillance and containment of possible diversion routes (all important points) between core and spent fuel store
	Substitution with dummies	Bundle counters Sealing of storage baskets or storage trays
	Making access to material in cooling pond difficult	NDA measures
Removal of fuel elements from consignments when or after they leave the facility	Substitution with dummies in consignment. Understating of number of elements shipped and substitution with dummies in the spent fuel pond	Verification and sealing of shipping container before shipment and verification of content at recipient facility, if possible

Detection Target

The technical objective of Agency safeguards in on-load fuelled power reactors is to detect the absence of a number of spent fuel bundles containing 8 kilograms of plutonium, within two to three months, the absence of fresh fuel containing 75 kilograms of U-235 within one year, and the absence of booster elements containing 25 kilograms of U-235 within three weeks for unirradiated elements, or within two to three months for irradiated elements.

Safeguards Approach

The Agency's safeguards effort at on-load fuelled power reactors normally varies between about 15 and 50 man-days where appropriate containment and surveillance devices are installed, depending on the specific reactor type. The Agency conducts per year about 6 inspections at a typical on-load fuelled facility.

Specific safeguards activities at on-load fuelled power reactors are as follows:

- **Audit of Accounting Records and Comparison with Reports to the Agency:** The accounting records are audited to ensure that they are formally correct (i.e. internally consistent and arithmetically correct). They are also checked to verify that the information contained in them is complete and consistent with the information contained in the reports submitted to the IAEA. This activity is meant to establish confidence in the book inventory stated by the facility, i.e. the amount of material to be accounted for. "Reports" include, for example, Inventory Change Reports, Material Balance Reports and Physical Inventory Listings;

- **Determining Fuel Charge/Discharge Rates:** This involves a variety of activities, all aimed at determining the distribution of inventory within the facility. Accounting records are compared with operating records. Records of fuel charged into the reactor are reconciled with those of fuel discharged. Physically verifying the fresh fuel store, at least during each physical inventory taking, guards against diversion of fresh fuel and, more important, provides an independent determination of the number of items charged and hence discharged, assuming no undeclared fuel items are available. Fully operational fresh and irradiated bundle counters are not yet available for all reactors and would be useful as a means of ascertaining the number of items charged to and discharged from the reactor. They would be particularly desirable as a means of verifying the number of items discharged to the spent fuel bay. This method would provide an independent check of the relevant operating records.

Plutonium produced in the fuel items discharged from the reactor core is normally reported upon discharge. Based on the design information review and burnup calculations by the operator, plutonium production is estimated as a check on the data in the records and reports. Gamma measurement on spent fuel is sometimes used as a means of classifying spent fuel into categories in respect of nuclear loss and production.

Containment and surveillance measures are normally heavily relied on in such facilities although the continual refuelling feature places an inherent limitation on the use of seals with respect to fuel items. The major inspection effort is focussed on the verification of the spent fuel transfers between material balance areas and between facilities by establishing containment over the reactor area, (possibly only the exit routes) and the spent fuel storage area, possibly by a surveillance camera, and counting the number of discharged fuel elements by the discharge monitor.

If the heavy water at the facility is subject to safeguards, the inspector observes operator readings and calculations of the heavy water inventory and may independently verify the stock by weighing drums and taking samples on a random basis. If the reactor is operating, this fact alone provides assurance that the moderator is heavy water.

Specific safeguards activities at particular inventory locations of on-load fuelled power reactors are as follows:

Fresh Fuel Store

Considering the low strategic value of natural uranium, physical inventory verification by items counting at long intervals (e.g. once annually) is considered adequate for the verification of fresh fuel while it is in store.

The physical inventory must be verified annually by item counting. The inventory in the fresh fuel store may be several thousand elements, such that it might not be practical to count all the items. One practical procedure used for physical inventory verification is counting the number of fuel transfer boxes and verifying the number of elements in selected boxes. Eventually, bundle counters may be used at the point where fresh fuel elements go into the final loading mechanism.

Booster rods, where these are used, must normally be verified individually.

Reactor Core

Above and beyond auditing of operating records for fuel loaded into and discharged from the reactor core, routine verification activities are limited to containment and surveillance verification.

Spent Fuel Storage

The physical inventory must be verified by item counting annually at the time of the physical inventory taking. The inventory in the spent fuel storage is expected to be several tens of thousands of fuel elements or bundles. Taking of physical inventory in the spent fuel storage of on-load fuelled power reactors is complicated by this large number of items, by the fact that spent fuel is stored such that some bundles obscure other bundles, and, on occasion, by poor visibility due to murky pond water. Moreover, it is difficult to determine quantitatively what material is in the stored spent fuel assemblies. To obviate these difficulties the safeguarding of the spent fuel storage in these facilities relies heavily on optical surveillance systems to assure that no unreported inventory changes occur. In the case where the spent fuel will be stored for long periods of time, inspectors will increasingly apply seals on containers holding a large number of spent fuel bundles.

A complete item-count of the storage pond is made:

- After each shipment in those cases where the number of shipped items was not verified.
- In cases where containment/surveillance measures have failed to provide sufficient assurance of non-diversion.
- At the time of the initial inventory verification of an operating facility.

In the event spent fuel is transferred out of the spent fuel bay for long-term storage in an auxiliary bay or in canisters, continuous inspection may be employed during the fuel transfer. Normally, the verified spent fuel is stored in cages and sealed.

Shipments

Special measures are required when spent fuel shipments take place (e.g. to long-term storage). The inspector must be present at the time they occur. In such cases, the inspector seals the casks. For frequent spent fuel shipments, the normal procedure is to employ a fixed interval surveillance camera set to photograph each cask leaving the building. The number of fuel elements shipped may be calculated, assuming that all casks are full, or that they contain the number of assemblies stated by the operator, but this should be considered solely as corroborative evidence. The primary verification occurs on receipt at the receiving facility.

BULK-HANDLING FACILITIES

Bulk-handling facilities, particularly reprocessing facilities and plants that convert and fabricate high-enriched uranium or plutonium-containing fuel are the stages of the fuel cycle which contain material from which nuclear weapons or other nuclear explosive devices could most readily be made. In the case of NPT countries, the Agency, in conformity with paragraph 6(c) of INFCIRC/153, deploys a large part of its total inspection effort on such facilities in countries where such facilities exist and are under safeguards. (Paragraph 6(c) indicates that the Agency should concentrate its " . . . verification procedures on those stages in the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear weapons or other nuclear explosive devices could readily be made . . . ").

Recently, large and complex facilities (that is, large relative to facilities already under safeguards) handling materials of high strategic value have begun to come under Agency safeguards, either because of the entry into force of new safeguards agreements or because of the start-up of new facilities. The bulk-handling facilities with which the Agency has considerable safeguarding experience are conversion and fabrication plants.

Agency safeguards on bulk-handling facilities are based on taking and verifying two physical inventories per year at facilities which convert and fabricate low-enriched uranium and four times per year at facilities which process high-enriched uranium or plutonium, unless there is very effective and accurate flow control maintained by the operator and verified by the Agency. In this case, at least two physical inventories per year would be taken and verified.

CONVERSION AND FUEL FABRICATION FACILITIES

Features of Relevance to Safeguards

"Conversion" in the nuclear fuel cycle may refer to any of several chemical conversion operations. As used in this paper, the term refers to operations immediately preceding fuel fabrication, e.g. conversion of UF_6 to UO_2 in preparation for fuel fabrication. Sometimes this type of chemical conversion operation is carried out at the same facility as fuel fabrication. Scrap recovery may be carried out at the same site or scrap may be accumulated and shipped elsewhere in batches. If conversion and fabrication are carried out at the same facility, it is normal to divide the process activities into two or more process material balance areas: one for conversion and one or more for fabrication and scrap processing. If individual facilities do not carry out conversion they are considered to be only one process material balance area for each process line. For purposes of this paper, it is assumed that the facility in question does include conversion, fabrication and scrap processing.

In addition to the process material balance area or areas, there normally is a feed storage material balance area in which shipper/receiver difference data are established, plus a product storage material balance area in which item accountability on fuel assemblies awaiting shipment is maintained.

Key measurement points are established for the measurement of all feed materials as received, for the measurement of fuel elements or assemblies prior to shipment, and for the measurement of waste discards. Key measurement points are also established for the transfer of intermediate materials between material balance areas. If scrap is shipped offsite for recovery, its measurement requires a key measurement point. There are also inventory key measurement points established in the facility.

Conversion and fabrication facilities are stages in the fuel cycle where nuclear material becomes contained in discrete, identifiable items. It is possible to simplify the verification of nuclear material items by the use of identification and counting of items, augmented by appropriate tests to verify the integrity of the containers and checking the IAEA seals. The inventory in the facility, however, may be upwards of a hundred tonnes of material in a variety of forms such as pure powder, assemblies, rods, unsintered pellets, sintered pellets, reject materials awaiting recycle, and scrap material in a variety of inhomogeneous forms. In addition to this feature, at plants fabricating natural and low-enriched uranium fuel, only limited precautions are required from the standpoint of toxicity and criticality for the handling of material. Therefore the possibility exists at all times and at all stages for diversion of material simply by direct removal from storage or process. Generally, conversion and fabrication facilities are shut down one to four times a year for a physical inventory (depending on the type of plant and in the case of plants processing low-enriched uranium, the quantity of material processed). Production is usually stopped for about three days depending on the type and size of the plant. All material present is tagged and a list is compiled for Agency verification of the material.

Diversion Possibilities

The following are examples of diversion possibilities with possible concealment methods and appropriate safeguards counter-measures:

Diversion Possibilities	**Concealment Methods**	**Safeguards Measures**
Removal of natural or enriched uranium in bulk form	Failure to record receipts	Comparison of reports
	Understating amount received	Weighing, sampling and analysis of random selection of drums received
	Inflation of measurement uncertainty	Analysis of shipper/ receiver difference
		Independent measurements

Diversion Possibilities	Concealment Methods	Safeguards Measures
	Substitution with natural or depleted uranium (for enriched uranium)	Seals NDA measurements
	Borrowing from other facilities	Simultaneous inspections
	Hollow or low density pellets	Pellet checking
Removal of Fuel Assemblies	Substitution with dummies	Seals NDA
	Invention of shipment	Verification upon receipt at reactor
		Careful checking of records and item counting
	Borrowing from other sites	Simultaneous inspection
Diversion of scrap pellets	Inventing shipments and inflating amounts shipped (if separate recovery plant)	Thorough checking of records and on-site verification at recovery plant
	Inflation of measurement uncertainty	
	Inflated processing losses	Analysis of historical data

Detection Target

Safeguards at fuel fabrication facilities are designed to detect, with 95% confidence, a protracted diversion of any or all types of nuclear material at a minimum rate of one significant quantity per year. In addition, safeguards at facilities which process plutonium, high-enriched uranium and uranium-233 and hold more than one significant quantity of any of those materials, are designed to detect with a high degree of confidence the sudden diversion of significant quantities of special fissionable material within a period of one to three weeks.

Safeguards Approach

For purposes of discussing Agency safeguards, conversion and fuel fabrication plants can be divided into two groups: plants which handle depleted, natural and/or low-enriched uranium and those which handle plutonium, high-enriched uranium and uranium-233.

Nuclear materials accountancy is established as the fundamental mechanism of IAEA safeguards with containment and surveillance as important complementary measures. However, containment and surveillance measures are of limited practicability at conversion and fuel fabrication plants, and reliance by the Agency inspector must be on materials accountancy, focussing on careful verification of the operator's claims regarding amounts of material received, shipped, stored or lost and his own observations.

Facilities which Process only Depleted, Natural and/or Low-Enriched Uranium

The basic concept underlying IAEA safeguards on commercial scale conversion and fabrication facilities handling depleted, natural and/or low-enriched uranium is material balance verification with heavy reliance on random sampling. More specifically, at such facilities the Agency's approaches and measures are as follows.

- Depending on the inventory and/or throughput of a plant, the Agency normally conducts ten or more inspections in the course of a year, two of which are to verify the operator's physical inventory. These inspections amount to about 50 to 70 man-days of effort and are planned over a material balance period. The actual number of visits is in accordance with a sampling plan drawn up on the basis of the design flow of material over a campaign, i.e. between inventories (see below).

- Audit of accounting records and comparison with reports to the Agency, to establish the book inventory of the facility. Among the reports involved are Inventory Change Reports, Material Balance Reports and Physical Inventory Listings for facilities safeguarded under NPT agreements, and Material Balance Reports and Joint Notifications for those safeguarded under INFCIRC/66/Rev.2 agreements. All routine inspections include an examination of records and a comparison of records and reports.

- Determination of material flows into, through and out of the facility: Flow verification consists of measurement and observation at the time of the intermittent inspections. Receipts at the facility are verified by random selection of containers of material. Flow verification includes, to the extent possible, tracing the progress of each assembly to the reactor and ultimately to a reprocessing facility. This procedure may require the planning of simultaneous inspections on reactors and fabrication plants to account for all assemblies. (For the present, flow verification activities are being kept to a minimum at facilities for the conversion of natural uranium and the fabrication of natural uranium fuel elements so as to permit the concentration of the Secretariat's resources on materials with a higher strategic value).

- Determination of nuclear material inventory: The general approach is to verify the total population of items identified by the operator by records audit and item counting and then to verify the amounts as stated by the operator through random sampling to achieve an acceptable level of confidence that diversion of a significant quantity of material has not occurred. The inspector thus verifies the operator's physical inventory, which is an important part of the overall material balance verification and provides supporting evidence for the amount of MUF declared by the operator. As noted, Agency inspectors carry out a records audit, item counting and quantity verification following a random sampling plan, employing weight checks of containers and attributes and variables testing methods.

Specifically, for example, loaded fuel rods are checked to ensure that no pellets are missing and that the stated quantities are unbiased. Finished fuel assemblies are counted and identified against the operator's records. Attributes tests are carried out on UF_6 (or other feed) cylinders, powder, drums, pellets, rods, assemblies and scrap, using appropriate non-destructive assay techniques such as gamma spectrometry, while variables tests are carried out on a random sampling of powder, pellets and scrap. Measurements of fuel assemblies are especially critical for safeguards purposes because they are the final product stage of the fuel fabrication plant and will normally remain intact for a number of years. Measurement is often difficult because the inner rods are effectively secured and cannot be conveniently exposed. Moreover, current instrumentation does not provide a sufficiently precise quantitative measurement of uranium in LWR assemblies. The assemblies are generally the area of greatest uncertainty of verification in a conversion and fabrication plant. Continuous inspection would be the only means of eliminating this uncertainty. Rods can be directly and accurately measured by the Agency at the rod filling station and continuous surveillance from there through the final product stage would enable the Agency to have an accurate picture with respect to the content of assemblies. Material awaiting disposal, like that awaiting recovery, accumulates in drums. The specific approach to verifying this material is examination of documents to establish the amounts claimed for disposal, with sampling and weighing or non-destructive assay to verify the operator's statements regarding quantity and quality.

Seals are normally employed as part of the physical inventory verification to ensure that all items are inventoried without duplication and to ensure the integrity of samples taken for analysis. If part of the inventory, in particular waste and recoverable scrap, is stored for extended periods at the facility, it is measured, sampled and sealed.

Facilities which Process Plutonium, High-Enriched Uranium or Uranium-233

Fuel fabrication facilities which process plutonium, high-enriched uranium or uranium-233, depending on their size, require the application of additional safeguards measures in order to achieve the short-term detection capabilities referred to earlier.* A plutonium mixed-oxide fuel fabrication facility may contain several hundred kilograms of plutonium.

One safeguards approach being considered by the Agency at such plants is based on continuous or high frequency inspections and would involve obtaining adequate assurance that the operator maintains adequate flow control, an approach intended to extend the validity of nuclear materials accountancy as the mechanism of fundamental importance. Further, since it may not be practical for the operator to make available all plutonium, high-enriched uranium or uranium-233 for verification at intervals permitting a short detection time, access to specific points will be necessary for all such materials at all times, including the process areas, as will access to relevant operator data. Data collection and analysis activities, conducted by Agency inspectors, are geared to operating patterns established by the facility operator to achieve desired detection capability with a minimal degree of intrusion into normal plant operations.

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* See **Detection Target**, page 20.

Features of this flow control verification approach are as follows:

- The location and quantities of all nuclear materials established through verification of the complete physical inventory performed semi-annually serve as reference points for tracking the flow of materials within the plant during the operating period between successive inventories.

- Starting from these reference points, procedures are established for the complete verification of all receipts prior to processing, and all shipments prior to dispatch, and the re-verification of all stores at least once during each sequential short detection time period. (The precise period is determined by operational practice).

- Seals are used extensively on feed, in-process storage, and products, to the limit practicable, to permit rapid, frequent and expeditious re-verification.

- Separate records may be maintained by Agency inspectors tracking the flow of materials through each separate process stage. These records are derived from operator production control records, checked to the extent possible with the process operators.

- At least once each period, Agency inspectors verify the in-process inventory to the extent possible. For example, they may start at the first process stage and work stage-by-stage through the process material balance area. The inspectors come to each stage with an updated listing of the amount of material which should be present in that stage and attempt to verify that in-process inventory without interrupting the process activities. To the extent possible, this scheduling is chosen to coincide with a break in process activities at each stage.

- In-process verification includes visual observations to count all material containers within each work area and of the process equipment to gauge the probable amount present in each stage. The inspector observes and records any weight measurements or other characteristics of material present at that stage. He attempts to verify the quantity of nuclear material contained in items transferred out of each stage, especially if the item is to be transferred to another material balance area. Finally, he may make radiometric measurements at selected positions to establish a pattern of material quantities and distributions encountered in normal operations. Information gained with respect to these indications is used to establish a calibration. That is, a series of readings taken in one period may be compared to the amount projected to be in the zone viewed by the collimated survey instruments in that period and later compared to the amount of material processed through or recovered from that zone, as appropriate.

- During this in-process verification, samples are obtained as part of an on-going check on bias detection procedures. As the results of these analyses become available, they are used to update the calibration of Agency NDA instruments, as appropriate.

- At the conclusion of each period, the inspector summarizes his findings for that period, investigates any problems observed, and concludes on the basis of preliminary information the current plant status. The inspector concludes with this information and his observations of process activities whether it is likely that any diversion has occurred during the period under consideration. He attempts to conclude that the likelihood that one significant quantity of plutonium, high-enriched uranium or uranium-233 could have been diverted from the plant during the period under consideration without being detected is acceptably low.

REPROCESSING PLANTS

The Agency has limited experience applying safeguards to reprocessing plants. Although it has had the opportunity to conduct safeguards exercises at several plants in the USA, Belgium and Italy, it has undertaken the routine application of safeguards to continuously operating facilities only since May 1977. The procedures discussed initially in this section are directed at the small-to medium-size plants (i.e. up to 300 tonnes of fuel throughput per year) the Agency is faced with at the present time. These procedures are still in a formative stage and can be expected to evolve with increasing experience. The Agency is not expected to be faced with safeguarding large-scale commercial facilities for some years to come. Nevertheless, the Agency has preliminary views as to an effective safeguards approach to such plants and these are discussed briefly in a separate section.*

The only reprocessing method presently operated on an industrial scale is the Purex process. Therefore, this is the only process addressed in this section.

Features of Relevance to Safeguards

Reprocessing plants are very significant from the standpoint of safeguards because they produce material – purified plutonium– which could be used for nuclear explosives with a minimum of further work and in a short period of time. A plant with a throughput of 300 tonnes of spent fuel per year separates about two to three tonnes of plutonium per year.

Reprocessing plants present a unique safeguards problem insofar as, unlike all other plants, their input is defined only by the input analysis itself since the composition of the irradiated fuel rods at the time of initial receipt is only known from reactor calculations. In addition, there is a major difficulty arising from the fact that a reprocessing plant is complex and most of the equipment inaccessible during operation. Since the plant is dealing with highly irradiated fuel, the early stages must be carried out behind shielding, which is normally concrete walls. The measurement vessels are likewise hidden from view so that no direct observation is possible. These features provide a would-be diverter many opportunities to conceal a diversion carried out either at the reprocessing plant or at an earlier stage of the fuel cycle.

There are additional complications. Reprocessing plants usually operate on shifts 24 hours per day, 7 days per week for extended periods, so there is continuous flow of nuclear material. Moreover, it is possible to determine the real input of plutonium into the process area only by means of sampling from the accountability vessel, which means that IAEA inspectors must be present to verify the operator's measurements for each transfer of nuclear material. Taking into account the complex nature of reprocessing plants and the amount of sensitive material involved, the Agency has concluded that continuous inspection is required. In addition, the following general conditions need to be met:

- all accountancy vessels are carefully calibrated
- reliable samples are taken of input, output and all streams leaving the plant
- frequent assessments of the amount of material present
- the output can be placed under an easily checked seal or continuous surveillance.

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* At present the Agency is applying safeguards to five reprocessing plants.

Reprocessing facilities are normally divided into three material balance areas for the purpose of safeguards, not including any areas which may exist for further conversion of product materials. These include, first, the feed storage area, where fuel assemblies are received, stored and from which they are transferred to process. The normal inventory in the feed storage area consists of unreprocessed fuel assemblies awaiting recovery. Within the fuel storage area, receipts of nuclear material are recorded on the basis of shippers' data (i.e. the above-mentioned calculated values from the reactor operation) and removals to process are based on input analysis. The shipper/receiver difference results from deducting such receivers' values (adjusted to account for heels, hulls, etc.) from the corresponding shippers' figures.

The second material balance area is the process area, where measured dissolver solution is processed to separate the three main components — plutonium, uranium and fission products. Product, especially plutonium, may be recycled back to the process area for rework and additional purification. The boundary between the first and second material balance areas must be established in such a way that the only inventory changes which would normally take place in the first material balance area are shipments and receipts. The shipper/receiver difference would arise as the difference between receipts (on shippers' values) and shipments (transfers to the second material balance area) as measured.

The third material balance area is the product storage area. The receipts into, and shipments from the third material balance area are recorded and reported based on measurements made at the input to the product storage area. Thus receipts into and shipments from the process material balance area are measured only once. This eliminates the possibility of shipper/receiver differences involving that material balance area; the only inventory adjustment which may be made in it is MUF in case blending operations occur. The storage area usually operates in one of two ways. At some facilities containers of product material are stored pending shipment. In this case there is usually only one measurement, shipments being made at the measured values obtained when the material was placed in storage. Other facilities may use storage tanks, such that a second set of shipping measurements is sometimes required after blending. A combined approach may also be used, with one material, usually plutonium, being bottled for shipment as it is produced, and the other being collected in tanks. A reprocessing facility might also convert its product uranium into other forms, such as UF_6 for recycling to an enrichment plant, or its product plutonium into PuO_2 for fabrication into fuel. Such operations would normally be treated as separate material balance areas with those inspection procedures applied which would be applied were they separate facilities.

Diversion Possibilities

Listed below are examples of possible diversion activities divided into six areas of a reprocessing facility where they could take place. The possibilities vary from the simple case of direct removal of material, such as plutonium from storage, to the most subtle case of diversion or withdrawal of part of the process flow through some of the innumerable pipes which form part of the plant. Except in the case of whole assemblies, these activities could be carried out either as abrupt or as protracted diversion.

Detection Target

The IAEA assumes the possibility of abrupt and protracted diversion strategies at reprocessing plants. With respect to protracted diversion, the Agency's safeguards are designed to detect with 95% probability, a diversion of one significant quantity of nuclear material per year. With respect to abrupt diversion, safeguards are designed to detect, with a high degree of probability, the sudden diversion of significant quantities of special fissionable material within a period of one to three weeks.

Safeguards Approach

The Agency carries out continuous inspection at reprocessing plants. The actual inspection effort at a reprocessing plant is at least 900 man-days per year (i.e. 3 man-days per day) depending on the inventory and throughput of the plant. However, for quite a number of activities the work is unevenly distributed during the time span. In an optimum schedule inspectors residing near the plant should be called in for particular verification activities, such as input volume measurements, one or two hours before the operator is ready to do the measurement. During the day shift inspectors would be called in from their office in the plant. During nights shifts they would be called in from a nearby residence. They also maintain a right to drop in to check on agreed strategic points at any time.

Diversion Possibilities	**Concealment Methods**	**Safeguards Methods**
Transfer to and Treatment in the Chop and Leach Section		
Unrecorded transfer of assemblies to chop and leach	Falsification of records of number of assemblies transferred and dissolved	Surveillance to obtain independent evidence of transfer
Assembly removed in transfer (recorded but not actually received in chop and leach)	Falsification of records	Counting and identification of fuel assemblies into chop and leach
Chopped pieces removed from dissolver		
Plutonium and uranium not fully dissolved (for unrecorded dissolution later)	Falsification of records of Pu and U contained in hulls	Verification by NDA or by sampling and analysis of the Pu and U content of the hulls
		Presence during the removel of hulls from the leach vessel and verification of transfer to storage
Liquid from dissolver by-passes the accountancy tank		Use of containment and surveillance technique to detect diversion of material by-passing the accountancy tank to the process stage

Diversion Possibilities	Concealment Methods	Safeguards Methods
Input Accountability Tank		
Unrecorded transfer from accountancy tank to process		Surveillance to provide independent evidence of all transfers
Incorrect statement of volume (weight) or of the Pu and U concentration of transfers to the process area	Inaccurate calibration	Verify calibration of instruments for volume (weight) measurement
	Plant measurement (diptube/manometer or weighing) system falsified	Verify measurements of volume (weight), temperature and density
	Falsification of analytical results either by using a non-representative sample or in the analysis itself	Presence when the solution is homogenized and the samples are taken Verify analysis and homogeneity of samples
	Overstatement of measurement uncertainties in design information or introduction of additional errors in recorded measurements to conceal diversion in MUF	Obtaining of samples for independent analysis to detect bias and to assess measurement uncertainties
	Recycle acid (or other additions) containing undeclared uranium, and/or plutonium	Obtaining of samples of recycled acid for independent analysis
Process Area		
Removal of solutions through pipework which does not form part of normal declared production stream	Falsification of records of Pu and U content in various wastes, including those retained on site, those shipped and those discarded	Verify the discharge or transfer of waste streams, including volume measurements Obtain samples of wastes for independent analysis

Diversion Possibilities	Concealment Methods	Safeguards Methods
	Invention of accidental losses and falsification of records on Pu and U in accidental losses (e.g. spills or effluent discharges)	Obtain copies of plant procedures for handling abnormal incidents such as accidental losses, monitor implementation of these procedures and, when appropriate, make independent measurements of amounts of Pu and U involved
	Falsification of records of Pu and U hold-up in process vessels at times of physical inventory taking	Presence during clean-out operations and verify that established clean-out procedures are followed. Should there be significant hold-up, independent measurements of Pu and U involved
Output Accountability Tank		
Unrecorded transfers of product material from the output accountability tanks and transfers which bypass these tanks		Surveillance to provide independent evidence of all transfers
Incorrect statements of volume (weight) or of the Pu or U concentration of transfers from the process area	Inaccurate calibration	Verification of the calibration of instruments for volume (weight) measurement
	Falsification of plant measurement (diptube/manometer or weighing) system	Verification of measurements of volume (weight), temperature and density
	Falsification of analytical results either by using a non-representative sample or in the analysis itself	Presence when the solution is homogenized and the samples are taken
		Verification of the analysis and homogeneity of samples

Diversion Possibilities	Concealment Methods	Safeguards Methods
	Overstatement of measurement uncertainties in design information or introduction of additional errors in recorded measurements to conceal diversion in MUF	Obtaining of samples for independent analysis to detect bias and to assess measurement uncertainties
	Recycling of acid (or other additions) containing undeclared uranium, and/or plutonium	Obtaining of samples of recycle acid for independent analysis
Product Storage Area		
Unrecorded or incorrectly recorded shipments of Pu and U	Falsification of shipping documents	Verification of shipping documents and records
	Falsification of inventory records, including entry of fictitious items, recording an item more than once and moving and relabelling items to cause multiple counting by the IAEA	At time of measurement verification, application of seals to all stored nuclear material in sealable containers and to all shipments During inventory verification, conducting of an item count (tag check) of all items recorded on the inventory listing
	If the material is measured at the time of shipment, same as for input accountability tank	Same as for input accountability tank.

The following is a general list of safeguards activities which would be likely to be undertaken by the Agency at the present time at a typical reprocessing plant:

- Log books would be prepared in advance for keeping up-to-date records by the inspectors of the essential safeguards parameters such as input, hold-up, output, intermediate storage, etc. Such records would provide a kind of floating MUF analysis on which provisional safeguarding conclusions could be drawn. Under NPT safeguards agreements a final, formal conclusion in the form of a statement would be worked out at Headquarters according to a periodicity to be defined in accordance with the actual operating schedule of the plant.

- The flow of irradiated fuel from the reactor to the dissolver at the reprocessing plant has to be checked to assure that it is complete. The buffer storage of irradiated fuel at the reactor facility is normally under surveillance by photographic or TV cameras which have to be adjusted to detect any fuel cask movement with a high probability – normally 100%. Where the transport of the fuel casks is infrequent each transport should be checked by sealing the cask; however, highly irradiated light-water reactor fuel assemblies can only be transported in very low numbers per cask; consequently, the number of transports is so high that it is often difficult to seal all of them. In such cases flow control must be assured by correlating intermediate inventory takings at the reactor spent fuel pond with corresponding inventory takings at the reprocessing plant's reception pond. In most cases visual identification by reading the numbers on the assemblies should be sufficient. Additional "finger printing" by photographing number plates and welds should be applied when identification by numbers alone would be difficult and/or give rise to doubts. For a number of fuel types it is also possible to check on the basis of a sampling plan the radiation history by gamma measurement. Before chopping and dissolver loading, the fuel has to be fully identified as to its origin.

- Material transfer via the boundary between the first and second material balance areas is 100% verified. This location is the first and only point in the fuel cycle at which the produced plutonium can be independently established. Source data for establishing the plutonium quantity are prepared by the plant operator in two equally important groups:

(1) those related to the determination of volume and,
(2) those related to the determination of plutonium concentration and ratios of isotopes as well as the ratio of plutonium to uranium.

For the source data related to volume each individual variable, such as temperature, length of manometer column, specific gravity of manometer fluid, quality control and check programme has to be established. For the source data regarding concentration, sampling, with and without previous spiking, has to be prepared. In this particular field improvements derived from new technical developments may be expected, but at this moment only the above-mentioned classical methods can be taken into account and must be studied in detail.

- As regards vessel calibration, i.e. the volume as a function of the liquid level (assuming that the specific gravity of the dissolver solution has been determined in connection with the concentration determination), the series of calibration results has to be carefully analysed statistically in order to determine the random and systematic components of uncertainties. Calibration data for each vessel should be carefully examined for the possible effects such as thermal distortion of the vessel shape. The calibration of the input accountability vessel is of the same importance for the plutonium quantity determination, as, for example, the analysis of plutonium concentrations in dissolver solution samples. Therefore, it must be fully verified, including tank calibrations.

- The established plutonium input to the process material balance area must be checked against the amount of plutonium calculated as being produced at the reactor(s). The shipper/receiver difference established on the basis of the reported plutonium production and ordinary computerized burn-up calculations at power stations may be affected by a large uncertainty. However, the uranium content is less affected by those inaccuracies and the plutonium inaccuracy can be reduced by the use of the Pu/U ratio method and other isotopic correlations such as U-235 depletion ratios, fissile isotope ratios and fission product ratios. Using these methods the plutonium production can be determined with a higher accuracy of the order of ± 3% and in some cases of ± 1%.

- The plutonium and uranium input to the process area must be checked for completeness and overstatement. It is actually impossible to assure that there is no by-pass line out of the process material balance area for any reprocessing plant whether visited or not during construction. Therefore the essential safeguards control must be based on a continuous material balance check across the processing area.
- Another difficulty is connected with the measurement of material in the leached hulls. This is a difficult material to verify and each case has to be examined separately because the available verification techniques are limited. However, close process control provides the possibility of assuring that fissile material content in leached hulls is very low.
- Another problem regarding plutonium input definition is related to nitric acid recycling. Most dissolutions are done with large amounts of acid already used for the same purpose before. This recycle acid usually contains considerable amounts of highly polymerized plutonium, which is determined by sampling and analysis. Subtraction of this recycled plutonium analysis value from the raw input analysis value may lead to overstatement of the plutonium input because of the inherent difficulty of such analysis. Alternatively, overstatement of the plutonium content in the recycle acid may lead to understatement of the plutonium input. Therefore, careful on-the-spot checking, including sampling, of the recycle acid is necessary.
- The plutonium output from the process material balance area is another important key measurement point level. In case of output in the form of plutonium nitrate solution the quantity determination is again dependent on two major components: (1) those source data related to the volume determination, including tank calibration and (2) the concentration measurement component which can be based on straightforward plutonium measurement — the plutonium being normally of high purity at this end of the flow sheet — using the most precise methods such as controlled potential coulometry (± 0.1%).
- In large facilities, an intermediate check point for plutonium flow might be installed just after the partition cycle.
- Uranium output has to be verified and compared to the plutonium output and the Pu/U ratio found at the input to the plant. In case a calcination process step to produce U_3O_8 is operating, an intermediate check point for uranium in uranyl nitrate form should be established considering the source data for volume and the source data for concentration. Intermediate uranium buffer storage, whether in solid or liquid form, should be checked at low frequency only, i.e. every 3–6 months, depending on the residual enrichment.
- Conversion of plutonium nitrate into plutonium oxide has to be dealt with by establishing a separate process material balance area. The measurement principles for receipts into and shipment ouf of this material balance area are *mutatis mutandis* the same as in the process material balance area mentioned above.
- Plutonium product storage at the output of the reprocessing plant has to be verified with a high frequency and confidence level. Intermediate inventory verification (e.g. by means of seal checks) should be repeated every two to three weeks. Shipments from the tail-end storage should be sealed and re-checked immediately after arrival at the receiving material balance area.

- Inspection results and safeguards conclusions must be worked out on the site continuously to assure short detection times. Most analytical results worked out by the operator of a reprocessing plant are established in at least two stages. For process purposes the operator needs analytical results within a few hours, but can accept lower accuracy sometimes of the order of up to ± 20%. Analysis of that kind is usually called "process analysis". All analyses essential for accountancy are repeated with much higher precision, but with a delay of several days, exceptionally weeks. This type of analysis is usually called "accountability analysis". Inspection results should be worked out on a continuous basis using a similar 2-stage procedure. The first stage is based on observation of "process analysis" and at the second stage a correction is introduced based on the verification of the "accountability analysis". Only the second stage results are later compared with the official reports sent to Headquarters.

Safeguards on Large Reprocessing Plants

A large reprocessing plant, with a capacity of about 1 500 tonnes of LWR irradiated fuel elements per year, will produce annually between 10 to 14 tonnes of plutonium. The IAEA has done some preliminary work on the nature of safeguards on large reprocessing facilities. It is suggested that safeguards on large reprocessing plants would not be based mainly on traditional material accountancy methods because measurement errors and uncertainties in the material balance would be too great. Safeguards would, instead, be based primarily on the concept of containment, complemented by human and instrumental surveillance and monitoring. One possibility would be to erect a highly sensitive barrier or barriers around particularly critical parts of the plant. This barrier would use highly sensitive plutonium monitors which detect the radioactivity of plutonium. The technology would be used for personnel monitoring at a limited number of doors (i.e. portal monitors) and for keeping entire halls, containing glove boxes, under control. It would be supplemented by surveillance. Such an approach also assumes that possibilities for continuously verifying the integrity of the physical containment would be built-in during design and construction of the plant.

Another point with respect to such large reprocessing plants, which would also apply to a lesser degree to other large bulk handling facilities of the future, is that it would be almost essential that they incorporate design features which facilitate the application of safeguards. These design features would be mostly minor and should not appreciably increase construction or operating costs. They would include assuring adequate sample lines, designing tanks so that they drain empty, or at least so that the remaining heel can be measured, providing sufficient valves so that tanks can be isolated for measurement. A number of studies related to safeguards design criteria are underway, both within the IAEA and Member States.

URANIUM ENRICHMENT PLANTS

The Agency has no actual experience safeguarding uranium enrichment plants, even pilot plants, but has been considering this matter for some years in anticipation of applying such safeguards. The first enrichment plants to come under Agency safeguards are of the centrifuge type. The first commercial diffusion plants to be safeguarded are still under construction. The Agency will probably also eventually be faced with applying safeguards to plants employing the nozzle process, and possibly to plants employing other processes as well.*

The Agency has not defined in detail a safeguards strategy applicable to all types of enrichment plants. Most of the study effort to date has centered on centrifuge facilities of the type the Agency is immediately faced with safeguarding. This section discusses a general approach to safeguarding enrichment plants and concludes by discussing some of the specific aspects of the Agency's expected approach to safeguarding centrifuge facilities based on studies to date.

Features of Relevance to Safeguards and Diversion Possibilities

Uranium enrichment facilities have a number of features in common which are relevant to safeguards. Apart from accumulated waste the material is all in one chemical form of high purity (uranium hexafluoride) throughout the process. The feed can be natural uranium, depleted or enriched uranium which has been recycled after irradiation in a reactor and purification, or depleted tails (or low-enriched uranium) recycled from another facility or from prior operations. Plants can be arranged to have several feed and product take-off points and may be followed by some blending operation to achieve the specific enrichment per contractual obligations. All multi-stage enrichment processes are true continuous processes; both a constant feed and a constant product (and tails) removal are essential for efficient process operation. Enrichment facilities can be expected to have associated storage areas for feed, tails, and product. These areas may have capacities approaching or exceeding the equivalent of one year of normal operations, although this feature is not a necessity.

Uranium enrichment plants, like reprocessing facilities, entail a greater concern than other facilities in the fuel cycle from the standpoint of proliferation insofar as they may be used to produce material which is directly useable in a nuclear explosive device. This, however, is only true for certain modes of operation of such facilities. For commercial purposes, uranium enrichment plants preparing fuel for power reactors are typically designed to enrich material up to approximately five per cent U-235. For military purposes, enrichment above 90 per cent has been customary.

The central safeguards question in relation to enrichment plants is, therefore, whether the commercial plant can somehow be adapted or operated to produce the higher enrichments. The answer to this question depends to a large extent upon the type of plant. The centrifuge plant achieves commercial enrichment in only a few stages, but since the quantity that can be handled by each machine is usually small, a great many machines are operated in parallel at each stage to give the required throughput volume. A rearrangement to achieve a high degree of enrichment would be to increase the number of stages in series by reducing the number of machines used in parallel. The choice facing the operator is a high production rate at low enrichment or low production rate at high enrichment. The possibility of undeclared use therefore exists in principle for this type of plant, but such rearrangement may, in fact, require considerable effort.

For the classical gaseous diffusion plant, the problem of rearrangement is much more difficult still. The nature of the process is such that little separation is achieved at each

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* At present the Agency is applying safeguards to three enrichment plants.

stage, so, many stages are required even for low enrichments. In addition, a typical gaseous diffusion cascade is built up from units of different size starting with very large stages scaling down to smaller units as higher enrichments are reached. The possibility of subdividing the early stages to provide later stages is remote if an adequate throughput is to be maintained. Aside from cascade rearrangements another possibility would be to change the mode of operation such as to increase the enrichment level by increasing the enrichment per stage, although production would drop as a result. This, too, might require considerable effort, however, and the increase in enrichment would be limited.

There are also possible diversion concealment strategies which do not involve rearranging the equipment or changing the operating mode of an enrichment plant. Some of these strategies are as follows:

- Use of other than declared feed to produce higher enrichment
- Fictitious or overstatement of accidental losses of UF_6
- Borrowing material from another material balance area to conceal shortage at time of physical inventory taking
- Inclusion in inventory listing of items that do not exist or listing items more than once
- Overstatement of measurement data for UF_6 or solid wastes (hold-up in equipment)
- Recycle of product as feed.

General Safeguards Approach

Regardless of the type of uranium enrichment plant, a common feature influencing the safeguards approach is the potential sensitivity of the owners or operators regarding the commercial or weapons-proliferation value of the design. For this reason the basic international agreements recognized from the beginning the potential desire of the operator to have the sensitive parts of the plant treated as a "black-box", that is to say, a location where safeguards activities are carried out on the perimeter of these areas without access to the inner workings. This area must be as small as possible. Under Section 46(b)(iv) of INFCIRC/153 the State may request that some portion of the facility be identified as a "special material balance area". Presumably, IAEA inspectors would not enter such an area. INFCIRC/66/Rev.2 does not as yet contain special safeguards procedures for enrichment plants. However, similar arrangements for such a material balance area could be embodied in subsidiary arrangements negotiated pursuant to an INFCIRC/66/Rev.2 type agreement, assuming this was consistent with the terms of any bilateral co-operation agreement involved.

The safeguards approach to these plants must take into account this limited access when adopting the classical safeguards approach of careful material accountancy supplemented by containment and surveillance measures. This philosophy embodies the principle that all material entering and leaving is measured and a material balance with little uncertainty is periodically obtained. Fortunately, the process inventory of most enrichment plants does not routinely vary appreciably. Moreover, the typical enrichment plant has the highest standards of material accountancy of any type of nuclear plant. Both published and unpublished figures over many years of operation show a remarkable certainty in the material balance, and there is no reason why plants currently being designed and commissioned should not even improve upon this standard. Safeguards procedures at the plants will consist therefore of careful verification by the safeguards inspectorate of all material fed to the cascades and of all material withdrawn, both with regard to quantity and quality (enrichment). It would, of course, also be necessary to verify all abnormal transfers of material such as may occur through transfers of equipment. Containment and surveillance will play an important part in reducing the manpower effort required and maintaining continuity of knowledge for safeguards purposes. Examination of the material balance under these circumstances not only indicates whether material is missing but also indicates whether the mode of operation is as declared, since a change to high enrichment output inevitably is reflected in a change in the tails, product and feed ratios.

On the matter of maximum routine inspection effort at enrichment facilities, INFCIRC/153, Section 80 would permit continuous inspection (actually, 450 man-days per year) at facilities with annual throughputs greater than about 500 effective kg. At a nominal product enrichment of 4% U-235, this corresponds to about 300 tonnes uranium product or perhaps 1 300 tonnes/year separative work. Thus, larger facilities would qualify for continuous inspection, but pilot facilities, in a strict sense, would not. While INFCIRC/66/Rev.2 does not contain specific provisions for enrichment facilities, it does provide for access at all times at other specified nuclear facilities above a certain inventory or throughput. The Agency would expect to apply continuous inspection at any commercial enrichment facility.

Safeguards Approach to Centrifuge Facilities

The basic safeguards measures would be similar to those for other bulk facilities. The inspector would review design information, establish the initial inventory, audit the records, verify flow, verify the physical inventory and utilize containment and surveillance measures as necessary.

- Design information would be examined to establish that the planned safeguards strategy is feasible. In particular, miscellaneous pipes penetrating the cascade area from outside would be identified and the absence of secondary feed and take-off stations verified.

- In establishing the initial inventory, the inspector would verify that all UF_6 cylinders and other inventory items were listed and that none had been duplicated. He would take random samples of items to verify the stated quantity data. If there was a significant feed inventory of recycled uranium, the inspector would randomly sample cylinders containing such material. Thereafter, the inventory (including feed, product, and tails cylinders) would be verified periodically, taking into account the use of seals.

- The inspector should have routine access to all parts of the facility outside the special material balance areas including access to all boundaries on the special material balance areas in order to establish containment and surveillance. All entrances to the special material balance area would be sealed or monitored (with film cameras or TV cameras). Similarly, all flows of material through the process material balance areas (i.e. cylinders containing feed, product, tails) would be verified and sealed. Product and feed cylinders would first be quantitatively verified on a 100% basis and then sealed on the feed manifold. Tails cylinders would be weighed and sealed on the output manifold. Cylinders would be sampled in parallel with the operator's own sampling.

- The operator's measurement system must be evaluated, and the inspector must be able to verify independently the operator's materials accountancy data. The inspector must have routine access to all safeguards relevant data and input/output operations so as to be able to maintain continuity of knowledge.

- The inspector would pay careful attention to minor flow streams (in addition to the three main flows) such as wastes, system leaks, or the removal of equipment, since these may be used to conceal diversion.

- Minor isotope ratios and minor isotope material balances would be used as supplements to material accountancy, even though the sensitivity of these techniques remains to be determined.

- In establishing material balance areas and key measurement points, each cascade building (e.g. 600 separative work units per year) would be determined to be a separate material balance area. This would make it more difficult to conceal the rearranging of one of the modules in a cascade building to produce high-enriched uranium. Other material balance areas would be the input/output process areas, the UF_6 receipt, measurement and storage area, maintenance and waste storage areas, the UF_6 tails storage area and the UF_6 product storage and shipment area. If the facility had its own UF_6 conversion plant, this would be a separate material balance area.

FAST BREEDER (FBR) FUEL CYCLE FACILITIES

This section deals with several types of related facilities rather than one individual facility type. These facilities are those parts of the fast breeder fuel cycle which are currently under Agency safeguards. The IAEA's experience in applying safeguards in this area is very limited both in time and scope. Of the fast breeder reactor fuel cycles under development, the liquid metal fast breeder reactor (LMFBR) cycle has reached the most advanced stage, with development ranging from pilot and demonstration reactors to small support facilities. There are, as yet, no fully commercialized fast breeder reactors in operation. It is only the LMFBR fuel cycle with respect to which the Agency has any safeguarding experience. Those LMFBR fuel cycle facilities currently under Agency safeguards include a few small mixed-oxide fuel fabrication plants, a few fast breeder reactors and a small reprocessing plant designed to reprocess LMFBR spent fuel. Most of these facilities have only recently come under Agency safeguards. In the not-too-distant future, additional FBR cycle facilities are expected to come under Agency safeguards including several LMFBRs.

As larger, commercial size facilities, both within the LMFBR fuel cycle and within other FBR cycles, come on line in the future, the Agency will be faced with the same kind of problems which will be presented by large-scale reprocessing plants and the kind of measures described below will become less adequate. Not only will it become increasingly necessary that plants incorporate design features which facilitate the application of safeguards, but additional weight will probably have to be put on containment and surveillance versus material accountancy and perhaps even new concepts will be required.

The remainder of this section focusses on those types of LMFBR fuel cycle facilities which are currently under safeguards, and particularly the LMFBR itself.

General Features of FBR Fuel Cycle of Relevance to Safeguards

The major difference between the LWR and FBR fuel cycles from a safeguards standpoint is that in the FBR fuel cycle direct-use material is present from the fabrication stage in direct-use form and in amounts of many significant quantities. There is more plutonium in the FBR cycle and it is more concentrated. In addition, the plutonium produced in the blankets of fast breeder reactors is generally better-suited for nuclear explosives than that normally produced in LWRs. Furthermore, the uranium in the core may be enriched up to about 20% as well.

Safeguards procedures for fuel fabrication facilities of the type associated with the LMFBR fuel cycle are discussed under "Facilities which Process Plutonium, High-Enriched Uranium or Uranium-233" on page 22, and therefore, such procedures need not be addressed specifically in this section. With respect to reprocessing, the plutonium to uranium ratio of the material being processed in the LMFBR reprocessing plant is higher than at the plant processing LWR fuel. However, there is no major difference between the plants from a safeguards standpoint. Hence the procedures outlined under "Reprocessing Plants" on page 24 would generally apply to either type of plant.

As far as the reactor stage is concerned, there are significant differences between an average commercial size LWR and an LMFBR from a safeguards standpoint. Generally speaking, the safeguarding of an LMFBR power plant is much more complex than the safeguarding of an LWR power plant. LMFBRs may have multiple times the physical inventory of special nuclear material that LWRs normally have in terms of effective kg. Moreover, significant amounts of special nuclear material are contained in the LMFBR fuel assemblies at all stages in the reactor facility. Fresh fuel, as well as irradiated fuel and blanket assemblies, contain substantial quantities of plutonium. Plants currently existing and under Agency safeguards and those under construction have plutonium inventories ranging from about 200 to 500 kg of plutonium in core fuel assemblies, which are multi-pin type and are mixed oxide in composition — specifically, a mixture of about 10—20% plutonium and 80—90% uranium. The uranium in the core may be enriched, for example, to about 20% in the case of start-up cores for some breeders. Some of the plutonium may be in radial and axial blanket assemblies, which are initially made up of depleted uranium. Currently LMFBRs produce on an average up to 15% more fuel each year than they consume.

Another feature of LMFBR power plants is that gaining access to the irradiated and to part of fresh fuel assemblies containing special nuclear materials is generally much more difficult than for LWR power plants and in certain instances the fuel assemblies may be virtually inaccessible. These assemblies remain and are handled in a sodium or inert gas environment within closed and leak-tight handling equipment during most of the time they are at the plant. Assemblies are loaded into the core by machine and at no stage can the quantity of material in the core be verified. The storage of spent fuel varies somewhat among LMFBRs, but verification of assemblies at this stage is similarly difficult. In the case of one plant under safeguards the spent fuel is stored in a liquid sodium tank for several months and cannot be directly verified during that period. Later it is transferred to a hot cell where it can be verified. In another case the spent fuel is initially washed and then put in cans which are stored in pools. The assemblies cannot be directly identified while in the cans.

Refuelling of LMFBRs is generally similar to LWRs, with about one-half the core and one-third the blanket replaced each year.

Diversion Possibilities

LMFBR Fuel Fabrication Facilities

The diversion possibilities at an LMFBR fuel fabrication plant would be generally similar to those examples described under the heading "Conversion and Fuel Fabrication Facilities", pages 18–23, but the specific possibilities would depend on the material components of the fuel being fabricated. The input to the fuel fabrication plant would consist of uranium in the form of depleted or natural uranium dioxide and possibly enriched uranium (about 20% U-235) dioxide as well. It would also consist of pure plutonium dioxide either from the LMFBR reprocessing plant or an LWR reprocessing plant or stockpile. The uranium dioxide and plutonium dioxide are mixed at the fabrication plant and compressed into fuel pellets.

LMFBRs

Depending on the particular characteristics of the plant the most vulnerable point for diversion at an LMFBR would be the fresh-fuel storage area. However, if the plant has a facility for assembling the fuel pins into assemblies, this facility would present a more attractive diversion location because access to the fuel pins would be less complicated. One or more means of concealment could be utilized including substituting dummy pins, falsifying records, tampering with containment and surveillance devices, etc.

Diversion from the reactor itself and from the spent-fuel area is, in most cases far more difficult. While material quantity in the core and blanket assemblies in the reactor and spent fuel area are virtually impossible to verify directly from the standpoint of the safeguards inspectors, they are also less accessible to a would-be divertor, primarily because they are highly irradiated. Nevertheless, this possibility must be considered.

A last diversion possibility is clandestine irradiation of depleted or natural uranium in the blanket.

LMFBR Reprocessing Plants

In general, diversion opportunities at an LMFBR reprocessing plant would be similar to those at an LWR reprocessing plant (see Diversion Possibilities, page 25) heightened by the fact that the throughput of plutonium per metric ton of fuel input would be greater by a factor of approximately 10.

Detection Target

The aim of Agency safeguards at LMFBR fuel cycle facilities is to be able to detect, with 95% confidence, a protracted diversion of any or all types of nuclear material at a minimum rate of one significant quantity per year; or the abrupt diversion of more than a significant quantity of quickly convertible special fissionable material within a period of one to three weeks.

Safeguards Approach

LMFBR Fuel Fabrication Facilities

The Agency carries out continuous inspection at LMFBR fuel fabrication plants, employing the safeguards approach outlined on pages 22–33.

LMFBRs

Generally, the Agency inspection effort at LMFBRs involves about 50 man-days per year.

Many of the safeguards measures applied at LWRs are also applied at LMFBRs with the major differences arising from the large quantity of sensitive material at the latter and the consequent need for relatively short detection times. The accounting records are audited to ensure that they are formally correct and are checked to verify that the information contained in them is coherent and consistent with the information contained in the reports submitted to the IAEA. The operating records are audited in the same fashion as the accounting records and are used to establish the distribution of fuel assemblies within the facility.

LMFBRs, as in the case of other reactor types, normally consist of one material balance area. The material balance area may be divided for physical inventory purposes into several key measurement points including the fresh fuel storage, the core and the spent fuel storage area. An additional material balance area may be agreed upon in the event the reactor facility has its own facility for assembling fresh fuel pins or disassembling assemblies containing spent fuel. Key measurement points for determination of nuclear material flow include: receipt and de-exemption of nuclear material, accidental gain, nuclear loss and production in fuel discharged from the reactor, and shipment and exemption of nuclear material, accidental loss. Strategic points for application of containment and surveillance normally include the fresh fuel and blanket assembly storage and transfer routes to the core, the reactor hall, the spent fuel transfer routes, canning operation and storage area, and access routes to other locations of nuclear material at the facility. Normally, physical inventories are taken twice a year and verified by the Agency's inspectors. The operator prepares an itemized list by key measurement point in advance. Procedures used include item counting and identification and non-destructive analysis.

Generally, fresh fuel assemblies shipped to LMFBRs from the mixed-oxide fuel fabrication facility have been verified by using non-destructive assay techniques before shipment and seals have been applied to the shipping containers. Upon arrival at the reactor the seals on the shipping containers are checked by the inspector and the assemblies are verified by identification (from the serial numbers) and item counting as they are transferred from the shipping containers to containers in the fresh fuel storage area. (Each type of container is leak-tight and contains inert gas). Each individual fresh fuel and blanket assembly storage receptacle or container is sealed by the Agency inspector and the storage area is subject to optical surveillance. The mechanisms for the transfer of fuel to and from the core may also be sealed.

Whenever the integrity of containment becomes questionable in the judgement of the Agency's inspectors or in the case of malfunctioning of surveillance devices, verification by item counting and/or non-destructive analysis is likely to be considered necessary at all strategic points at the plant. Barring some such unexpected occurrence, the Agency normally checks the integrity of seals and any other surveillance and containment measures consistent with the detection time for the facility.

Once the fresh fuel (core blanket) assemblies are loaded under sodium by charging machines for transfer to temporary storage or for insertion into the reactor itself the verification procedure becomes very complicated. In fact, it is not possible to verify directly the inventory of the core of the reactor. Therefore, it is necessary for inspectors to be present during the initial loading of the core and blanket for verification of the initial inventory. The core itself is sealed after loading. Thereafter the presence of inspectors is called for during the subsequent loading and unloading of the core and blanket. Otherwise, normal optical surveillance (cameras) and seals are applied to the reactor core during operation. In addition to these measures, other surveillance measures such as a track etch monitor to monitor independently the reactor operation (i.e. power level) and bundle counters to monitor the movement of fuel assemblies into and out of the core may be used in the future. Such measures would help reduce the possibilities of undetected clandestine irradiation.

The safeguards applied to the spent fuel area are basically the same regardless of whether the assemblies containing spent fuel are washed first and then inserted into cans for storage or are transferred directly to sodium storage. There is heavy reliance on optical surveillance. The inspector is present when the spent fuel assemblies are to be shipped to outside facilities (e.g. for reprocessing). He observes the transfer of spent fuel containers to shipping casks, which are sealed after loading.

LMFBR Reprocessing Facilities

The Agency carries out continuous inspection at LMFBR reprocessing facilities, employing the basic approach outlined under "Safeguards Approach", pages 26–32.