Report of the LASCAR Forum: Large Scale Reprocessing Plant Safeguards

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Preface

This report has been prepared to provide information on the studies which were carried out from 1988 to 1992 under the auspices of the multinational forum known as LASCAR on safeguards for four large scale reprocessing plants operated or planned to be operated in the 1990s. The report summarizes all of the essential results of these studies.

The participants in LASCAR were from France, Germany, Japan, the United Kingdom, the United States of America, the Commission of the European Communities - Euratom, and the International Atomic Energy Agency.

As part of its contribution to LASCAR, the IAEA is pleased to publish this report, prepared by the LASCAR drafting committee and approved by the final plenary meeting.

Jon Jennekens

Deputy Director General
Head of the Department of Safeguards
International Atomic Energy Agency
Vienna

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Introduction and summary findings[1]

The International Atomic Energy Agency has successfully implemented safeguards at small and medium sized reprocessing plants since the 1970s. The new reprocessing plants envisaged for the 1990s have been designed to process spent fuel in quantities about four times larger than those of plants built in the 1970s, utilizing more advanced process technology.

In view of the importance of safeguards for such plants, development and testing of new safeguards techniques have been pursued intensively by operators and safeguards technology developers in France, Germany, Japan, the United Kingdom and the United States of America. They recognized that a mutual awareness and understanding of these new safeguards techniques would benefit all parties. In 1987, the Government of Japan offered the IAEA extrabudgetary funding to accelerate and broaden these activities, and this initiative led to the formation of the consultative forum for large scale reprocessing plant safeguards, referred to as LASCAR.

OBJECTIVES

The overall goal of LASCAR was to assist the IAEA through the provision of information and expert advice in the development of effective and efficient safeguards for the large reprocessing plants studied by LASCAR. Specific objectives included exchanging information on recent advances in reprocessing and safeguards technologies, reviewing a range of possible safeguards techniques and providing recommendations on the continued development and potential application of these techniques at new plants. Thus LASCAR concentrated on examining the applicability of safeguards techniques for possible use in these large plants, rather than defining specific safeguards approaches. LASCAR served as a technical forum and not as a forum for the negotiation of safeguards approaches or the resolution of safeguards policy issues.

[1] Information on reprocessing plant operations relevant to safeguards is given in the diagram at the end of the book.

PARTICIPATION

More than fifty experts from France, Germany, Japan, the UK and the USA participated in LASCAR. These included government officials and representatives from the large reprocessing plants, either operating or planned for operation by the end of this century, and experts actively engaged in developing safeguards techniques for such plants. Representatives of the Commission of the European Communities (CEC - Euratom) and the IAEA also participated in all LASCAR activities.

MODUS OPERANDI

LASCAR studies were conducted at two levels. During 1988-1992, representatives from participating countries and organizations met annually in plenary meetings held under the chairmanship of a host country. The plenary meetings provided guidance on the general direction of the work, and reviewed and approved the findings and conclusions of the various studies. The plenary meetings established four working groups. The working group meetings were held in the participating countries, with each group under a permanent chairman.

The scope of operations in a typical reprocessing plant was divided into four primary areas: spent fuel storage, head end operations, chemical processing and product storage. Each of these areas was the focus of study for a separate working group which examined nuclear material accountancy, containment and surveillance (C/S) and other verification measures which could be used in combination to meet the IAEA's safeguards requirements. The compatibility of the techniques with plant design features, operational characteristics and regulatory requirements was a major consideration. To assist the participants, the working groups studied the basic designs of four plants: COGEMA-UP3 in France, BNFL-THORP in the UK, JNFS-RRP in Japan and DWK-WAW in Germany.

In addition, generic safeguards concepts and techniques were examined, including design information verification, authentication of operator provided equipment, the use of redundant and independent C/S measures, and the acquisition and transmission of safeguards relevant data.

A drafting committee met twice in 1992 to prepare the LASCAR report for review at the final plenary meeting. This report is based on the findings of all working groups and summarizes all of the essential results of the LASCAR studies.

SUMMARY FINDINGS

The major technical findings of LASCAR indicate that a wide range of techniques, currently available or being introduced into practice, could be used to safeguard large reprocessing plants. These techniques include nuclear material accountancy and C/S techniques long employed in the nuclear industry, as well as techniques recently made available from research and development programmes. Procedures were identified for meeting timeliness requirements, for verifying plant design information, for authenticating equipment made available to inspectors by the operator, and for acquiring and transmitting safeguards related data. It was noted that early collaboration between the IAEA, the State and the facility operator would be essential for the design and successful implementation of safeguards at new reprocessing plants. It was concluded that appropriate combinations of these techniques selected to meet the specific requirements of each new plant studied will enable effective safeguards to be implemented.

Safeguards techniques for large reprocessing plants

SAFEGUARDS OBJECTIVES

Document INFCIRC/153[2] states that the objective of IAEA safeguards under the Treaty on the Non-Proliferation of Nuclear Weapons is "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other

[2] The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (Corrected), International Atomic Energy Agency, Vienna (1972).

nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection." By meeting this objective the IAEA provides assurance that nuclear material subject to safeguards remains in peaceful use.

Safeguards relevant information on plant design and operation and nuclear material accounting is an essential part of the technical basis for implementing safeguards. This information is provided to the IAEA by the plant operator through the responsible authorities and is then verified by IAEA inspectors according to agreed procedures. Other key factors in safeguards implementation are the experience gained in safeguarding small and medium sized reprocessing plants and other nuclear facilities, and the results of recent research and development programmes.

REPROCESSING PLANT SAFEGUARDS

Techniques for achieving the safeguards objectives were studied for their applicability in each of the four major areas of a reprocessing plant:

- Spent fuel storage,
- Head end operations,
- Chemical processing,
- Product storage.

A broad range of techniques were examined to investigate how they could be combined for effective and efficient safeguards.

Spent fuel storage area

Spent fuel storage areas are used for receiving the spent fuel assemblies (SFAs) shipped from power reactor sites, for storing the SFAs prior to reprocessing, and for transferring the SFAs to a mechanical cell for shearing into small pieces.

Although the detailed storage designs differ from plant to plant, some common features which are relevant and may be used for effective safeguards were recognized. Two methods of storing SFAs were reviewed. In one method, the SFAs remain in heavy, closed containers which are placed either in a water filled reinforced concrete structure, often referred to as a storage pond, or in a dry storage facility, until they are transferred to the head end area. The second method involves opening the transport containers shortly after receipt, unloading the SFAs and storing them in baskets or racks in a water filled storage pond.

The storage capacity at a reprocessing site is considerably larger than that at a reactor site and transfer operations are almost fully automated and are remotely supervised. Nuclear material accounting data are available continuously to the operator.

The safeguards measures applied in the spent fuel storage area are based on item accountancy and the use of redundant and independent C/S measures. The techniques applied in a specific reprocessing plant may differ somewhat from those at power reactor spent fuel storage facilities but they could include mechanical seals, electronic seals, underwater television cameras and non-destructive assay (NDA) equipment. These proven methods provide a sound technical basis for effectively safeguarding the spent fuel storage area while minimizing the inspection resource requirements.

Head end operations area

Within the head end operations area the SFAs are sheared into small pieces which are then transferred into a vessel containing nitric acid solution that dissolves the fuel, separating it from its metal cladding. After dissolution, the volume and/or weight of the dissolved solution is measured in a specially designed and calibrated accountancy tank. The solution is also sampled for chemical analysis to determine its nuclear material content. The head end area involves a transition from item accountancy to bulk material accountancy.

Two different dissolver designs were reviewed: a system in which the shearing and dissolution processes operate continuously during a reprocessing campaign; and a system in which these processes operate in a series of 'batches'.

The measurements of the contents of the dissolved fuel solutions, known as input measurements, are important for safeguards as they are the basis for auditing the results of the annual statement of account of the nuclear material processed in the area. Techniques for making volume and weight measurements of fuel solutions were extensively studied. The studies confirmed the availability of highly sophisticated designs of measurement devices and high precision sensors. The use of these techniques will enable the achievement of greatly improved measurement accuracy in comparison with systems presently in operation at small and medium sized reprocessing plants.

Attention was also given to other factors affecting input measurements and their verification, notably the influence of material sampling and analysis. The study found that the large reprocessing plants studied by LASCAR will all be equipped with state of the art systems for homogenization, sample withdrawal and sample transfer to an on-site analytical laboratory.

For safeguards verification purposes it is recommended that the IAEA maintain on the plant site a capability for independent measurement of the samples taken from the accountancy tank. Examination of the plans for such arrangements will include consideration of such matters as safety regulations, sample transportation, timeliness requirements and resource requirements.

Safeguards in the head end area also involve the determination and evaluation of the differences between the quantity of nuclear material in SFAs declared by the shipper and that measured in the accountancy tank. The difference in a continuous dissolver could be established when the head end area is cleaned out, as would be practical, for example, at the end of a process campaign. For this and other reasons, surveillance measures should be applied to the head end operations area to provide the inspector with continuity of knowledge about the movement of all nuclear material into and out of the area.

The quantity of nuclear material in waste transferred from the head end area is small. Effective techniques are available to characterize and measure the waste material before it is transferred out of the area.

It was concluded that the nuclear material accountancy and C/S measures currently available or being introduced can provide a high level of assurance of the correctness and completeness of the nuclear material measurements in the head end area.

Chemical processing area

The main function of the process area is the separation of plutonium, uranium and fission products contained in the nitric acid solution and the production of the final products, the most important of which are plutonium dioxide and mixed plutonium and uranium oxide (MOX). Products are loaded into cans,

which are tightly closed. One or more cans are then placed into a storage canister, which is closed by welding or bolting.

For material accountancy, the measurements conducted in the head end accountancy tank are also used as the input measurements for this area. The quantity of nuclear material in waste is measured before the waste leaves this area.

The output measurements are carried out by weighing and chemical analysis of samples taken from the product material before the product is loaded into cans. The output measurements for the process area are at the same time the input measurements for the storage area. In addition, the measurement and loading of oxide powders at the packaging station serve to define the identity of the cans and thus establish the basis for item accountancy in the product storage area. The loading of these oxide powders into the cans therefore constitutes a transition from bulk accountancy to item accountancy.

Recent technological developments were examined, in particular techniques for implementing safeguards without having to stop and empty the process system more frequently than the annual clean-out physical inventory taking. Two lines of enquiry were pursued to determine:

- The extent to which basic nuclear material accountancy methods and C/S methods could provide the necessary safeguards assurance over one year of operation;
- What safeguards methods and what conditions of plant design and operation could provide short term assurance against the diversion of plutonium, on a time-scale consistent with the IAEA's requirements.

Containment and surveillance measures, including inspector surveillance, can contribute to timeliness attainment. In addition, advanced material accountancy systems incorporating limits on the variation of in-process inventory have been developed and are presently in use.

Four advanced accountancy techniques were studied for timeliness attainment, each involving assessment of the plutonium inventory in the process areas on a relatively frequent basis (at least monthly) while the plant is operating. Two (running book inventory, cumulative flux method) are based on the principle that, in a plant operating under steady state conditions, the process will operate within a limited inventory range. The book inventory can be calculated from the beginning physical inventory and input and output measurements and, provided that it remains within predetermined limits, the plant may be assumed to be operating normally. The other two techniques (adjusted running book inventory, near real time accountancy) involve measurements of the major portion of the in-process inventory. The unmeasurable part of the inventory is reduced to the extent practicable such that errors in estimating it on the basis of verifiable operating data or from historical data do not contribute significantly to the overall uncertainty of the material balance analysis. They both use the same statistical tests and are expected to provide similar results.

The two book inventory techniques have already been used at a medium sized plant, and one of the measured inventory techniques (near real time accountancy) has been demonstrated at two small plants. All the necessary technical facilities to use these techniques are available. It was concluded that each of the four could be effective for timeliness attainment, with the choice strongly dependent upon plant design and the complementary measures to be taken for verification. The measured inventory techniques are more complex and intrusive, but are more sophisticated and are necessary in large reprocessing plants where the inventory is large and variable.

It was concluded that the techniques currently available and embodied in the new plant designs are capable of achieving the necessary high level of safeguards assurance.

Product storage area

Although the detailed storage designs differ from plant to plant, some common features were recognized which are relevant and may be used for effective safeguards.

The containment features of the plutonium oxide and MOX storage facilities resulting from the reinforced concrete construction (which must meet physical protection and radiation safety requirements) and the limited number of openings for access provide an excellent basis for the application of C/S measures. These measures include seals, closed circuit television (CCTV) cameras, door opening detectors, radiation sensors and systems integrating different types of devices. Within the structure, the product canisters are placed in storage compartments. Movement of the canisters is performed by computer controlled, CCTV monitored and remotely operated equipment.

All transfers of product canisters into and out of the storage area are subject to item counting, item identification and, as appropriate, NDA testing.

Systems combining C/S and NDA components could permit unattended verification of the item transfers and thereby provide more efficient safeguards while being less intrusive. Application of C/S systems with high reliability and assurance could allow continuity of knowledge to be maintained of the nuclear material in storage and thereby reduce substantially the need for reverification of the inventory by item accountancy methods.

Generic safeguards concepts and techniques

LASCAR working groups identified four generic subjects to be addressed in the optimization of the independent verification by the IAEA of the data declared by operators: design information verification; the authentication of plant instruments and systems made available by the operator for use by the IAEA; the use of C/S measures; and the acquisition and transmission of safeguards relevant data.

DESIGN INFORMATION VERIFICATION

Design information provided to the IAEA by the operator through the State authority includes information concerning nuclear material subject to safeguards and the features of facilities relevant to safeguards. Such information is used, inter alia, for preparing the safeguards measures to be applied at a particular facility.

It was concluded that the early presentation of design information to the IAEA will allow for early consultations on safeguards measures between the operator/State and the IAEA which can benefit all parties. Additional benefit will accrue from continuing these consultations throughout construction and commissioning. Such early consultations would be pursued in accordance with existing safeguards agreements on a co-operative basis between Member States and the IAEA.

Most of the equipment in large reprocessing plants will be enclosed in heavy radiation shielding and will become inaccessible some time before plant operation commences. Verification of design information will have to be planned and co-ordinated to be compatible with the operator's schedule.

Safeguards relevant plant design features which should receive particular attention before nuclear material is introduced into the plant include the dimensions of major process tanks, the design of key measurement systems, key pipework, instrument signal sensors and the routing of associated wiring and piping.

AUTHENTICATION OF OPERATOR'S INSTRUMENTS

Authentication of instruments and equipment that have been made available by the operator is needed to ensure the validity of the data for IAEA safeguards purposes.

It was recognized that the installation of completely dedicated safeguards measurement and surveillance systems for use by the IAEA is preferable and even likely in the spent fuel storage and product storage areas, but would not be generally practicable in other areas. Therefore, the use of some operator's instruments by the IAEA may be desirable and, in some cases, unavoidable.

A set of guidelines was proposed to assist the IAEA in devising methods and procedures for authenticating operator's instruments necessary for maintaining an independent verification capability. The simplest way for the IAEA to make use of such equipment after verifying the location and integrity of measurement sensors would be to take the raw (original) signal from the sensors and transmit it through tamper resistant lines to IAEA recording equipment.

USE OF CONTAINMENT AND SURVEILLANCE MEASURES

LASCAR participants recognized the importance of C/S measures in the application of safeguards to both item accountancy storage areas and the bulk material processing areas at large reprocessing plants. It was concluded that C/S systems capable of providing the necessary reliability and assurance can improve the efficiency of safeguards, particularly in relation to storage areas, by substantially reducing the need for reverification of the inventory by item accountancy methods.

The required reliability and assurance could be provided by combinations of redundant and independent techniques, for example devices based on different physical principles, such as CCTV cameras, radiation sensors and motion detectors. These techniques have been applied in existing nuclear facilities.

Systems combining C/S and NDA components could permit unattended verification, including item counting, identification and, where applicable, NDA testing, of items transferred into and out of a storage area. Such systems would provide more efficient safeguards while being less intrusive in plant operations.

The participants noted that surveillance by the inspector, when present at the site during plant operation, could provide still higher safeguards assurance resulting from comprehensive observation of the plant, experience and judgement.

DATA ACQUISITION AND TRANSMISSION

In modern plants, almost all accountancy measurement data and surveillance data are processed by computers; thus verification of the data is essential. Two possible ways of verifying the data were identified.

Where it would be acceptable to both the operator and the IAEA, the data processing software could be made available for examination by the inspectorate. Thereafter, at the necessary intervals, the software could be verified by source code comparison routines.

It could also be possible to give the inspector access to data used by the operator, or to data obtained directly from local instrumentation, for comparison with computer supplied data; in this case the local instruments could be made available for random access, or the data could be recorded.

Safeguards research and development

All relevant research and development programme tasks carried out in LASCAR participating countries were examined, focusing on measurement and verification methods for bulk material and on C/S measures. Careful attention was given to the results of safeguards research and development already integrated into large reprocessing plant designs.

The safeguards techniques identified by the working groups have an excellent technical foundation through safeguards experience gained at small and medium sized reprocessing plants and at a large number of related facilities.

It was concluded that the present strong technical basis for safeguarding large reprocessing plants could be further reinforced by additional research and development activities and thus further optimize IAEA safeguards. These research and development activities involve measurement accuracy, C/S systems, design information verification, authentication of operator provided equipment, data processing and analysis, and studies of operational experience in reprocessing plants.

Findings and conclusion

The major technical findings and the conclusion of LASCAR can be summarized as follows.

MAJOR TECHNICAL FINDINGS

Consultations between the IAEA, the State and the facility operator

The State, the operator and the IAEA would benefit from early consultations on facility characteristics relevant to safeguards and on a plan for design information verification. A continuation of these consultations throughout the construction and commissioning of a large reprocessing plant would also be beneficial. Among the advantages would be the implementation of a more efficient and less intrusive safeguards approach. The subjects for these consultations include: design information, advanced nuclear material accountancy methods, on-site IAEA sample verification, authentication of equipment and systems made available by the operator, and C/S systems.

Measurement accuracy

Highly accurate measurements of the nuclear material throughput and inventory of a reprocessing plant are essential for operator compliance with national accountancy and regulatory requirements and for the achievement of effective safeguards. Measurement accuracy should continue to be the highest practicable. Nuclear materials have a number of unique characteristics, including radiation emission and distinctive chemical properties. Measurement systems have been developed which use these characteristics, thus substantially improving the accuracy of plutonium material balances.

Timeliness of verification

The completion of specified IAEA safeguards verification activities within prescribed time intervals is an important safeguards requirement. Advanced nuclear material accountancy techniques, such as near real time accountancy, in combination with C/S measures, enable the attainment of these timeliness requirements.

Containment and surveillance measures

The use of C/S systems, incorporating redundant and independent features for verifying SFAs and product material stored at large reprocessing plants, could further optimize safeguards by reducing demands on IAEA resources while maintaining the necessary high level of assurance.

On-site verification capability

In view of the administrative and technical complications associated with shipping nuclear material samples to an off-site laboratory, it is recommended that the IAEA maintain an on-site sample verification capability and hold discussions with the operator and the State concerning the provision of appropriate practical arrangements.

Authentication of equipment made available by operators

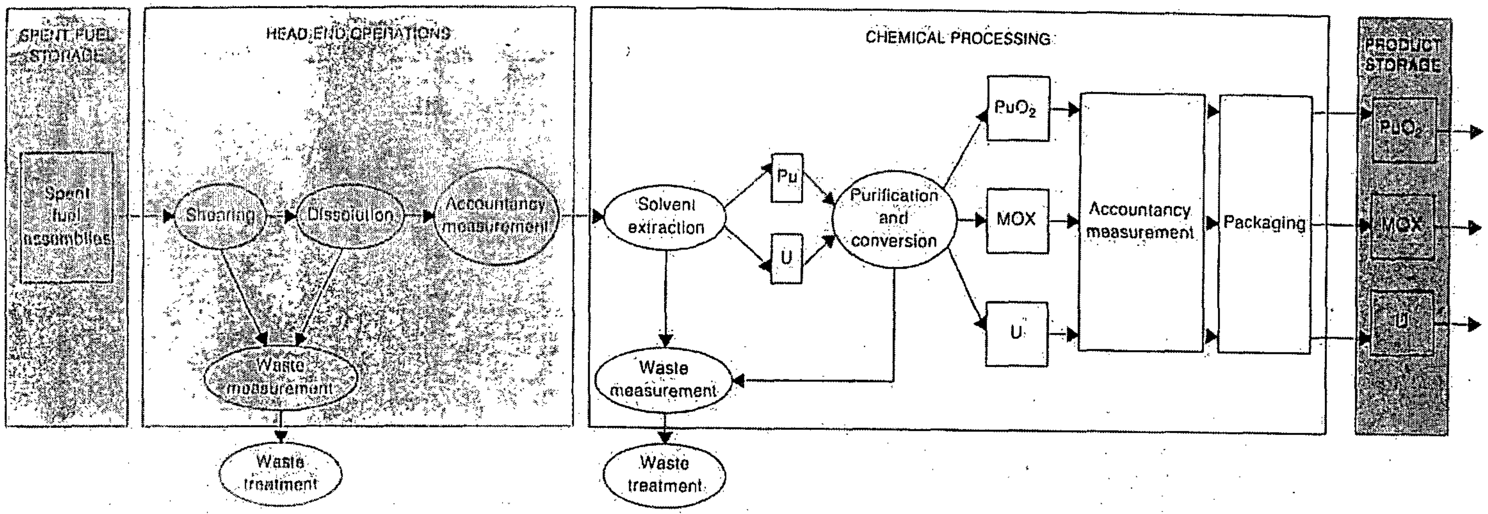
The installation of completely independent safeguards measurement or surveillance systems for use by the IAEA would not be practicable for certain segments of a large reprocessing plant. For safeguards purposes, it would be necessary for the IAEA to authenticate information obtained from operator provided equipment. A set of guidelines was drawn up which the IAEA could use to develop such authentication methods.

Research and development

The present technical basis for providing the necessary high assurance for safeguarding large reprocessing plants is both comprehensive and practicable. Research and development programmes are under way which will further optimize the implementation of IAEA safeguards.

GENERAL CONCLUSION

A wide range of techniques are currently available or being introduced for safeguarding large scale reprocessing plants. These include design information verification, advanced material accountancy for meeting timeliness requirements, independent and redundant C/S measures, the authentication of operator provided equipment, and computer data acquisition and transmission. LASCAR participants concluded that appropriate combinations of these techniques selected on a plant specific basis will enable the successful implementation of effective safeguards at the large reprocessing plants whose designs were considered by LASCAR.



Reprocessing plant operations

A nuclear fuel reprocessing plant utilizes specialized technology for recovering plutonium and uranium from spent fuel discharged from nuclear power reactors for reuse in the nuclear fuel cycle. Typically a reprocessing plant includes four main operational areas.

Spent fuel storage area: The spent fuel assemblies transported from nuclear power reactor sites in heavily shielded containers are received and stored, awaiting transfer to the head end operations area. All transfers of the assemblies are conducted by computer controlled and remotely operated equipment.

Head end operations area: The spent fuel assemblies are mechanically sheared into small pieces and are then transferred to a vessel where nitric acid dissolves the fuel, separating it from its metal cladding. Waste is collected and measured for its nuclear material content before leaving this area for treatment. The dissolved solution accumulates as batches in a specially designed accountancy tank where the volume and/or weight of the solution is measured and from which representative samples are taken for chemical analysis to determine the nuclear material content of the solution.

Chemical processing area: The fuel solution is chemically processed through solvent extraction cycles that first separate the highly radioactive fission products from the uranium and plutonium and then separate the uranium and plutonium from each other. The uranium and plutonium are purified and converted into final products, the most important of which are plutonium dioxide and mixed plutonium and uranium oxide. The products are measured and sampled to determine their weight and nuclear material content at the point of loading into cans. After closure, one or more cans are placed into a storage canister which is then welded or bolted closed, awaiting transfer to storage. The quantity of nuclear material in waste is measured before the waste leaves this area.

Product storage area: The product canisters are stored in facilities which have a limited number of openings for access. The facility structure provides a high level of containment by virtue of its reinforced concrete design, which must meet stringent physical protection and radiation safety requirements. All movement of the product canisters is conducted by computer controlled and remotely operated equipment.

Safeguards techniques

Safeguards are the technical measures implemented by the IAEA to provide assurance that nuclear material subject to safeguards remains in peaceful use. What follows is an outline of safeguards techniques applied in the four main operational areas of a typical reprocessing plant.

Spent fuel storage area: The IAEA uses item accountancy to verify the declared inventory of spent fuel assemblies and the changes in that inventory. Containment and surveillance techniques and non-destructive assay tests serve to ensure the correctness and completeness of the information collected by the IAEA about the assemblies.

Head end operations area: This area is a transition zone where the spent fuel assemblies lose their item identity and become bulk material. Item accountancy and containment and surveillance techniques are used to verify all transfers of the assemblies prior to their being sheared into small pieces. Following the dissolution of the nuclear material in acid, bulk material accountancy serves to verify the declared inventory of dissolved material and the input accountancy measurements. Containment and surveillance techniques serve to verify that all nuclear material introduced into the area has been measured either at the input accountancy tank or as waste at the point of transfer outside the area.

Chemical processing area: The IAEA uses bulk material accountancy to verify all transfers of nuclear material, including those of waste, into and out of this area and the declared physical inventory of material determined annually during plant shutdown and clean-out. Advanced nuclear material accountancy is used during plant operation for frequent verification of the plutonium inventory in this area.

Product storage area: The IAEA uses item accountancy to verify the declared inventory of plutonium and uranium product and the changes in that inventory. Containment and surveillance techniques and non-destructive assay tests are used to verify the correctness and completeness of item accountancy data and to confirm the continuing validity of information about the nuclear material stored in the area.