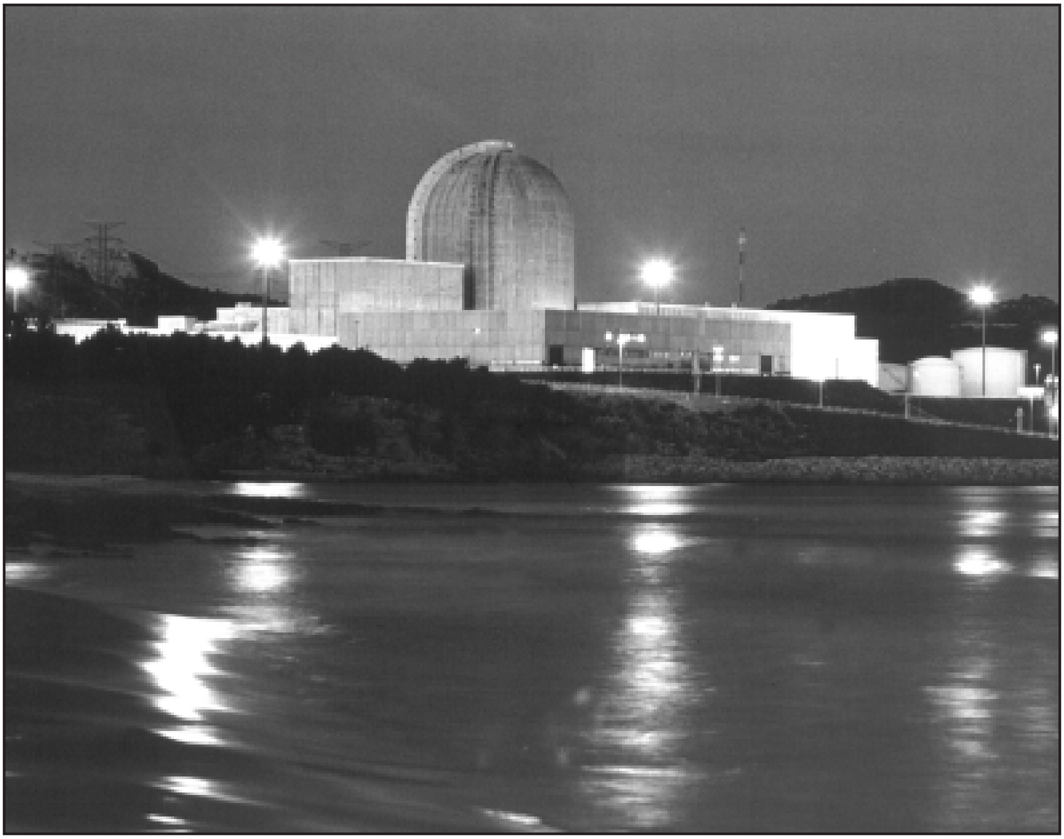

TECHNICAL REPORTS SERIES No. **392**

Design Measures to Facilitate Implementation of Safeguards at Future Water Cooled Nuclear Power Plants

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1998

DESIGN MEASURES TO FACILITATE IMPLEMENTATION OF SAFEGUARDS AT FUTURE WATER COOLED NUCLEAR POWER PLANTS

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

Printed by the IAEA in Austria
January 1999
STI/DOC/010/392

TECHNICAL REPORTS SERIES No. 392

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VIC Library Cataloguing in Publication Data

Design measures to facilitate implementation of safeguards at future water cooled nuclear power plants. — Vienna : International Atomic Energy Energy, 1998.
p. ; 24 cm. — (Technical reports series, ISSN 0074–1914; no. 392)
STI/DOC/010/392
ISBN 92–0–104798–3
Includes bibliographical references.

1. Water cooled reactors—Design and construction. 2. Water cooled reactors—Security measures. I. International Atomic Energy Agency. II. Series: Technical reports series (International Atomic Energy Agency); 392.

VICL 98–00212

FOREWORD

This report is intended to present guidelines to the designers of future water cooled power reactors which, if taken into account in the design of these plants, will minimize the impact of IAEA safeguards on plant operations and ensure efficient and effective acquisition of safeguards data to the mutual benefit of the Member State, the plant operator and the IAEA. These guidelines incorporate the IAEA's experience in establishing and carrying out safeguards at currently operating nuclear power plants, the ongoing development of safeguards techniques and the feedback of experience from plant operators and designers on the impact of IAEA safeguards on plant operation.

The technical officers responsible for the preparation of this report were J. Cleveland, of the Department of Nuclear Energy, and R. Fagerholm, of the Department of Safeguards.

CONTENTS

1. INTRODUCTION

1.1. OBJECTIVE

The technical objective of safeguards is the timely detection of the diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by risk of early detection. This report provides State authorities, designers and prospective purchasers of future water cooled nuclear power plants with an outline of the IAEA's safeguards system and with design guidelines for future nuclear power plants to facilitate the implementation and application of these safeguards. While the guidelines identified in this report are in no sense requirements, it is hoped that they will permit the most cost effective and acceptable safeguards systems to be applied to future plants to the mutual advantage of the State, the operator and the IAEA. The discussion in this report is limited to water cooled reactors, as these types comprise by far the majority of current and foreseeable nuclear power plants.

A main focus of current efforts in water cooled reactor design and development is on units with power outputs up to 1500 MW(e), typically aiming at achieving improvements over existing designs. In this approach, the alterations and modifications to a specific design are generally kept to a minimum to take maximum advantage of successful proven design features and components, while also taking into account feedback of experience from the licensing, construction, commissioning and operation of the water cooled reactors currently in operation. Water cooled reactors in the 600–1000 MW(e) range are also being developed in a number of countries, in most cases with great emphasis on the utilization of passive safety systems. Nuclear fuel continues to be improved, with the advances being incorporated in the supply of fuel for reloading existing reactors. The reactor and fuel design improvements have the objectives of increased reliability, better economics, more user friendly systems and a very high degree of safety.

The designs of all nuclear facilities are subject to many economic, technical, legal, security, safety, environmental and other constraints, and it is the function of the design team to find solutions which are optimal within these constraints. Safeguards implementation is an additional factor which should be taken into account, preferably during the design stage. This report has been prepared with the aim of contributing to the incorporation of safeguards relevant features in the design of future plants in order to:

- Minimize the burden on plant operations;
- Promote better understanding of safeguards operations and needs by reactor designers;

- Ensure the effectiveness of the safeguards regime and promote advances in the quality, methods of acquisition and integrity of safeguards data;
- Minimize the cost of safeguards, including the burden on IAEA inspection resources;
- Improve, for both operators and inspectors, the conditions under which inspections are carried out;
- Take advantage of advances in safeguards technologies.

Historically, IAEA safeguards at nuclear power plants have been applied mainly to existing or already designed plants; the safeguards techniques and methods used have been adapted to take this into account. Both nuclear power plants and safeguards techniques continue to be developed and these should lead to a streamlining of the methods by which safeguards are applied to future plants currently being designed. Specific developments affecting the application of safeguards to future nuclear power plants include:

- Freezing, prelicensing and certification of standardized designs of new nuclear power plants long before any commitment to build has taken place;
- More widespread use of the reconstitution of fuel assemblies in the majority of LWR plants;
- Use of mixed oxide (MOX) fuel in some reactors;
- Use of remote interrogation of installed safeguards equipment, leading to more efficient safeguards coupled with fewer on-site inspections.

1.2. SCOPE

This report covers the features of water cooled nuclear power plants relevant to safeguards and includes activities which take place at the plant from the receipt of fresh fuel to the shipment of irradiated fuel from the spent fuel pool for reprocessing or storage either on-site or elsewhere. Previous studies of the design features of nuclear power plants which would facilitate safeguards are presented in Refs [1, 2].

1.3. STRUCTURE

The IAEA safeguards system is presented in the first part of this report. The functions of the IAEA safeguards system are described in Section 2, its political and legal foundations are described in Section 3, and the technical objectives of safeguards at nuclear power plants and the IAEA's procedures for obtaining and reviewing design information for new plants are described in Section 4. The approaches used in the application of safeguards are covered in Section 5, the implications of the IAEA's experience in safeguarding nuclear power plants for the design of new plants are discussed in Section 6, and the safeguards guidelines for new designs are detailed in Section 7.

2. THE IAEA'S SAFEGUARDS FUNCTION FOR CURRENT AND FUTURE NUCLEAR POWER PLANTS

It is generally accepted that international confidence is increased if States commit themselves to not having and not planning to develop a nuclear explosive capability. The verification by the IAEA that all nuclear activities in a State are being undertaken exclusively for peaceful purposes is an important component of what has been termed the 'non-proliferation regime', i.e. the various treaties and other arrangements that have been concluded to prevent or impede the spread of nuclear weapons. The verification activities carried out by the IAEA in connection with these treaties and arrangements are generally known as 'IAEA safeguards', or just 'safeguards'.

This report concentrates on design features relevant to the implementation of IAEA safeguards under comprehensive safeguards agreements between States and the IAEA as required by the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). The same design features may be relevant to the application of IAEA safeguards under other types of safeguards agreements. Unlike national regulations on facility design required for health, safety and physical security reasons, the IAEA has no direct authority to insist on the incorporation of specific design features in any facility. The design guidelines in this document are for guidance only, and are in no sense requirements for the implementation of safeguards at facilities. Alternative design solutions that also meet the basic safeguards requirements should be acceptable, i.e. the design guidelines may present one acceptable approach but other approaches may also be acceptable. It is believed that the inclusion of design features in accordance with the guidelines will promote a cost effective safeguards system which will be in the best interests of the State, the designer/vendor, the facility owner/operator and the IAEA.

Safeguards agreements between States and the IAEA contain provisions for the supply to the IAEA of design information, i.e. information on the design and operation of the facility, which the IAEA needs to enable it to apply effective safeguards to the facility in question. Information on the features of the design of new plants relevant to safeguards has in the past been provided to the IAEA, on an iterative basis, during the planning and construction phases of new facilities in order to create confidence in the peaceful purpose of the facility and to provide adequate lead time for the necessary discussions between the State and the IAEA on the specific safeguards measures to be applied to the new plant. A description of the information required and the timing of its submission to the IAEA is given in Section 4 and Appendix I.

The protection of nuclear materials and facilities against forcible seizure, theft, terrorism and other criminal activities is the responsibility of the State, not of the IAEA. While in some countries ‘safeguards’ are taken to include physical protection measures, the objective of international safeguards is, as mentioned earlier, the timely detection of the diversion (i.e. use for purposes proscribed by the relevant safeguards agreement) of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection. The measures required by the State for the physical protection of nuclear material and the measures required for the application of international safeguards are not necessarily the same. The objectives and the criteria applied are different. In general, the safeguards system is concerned with the removal of larger quantities of material and longer time-scales than the State’s system of physical protection. A State’s physical protection system may have to be designed to detect unlawful action within hours or even minutes, and to recover quite small quantities of material whenever possible (a goal which is greatly facilitated by almost immediate detection). The IAEA’s recommendations for physical protection measures to be taken by States are given in an Information Circular [3].

3. SUMMARY OF THE POLITICAL AND LEGAL FOUNDATIONS OF THE IAEA’S SAFEGUARDS SYSTEM

3.1. INTERNATIONAL AGREEMENTS ESTABLISHING SAFEGUARDS

The IAEA was established in 1957 as an independent intergovernmental organization in the United Nations family. The aim of the IAEA, as set out in Article II of its Statute, is to “seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world”. Article III.A.5 of the Statute authorizes the IAEA

> “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".

The first section of Article III.A.5 refers to the original concept of the IAEA as a major supplier of nuclear material and equipment. However, IAEA safeguards are based largely on the second part of that article. Safeguards are, broadly speaking, activities by which the IAEA seeks to verify that a State is not using nuclear material or equipment to develop or produce nuclear weapons.

The successful conclusion in 1968 of negotiations on a treaty designed to prevent the further spread of nuclear weapons — the NPT — was a landmark in the history of non-proliferation. The Treaty entered into force in March 1970 for an initial period of 25 years, and over 170 States are now party to it. These include the five declared nuclear weapon states (China, France, the Russian Federation, the United Kingdom and the United States of America). In 1995, it was agreed by the signatories of the NPT to extend it indefinitely.

Each non-nuclear-weapon State that becomes party to the NPT agrees not to acquire nuclear weapons or other nuclear explosive devices (Article II). It also agrees to conclude a comprehensive safeguards agreement with the IAEA for the application of safeguards to all its peaceful nuclear activities, present or future, with a view to verifying the fulfilment of its obligations under Article III of the Treaty. In return, the Treaty recognizes (in Article IV) the right of all parties to participate in the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy. The parties to the Treaty also undertake to pursue negotiations in good faith towards nuclear disarmament (Article VI) and reaffirm their determination to achieve the discontinuance of all tests of nuclear weapons (Preamble).

In addition to the NPT, two regional treaties which have the objective of preventing the spread of nuclear weapons have been concluded. The Treaty for the Prohibition of Nuclear Weapons in Latin America (the Tlatelolco Treaty), concluded before the NPT, is now in force for many countries in that region. This treaty requires its parties to conclude comprehensive safeguards agreements with the IAEA. The South Pacific Nuclear Free Zone Treaty (the Rarotonga Treaty) also requires each State party to it to conclude with the IAEA a comprehensive safeguards agreement equivalent in its scope and effect to agreements required under the NPT.

3.2. SAFEGUARDS AGREEMENTS BETWEEN THE IAEA AND STATES

To implement the safeguards requirements of the NPT, the IAEA has devised a comprehensive model safeguards agreement suitable for application to the complex nuclear fuel cycles of the advanced industrial countries that have joined the treaty, i.e. a safeguards agreement applicable to reactors and to the conversion, enrichment, fabrication and reprocessing plants which supply and process the reactor fuel. This model safeguards agreement is set out in IAEA INFCIRC/153(Corrected) [4]. States which have signed the NPT, or one of the two regional treaties, are required to sign a safeguards agreement with the IAEA based on this document. The NPT, the Tlatelolco Treaty and the Rarotonga Treaty require that all of the nuclear material in a signatory State be declared and submitted to safeguards. The treaties also require that any nuclear material which the State subsequently acquires should also be declared and safeguarded.

The general principles of the implementation of safeguards in a State which has signed a comprehensive safeguards agreement are specified in the Subsidiary Arrangements and associated Facility Attachments. *Subsidiary Arrangements* are a codified set of technical and administrative procedures designed primarily to implement the safeguards procedures laid down in safeguards agreements. They deal with matters such as design review, records and reporting requirements, and inspections. They consist of a *General* part applicable to all nuclear activities of the country concerned and *Facility Attachments*, which contain specific procedures for each facility.

A *Facility Attachment* contains, among other things:

- A short description of the facility,
- A provision to submit to the IAEA any changes in the information on the facility,
- The accountancy measures to be used at the facility,
- Provisions for containment[1] and surveillance measures;
- Specific provisions and criteria for the termination of and exemption from safeguards of nuclear material,
- A detailed description of the records and reports system,
- A description of the mode and the scope of IAEA routine inspections,
- Provisions for administrative and financial procedures concerning the application of safeguards at the facility.

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[1] Containment, as used in safeguards, has a meaning different from its normal use by reactor designers. The special safeguards usage is explained in Section 5.2 and given in the Glossary at the end of this report. Whenever the word ‘containment’ is used by itself (or with modifiers, such as in ‘reactor vessel containment’) in this report, the special safeguards meaning is intended; whenever the term ‘reactor containment’ is used, the system of buildings, structures and isolation devices provided to protect the surroundings of the reactor in the event of an accidental release of radioactive material is intended.

The legal basis for safeguards, which are applied to specific material and equipment only and not to the entirety of a State's nuclear activity, is described in INFCIRC/66/Rev.2 [5]. Many of the States which concluded this type of safeguards agreement with the IAEA did so because the States supplying nuclear material or equipment to them would only do so if IAEA safeguards were applied to that material or equipment in the recipient State.

The principal result of the independent verification of a State's nuclear activities by the IAEA safeguards inspectorate is to assure the international community that no diversion of the nuclear material or equipment subject to safeguards has taken place. IAEA verification is also intended to have the effect of deterring diversions or undeclared activities by the risk of early detection. The assurance obtained from the IAEA as an effective and objective auditor increases confidence among States and helps to allay concerns which could provide the political motivation for the acquisition of nuclear weapons.

4. THE TECHNICAL OBJECTIVE OF SAFEGUARDS AND THE SUPPLY AND USE OF REQUIRED DESIGN INFORMATION

4.1. THE TECHNICAL OBJECTIVE OF SAFEGUARDS

In comprehensive safeguards agreements concluded under the NPT or other treaties, the objective of safeguards is defined as "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown and deterrence of such diversion by risk of early detection" (Article 28 of INFCIRC/153 [4]). In safeguards agreements concluded under the non-NPT system (INFCIRC/66/Rev.2 [5]), there is no specific definition of the objective, but in practice essentially the same objective is sought as for comprehensive safeguards agreements.

The definition of the objective of safeguards given in Article 28 of INFCIRC/153 [4] contains two expressions requiring quantification: 'significant quantities' of nuclear material and 'timely detection' of diversion. For international safeguards the significant quantity is the approximate quantity of nuclear material which could be used to manufacture a nuclear explosive device. Significant quantity values currently in use are 8 kg of plutonium or ^{233}U, or 25 kg of ^{235}U contained in high enriched uranium (HEU), these being direct use materials. Similarly, in the context of international safeguards, timely detection can be related to the time required to convert diverted material into the components of a nuclear explosive device, i.e. the conversion time. The conversion time is of the order of weeks or months, depending on the nature of the material concerned. These parameters are provisional and subject to periodic review by a group of designated experts comprising the Standing Advisory Group on Safeguards Implementation (SAGSI).

From a consideration of the objective and the concepts of significant quantity and timely detection, the IAEA has derived the detection goals which are used in establishing the safeguards approaches used at various types of nuclear facilities, and in establishing the goals to be achieved at individual inspections. For nuclear power plants the objective is to detect, with a specified probability, the diversion of:

- 75 kg of contained ^{235}U, in uranium enriched to less than 20% ^{235}U, in natural uranium or in depleted uranium. Uranium enriched to less than 20% is termed low enriched uranium, or LEU. A diversion is to be detected within 12 months of its taking place. (LEU, depleted and natural uranium cannot be used directly to make a nuclear explosive; they must be transformed into HEU or plutonium.)
- 25 kg of contained ^{235}U, in uranium enriched to 20% ^{235}U or more. Uranium enriched to 20% or more is termed HEU. A diversion is to be detected within one month of its taking place.
- 8 kg of plutonium (all isotopes) in fresh fuel. A diversion is to be detected within one month of its taking place.
- 8 kg of plutonium (all isotopes) in spent (irradiated) fuel. A diversion is to be detected within three months of its taking place.
- 8 kg of ^{233}U in fresh fuel. A diversion is to be detected within one month of its taking place.
- 8 kg of ^{233}U in irradiated fuel. A diversion is to be detected within three months of its taking place.

In addition, the unrecorded production of 8 kg or more of plutonium or ^{233}U per year is to be detected.

Sampling plans are used at most safeguards inspections at power plants. The detection probability used varies, and is dependent on the type of material and the circumstances under which it has been stored or used since the last inspection. For example, at the annual inventory fresh LEU fuel is verified to the extent necessary to have a 50% probability of detecting the removal of all nuclear material from one assembly.

The basis of the IAEA's verification system, as laid down in paragraph 29 of INFCIRC/153 [4], is a system of material accountancy complemented by containment and surveillance (C/S) measures to monitor access to, or movements of, the nuclear material. The purpose of the nuclear material accountancy system is to establish the quantities and locations of the nuclear material present in a nuclear facility and the changes that take place in these quantities and locations. The essential elements of such an accounting system and the associated inspection procedure are that:

- The operator identifies, counts or measures the nuclear material in the facility and maintains inventory records;
- The operator keeps a record of all use and production of nuclear material, and of transfers into and out of the facility, i.e. of all the inventory changes.
- The operator prepares reports on the inventory and its changes and submits these reports to the IAEA through the State's Systems of Accounting and Control (SSAC);
- IAEA inspectors visit the facility to verify the inventories and inventory changes, to determine the validity of the operator's accounting system and the correctness of the reports made to the IAEA. Verification of the inventories and inventory changes includes on the spot identification or measurement of the material. The inspectors also review the information from surveillance equipment installed at the facility to determine if the surveillance results are consistent with the operator's records.

4.2. DESIGN INFORMATION[2]

Much of the information required by the IAEA to enable it to plan the safeguards approach is included in the design information for the facility. This information has to be provided to the IAEA by the State after the safeguards agreement between the State and the IAEA has been concluded. For facilities which are in existence at the time the State signs the safeguards agreement with the IAEA, the required information is obtained by the State providing a completed copy of the IAEA's 'Design Information Questionnaire' (DIQ), an example of which is shown in Appendix I.

For new facilities a rolling programme of the provision of design information has been adopted by the IAEA's Board of Governors. The information provided by this programme creates confidence in the peaceful purpose of the facility, and is intended to provide an adequate lead time to:

- Ease the incorporation into the facility design — including the design of the nuclear materials accountancy system — of features which make it easier to

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[2] This section is based on the process currently employed by the IAEA to use design information to establish safeguards.

implement safeguards at the facility (any proposed design modifications being consistent with the prudent management practices required for the economic and safe operation of the facility and to avoid hampering or delaying construction, commissioning or operation);

- Allow time for any safeguards research and development work that may be necessary;
- Enable the IAEA to carry out the budgetary planning necessary for the effective and efficient implementation of safeguards;
- Permit the identification and scheduling of actions which need to be taken jointly by the State, the facility operator and the IAEA, including:

  (1) installation of safeguards equipment during construction of the facility,
  (2) verification of information on the design of the facility.

The Subsidiary Arrangements of comprehensive safeguards agreements provide that States make available, on an iterative basis, information on the safeguards relevant features of facility designs early in the planning and construction phases of new facilities (including imported facilities) and modifications to existing facilities. These phases are: project definition, preliminary design, construction and commissioning.

The information required during the project definition phase consists of the identification of the facility and a short description of its general character, purpose, nominal capacity and geographical location. Information on the form, location and movement of nuclear material and on the general layout of important items of equipment which use, produce or process nuclear material should also be provided. During the subsequent preliminary design phase, discussions with the IAEA on the safeguards approach to be used at the facility will have generally taken place, and appropriate information on the design provided as the design develops. It is during the preliminary design phase that alterations can most easily be made to the design so as to make it more safeguards friendly and/or permit the incorporation of the equipment or instrumentation required for safeguards purposes. A completed DIQ based on the preliminary construction plan is required as early as possible, and in any event not later than 180 days prior to the start of construction. A completed DIQ based on the 'as-built' design is also required as early as possible, and in any event not later than 180 days before the first receipt of nuclear material at the facility. The IAEA will verify design information through the physical examination of new or modified facilities during construction, commissioning, operation and subsequent phases.

It should be emphasized that the procedures described above have as their objective the setting up of discussions and information exchange between the IAEA, the States and the designers of the new plant as early as possible so that a reasonably cost effective safeguards system is produced.

4.3. EXAMINATION, VERIFICATION AND USE OF DESIGN INFORMATION BY THE IAEA

The IAEA currently examines, verifies and uses design information received for a proposed plant according to the following schedule, which is quoted (with slight editing) from the IAEA's documentation of its procedures. It should be understood that certain steps which follow may be conducted jointly by the IAEA, the State and the owner/operator, and decisions resulting from those steps may be negotiated between these parties.

The design information for a specific facility, based on the IAEA DIQ as submitted to the IAEA by the State, includes: a comprehensive description of the facility; the types, quantities and form of nuclear material being used; the facility layout; and containment features relevant to safeguards. This information is used to prepare the safeguards approach. The design information, the safeguards approach and any other relevant information serve as the basis for preparing a draft for inspection goals and procedures.

The design information examination is a review to see whether further information is necessary for the IAEA in order to establish adequate safeguards. Those features of the facility and the nuclear material handling and storage procedures which may have an impact on the safeguards approach and methods are identified.

The design information verification is on-site verification by the IAEA that the information is complete and correct and satisfies its needs as specified in the safeguards agreement. This verification is performed during a visit, which is not to be confused with the various inspections described elsewhere.

The examination and verification of the design information are carried out to:

(a) Identify those features affecting the application of safeguards. This should be done in sufficient detail to ensure that the safeguards objectives, as laid down in the safeguards agreement, can be met and the IAEA safeguards goals fulfilled.
(b) Determine the Material Balance Areas (MBAs) to be used for IAEA accounting purposes and select Key Measurement Points (KMPs) that will be used to determine the flow and inventory of the nuclear material. When determining an MBA, the following criteria are taken into account:

    (i) The size of the MBA, which is dependent on the material balance accuracy obtainable.
    (ii) The use of C/S measures to help ensure the completeness of flow measurements. Advantage should be taken of any opportunity to use these measures. This simplifies the application of safeguards and concentrates measurement efforts at KMPs.

    - (iii) Multiple MBAs at a facility or at defined locations outside facilities, as used by the operator, which may be combined into one MBA if the IAEA determines that this is feasible.
    - (iv) Establishment of a special MBA, at the request of a State, around a process step involving commercially sensitive information.

(c) Establish the nominal timing and procedures for taking physical inventory for IAEA accounting purposes.
(d) Establish the requirements for records and reports and the evaluation procedures.
(e) Establish the requirements and procedures for flow and inventory verification, specifying quantities and identifying the locations of nuclear material.
(f) Select appropriate combinations of C/S methods and techniques and the strategic points at which they are to be applied.

Actions to be undertaken before the visit include:

(1) Examining the design information to establish its completeness (according to the DIQ) and its self-consistency. Determining whether any additional information or clarification that could have an effect on safeguards is needed. Such additional information must be requested formally from the State.
(2) Preparing a preliminary *safeguards approach* for the facility, based on the design information and any other relevant information available. This draft safeguards approach should take into account specific features of the facility and other relevant features indicated in the safeguards agreement. Important elements are:

- — Determination of possible diversion strategies; identification of possible diversion paths; and specification of the detection goals (detection times, significant quantities and detection probabilities) to be achieved for the facility.
- — Detailed analysis of the identified diversion paths.

(3) Preparing the draft Facility Attachment based upon the model Facility Attachment, the design information, the goals and procedures and any other relevant facility information.
(4) Planning the on-site verification activities.

During the visit to verify the design information, its completeness, correctness and self-consistency should be checked. To the extent possible the planned safeguards approach, inspection goals and procedures should also be checked against the design information and any additional information received on facility practices or SSAC activities. Features of the facility that are of special interest include:

(a) Containment features;
(b) Operational practices, including MBAs and KMPs established by the operator and as used by the SSAC;
(c) The flow of material, its type and its physical and chemical form;
(d) Possible identification methods of items and batches;
(e) The measurement methods used and their accuracy;
(f) Sampling procedures and methods for ensuring the integrity of samples;
(g) Methods of storage and containment of material from the viewpoint of measurement techniques used by the IAEA;
(h) Recording and reporting procedures;
(i) Possibilities of using C/S equipment.

5. SAFEGUARDS APPROACHES FOR NUCLEAR POWER PLANTS

5.1. SAFEGUARDS APPROACH

For all facilities under safeguards an approach is developed to enable the safeguards objectives for that particular facility to be achieved. In establishing the safeguards approach for a particular facility, the IAEA analyses the possible diversion paths which exist at the facility and takes into account the facility management practices, the physical design of the facility and the role of the SSAC. The resulting *safeguards approach* includes the system of nuclear material accountancy, the C/S and other measures to be used at the facility, the frequency and type of reports and the frequency and type of inspections.

A nuclear power station is an example of an item facility from the point of view of IAEA safeguards, i.e. the nuclear material at the facility is confined in identifiable fuel assemblies, the integrity of which normally remains unaltered during their residence at the facility. (Reconstitutable fuel assemblies designed to permit disassembly may result in the presence of individual fuel rods, which would be safeguarded by identification and accounting of rods or groups of rods and, for a power reactor where this type of assembly is used, the facility attachment would take this into account.) The quantity of nuclear material initially present in each fuel assembly is declared at the fuel fabrication plant. In safeguarded fabrication plants the nuclear material is quantitatively verified by the IAEA. If the fuel fabrication plant is not under safeguards, the verification by the IAEA of the amount of nuclear material in the fuel assemblies is carried out at the reactor site. This quantity is assumed to remain unchanged until the fuel assembly is discharged from the core. Plutonium production and fissile material depletion from burnup are calculated by the reactor operator from the irradiation history of each fuel assembly, and the fissile material inventories of discharged fuel assemblies are modified accordingly. At both off-load refuelled LWRs and on-load refuelled PHWR stations, the entire facility constitutes one MBA. Hence, the loading of fresh fuel into the reactor core and the discharge of irradiated fuel from it to the on-site spent fuel storage do not constitute an inventory change. Nevertheless, information on these movements is essential for effective IAEA safeguards, and the facility operator maintains detailed operating records on these internal transfers.

The essential elements of safeguards are organized to provide an information system that permits the IAEA to monitor operational activities so that the validity of the operator's account of fuel operations can be verified. This is illustrated schematically in Fig. 1. The top route represents the real material storage areas and transfer routes, including the possibilities for diversion.

The middle route in Fig. 1 represents the nuclear material accounting by the operator concerning the activities that have occurred. If this declared record of storage status and transfers accurately reflects the real inventories and transfers, then there can be a high degree of confidence that diversion activity has not occurred.

The IAEA's safeguards activities, represented in the bottom route of Fig. 1, monitor the physical activity in the storage and material transfer areas for accountancy verification purposes. Any activity observed that does not correspond to that declared will initiate a preplanned process to re-establish confidence that the declared record reflects the real inventory. That process might lead to an examination and validation of the entire inventory, an expensive task which should be avoided.

The frequency of surveillance can range from continuous to intermittent. The frequency would be determined from the estimated operating time required to accomplish a diversion. For example, at an off-load refuelled reactor, refuelling operations occur over a long cycle so that storage areas can be placed under surveillance and/or sealed for long periods. The integrity of the area boundaries, seals on access points and evaluation of surveillance records thus provide evidence of no activity for declared operations in that area. At an on-load refuelled reactor, however, fuel transfer can occur on a daily basis so that continuous monitoring of some pathway activities is required. Optical surveillance cameras monitoring a work area may capture a frame once per minute or slower if a safeguards relevant activity would take, for example, 10 min. Motion sensors may also be used to trigger the cameras.

Accidental or inadvertent loss of surveillance has to be interpreted as a potential safeguards concern and would trigger a process which may lead to reverification.

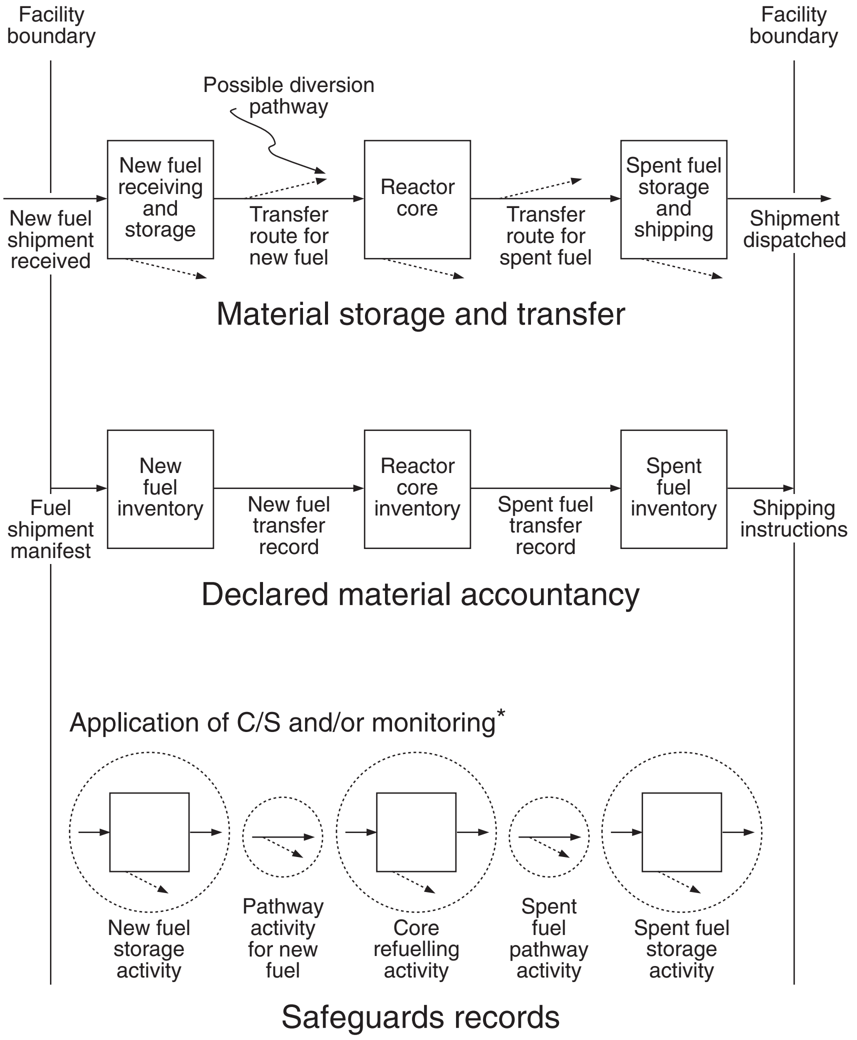

FIG. 1. Elements of safeguards (: these areas are dictated by the facility and can be in any combination of those shown).*

Since reverification is disruptive and costly, additional safeguards provisions such as redundant surveillance or the subdivision of sealed enclosures have been found to be useful in either avoiding surveillance loss or in significantly simplifying the reverification process.

The ideal safeguards system would not be intrusive on plant operations. Backfitting safeguards equipment and measures into existing plants or designs has been proven to provide a less than ideal safeguards system. Since it is in the interests of both the IAEA and the plant operator to conduct safeguards tasks as efficiently and unobtrusively as possible, advance planning and design to incorporate the safeguards equipment into the plant is desirable, if not essential. Avoidance of accidental or inadvertent interruption of safeguards continuity of knowledge should be considered a plant design objective because of the potential disruption to operations and the cost of the reverification process.

The differentiation in safeguards approaches, experience and guidelines between off-load and on-load refuelled reactors results from the following differences in the reactor concepts:

- For off-load refuelled reactors, refuelling operations and the associated fuel movements are conducted at a low frequency and with large numbers of items moved per refuelling;
- For on-load refuelled reactors, fuel movements and refuelling operations are carried out at a high frequency and with a small number of items moved per refuelling.

LWRs are refuelled off-load. Refuelling operations occur with an open vessel and transfers occur in channels filled with transparent water shielding. This combination of off-load refuelling and transparent shielding permits direct visual observations for safeguards purposes. Transparent shielding is impractical for refuelling operations in on-load refuelled reactors so observations by other means are required. In these plants, detection of variations in radiation fields from continuously operating instrumentation together with optical surveillance provide the information needed on refuelling sequences for safeguards purposes.

The safeguards approach for a facility also depends on its fuel option, specifically on the significant quantities of the nuclear material used and the associated timeliness requirements for the detection of diversion. Some plant designs have sufficient design and operating flexibility to permit alteration of the fuel option during the lifetime of the plant, e.g. changing from uranium fuel to also using MOX (mixed oxides of plutonium and uranium). If for a new plant the use of more than one fuel option is foreseen, the safeguards design needs to be based on the use of any of the options, i.e. individual safeguards provisions should be based on the most stringent case or, alternatively, duplicated for different fuel options.

TABLE I. DIVERSION STRATEGIES

Diversion possibilities	Concealment methods	Safeguards measures
Removal of fuel rods or assemblies from the fresh fuel storage area	Substitution with dummies Falsifying records	Application of seals, NDA measurements
Removal of fuel assemblies from the core	Substitution with dummies Falsifying records	Seals, optical surveillance, CDMs, spent fuel bundle counters
Irradiation of undeclared fuel assemblies or other materials in or near the core, and removal of the material from the facility		Seals, optical surveillance, NDA measurements, CDMs, spent fuel bundle counters
Removal of fuel rods or assemblies from the spent fuel pool	Substitution with dummies Falsifying records	Seals, optical surveillance, NDA measurements, spent fuel bundle counters
Removal of fuel rods or assemblies from a consignment when or after they leave the facility	Substitution with dummies in the consignment Understating the number of assemblies shipped and substitution with dummies in the spent fuel pool	Verification of content of shipping container, sealing of shipping container before shipment and verification of content at receiving facility.

CDM: Core Discharge Monitor; **NDA:** non-destructive assay.

5.2. DIVERSION STRATEGIES AND MEANS TO COUNTER THEM

The significant quantities and timeliness goals for the nuclear materials used in nuclear power plants are given in Section 4.1. For LWR fuel, the significant quantities of nuclear materials, 75 kg of ^{235}U in LEU, could be contained in approximately five fuel assemblies, and 8 kg of plutonium is contained in approximately two irradiated fuel assemblies or in less than one fresh MOX fuel assembly. For pressure tube PHWRs, 75 kg of ^{235}U in natural uranium is contained in approximately 550 fresh fuel bundles and 8 kg of plutonium in approximately 100–120 irradiated fuel bundles. If pressure tube PHWRs were to use MOX fuel, it is estimated that for the most demanding safeguards case a significant quantity of plutonium would be contained in about 20–35 fresh fuel bundles. Consequently, for uranium fuel the strategic value of fuel for diversion is relatively low for fresh fuel and increases (not uniformly) with burnup, while for MOX fuel this strategic value is highest for fresh fuel and decreases with irradiation. The safeguards approach for MOX fuel is covered in Section 5.5.

There are two basic diversion threats for nuclear power plant fuel:

- *Diversion from declared inventory:* Removal of one or more discrete rods or assemblies, with or without substitution by falsified, or partially falsified, rods or assemblies;
- *Undeclared production:* Irradiation in the reactor core of undeclared fertile materials and consequent undeclared production of plutonium or ^{233}U.

Table I shows examples of the diversion possibilities, concealment methods and corresponding safeguards countermeasures used at nuclear power plants.

The detection of nuclear material diverted from a power plant relies upon two basic tools:

(1) *Nuclear material accountancy*. The facility is considered as a single MBA with a number of well defined points, KMPs, through which material is transferred — physically or as accountancy transactions — or where it is stored or used. Accountancy is carried out on an item basis, sometimes using the fuel assembly identification number. The nuclear material content of each assembly is based on the verified manufacturer’s measurements and on the reactor operating data. The operator keeps accountancy records of the inventory of nuclear material at each location, of the transfers into and out of the facility and of transfers between locations within the facility. Reports on inventories and external transfers are made periodically to the IAEA. Verification by the IAEA of the correctness of the records and reports is carried out by record audit, item counting, item identification and NDA examination. The detailed inspection requirements for all facility types are laid down in the IAEA’s ‘Safeguards Criteria’, which are updated at regular intervals [6]. All inspection requirements involve some form of records and reports audit, the physical verification of inventories and transfers, the examination of containments used as parts of the C/S systems, the examination of seals and surveillance results and the verification of design information. An important part of the safeguards approach is that at approximately annual intervals the operator is required to carry out an inventory of all the nuclear material at the facility. The results of the operator’s inventory are verified by the IAEA at the Physical Inventory Verification (PIV). The verification of the location of nuclear material may be carried out using unattended

surveillance or measurement devices, e.g. the CANDU spent fuel bundle counter, or the CDM.

(2) *C/S measures.* These measures are used to complement material accountancy by: preserving the integrity of verified accountancy data; providing information on the movements, or possible movements, of nuclear material; or ensuring that the fuel movement counts at KMPs are complete.

For IAEA safeguards purposes, the *containment* used in a C/S system consists of structural features of a nuclear facility or of equipment which permit the IAEA to establish the physical integrity of an area or item by preventing undetected access to, or movement of, nuclear or other material, or interference with the item, IAEA safeguards equipment, or data. Examples are the walls of a storage room or a storage pool, transport flasks and storage containers. The continued integrity of the containment is ensured by containment examination, and by C/S measures for penetrations of the containment such as doors, vessel lids and water surfaces.

Similarly, *surveillance* is the collection of information through inspector and/or instrumental observation, which is aimed at monitoring the movement (or non-movement) of nuclear material, detecting interference with the containment, or tampering with IAEA safeguards devices, samples or data. There is a range of surveillance devices available, and the use of any particular one depends on the individual circumstances.

The instruments used to measure declared movements of nuclear material or detect undeclared movements can be interrogated at intervals at the site by visiting inspectors. The automatic transmission of the (authenticated and encrypted) data from the nuclear facility to IAEA Headquarters or to a regional office is a preferable alternative and is likely to become more widely used. In all C/S and NDA systems used for safeguards purposes, the system design must take into account the possibility of intentional actions by a potential diverter to defeat the system and thereby conceal the undeclared removal of material. To counter these actions, measures have to be taken to make the equipment tamper resistant and/or to prove the validity of the stored and transmitted data.

The IAEA has considerable experience in making the installed instrumentation tamper resistant. For optical surveillance systems there are special tamper resistant transmission lines. For radiation monitoring and NDA systems, attention has to be paid to the detection of tampering with the detectors, e.g. by using radiation sources. The best method to make the system less vulnerable to tampering is to place the detector as close as possible to the item to be verified in order to get a strong and unique signal. Another method is to have the detector in the field of view of the optical surveillance. A highly sensitive detection system allowing background monitoring or a watchdog source can be used to exclude intentional interruption of the signal and data transmission chains.

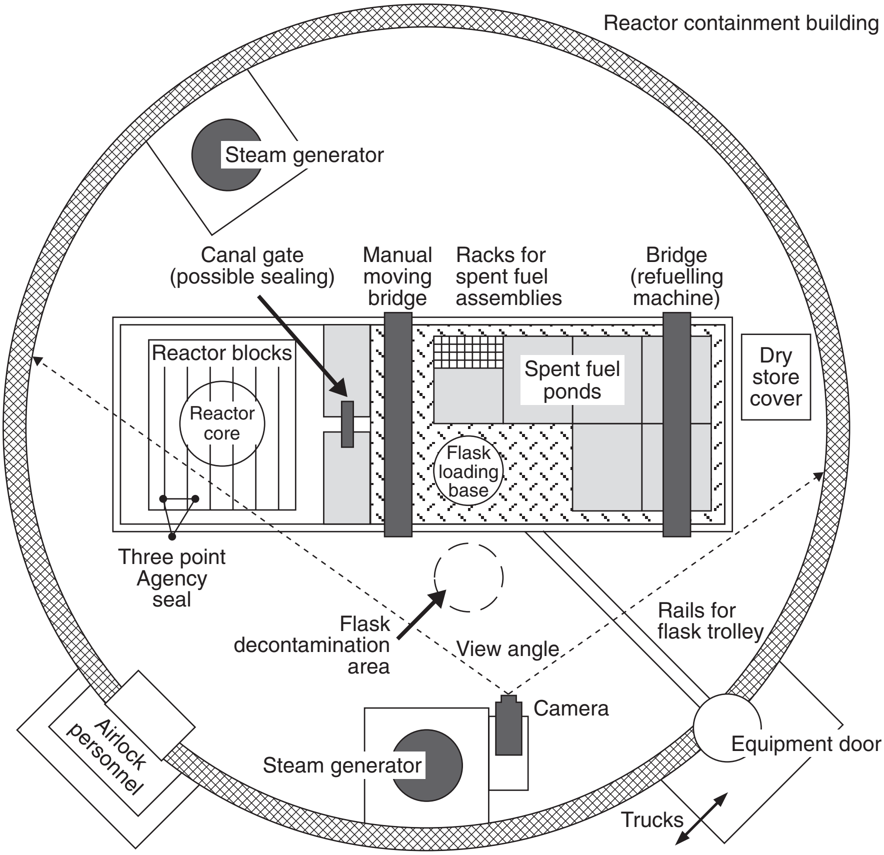

FIG. 2. Typical layout of an LWR Type I plant design.

5.3. SAFEGUARDS AT OFF-LOAD REFUELLED REACTORS

Off-load refuelled reactors are LWRs and include PWRs, BWRs and WWERs. The examples given in this section are for PWRs, but the general principles apply to all off-load refuelled water cooled reactors. There are a variety of specific designs of refuelling systems and pathways used in LWRs. Hence, only general statements about these designs and the approaches used to safeguard them are made here.

From the point of view of the type of C/S system used, LWRs can be divided for safeguards purposes into two types, depending on whether the spent fuel pool is within the reactor containment building (Type I) or outside it (Type II).

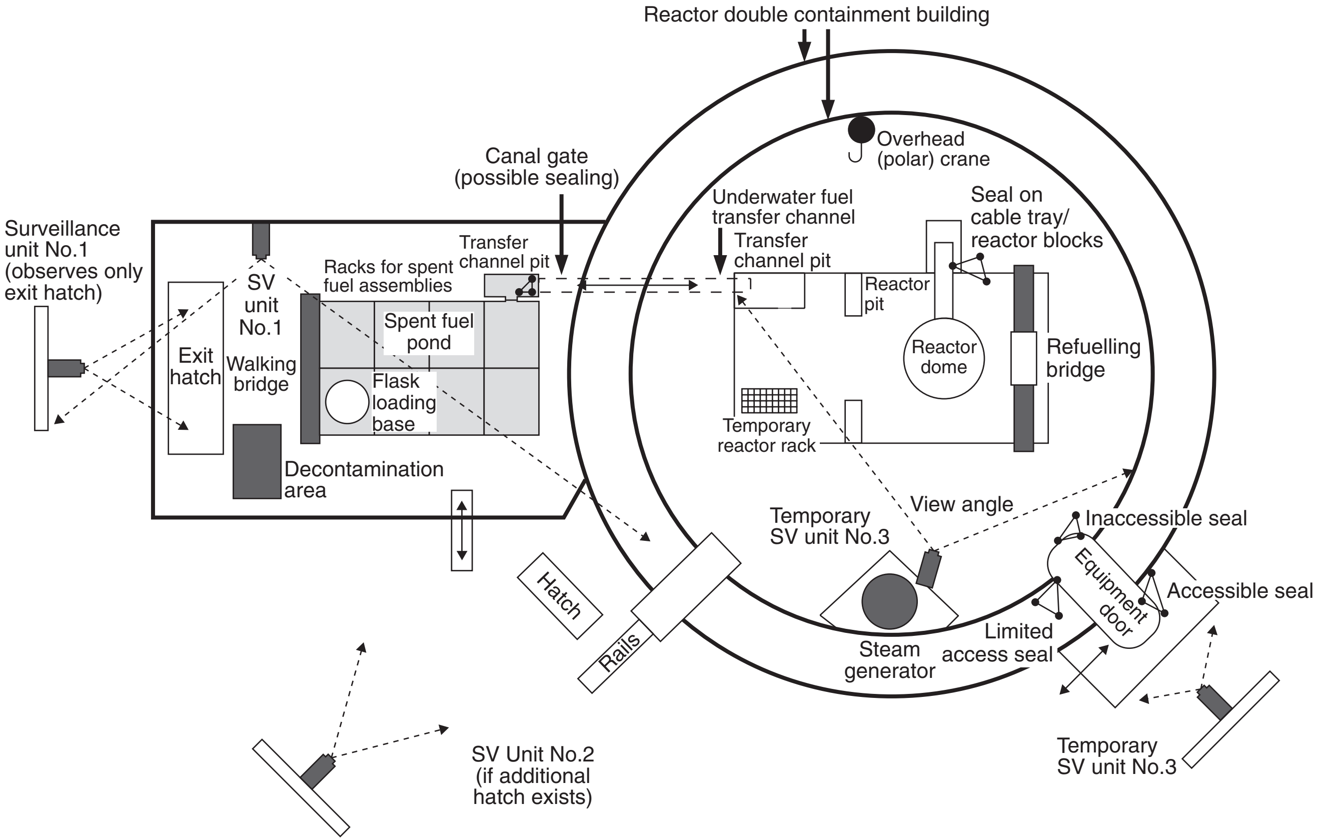

FIG. 3. Typical layout of an LWR Type II plant design (SV: surveillance).

Type I. LWRs where the C/S measures applied to both core fuel and spent fuel employ a *single* C/S component (e.g. surveillance in the reactor hall). Most of the LWRs of this type are BWRs, WWERs and PWRs of Siemens design.

Type II. LWRs where the C/S measures applied to core and spent fuel employ *at least two* C/S components complementary to each other (e.g. pool surveillance in the fuel storage building and hatch seal/surveillance in the reactor containment). Most of the LWRs of this type are PWRs other than of Siemens design. The basic concepts of each type of design are illustrated in Figs 2 and 3.

At off-load refuelled reactors the C/S measures include applying seals and/or optical surveillance to ensure that there is no undetected opening of the reactor vessel, and the use of optical surveillance to detect diversion from the spent fuel pool or from an open pressure vessel.

As indicated previously, the LWR, owing to its pressure vessel design and its off-load refuelling, permits the top of the entire core to be viewed when the pressure vessel head and any internals normally above the core are removed. By flooding the region above the core with clear water and connecting it with the spent fuel pool, fuel can be moved while being cooled and shielded by the water. This water shielding is transparent to visible light, permitting direct observation of refuelling activities by optical instruments and inspectors. The water is also transparent to ultraviolet light, permitting the use of Cerenkov glow from irradiated fuel to verify the irradiated fuel contents in the spent fuel pool and, if agreed by the State authorities, in the core. The safeguards approach takes advantage of this water clarity and visibility.

5.3.1. Fresh fuel verification

In the current LWR safeguards approach, fresh fuel assemblies received at the reactor site are considered to be identifiable items and all subsequent inspection activities are concerned with the verification of item identity and integrity (i.e. whole assemblies remaining as such). This verification ensures that the nuclear material stated to be present is in fact there. The assemblies present are counted and their identification numbers noted. Additionally, or as an alternative to identification, the IAEA may also carry out NDA measurements as a sampling basis to confirm the fresh fuel receipt declaration or to detect if there are any discrepancies in the nuclear material content. The NDA techniques used are based upon low resolution gamma ray spectroscopy using a portable multichannel analyser and either an NaI scintillation counter or a CdTe solid state detector. Both systems are designed to measure enrichment. The probe of the CdTe based system is less than one centimetre in diameter and can be used to verify both BWR and PWR assemblies. For reasons of economy, the plant operator often arranges to receive fresh fuel as close as possible to the scheduled refuelling shutdown. To enable the necessary verification measures to be completed there is a need to plan for an inspection at a time, just prior to refuelling, when all the fresh fuel has been received but before it has been transferred to underwater storage.

5.3.2. Verification of fuel assemblies in the reactor core

The seals on sealed reactor vessels are verified at the annual PIV and also at three month intervals. Direct verification of the fuel in the core is timed to coincide with the operator's checks to ensure that the refuelling of the core has taken place as declared. Alternatively, if the entire core has been discharged to the spent fuel pool, the core fuel is verified as part of the spent fuel inventory. Verification involves counting the number of assemblies in the core and in practice also the verification of the serial numbers of all of the assemblies using the operator's underwater television system. This approach is justified by the fact that the reactor area is maintained under surveillance from the time that the reactor vessel containment seal is detached and the assumption that, provided no spent fuel transport container movements have been detected, the spent fuel was transferred from the core to the spent fuel pool and has been replaced by fresh fuel. Furthermore, it is usually possible to distinguish between fresh fuel assemblies newly loaded into the core and irradiated assemblies remaining in the core from previous power cycles.

The only obvious weakness in this approach is that the verification knowledge of the reactor core following the PIV is maintained solely through an optical surveillance system, which may not be capable of detecting all transfers of fuel assemblies between the core and the spent fuel pool. This problem could be solved by the design and implementation of a more comprehensive surveillance system that is capable of monitoring the movement of items into and out of the reactor core itself. A diversion strategy to which the core fuel is vulnerable is the removal from the core of plutonium rich irradiated fuel and its substitution by fresh or dummy fuel assemblies or rods. In this scenario it is assumed that, after core closure, the diverted irradiated fuel could be removed from the spent fuel pool under cover of a contrived surveillance failure. This particular diversion strategy is counteracted if the verification of the fuel in the spent fuel pool is carried out at the inspection at which the reactor vessel containment seals are attached.

Sealing the reactor vessel containment may be employed as a means of maintaining the verification knowledge of the core fuel gained during the inspection activities performed in connection with the PIV. Additionally, in the majority of installations, it is possible to maintain the reactor vessel containment under optical surveillance so that core–fuel verification knowledge is independently maintained by both seals and surveillance, i.e. under a dual C/S system. In some reactors there is a problem of access to the seal, either because it is necessarily located in an area of high radiation dose rate, and thus not accessible during reactor operation, or owing to the high risk of contamination in the area surrounding the sealing point. Under these circumstances, verification of the core to meet the specified timeliness goals can only be accomplished through surveillance of the reactor vessel containment closure. The surveillance camera is sited within the high radiation area but the recording equipment is placed outside the high radiation area so that access to it can be obtained at any time.

5.3.3. Spent fuel verification and C/S

At LWRs the spent fuel verification activities currently applied in conjunction with the annual PIV involve item counting of the whole ‘population’ and NDA measurements to detect undeclared removal of the nuclear material. These measurements are usually based on observation of the Cerenkov glow using an optical intensifier (see the ICVD in Appendix II). Another option, based on gross neutron and gamma detection, is the Fork Detector (FDET) (Appendix II). Use of the FDET requires raising the spent fuel assembly and is therefore only used if necessary. A new technique to detect major changes in the nuclear material content of spent fuel, the Spent Fuel Attribute Tester (SFAT) (Appendix II), has recently been introduced for routine inspection usage and has the capability of measuring a fission product attribute (^{137}Cs). The equipment consists of a waterproof housing containing a collimated NaI detector which can be submerged in the spent fuel pool and positioned in line with the axis of a selected fuel assembly. These NDA activities are part of the PIV and are normally undertaken immediately after the attachment of the seal to the reactor vessel containment.

In accordance with the principle contained in agreements based on INFCIRC/153 [4], whereby C/S is an important complementary measure to nuclear material accountancy, the IAEA uses C/S systems to maintain the knowledge gained from the NDA measurement of spent fuel. Surveillance systems based upon closed circuit television (CCTV) which have been developed for this purpose include the Modular Integrated Video System (MIVS), the Compact Surveillance and Monitoring System (COSMOS) and the Multiplexed System (MUX) (see Appendix II).

Surveillance systems are installed to survey spent fuel storage areas, spent fuel transfer routes and/or the reactor pressure vessel when it is open for refuelling. During refuelling, arrangements are made to ensure that no spent fuel shipments occur. The principal objective of the surveillance is to detect the presence of spent fuel transport containers or other objects capable of containing irradiated nuclear material. The assumption is made that if a transport container or similar object is seen to leave the area covered by the surveillance, then a change in the inventory of the spent fuel may have occurred. To ensure that a complete optical surveillance record is obtained, it is vital that adequate lighting be maintained at all times. In order to be able to interpret the optical or other surveillance record, the IAEA relies on the operator to maintain detailed records of operations involving transport containers or container-like objects in the surveillance zone, and to make these records available to the IAEA inspector either for transcription or as retainable copy. Subsequently, the surveillance record is compared with the operator's information. The chronology of events is compared with the declared inventory changes to determine whether the surveillance record may be accepted as providing conclusive confirmation of the operator's/State's declaration.

Traditionally, the IAEA has applied a simple interpretation to data obtained from surveillance reviews, in that it accepted that an object that could be confidently recognized to be a transport container of the type described in the design information could be taken to contain no more than its declared capacity of fuel assemblies. However, the increasing use of reconstitutable assemblies introduces a significant uncertainty, in that assembly dismantling could permit a change in the 'packing fraction' of the container. As a consequence, the detection of a transport container or similar object leads to the conclusion that the knowledge of spent fuel has been compromised and reverification is necessary. Provided that the surveillance system has otherwise provided conclusive results, reverification of the spent fuel inventory would be undertaken in conjunction with the PIV and would, under normal circumstances, be based upon the use of the ICVD.

5.3.4. Detection of the unrecorded production of direct use material

Current practice depends largely on the ability of the inspector to examine in detail the spent fuel storage pool, either at the time of the operator's verification of core loading (called 'core control' in safeguards terminology) or, equally effectively, at the time of the verification of the spent fuel assemblies conducted when the reactor vessel containment seal is attached. To be able to ensure that no undeclared irradiation has taken place, it is essential that either the reactor vessel is closed and under C/S or that, during the period when the core is accessible, it is verified that material is exchanged only between the core and the spent fuel pool.

5.4. SAFEGUARDS AT ON-LOAD REFUELLED REACTORS

On-load refuelled reactors have fuelling machines that are capable of attaching to fuel channel end fittings, pressurizing to reactor coolant conditions, opening an access to the channel, removing irradiated fuel and inserting replacement new fuel.

The fuel channel can then be reclosed and the fuelling machines depressurized and detached from the fuel channel.

On-load refuelling of water cooled reactors is possible in a number of designs; the most prominent are pressure tube PHWRs.[3] The application of the general principles for the safeguards approach are common to all pressure tube PHWRs. Most of the IAEA's experience has been gained from CANDU reactors and safeguards have been successfully applied at this reactor type, as discussed in Ref. [7]. Therefore, in the discussion of the general principles of safeguarding on-load refuelled reactors, the CANDU will be used as the primary reference.

CANDU power stations have been built in various configurations, including some where each reactor unit has its own containment and fuelling, i.e. fresh fuel storage, fuelling activities and spent fuel storage. Other CANDU power stations are multi-reactor unit stations that share common containment, fresh and spent fuel storage areas, and some aspects of fuelling activities. An example of shared fuelling and storage facilities is the Darlington station in Canada. Examples of 'stand-alone' units are Embalse, in Argentina, with one unit at the site, and Wolsong, Republic of Korea, with four units at one site. Both types of stations are under IAEA safeguards.

The CANDU reactor has horizontal pressure tubes and is heavy water cooled and moderated. The refuelling system design uses two machines, one at each end of the horizontal reactor channel, to insert new fuel at one end and to receive spent fuel at the other. On-load refuelled reactors require that all fuelling operations be shielded to protect operating personnel either by the use of shielded fuelling machines or, in the CANDU design, unshielded machines which operate in shielded vaults that enclose the ends of the reactors. Consequently, in a CANDU the positioning of the fuelling machines at the reactor channels and the refuelling sequence are done by remote control.

At CANDU reactors fresh fuel assemblies known as bundles are received from the fabrication plant and placed in an on-site storage area. By means of the on-load refuelling system, fresh fuel is loaded into the core typically every day, pushing the same number of spent fuel bundles out of the core.

The fuel comes in short bundles, typically 500 mm. In practice, refuelling changes are multiple bundle and a typical charge is four, six or eight bundles. The fuelling operation concludes when end closure and shielding plugs are replaced in the channel, and only spent fuel is transported away from the reactor.

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[3] The other two on-line refuelled, water cooled reactor types are the Siemens designed pressure vessel PHWR Atucha reactors and the Russian designed graphite moderated, pressure tube, boiling light water cooled RBMK reactors. The safeguards principles for these plants are the same but there are considerable differences in application. If future plants of these designs are proposed, the appropriate safeguards issues would need to be addressed.

The fuel handling system transfers the spent fuel into the spent fuel receiving bay. The main storage bay has a capacity of at least ten years of discharged spent fuel. CANDU stations have not routinely shipped spent fuel off-site; however, large quantities are now transferred into dry storage canisters which are on the same site.

Item accountancy and maintaining continuity of knowledge using C/S measures form the basis of the CANDU safeguards approach. Direct verification of the operator's declared nuclear material inventory is implemented for fresh and spent fuel. Although fuel bundles in the core remain inaccessible for verification, continuity of knowledge is maintained by a monitoring system when they are discharged. C/S covers the discharge of spent fuel from the reactor and storage in the spent fuel bays to provide continuity of knowledge.

Integrated instrument systems are used to monitor the movement of nuclear material out of the core and to detect diversion from the spent fuel pool. The systems use a combination of CDMs, spent fuel bundle counters, radiation detectors, optical surveillance and electronic and other seals attached to containers of spent fuel, equipment hatches, etc.

5.4.1. Fresh fuel verification

For uranium fuel, an annual PIV is done on the fresh fuel inventory. Transfers into the fresh fuel store may be verified throughout the year or, depending on the safeguards approach applied, at the PIV. The amount of effort for item accounting can be reduced if a containment sealing system is used to isolate segments of the fresh fuel storage for continuity of knowledge, while still providing for the required flow of fresh fuel for operation. Where different fuel materials are involved, such as natural and depleted uranium and LEU, they should be accounted for separately for material control.

The annual PIV on fresh fuel consists of item accounting and attribute testing of selected bundles, and may involve checks of the serial number.

5.4.2. Core and fuelling verification

There are currently two options for monitoring refuelling of the reactor core. A C/S system used for some existing CANDU-6 reactors is shown in Fig. 4. The C/S measures applied to the fuel in the core consist of a system of four CCTV cameras viewing the reactor faces and the refuelling machine transfer routes. Fuelling machine operation, including visits to the new fuel and spent fuel ports, is recorded by optical surveillance. Four thermoluminescent dosimeters (yes/no monitors), or PIN detectors, are placed at the new fuel and auxiliary ports to monitor a possible diversion pathway of reverse flow through the new fuel ports.

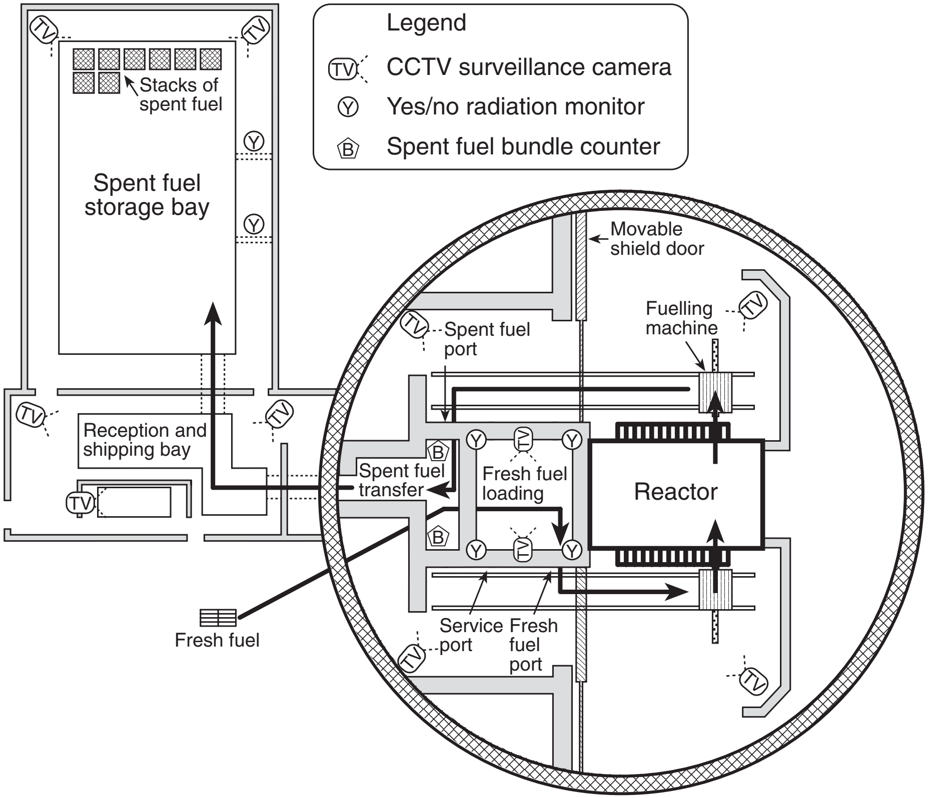

FIG 4. Location of safeguards equipment instrumentation in a typical CANDU-6 reactor (copyright: Atomic Energy of Canada Limited).

An alternative safeguards system for CANDU cores is based upon the detection of the neutron and gamma radiation produced when an irradiated fuel bundle enters the unshielded end fittings of the fuel channels (Fig. 5). The CDM (Figs 6 and 7) detects both normal on-load discharges and discharges of fuel bundles after long (approximately one year) periods of reactor shutdown. It has the following attributes:

- It is installed in the reactor vault to continuously monitor the reactor face for a characteristic pulse of radiation when fuel is discharged. If the reactor is operating, one part of the pulse is intense gamma radiation, while the other is a neutron pulse that occurs from photoneutron production in the heavy water coolant.[4] With the reactor shut down the gamma signal is sufficiently strong to be unique to refuelling for the first year of shutdown.
- Provides an indication of the direction of refuelling, including any rare cases of fuel reshuffling.
- The signals are strong, unambiguous and indicate the number of bundles discharged. They are also amenable to simple analysis and data transmission.
- A mismatch between the spent fuel count provided by the CDM and the bundle counters would indicate a deviation of spent fuel movement from the normal flow path.

5.4.3. Spent fuel verification and C/S

Direct verification of the irradiated fuel inventory in the spent fuel bays would be time consuming and physically demanding. Therefore, as an alternative the movement of irradiated fuel bundles discharged from the reactor core and transferred to spent fuel storage is continuously verified item by item at defined KMPs by spent fuel bundle counters. C/S is then used to ensure continuity of knowledge until the bundles are placed in sealed containment, i.e. surveillance ensures that any undeclared spent

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[4] This photoneutron signal is strong because there is an abundance of gamma radiation above the 2.2 MeV threshold for the $D(\gamma, n)H$ reaction. These high energy gammas are characteristic for very short lived fission products, while only a few longer lived fission products like the kryptons and lanthanum provide the so-called source term for heavy water moderated reactors. As a by-product this neutron signal becomes very weak in the shut down state. The other prominent photoneutron reaction is associated with the N-16 and N-17 coolant activation products; this is what provides the convenient reactor power measurement by the CDM, since the outlet feeders are not shielded from the monitors.

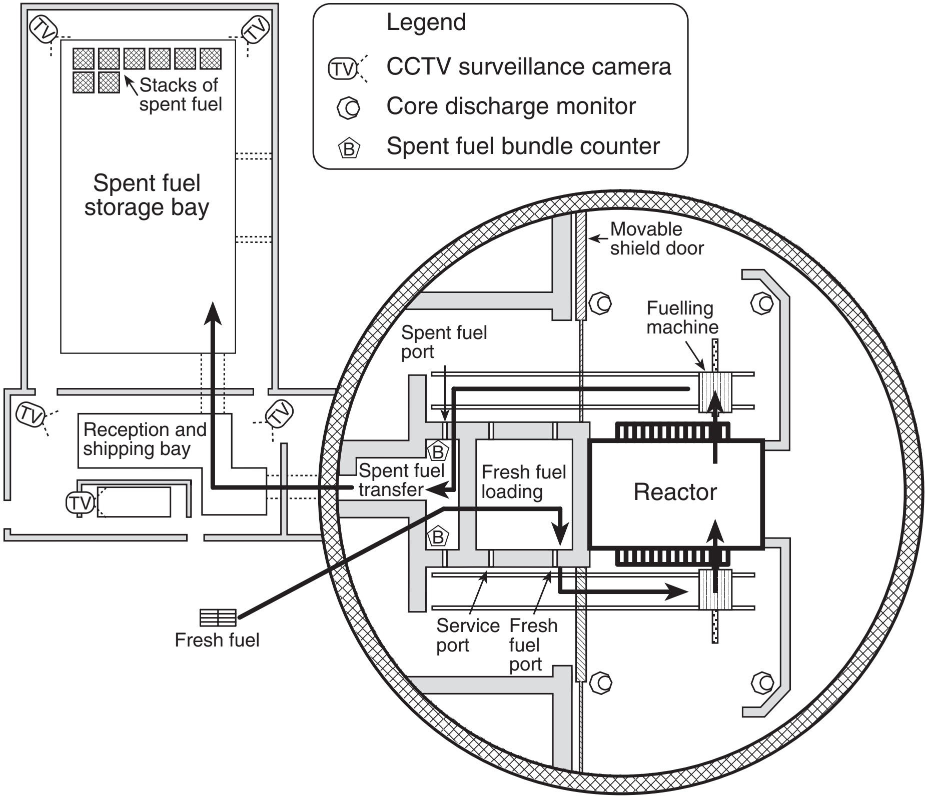

FIG. 5. Location of safeguards equipment instrumentation in a typical CANDU reactor with a CDM (copyright: Atomic Energy of Canada Limited).

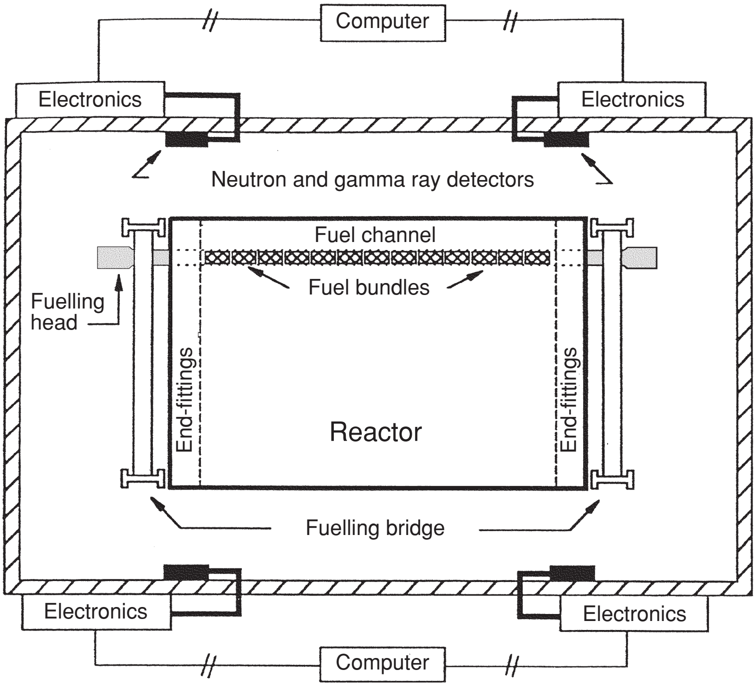

FIG. 6. Layout of a CDM.

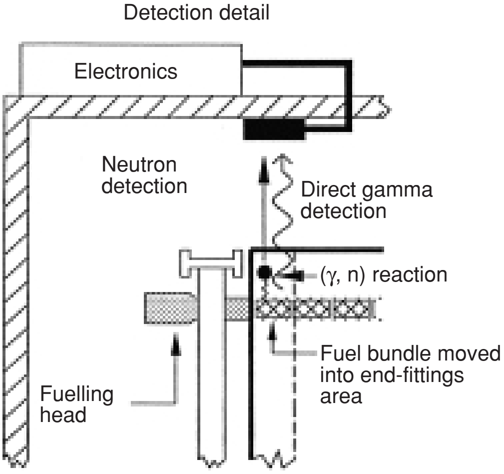

FIG. 7. Schematic drawing of a CDM.

fuel removals along other routes will be detected. Bundle storage containers with special covers and ultrasonic seals can be used in combination with surveillance in the spent fuel bays as a complete dual C/S system.

Thus, for spent fuel storage at CANDU reactors, the safeguards approach uses a combination of:

- CCTV surveillance of reactor faces and fuelling machine transfer routes to detect any deviation from routine fuelling procedures, or use of CDM to establish the spent fuel item count;
- Spent fuel bundle counting to confirm the item count into the storage area;
- Optical surveillance to monitor the area for unusual activity and undeclared shipment;
- Sealed containers for long term bundle storage.

This system defines a complete safeguards containment boundary covering all diversion routes for core and spent fuel.

(a) *Monitoring discharges to spent fuel storage.* The fuelling machine which receives the spent fuel delivers it to the spent fuel port and continuous gamma monitoring for high radiation is carried out at several closely spaced points along the pathway to the spent fuel bays. These signals identify the passage and direction of the individual spent fuel bundles. This bundle counter gives a combined attribute check and item count to correspond to the CDM record and the declared receipts in the spent fuel bay.

To effectively monitor the fuel discharge process, the monitors and associated collimators have to be housed in penetrations along the fuel path, i.e. special purpose embedded parts in or on the walls of the fuel transfer canal.

(b) *Spent fuel surveillance.* The spent fuel surveillance system, consisting of a system of CCTV cameras, views the entire exposed water surface of the spent fuel bays and ensures detection of the removal of irradiated fuel through the water surface in any of the bays. The spent fuel reception bays at CANDU reactors may be connected to the primary spent fuel bay by underwater tunnels or openings. However, the water surfaces of both bays are under surveillance. The safeguards containment boundary is defined by the walls of the bays and the water surfaces.

(c) *Dual C/S.* This is effective in reducing the verification effort. Dual C/S is achieved when the flow of spent fuel is accumulated into a sealed container within a period of three months (the spent fuel timeliness period, see Section 4.1) after the attribute test performed by the spent fuel bundle counters. The bundles are currently stored horizontally on trays or modules which are assembled vertically into engineered stacks that ultimately comprise sealed containers (see Fig. 8). This inventory segmentation and the use of sealed containment can simplify inventory

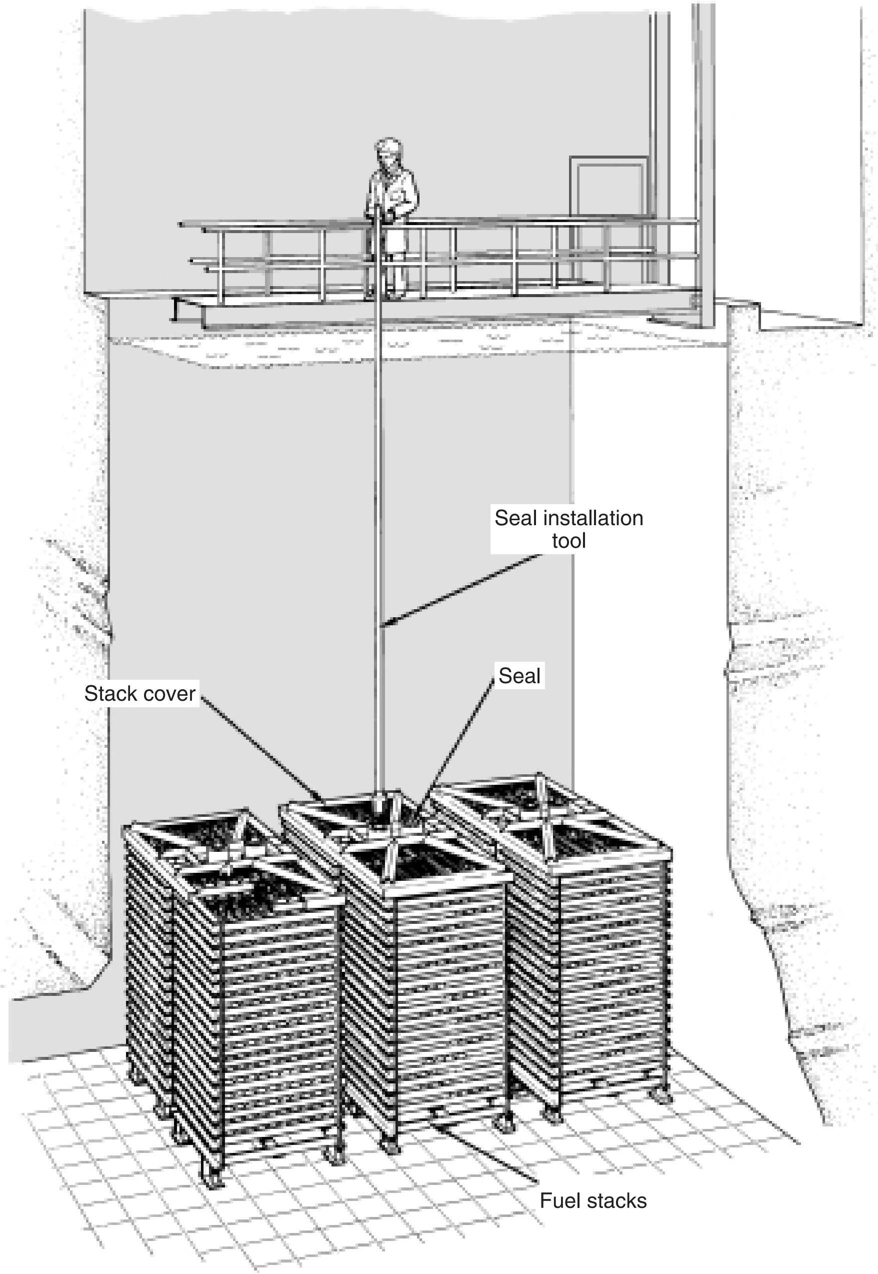

FIG. 8. CANDU-6 sealed containment assemblies.

control and verification. The verification effort is also reduced if there is a loss of optical surveillance, since the sealed inventory can be re-established by verification of the stack seals rather than by NDA on individual fuel bundles.

The storage sequence is to receive the bundles and accumulate them in an interim storage under single surveillance. When a number equivalent to a storage stack is accumulated, prior to the end of the three month timeliness period, the engineered container will have the IAEA cover, and underwater in situ verifiable seals (e.g. AECL Random Coil (ARC) seals) are installed under the supervision of an IAEA inspector. At this time the seal signature will be recorded.

The combination of surveillance of the bays and of the sealed underwater spent fuel stacks using an ultrasonic sealing system of ARC seals ensures continuity of knowledge for the sealed stratum should bundle counter or surveillance failure occur. If either of these events occur and the sealing system is not in place, reverification of the spent fuel inventory based on the fuel bundle as a single item may be required.

The C/S systems used at CANDU stations frequently employ redundancy in order to obtain the necessary system reliability, i.e. two or more devices serve the same function. To deliver conclusive results under all operational circumstances, the devices can often be sited to provide backup information for each other, e.g. a surveillance record of the same events but from a different perspective. Evaluation of the results of the C/S devices can, therefore, be limited to a subset of the devices to provide acceptable conclusions covering all diversion paths.

5.4.4. Detection of the unrecorded production of direct use material

To detect the unrecorded production of direct use material in the core, current practice depends largely on the ability of the inspector to examine in detail the spent fuel storage bay. Unrecorded production of direct use material would also be indicated by the safeguards instrumentation which records the discharge of material (declared or undeclared) from the reactor faces or end fittings of the fuel channels.

5.5. SAFEGUARDS FOR FUEL CONTAINING DIRECT USE MATERIAL IN ON-LOAD AND OFF-LOAD REFUELLED REACTORS

Direct use material is plutonium, ^{233}U and HEU, and for commercial nuclear power plants the direct use material would normally be mixed with fertile material, either natural or depleted uranium or thorium. The principal such mixture of current and future interest is MOX, plutonium dioxide mixed with uranium dioxide. Since fresh fuel containing direct use material could in principle be diverted and used to recover the direct use material through chemical separation, such fuel requires a safeguards approach that is more stringent than that for fresh fuel containing LEU.

Some LWRs now routinely utilize MOX fuel assemblies. Such assemblies may contain different concentrations of plutonium in different rods, with the whole assembly typically containing an average of about 5% by weight of plutonium. Depending on the reactor size and the fuel strategy adopted, a MOX assembly can contain up to approximately 30 kg of plutonium, i.e. more than three significant quantities of material. The verification requirements for fresh MOX fuel (one month timeliness goal) are more stringent than those applied to fresh LEU fuel (12 months timeliness goal). The implementation of safeguards to fresh MOX assemblies is complicated in many cases by the need for the operator to transfer the assemblies to temporary storage in the spent fuel pool very soon after their receipt on-site. This practice, based on security and radiological protection concerns, makes it difficult to access the fuel assemblies for verification through presently available NDA techniques. The currently implemented approach for the application of safeguards to plutonium in fresh MOX fuel assemblies involves the use of C/S measures to maintain the verification knowledge gained during fabrication. In its simplest form the approach is highly labour intensive, requiring inspector presence during the transfer of the MOX fuel from dry storage or pool storage to the reactor core, and the utilization of surveillance devices to monitor the location of the fuel in the spent fuel pool and in the open core. NDA equipment to verify fresh MOX fuel stored under water is being developed.

Spent MOX fuel is safeguarded according to the same principles as spent LEU fuel. Similarly, irradiated MOX assemblies in the core and along transfer routes during refuelling would be safeguarded in the same way as, and along with, the irradiated LEU fuel in the core and along the transfer routes.

The use of reconstitutable fuel assemblies at LWRs complicates the application of safeguards because of the possibility of undeclared removal of fuel rods and their replacement by dummies. Unirradiated MOX fuel rods would be especially tempting to a diverter. Methods to detect the removal of fuel rods include NDA applied to fuel assemblies. The application of C/S measures to the reconstitution stations and storage areas holding reconstitutable fuel assemblies and individual fuel rods is under development.

All of the current pressure tube PHWRs use natural uranium fuel, although future fuel options may include LEU, most likely as slightly enriched uranium (e.g. 1.2% enrichment), or mixtures containing direct use material such as uranium–plutonium, thorium–plutonium or thorium–^{233}U. The safeguards principles are the same for pressure tube PHWRs as for LWRs and must be addressed if and when these direct use material fuel options are adopted.

5.6. SUPPLY OF SAFEGUARDS EQUIPMENT AND SERVICES

The supply and ownership of safeguards equipment is a complex subject since equipment may be supplied and owned by the IAEA, provided by Member State support programmes to the IAEA, or supplied and owned by the operator of the plant. The supply arrangements depend on who pays for and/or who owns the equipment. The IAEA often pays for the direct cost of safeguards equipment, inspection personnel, collection, processing and transmission of data, and the analysis and interpretation of the information. It is the responsibility of the State, which may be delegated to the owner/operator, to provide ancillary facilities and services within the plant to enable safeguards activities to be conducted. This often includes power supply, illumination and space for equipment and cable routes, as agreed with the IAEA.

5.7. THE STRENGTHENED SAFEGUARDS SYSTEM

The IAEA is currently implementing measures for strengthening the present safeguards system, including enhancement of its ability to detect undeclared nuclear material, facilities or activities. These measures have been analysed in terms of their technical aspects, cost or effort, benefits and legal aspects. The Board of Governors of the IAEA has endorsed the programme for strengthening the effectiveness and improving the efficiency of safeguards. The IAEA has divided the strengthened safeguards system into two parts: measures that can be implemented under existing legal authority (Part 1), and measures for implementation under yet to be negotiated legal authority (Part 2). Work on Part 1 includes, for example, further development and installation of safeguards equipment capable of operating in an unattended mode, together with remote interrogation and transmission of safeguards data from such equipment. Part 1 is expected to have a relatively mild impact, if any, on the general safeguards approaches discussed in this section. Part 2 is a longer range programme which includes, for example, environmental monitoring to provide credible assurance of the absence of undeclared activities. This part, upon full implementation, could have a substantial impact upon the safeguards approaches presented in this section.

Should the strengthened safeguards system cause the safeguards approaches described here to undergo substantial change, it will become necessary to review and revise the design measures and guidelines given in this report to facilitate safeguards implementation at future water cooled nuclear power plants.

6. DESIGN IMPLICATIONS OF EXPERIENCE IN SAFEGUARDING NUCLEAR POWER PLANTS

This section draws primarily upon the experience of the IAEA in applying safeguards to present nuclear power plants to identify areas where certain features in the design of future nuclear power plants could facilitate the application of safeguards and make them less burdensome to the operator. The IAEA's experience is given in Sections 6.1–6.8. Some additional suggestions for improving safeguards from nuclear plant owners/operators and designers/suppliers are given in Section 6.9.

6.1. NEED FOR EARLY INTERACTION

The addition, or backfitting, of safeguards equipment to existing or new but frozen-design plants is, in general, not the most efficient procedure. The importance of early interaction between designers and the IAEA to facilitate the incorporation into the facility design of features which make it easier to implement safeguards was already emphasized in Section 4. Early discussions are also desirable to enable designers to take into account the most recent developments in safeguards methods and techniques.

6.2. BARRIERS WHICH FORM PART OF C/S SYSTEMS

IAEA safeguards take advantage of the containment provided by physical barriers such as walls, tanks, pressure vessels and pipes to restrict or control the movement of, or access to, nuclear material. Physical barriers which are to be used for safeguards purposes should have as few penetrations as possible. Any necessary penetration which is not intended to be used as a nuclear material transfer route should, if possible, be designed in such a way that it is physically impossible to transport nuclear material through it. All penetrations of barriers used as containment for safeguards purposes and through which nuclear material can move may be divided into those through which the facility operator moves nuclear material for operational reasons, and those which are used for other purposes and through which movements of nuclear material do not normally occur. The normal operational routes are covered by a material accountancy device or system to determine the quantity of material which is moved. The other routes are assessed to decide if they constitute credible diversion routes. If they do it is necessary to apply seals or to install a suitable surveillance device to detect the presence or passage of nuclear material. Also, as construction progresses, verification that the as-built design is consistent with the declared design information is a key part of the IAEA's activities, which include visits to verify that there are no concealed routes through the physical barriers by which undeclared access to nuclear material is possible.

Radiation detectors of various kinds are used to detect the movement of nuclear material through routes which the operator has declared will not be used for this purpose. They are also used to count or measure the movement of nuclear material along declared normal movement routes. Provision for the installation of these devices should be made at the design stage.

6.3. SEALS

The design of the plant should take into account the possibility of applying seals and/or surveillance devices to all credible routes for moving nuclear material into and out of the core. These routes include the canal gate and the equipment hatches, as well as an open reactor vessel. Similarly, appropriate use of containment and seals in the spent fuel pool facilitates verification of the inventory of spent fuel stored there, and seals on spent fuel shipping casks are used to ensure that fuel shipments remain as declared.

Seals are commonly used by the IAEA to join movable parts of the barriers used as containment so that access to the material is impossible without breaking the seal, e.g. seals may be attached to the reactor missile shield to detect access to the core, or to the canal gate to prevent undeclared movement of fuel between the core and the spent fuel pool (see Figs 2 and 3). In all cases it is necessary to ensure that the seal wire or cable can be easily inserted through the fixed and movable parts of the containment, that the operation of the seal cannot be bypassed (e.g. by removing the hinges from a door), and that the seal and seal wires are protected so that they cannot be easily broken or damaged during normal operations. The method of attaching the seals to the item to be sealed should not involve using welded parts or brackets, but rather multiple holes in the main structure of the item for threading and attachment of sealing wires. Provision must be made for access to the seals to allow them to be applied and removed, if necessary, for the later verification of their integrity. In some cases the use of duplicate seals or the simultaneous use of optical or instrument surveillance and seals gives added confidence that diversion has not occurred and allows reduction of verification efforts. Special seals have been developed with a characteristic signature that can be read in situ by an interrogating instrument, for example the underwater ARC, VACOSS and COBRA seals.

6.4. SURVEILLANCE

Optical surveillance units, including backup units, should be placed to cover directly the areas of safeguards significance, such as the reactor cavity and the open core of LWRs, the reactor faces in CANDU reactors (if not covered by CDMs), the spent fuel pool and fuel movement routes. These may operate at fixed or varying time intervals and/or be triggered by motion detectors. The viewing area should be unobstructed and well illuminated, and the viewing camera should not be blinded by spotlights. A major problem in the interpretation of optical surveillance information can occur when large pieces of equipment which might contain or appear able to contain nuclear fuel are observed. It would be helpful if movements of such large objects were planned to avoid routes which cross areas of safeguards interest. The camera locations should also be selected so that the equipment, including cables, is not exposed to extreme conditions of moisture, temperature or radiation. If it is nevertheless necessary to locate equipment in high radiation areas, shielding needs to be provided to protect it.

Surveillance equipment and transmission lines carrying safeguards data must be designed to be tamper resistant and/or tamper indicating. Penetrations needed for cables serving surveillance equipment need to be foreseen and provided at the design stage. Separate local area networks at the reactor sites to carry safeguards information from a variety of installed safeguards equipment may be used in the future. It is expected that increasing use will be made of electronic data transmission systems so that IAEA surveillance systems can be interrogated remotely from the IAEA's Headquarters or its regional offices.

Easy access to surveillance units for the maintenance or replacement of tapes or film is desirable. Failure of the surveillance system may result in time consuming and expensive reverification of the nuclear material covered by the failed system. It is important that a stable, uninterruptible, redundant power supply to the surveillance units is provided. It would also be helpful if any interruption of the power supply to safeguards equipment caused a warning signal in the control room, so that prompt action to restore power could be taken.

A number of advanced surveillance systems have recently been implemented and more are under development, e.g. the use of lasers for surveillance, of reactor power monitors to detect if the reactor is operating and to measure its power output, and the use of unattended radiation monitoring systems.

6.5. FUEL IDENTIFICATION AND FUEL VERIFICATION

The reading of the assembly identification number is one alternative in the current safeguards accountancy system at LWRs. These numbers should be located on the assembly so that they can be easily seen by inspectors when the fuel is in the several locations where it may be inspected. When fresh LEU fuel is stored in air the verification of the nuclear material content may be carried out by counting the assemblies, and either by verifying their identifiers or by NDA measurements using portable equipment. If verified by measurement, adequate space needs to be available and the fuel needs to be easily accessible. Underwater storage of fresh fuel makes verification for safeguards purposes more difficult. The water needs to be clear since inspectors need to view objects in the pool or in the core, e.g. to use the ICVD, to read assembly numbers with the operator's CCTV system or to use underwater optical surveillance devices. The Cerenkov radiation is weaker for older fuel and since most of the Cerenkov radiation is in the ultraviolet range, water transparency in that spectrum region is particularly important when the fuel pool contains old or low burnup spent fuel.

Reactors where rod exchange and/or rod consolidation take place are of special concern from the safeguards point of view. C/S and NDA systems are necessary to safeguard against the diversion of rods when these operations are carried out. An underwater tomography system to check for missing rods in assemblies is being developed and designers may wish to foresee and plan for its installation.

Some methods for the quantitative verification of spent fuel can be applied to the spent LWR fuel in its storage position using equipment attached to the pool bridge; others require movement of the assembly to special measurement positions. Direct access to all assemblies from above is desirable and should minimize the need to move assemblies. Low density racks minimize the effect of neighbouring assemblies during NDA verification; however, if that is not feasible, a procedure for storing fuel of similar burnups and cooling times together and for isolating old fuel is helpful. Storage of spent fuel in a single layer is preferred; however, if it is planned to store spent fuel in more than one layer, material in layers below the top one needs to be verified and the storage arrangements sealed so that the rods or assemblies in the lower layer(s) cannot be removed without the seals being broken. The sealing system must be capable of periodic verification. Sealed covers for storage racks should be tamper indicating. It may also be desirable to install surveillance as a complement to the sealing system. Should the sealing or surveillance systems fail or otherwise give an indication that a diversion might have occurred, it may be necessary to verify again that the content of the store is as declared. Methods must be available to count, read the identification numbers and carry out NDA on all fuel units, including, if needed, those in the lower layers.

6.6. DETECTION OF THE UNRECORDED PRODUCTION OF DIRECT USE MATERIAL

Potential irradiation in the cores of power reactors of undeclared fertile material is of concern in safeguards. A review of the potential for such irradiation to produce plutonium in LWRs is given in Ref. [8]. Possible inspection activities related to the visual examination of LWR reactor internals are currently being discussed in the IAEA.

6.7. TRANSFER OF SPENT FUEL FROM THE SPENT FUEL POOL TO STORAGE OR REPROCESSING

Safeguards verification of the transfer of spent fuel from the spent fuel pool to dry storage or for reprocessing — using current methods — has proven to be a very labour intensive process for both the operator and the IAEA. When it is planned to transfer irradiated fuel from the facility for purposes of mid-term dry storage, long term storage or reprocessing, such transfer should be considered in the facility design, fuel handling process and storage configuration to facilitate the transfer verification process (e.g. by a monitoring system operating in an unattended mode).

The storage configuration in the spent fuel pool should allow verification without undue handling for safeguards. Ease of verification by incorporating a suitable safeguards system which uses unattended detection of fuel movements and containment/surveillance is beneficial.

6.8. SAFEGUARDING MOX FUEL

Fresh MOX fuel is more safeguards sensitive than natural uranium or LEU fuel, particularly when used in reconstitutable fuel assemblies. The NDA of MOX fuel stored in air is relatively straightforward using portable equipment. Measurement and surveillance of MOX fuel in reconstitutable fuel assemblies stored under water require special design features, e.g. monitoring systems to detect movements of the assemblies after they have been placed in the storage locations. Dedicated locations in the pool for MOX fuel would facilitate safeguarding such fuel, but are not permissible in all countries because of national regulations instituted for reasons of physical security. For these reasons, dry storage of fresh MOX fuel is easier to safeguard than underwater storage. In general, it is desirable from a safeguards perspective to minimize the storage time of fresh MOX fuel at reactor sites.

The use of seals on storage locations may be necessary for fresh MOX fuel. Provision should be made for the transfer routes used for fresh MOX fuel assemblies to be covered by an optical and/or neutron plus gamma surveillance system. It is desirable to be able to cover both the dismantling station and the locations for fresh MOX fuel storage in the spent fuel pool (if wet storage is used) by a single surveillance camera.

6.9. UTILITY AND PLANT DESIGNER EXPERIENCE WITH SAFEGUARDS

This section presents additional suggestions from utilities and designers/suppliers, i.e. items of safeguards experience not already put forward by IAEA safeguards personnel.

It would be useful for each plant to have its own safeguards centre — a dedicated room for safeguards equipment and activities. Identification by the IAEA of all plant facilities that would be needed for inspection (e.g. cranes) prior to the carrying out of inspections would help operators plan for use of the equipment and integrate this with the plant's uses. Inspections should be planned to be as unobtrusive as possible. Safeguards equipment in inaccessible areas needs to be particularly redundant and reliable. Protection is needed against loss of off-site power, particularly in countries that may experience more frequent blackouts. Safeguards equipment should never be powered from the same circuit as other operating equipment to avoid the inadvertent switch-off of the safeguards equipment when the other equipment is turned off.

For multiple unit stations, material control and accounting systems should accommodate the movement of fuel from one reactor to another, as it may sometimes be desired to pool fuel assemblies among units for common fuel management purposes. Similarly, the systems should be able to accommodate the shipment of fresh fuel from one plant site to another. The use of dummy rods when reconstituting fuel is often desirable, and the safeguards system should be structured to accommodate this.

7. GUIDELINES FOR DESIGN PROVISIONS FOR FUTURE WATER COOLED REACTORS TO FACILITATE THE IMPLEMENTATION OF SAFEGUARDS

The design guidelines for future water cooled reactors given in this section are based in part on the safeguards objectives and approaches described in earlier sections and in part on the feedback of experience with the safeguarding of operating nuclear power plants. This feedback has been obtained primarily from the IAEA, with some additional inputs also from the designers/suppliers of safeguards technology and equipment and from the owners/operators of safeguarded plants. The guidelines in this section should be considered for implementation with due regard to other guidelines and requirements for safety and security.

7.1. GUIDELINES COMMON TO ALL FUTURE WATER COOLED REACTORS

Safeguards design needs to achieve a high level of reliability, since loss of continuity of knowledge of safeguards information can require extensive efforts to re-establish inventories of safeguarded material, raise concerns if such inventories cannot be re-established to desired accuracies, and have an adverse impact on the confidence in the adequacy of safeguards at the facility concerned. General approaches used to achieve high reliability in nuclear power plant design — redundancy, diversity and quality assurance — are also applicable to safeguards design. C/S may be used as partial or full backup for each other, and individual items of safeguards equipment such as surveillance cameras and seals may be duplicated for the same or closely similar functions to provide redundancy.

An important concern in safeguards design is occupational radiation exposure of IAEA inspection personnel. Exposure control methods are generally well known to reactor designers because of the desire to minimize radiation exposure of the operations staff, and are not further elaborated here except to mention that the trend towards greater use of remote monitoring for safeguards purposes is helpful. Thus, the design should include measures to minimize such exposures and to provide the necessary radiation protection supplies and services such as protective clothing, dosimetry and showers for IAEA inspectors.

Another general safeguards concern is possible paths by which nuclear material could be diverted away from its normal, monitored route. The designers need to examine those parts of the plant through which nuclear material moves for possible diversion pathways, and either eliminate them or design to accommodate the installation of safeguards measures such as seals, surveillance equipment and monitors, or combinations thereof.

It is the responsibility of the State to provide ancillary facilities and necessary agreed services to support safeguards, such as: illumination, space for equipment and cable routes, power, telephones and operating space.

The following general design provisions would assist in the implementation of safeguards:

- Minimize the number of access points in the reactor containment and other shielding structures through which fuel movement could take place;
- Adequately illuminate the containment access points, the reactor vault and fuelling mechanism areas (see Section 7.1.3.2);
- Organize fuel transport routes so that C/S systems can be applied and safeguards information can be clearly interpreted, particularly the ability to distinguish between routine and non-routine fuel transfer and other activities;
- Minimize the effect of safeguards on plant operation by selecting locations for safeguards equipment that are accessible for inspection, monitoring and maintenance and which do not obstruct operations;
- Ensure that all safeguards activities can be accomplished safely and expeditiously and that safeguards equipment will be reasonably protected from unintentional damage;

- Clearly label all installed equipment relevant to safeguards (including cabling, power supplies and switches) to avoid inadvertent interruptions in surveillance and monitoring;
- Provide water purification equipment to ensure water clarity in the visible and ultraviolet spectra.

Many of these general guidelines could be easily met if a single dedicated space can be provided for the safeguards electronic equipment, plus additional data processing and transmission equipment that may become available in the future to simplify and expedite the safeguards activities.

7.1.1. Data and information collection and transmission

Safeguarding nuclear material in a nuclear power station is fundamentally a process of obtaining information that establishes that the declared record of nuclear material inventory items and fissile material quantities is reliable and that any discrepancies between the declared record and the physical inventory are revealed. The information set must be continuous in time but may be a sampled set; the frequency or period of sampling should be consistent with the individual plant requirements, taking into account the types of nuclear materials involved, the associated timeliness requirements and the estimated time required to accomplish a diversion. As stated earlier, a break in the information flow, whether unintentional or deliberate, must be treated as a potentially suspicious event that will initiate an investigation that could lead to a process of reverification.

The reverification would aim to re-establish confidence in the comparison between the declared record and the physical inventory. It can be treated as a new information set that restores the knowledge of the fuel materials record. Efforts to avoid loss of continuity of knowledge are made in a manner similar to other information systems, i.e. redundancy of equipment, diversity of technique and overlap of observation and measurement (a form of redundancy). The safeguards system must also be deployed with consideration of deliberate interference as a possibility along with normal failure modes.

The type of data and information that can be involved are:

(a) Images from optical surveillance (or other wavelengths),
(b) Results from Cerenkov inspection of irradiated fuel,
(c) Seal integrity,
(d) Containment integrity,
(e) Nuclear data from NDA:

- routine simple gross gamma single measurements or scans,

- — neutron counting, both single and coincidence,
- — gamma spectrometry by isotope windows and spectrum analysis,
- — gamma tomography (rarely).

(f) Data from monitoring and sensing equipment,
(g) Combinations and permutations of the above, sometimes in time coincidence.

These data can be collected manually by inspectors, continuously by operating monitors and at fixed intervals by monitors that record sampled data. A similarly wide range of data recording methods is used according to the circumstances — written records, tape recordings, photographic film and electronic media, among others. For each measurement and surveillance instrument, space should be provided for a recording device within a reasonable distance of the instrument and which is accessible to an inspector. Consideration should be given to networking instrumentation and remote transmission to the IAEA.

The information gathering, recording and transmission equipment require a suitable working environment and protection from accidental damage. Specifically, space, services and reasonably protected locations should be provided for such equipment.

On the basis of current practice, the data are gathered during a visit to the site by an inspector. Some of the data are assessed at that time for immediate use. The bulk of the information is carried to either IAEA Headquarters in Vienna or its regional office where it is analysed in detail for anomalies between the declared operating record and the independent safeguards record provided by the safeguards equipment.

Like all information systems, the safeguards information flow can benefit from the rapid advances taking place in information collection, processing, transmission and interpretation. These advantages are expected to reduce the costs of safeguards while improving effectiveness. Further, by using unattended systems, the intrusiveness of safeguards activities on plant operations would be reduced.

To take advantage of these information technologies the following actions are planned by the IAEA:

(1) To a large extent data and images will be collected and converted to digital form;
(2) Local area network methods will be developed to permit data recording at one central point at the plant site;
(3) Computer techniques will likely be used for local data recording and for a control system for safeguards equipment;
(4) These local computers may perform data processing for analysis, data compression and encoding;
(5) Data transmission from the plant to IAEA offices could take place in real time or by batches over common carrier or dedicated transmission channels, either land based or by satellite.

Designers/owners of future power plants can take advantage of these advances in information technology by:

- — Providing access to appropriate penetrations in the containment building for data transfer lines serving the remote monitoring equipment/instrumentation;
- — Providing support for an IAEA tamper resistant local area network connection at each safeguards measurement point;
- — Making allowance for digitizing equipment at the measurement sites;
- — Making a centralized site available for data recording, analysis and processing computers;
- — Giving consideration to permitting transmission facilities, e.g. a satellite dish, at the plant site.

All of the equipment associated with the advanced information systems would have to achieve a very high level of reliability and tamper resistance. Included in these protective standards would be information specific protection features such as data encryption for transmission and data/image authentication techniques as required.

7.1.2. Identifiers for fuel assemblies and fuel rods

The primary means of safeguarding fissionable materials at water cooled reactor facilities has historically been the accounting and control of fuel assemblies or bundles. Such accounting and control may be facilitated by a unique identifier for each fuel assembly; this is usually the fuel fabricator's serial number placed on the fuel assembly at the fuel fabrication plant. The identifier:

- — Should be readable from above when the fuel is in the fresh fuel storage area, the spent fuel pool and, for LWRs, the reactor core during refuelling;
- — Should ideally be impossible to remove or change and should retain its legibility throughout irradiation and storage. In practice, it is sufficient if tampering is difficult and is obvious upon viewing by safeguards inspectors.

For on-load refuelled plant fuel and for non-reconstitutable fuel for off-load refuelled plants, assembly identifiers are sufficient for identifying all fuel. Such identification may or may not be required for safeguards, depending on the safeguards approach. Most modern off-load refuelled plants already use and virtually all future, advanced off-load refuelled plants are expected to use reconstitutable fuel assemblies (i.e. assemblies which are designed for the removal and replacement of individual fuel rods), and to practice reconstitution routinely upon failure of individual fuel rods prior to the intended final cycle in the reactor core of the fuel assembly containing the failed rod or rods. Further, rod consolidation (i.e. the disassembly of fuel bundles into their individual rods and the other non-fuel hardware) has been developed and demonstrated and is an option in some countries for reducing the volume of spent fuel waste. Substantial reconstitution or rod consolidation operations make it impractical to use fuel assembly identifiers. Serial numbers on individual fuel rods could be used by the IAEA as identifiers for individual rods.

7.1.3. Containment and surveillance

C/S is the primary method for the IAEA to ensure continuity of knowledge of the nuclear material of the MBA (see Section 5.2, item 2). In practical applications the processes are based on:

- Optical surveillance of illuminated spaces,
- Continuously recording nuclear instruments that monitor strategic fuel transport locations,
- Sealing of access ports and doorways into areas or containers in which nuclear material is stored.

The installed safeguards equipment needs to be provided with a means to ensure that any tampering will be evident to IAEA inspectors.

7.1.3.1. Sealing systems

An acceptable means to demonstrate continuous closure of an opening in a barrier wall is to cover the opening sufficiently to prevent fuel movement and apply a seal. This is a general approach that can be applied at strategic points in fuel movement pathways and for rooms or other structures that constitute a secure ‘container’ storage for fuel. These barriers and containers are unique to the particular design situation and are the designer’s responsibility.

Sealing systems can be installed to contain:

- Spent fuel inventories stored in the ponds,
- Spent fuel casks,
- The reactor core,
- Transfer canal gates.

Sealing systems are an effective and versatile means of demonstrating secure containment during periods of inactivity. To be effective the design must provide:

- Barrier walls that are secure, i.e. continuous, have no openings large enough to permit the passage of a fuel item and cannot be easily breached without detection;

- Accessibility of the walls of the barrier for inspection for evidence of tampering;
- Protection of the wires and parts comprising the seal from damage or inadvertent breakage;
- Access to the attachment point, i.e. the holes, wire threading path, etc., that permit convenient application and removal of the seal.

The seals available for use in safeguards applications include the following:

- ‘E type’ metallic cap seals in which a copper or steel wire is knotted or crimped inside the seal. The seals are numbered and have a unique identification mark inside the seal.
- Fibre optic seals (e.g. the COBRA seal) in which the seal wire is replaced by a multistrand fibre optic loop, the ends of which are enclosed in such a way that a random pattern of fibres is produced. This is verified by shining a light into the end of the loop and observing the pattern either visually, photographically or by TV.
- Electronic seals (e.g. the VACOSS seal) which use electronic encoding methods in conjunction with fibre optic loops, and which can store information about the time of application and status of the seal. Electronic seals cannot always be used in high radiation fields and in other extreme environmental conditions.
- Ultrasonic seals (e.g. the ARC seal) which contain random patterns of bunches of fibre or wire. This pattern can be read by a suitable ultrasonic transducer which provides a signal unique for the pattern of the particular seal.

Some seals, such as the underwater ultrasonic seals which are designed to be read for integrity in situ, may require special tools and equipment. There are also some cases where ancillary parts and test tools are critical to the sealing concept. A design feature that would facilitate seal operations is the provision to store seal interrogation equipment (e.g. for ARC seals). The choice of seal depends on the application and will be decided by the IAEA on the basis of suitability, reliability, cost and convenience of reading.

7.1.3.2. Optical surveillance

Safeguards surveillance cameras can be installed to view:

- The spent fuel pool,
- Reactor closure,
- Exit doors and hatches through which spent fuel could be removed.

Suitable locations need to be identified by the IAEA for the cameras such that:

- Their viewing angles cover the area to be watched,
- The view is clear and unobstructed,
- The area viewed has adequate uninterruptible illumination,
- Interfering lighting arrangements, e.g. spotlights that could ‘blind’ the viewing cameras or reflected light that could degrade their image, are avoided.

The level of illumination that is adequate depends on the specific cameras to be used, and in future plants CCTV is most likely to be used. These cameras may incorporate features which provide indicators to alert IAEA inspectors to tampering. At times more than one camera may be installed to provide surveillance of a single area. Interruptions or failures of lighting, power supply to cameras or other equipment vital for surveillance represent potential safeguards concerns. The following design features facilitate optical surveillance:

- Provision of suitable measures to ensure adequate continuity of surveillance for known, expected interruptions, e.g. during leak rate testing of the reactor containment, when it may be desirable to extinguish all lights within the reactor containment;
- Provision of appropriate backups for reasonably expected power supply or equipment failures;
- Provision of independent electrical circuits and switch gear to avoid the possibility of inadvertent interruptions of electric power to safeguards equipment.

If continuity of surveillance is lost for a sufficiently long interval of time to be of safeguards concern, IAEA inspectors will need to come on-site to re-establish the inventory of fuel through direct verification. These inspections will include verification of the seal integrity of sealed areas containing fuel. The inspection might also extend to identification of fuel items and to the NDA of their characteristics. This kind of inspection is demanding of IAEA and operator resources and is likely to be inconvenient to the plant operator because of its intrusiveness. Good optical surveillance provisions ensure that inspections of this kind will rarely, if ever, be needed.

7.2. GUIDELINES FOR OFF-LOAD REFUELLED REACTORS

LWRs are item facilities, i.e. nuclear facilities where all nuclear material is contained in identifiable items (e.g. fuel assemblies), the integrity of which normally remains unaltered during their residence at the facilities. IAEA safeguards are applied according to standard item accountancy procedures, i.e. the inventory of nuclear material in the facility is periodically verified by the IAEA. Verification of transfers to and from the facility is used to assist in establishing verified inventories.

An LWR facility has the following kinds of items containing nuclear material which are subject to safeguards: fresh LEU fuel assemblies; fuel assemblies in the core undergoing irradiation; and irradiated, spent fuel assemblies and in some cases rods. In addition, some facilities use MOX fuel assemblies. Guidelines to facilitate safeguards specifically for the use of MOX fuel are given in Section 7.5.

The items subject to safeguards are normally present at three locations within the facility, which are considered as KMPs for inventory purposes. These are the fresh fuel storage area, the reactor core and the spent fuel storage pool. Fresh fuel is normally present in the fresh fuel storage area and may also be present in the spent fuel pool prior to refuelling. Irradiated fuel is normally present in the reactor core and in the spent fuel pool. During refuelling operations, both fresh and irradiated fuel are generally also present, temporarily, in the fuel movement and transfer facilities which connect the fresh fuel storage area, the reactor core and the spent fuel pool. Similarly, during fuel shipment operations, fresh fuel is temporarily present along the fuel receipt pathway and spent fuel is temporarily present along the spent fuel shipment pathway. The fresh fuel storage area, the reactor core and the spent fuel pool together constitute a single MBA for safeguards purposes.

The operation of an LWR typically involves replacing about one-fifth to one-half of the reactor core fuel during each refuelling, over time intervals ranging from one to two years. Refuellings are normally the only occasions when IAEA inspectors have access to the core for inventory verification purposes.

7.2.1. Fresh fuel receiving and storage areas

In the fresh fuel storage areas, the following design provisions may assist in the implementation of safeguards:

(a) A minimum number of openings in the building structure accessing the fresh fuel storage area (through which removal of fuel could take place), with suitable arrangements, if required by the safeguards approach, which allow sealing and/or surveillance of these openings;

(b) Layout of the fresh fuel storage area to allow inspectors to verify and progressively seal groups of fuel assemblies as they are put into storage without affecting the continuity of knowledge of the inventory already held;

(c) Provision of adequate space and illumination between assemblies to allow inspectors to read the identifiers on fuel assemblies and to conduct NDA; specifically:
    - provision for the use of the IAEA inspector’s portable NDA equipment;

- arrangement of fuel within the storage area to minimize the necessity for moving fuel to identify specific assemblies.

7.2.2. Fuel loading and unloading

The following design features would assist in the implementation of safeguards:

- A suitable mounting for surveillance equipment which inspectors can use to view the tops of the fuel assemblies when the reactor vessel is open,
- An indexing mechanism on the refuelling machine with a device which can identify the location of each assembly,
- Provisions for sealing the canal gate (when applicable) to prevent it being opened without the knowledge of the inspectors.

7.2.3. Reactor core

Design features that would assist in the implementation of safeguards for the fuel in the reactor core include:

- Suitable arrangements for the application of a sealing system to the nuclear material contained in the reactor core. Such a system should be accessible for inspection, easy to install and protected against damage. The preferred core seals are usually indirect in that they are multi-point seals applied to the missile shield, the reactor slab or some other component, rather than directly to the reactor vessel.
- Suitable arrangements for surveillance equipment to view reactor vessel operations whenever the vessel is open.
- Underwater illumination in the reactor vessel and sufficient water clarity to allow the inspector to count the fuel assemblies and read their identifiers.

7.2.4. Spent fuel storage and shipping areas

In the spent fuel storage and shipping areas, design features that would assist in the implementation of IAEA safeguards are:

- Suitable arrangements for the installation of surveillance equipment.
- Room light sources preferably selected so that their spectrum does not overlap the characteristics of the ICVD imager (which is sensitive to the ultraviolet range); otherwise the signal/background advantage could be lost.

- Storage racks preferably configured in a single layer, which permits the viewing of the top of each fuel assembly and its identifier from directly above, e.g. there should not be any overhang over fuel storage locations.
- Provision for verifying and sealing the fuel in the lower layer(s), if fuel is stored in more than one layer.
- An indexing system for the identification of specific fuel assembly locations from the fuel handling control point.
- A minimum number of openings in the building structure through which it is possible to transfer spent fuel, with suitable arrangements which allow sealing and/or surveillance of these openings.
- Water clarity to allow easy visual inspection of the fuel assemblies in their storage position and viewing of the Cerenkov glow from the assemblies. The latter requires water clarity in the ultraviolet as well as in the visible spectrum.
- Provisions that facilitate the annual PIVs, which consist of counting the total number of spent fuel items and verifying spent fuel attributes by NDA. Specifically:

    (i) Minimizing the movement of fuel for these purposes;
    (ii) Providing adequate working space on the bridge for inspectors and their equipment;
    (iii) For special cases (e.g. long cooled fuel or locations not vertically accessible) provision for raising assemblies to allow NDA by, for example, a Fork Detector;
    (iv) Provisions in the facility design, the fuel handling process and the storage configuration that facilitate the verification of fuel transfers out of the pool (e.g. by a monitoring system operating in an unattended mode);
    (v) To facilitate safeguards during fuel reconstitution, the location for reconstitution should be designed, if possible, such that the flow of assemblies and/or rods into and out of the area follows predefined routes which can be monitored by IAEA equipment.

7.3. GUIDELINES FOR ON-LOAD REFUELLED REACTORS

On-load refuelled reactors are characterized by routine fuel movements that are necessary for regular (e.g. daily) refuelling. Safeguards activities are therefore established in accordance with this fuel movement. Design measures for fuel transport routes which facilitate safeguards are:

- Layout of fuel transport routes to facilitate optical surveillance and/or radiation monitoring.

- Design to minimize the possible diversion pathways (see Section 5.2 for a discussion of pathway countermeasures).

The specific discussion that follows provides guidelines for design measures which facilitate the implementation of safeguards, with specific points illustrated in reference to CANDU reactors. Safeguards methods have been established for these reactors to provide continuous records of the nuclear material distribution between the new fuel storage area, the reactor core and the spent fuel storage. Figures 4–6 may be helpful in following the discussion.

7.3.1. Fresh fuel receiving and storage areas

The fresh natural or LEU fuel inventory is verified annually by item counting, NDA and, where applicable, serial number identification. As a general rule the material content of each assembly is established at the fuel fabrication plant and each assembly is given a serial number. The fuel shipment may be transported under seal.

Fresh fuel storage needs sufficient space and illumination so that IAEA inspectors can perform an annual PIV by counting boxes of fuel bundles, verifying serial numbers and performing NDA of randomly selected bundles. Design features which facilitate safeguards are:

- Sufficient aisle space between storage containers for inspection access,
- Ease of fuel bundle removal and placement back into storage,
- Adequate space for NDA equipment in a sufficiently low background area.

7.3.2. Fuel loading and unloading

For the reactor core refuelling monitors, the following design features facilitate the implementation of safeguards (recall from Section 5.4.2 that only one of the CCTV or CDM options need be used):

- *CCTV option:* Provision for the installation of optical surveillance capable of withstanding high radiation fields, e.g. radiation hardened CCTVs or shielded locations for standard cameras with overlapping fields of view to monitor the reactor end faces and transit routes to the new and spent fuel ports. As part of the CCTV option, provision should be made for the installation of yes/no radiation detectors, typically thermoluminescent dosimeters or PIN detectors, at new fuel ports. They should be shielded from the radiation emanating from other fuelling activities and mounted in tamper indicating enclosures.

- *CDM option:* Provision for the installation of CDMs (more than one detector assembly at each reactor end face) such that the signals are not obscured by shielding of the reactor components.
- The core refuelling monitoring equipment must operate with high reliability. Access to the equipment for maintenance activities without the need for reactor shutdown should be incorporated into the design. For components which remain difficult to access, consideration should be given to means of maintenance and possible replacement at the end of their duty cycle.
- Provision for cabling for power and signals that must be passed through the vault shielding penetrations for CDMs or surveillance equipment in ways that avoid damaging radiation fields and electromagnetic interference.
- Provision of space for tamper indicating cabinets for the associated electronics at a safe and convenient location outside the reactor vaults.

A spent fuel bundle counter typically consists of one counter assembly positioned at each fuel discharge port, if applicable, so as to be able to verify the flow of spent fuel. A counter assembly consists of a set of collimators and radiation detectors, plus guide tubes leading to an accessible area for detector installation and cable routing. The guide tubes are bent to prevent radiation streaming. The number of detectors and their location will vary with the fuel path and will be determined by a diversion analysis. Design features which accommodate the bundle counters are as follows:

- The spent fuel transfer path should preferably be defined so that the spent fuel enters the storage area via spent fuel discharge ports.
- A shielding penetration matching the collimator/guide tube design provided at the appropriate locations, along with an access route through the plant to permit the equipment to be installed;
- The available end of the guide tube should be accessible for IAEA inspection of covers and seals.

7.3.3. Spent fuel storage and monitoring

Four safeguards relevant factors which influence the design of the spent fuel handling system and storage ponds are:

(1) Type of fuel, e.g. natural uranium or LEU;
(2) Fuel flow or quantity;
(3) Storage period before shipping and capacity of the bay (typically ten years);
(4) Access points to the building where large containers can be moved.

7.3.3.1. Spent fuel storage surveillance

The complete water surface of the spent fuel bays and the dry deck working areas should be under continuous optical surveillance. Design features which facilitate the application of safeguards in the spent fuel storage area include:

- Provision for the installation of optical surveillance equipment such as CCTV cameras in tamper indicating enclosures, with fields of view unobstructed by normal activities, preferably overlapping for redundancy;
- Provision for appropriate, continuous illumination, above and below the pool surface, supplemented with portable lighting.

7.3.3.2. Bundle containment

The spent fuel bundles are currently stored horizontally in trays or modules containing, respectively, 24 and 96 bundles. Full trays or modules are stacked vertically. If stacking frames are provided for support and containment (see Fig. 8), they should have design features so that:

- Fuel cannot be removed from the bottom under any credible circumstances;
- Fuel can only be loaded and unloaded from the top;
- One end of each bundle is available for sample inspection, i.e. item counting (the serial number should be visible) and NDA;
- The sides of the enclosure should permit bundle inspection and show evidence of any attempt at tampering;
- The fuel stack covers and fastening arrangements should prevent the removal of bundles, show evidence of tampering and provide for the secure installation of one or more in situ verifiable seals, e.g. ARC seals and seal covers.

Safe, stable working and viewing platforms, tools for building and sealing stacks, as well as tools for inspection and attribute testing are necessary for both the facility operating staff and IAEA inspectors:

- The installation tools and equipment, especially items like the ARC seal cover and cover installation tool, should be designed for time efficiency to reduce costs and inconvenience to both the utility and the IAEA.
- The ARC seals are readable under water using special tools and instruments. Provision should be made for both secure storage and use of these tools and instruments.

The possible use of alternative fuel options involving LEU or direct use material (see Section 7.5) will not affect general spent fuel safeguards principles. However, the details of the safeguards approach could be affected because higher burnup will reduce the flow rate of fuel and affect the number of spent fuel bundles containing a significant quantity of fissile material.

7.4. TRANSFERS TO DRY STORAGE FROM ON-LOAD AND OFF-LOAD REFUELLED REACTORS

After a suitable cooling time, the spent fuel at some reactors is transferred to dry storage (see Section 6.7). Such transfers require safeguards activities for verification and to maintain continuity of knowledge of the transferred material. Design measures which facilitate these activities are a well defined flow path for the spent fuel and the provision of space for any safeguards verification equipment that might be needed.

7.5. GUIDELINES FOR ON-LOAD AND OFF-LOAD REFUELLED REACTORS USING MOX FUEL

As discussed in Sections 5.5 and 6.8, MOX fuel contains unirradiated, direct use material and consequently requires more stringent safeguards approaches. Fresh MOX fuel may be stored either dry or in the spent fuel pool. The transfer routes for MOX fuel from fresh fuel storage into the reactor need to be as direct as possible and allow coverage by human or optical surveillance and/or neutron/gamma monitoring systems.

If fresh MOX is in dry storage, the design features that facilitate safeguards are as follows:

- Storage time at the power plant should be minimized,
- Adequate space should be provided for the use of NDA equipment,
- Sealing of the fuel within dry storage should be easily accomplished.

If fresh MOX fuel is stored in the spent fuel pool, the design features that facilitate safeguards include the following:

- Storage time at the power plant should be minimized,
- Dedicated locations for MOX fuel in the pool are preferred,
- Provision should be made for the installation of underwater surveillance camera(s) covering the fresh MOX fuel,
- A layout that allows coverage by a single surveillance camera of both the area for fuel reconstitution (if applicable) and the locations for fresh MOX fuel storage in the pool is preferred.

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Appendix I

SUMMARY OF INFORMATION REQUESTED IN THE IAEA'S DESIGN INFORMATION QUESTIONNAIRE

GENERAL INFORMATION (all facilities)

1. Name of the facility (including usual abbreviation):

2. Location and postal address:

3. Owner (legally responsible):

4. Operator (legally responsible):

5. Description (main features only):

6. Purpose:

7. Status (planned; under construction; in operation):

8. Construction schedule dates (if not in operation):

   Start of construction Commissioning Operation

9. Normal operating mode:
   (days only, two shift, three shift; number of days/annum, etc.)

10. Facility layout: Drawing(s) attached under Ref. Nos
    (structural containment, fences, access, nuclear material storage areas, laboratories, waste disposal areas, routes followed by nuclear material, experimental and test areas, etc.)

11. Site layout: Drawing(s) and/or maps attached under Ref. Nos
    (site plan showing in sufficient detail, location, premises and perimeter of facility, other buildings, roads, railways, rivers, etc.)

12. Names and/or title and address of responsible officers:
    (for nuclear material accountancy and control, and contact with the Agency. If possible, attach organization charts showing position of officers.)

GENERAL REACTOR DATA (research and power reactors)

13. Facility description: General flow diagram(s) attached under Ref. Nos

14. Rated thermal output, electricity output (for power reactors):

15. Number of units (reactors) and their layout in the nuclear power plant:

16. Reactor type:

17. Type of refuelling (on or off-load):

18. Core enrichment range and Pu concentration:
(at equilibrium for on-load reactors, initial and final for off-load reactors)

19. Moderator:

20. Coolant:

21. Blanket, reflector:

NUCLEAR MATERIAL DESCRIPTION

22. Types of fresh fuel:

23. Fresh fuel enrichment (^{235}U) and/or Pu content:
(average enrichment per each type of assembly)

24. Nominal weight of fuel in elements/assemblies (with design tolerances):

25. Physical and chemical form of fresh fuel (general description):

26. Reactor assemblies[1]: Drawing(s) attached under Ref. Nos
(indicate for each type)

— Types of assemblies

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[1] Assembly is the combination of elements or handling units such as a cluster or bundle.

- Number of fuel assemblies, control and shim assemblies, experimental assemblies in the core, in blanket zone(s)
- Number and types of fuel rod elements[2]
- Average enrichment and/or Pu content per assembly
- General structure
- Geometrical form
- Dimensions
- Cladding material.

27. Description of fresh fuel elements: Drawing(s) attached under Ref. Nos

- Physical and chemical form of fuel
- Nuclear material and fissionable material and its quantity (with design tolerances)
- Enrichment and/or Pu content
- Geometrical form
- Dimensions
- Number of slugs/pellets per element
- Composition of alloy
- Cladding material (thickness, composition of material, bonding).

28. Provision for element exchange in assemblies of each type:
(indicate whether this is foreseen to become a routine operation)

29. Basic operational accounting unit(s): Drawing(s) attached under Ref. Nos
(fuel elements/assemblies, etc.)

30. Other types of units:

31. Means of nuclear material/fuel identification:

32. Other nuclear material in the facility (each separately identified):

NUCLEAR MATERIAL FLOW

33. Schematic flow sheet for nuclear material: Diagram(s) attached under Ref. Nos
(identifying measurement points, accountability areas, inventory locations, etc.)

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[2] An element is the smallest contained fuel unit.

34. Inventory:
State quantity range, number of items and approximate uranium enrichment and plutonium content for (under normal operating conditions):

- Fresh fuel storage
- Reactor core
- Spent fuel storage
- Other locations.

35. Load factor (power reactors only):

36. Reactor core loading (number of elements/assemblies):

37. Refuelling requirements (quantity, time interval):

38. Burnup (average/maximum):

39. Is the irradiated fuel to be reprocessed or stored? (If stored, indicate site.)

NUCLEAR MATERIAL HANDLING

40. Fresh fuel

- Packing (description)
- Layout, general arrangements and storage plant: Drawing(s) attached under Ref. Nos
- Capacity of store
- Fuel preparation and assay room and reactor loading area: Drawing(s) attached under Ref. Nos (description and indication of layout and general arrangement).

41. Fuel transfer equipment (including refuelling machines): Drawing(s) attached under Ref. Nos

42. Routes followed by nuclear material (fresh fuel, irradiated fuel, blanket, other material)

43. Reactor vessel (showing core location, access to vessel, vessel openings, fuel handling in vessel): Drawing(s) attached under Ref. Nos

44. Reactor core diagram: Drawing(s) attached under Ref. Nos
(showing general disposition, lattice, form, pitch, dimensions of core, reflector, blanket; location, shapes and dimensions of fuel elements/assemblies; control elements/assemblies; experimental elements/assemblies)

45. Number and size of channels for fuel elements or assemblies and for control elements in the core

46. Average mean neutron flux in the core:

— Thermal
— Fast

47. Instrumentation for measuring neutron and gamma flux

48. Irradiated fuel: Drawing(s) attached under Ref. Nos

(i) Layout, spent fuel storage plan and general arrangements (internal and external)
(ii) Method of storage
(iii) Design capacity of storage
(iv) Minimum and normal cooling period prior to shipment
(v) Description of irradiated fuel transport equipment and shipping cask (if no information on site, where is it held?)

49. Maximum activity of fuel/blanket after refuelling (at the surface and at a distance of 1 m)

50. Methods and equipment for handling irradiated fuel (except as already given in items 41 and 48(v)).

51. Nuclear material testing areas (except as already given in item 40).
For each such area briefly describe:

— Nature of activities
— Major equipment available (e.g. hot cell, fuel element decladding and dissolution equipment)
— Shipping containers used (main material, scrap and waste)
— Storage areas for both unirradiated and irradiated materials
— Layout and general arrangement

Drawing(s) attached under Ref. Nos

COOLANT DATA

52. Flow diagram: Drawing(s) attached under Ref. Nos
(indicating mass flow, temperature and pressure at major points, etc.)

PROTECTION AND SAFETY MEASURES

53. Basic measures for the physical protection of nuclear material

54. Specific health and safety rules for inspector compliance (if extensive, attach separately)

NUCLEAR MATERIAL ACCOUNTANCY AND CONTROL

55. System description: Specimen forms used in all procedures attached under Ref. Nos.
Give a description of the nuclear material accounting system, of the method of recording and reporting accountancy data, the procedures for account adjustment after inventory, and correction of mistakes, etc., under the following headings:

- General (This section should also state what general and subsidiary ledgers will be used, their form (hard copies, tapes, microfilms, etc.) as well as who has the responsibility and authority. Source data (e.g. shipping and receiving forms, the initial recording of measurements and measurement control sheets) should be identified. The procedures for making adjustments, the source data and records should be covered as well as how the adjustments are authorized and substantiated.)
- Receipts
- Shipments
- Physical inventory (Description of procedures, scheduled frequency, methods of operator's inventory taking (both for item and/or mass accountancy), including relevant assay methods and expected accuracy, access to nuclear material, possible verification methods for irradiated nuclear material, methods of verification of nuclear material in the core.)
  List of major items of equipment regarded as nuclear material containers attached under Ref. Nos
- Nuclear loss and production (estimation of limits)
- Operational records and accounts (including method of adjustment or correction and place of preservation and language)

56. Features related to containment and surveillance measures (general description)

57. For each measurement point of accountability areas, identified in particular in items 13, 33 and 34. Give the following (if applicable) (for each measurement point fill in separate sheet). If necessary, attach drawing(s):

- Description of location, type, identification
- Anticipated types of inventory change and possibilities to use this measurement point for physical inventory taking
- Physical and chemical form of nuclear material (with cladding materials description)
- Nuclear material containers, packaging
- Sampling procedures and equipment used
- Measurement method(s) and equipment used (item counting, neutron flux, power level, nuclear burnup and production, etc.)
- Source and level of accuracy
- Technique and frequency of calibration of equipment used
- Programme for the counting appraisal of the accuracy of methods and techniques used
- Methods of converting source data to batch data (standard calculation procedures, constants used, empirical relationships, etc.)
- Anticipated batch flow per year
- Anticipated number of items per flow and inventory batches
- Type, composition and quantity of nuclear material per batch (with indication of batch data, total weight of each element of nuclear material and, in the case of plutonium and uranium, the isotopic composition when appropriate; form of nuclear material)
- Access to nuclear material and its location
- Features related to C/S measures

OPTIONAL INFORMATION

58. Optional information (that the operator considers relevant to safeguarding the facility)

Appendix II

IAEA SAFEGUARDS INSTRUMENTATION COMMONLY USED FOR POWER REACTORS

VERIFICATION MEASUREMENTS

LWRs

Material category	Main stratum	Material type components	Defect type	Defect description	Measurements required	Applicable method[a]	Commonly used instruments
Unirradiated direct use	Fresh Mox fuel	Pu, DNLEU	G	Assembly missing or replaced with LEU assembly	Identification, Pu radiation	A, H	FDET
			P[b]	Pin replacements	Pu content[c]	F	PNCL+HRGS + HM-4[d]
Irradiated direct use	Core fuel	Pu, DNLEU	G	Assembly missing	Item count	I	—
	Spent fuel	Pu, DNLEU	G	Assembly replaced by dummy, or missing	Radiation	H	ICVD, CPMU, HSGM[e], SFAT
			G	Collections of dismounted pins missing or replaced	Radiation	H	ICVD[f], CPMU, HSGM[e], SFAT FDET
			P[g]	Half or more of pins replaced	Quantitative measure of irradiated fuel content	F	FDET

On-load reactors

Material category	Main stratum	Material type components	Defect type	Defect description	Measurements required	Applicable method[a]	Commonly used instruments
Indirect use	Fresh fuel	DNLEU	G	Assembly replaced by dummy, or missing	Identification or U radiation	A or H[h]	HM-4[i]
Unirradiated direct use	Fresh MOX fuel	Pu, DNLEU bundle	G	Bundle missing or replaced with NU	Identification, Pu radiation	A, H	
			P	Pin replacements	Pu content[c]	F	PNCL+HRGS+ HM-4[d]
	Fresh booster assemblies[j]	HEU	G	Assembly missing or replaced	U radiation	H	PMCG
			P	Pin replacements	^{235}U content	F	
Irradiated direct use	Core fuel	Pu, NU, DU	G	Missing	Item count of discharged fuel bundles	I, H	CSFC, CCDM
	Spent fuel	Pu, NU, DU	G	Replaced by dummy or missing	Radiation	K H	UWTV ICVD, CPMU, HSGM[k], CSFC, CBVB[l]
Indirect use	Fresh fuel	DNLEU	G	Replaced by dummy, or missing	Radiation	H	HM-4[i]

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[a] An item count is performed to establish the population to be verified.

[b] The partial defect to be detected is determined by assuming that 1 SQ of plutonium would be diverted by substituting the same number of MOX fuel pins in each fresh MOX fuel assembly in the inventory.

[c] Pu isotopic measurements are not required if the Pu isotopes have been confirmed at the fabrication plant and the assemblies can be identified.

[d] HM-4 used for active length measurement.

[e] In special cases, e.g. for fuel with long cooling time, or where visibility is poor; CPMU and HSGM for isolated fuel items only.

[f] For collection of pins that are visible.

[g] If required by the Deputy Director General of the IAEA Department of Safeguards in case of a conclusive negative C/S result, and when required for verification of material before becoming difficult to access.

[h] Identification can be used, where applicable.

[i] HM-4 can be used where the background level permits.

[j] Not expected to be used in future CANDU designs.

[k] In special cases, e.g. for fuel with long cooling time or where visibility is poor, and where fuel bundles are sufficiently isolated.

[l] Other specialized equipment is used for verification of the inter-bay transfer of spent fuel.

Abbreviations:
DNLEU — depleted natural and low enriched uranium; HEU — high enriched uranium.
Defect type: G — gross; P — partial.
Verification applicable method: A — identification (optionally using random selection); B — weighing; C — volume determination; D — sampling and analysis; F — variables by NDA in attribute mode (partial defects); G — criticality check for verification; H — attribute test by NDA (gross defects); I — item counting (optionally using random selection); K — spent fuel inventory check (for multiple layer spent fuel stores).

Code/name: CBVB/CANDU Bundle Verifier for Baskets.

Nuclear material/location: Spent fuel/spent fuel pool.

Application: Attribute test by NDA; spent fuel inventory check.

Facility equipment required: Crane or hoist.

Instrument description: CdTe detector with associated pre-amplifier in a collimator unit, PC, MCA, detector drive unit connected to an electronic controller, AC cable, detector cables;

Power supply: AC.

Photo: IAEA inspector using the CBVB at a CANDU reactor.

Code/name: CCDM/CANDU Core Discharge Monitor.

Nuclear material/location: Spent and irradiated fuel/CANDU reactor vault.

Application: To monitor spent fuel discharges from the core.

Facility equipment required: Mounting equipment for permanent installation of each detector assembly (connected to one data acquisition and control module via cabling through penetration modules).

Instrument description: Four detector assemblies, penetration module, electronics assemblies (one data acquisition and control module, and pre-amplifier), three computers, detector cable, AC cable.

Size: Detector assembly: 100 × 80 × 50 cm, electronic enclosure: 42 × 20 × 51 cm, CPU assembly: 220 × 50 × 80 cm.

Power supply: AC, batteries.

Recording media: Digital media.

Remarks: The detector assemblies require no servicing and contain no active electronics. All components located inside the reactor vaults are fully redundant and passive, with life expectancies exceeding ten years.

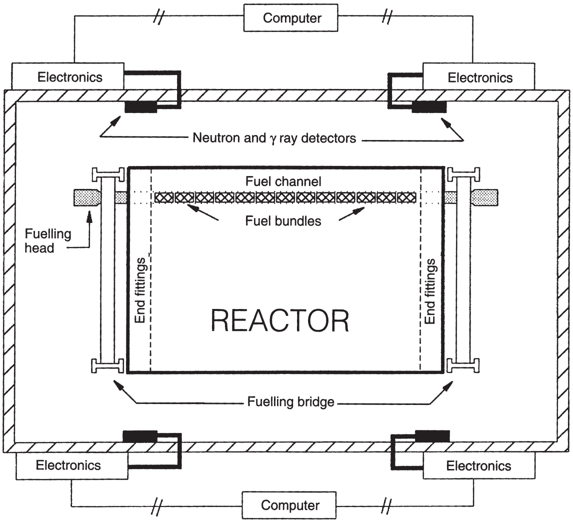


Figure: CCDM layout in a CANDU reactor vault.

Code/name: CPMU/High Range Underwater Monitor ('Cutie Pie').

Nuclear material/location: Spent fuel/spent fuel pool.

Application: Attribute test by NDA.

Facility equipment required: None; hand-held.

Instrument description: Ion chamber, monitor, detector cable, AC cable for battery recharge.

Power supply: Batteries (AC for battery recharge).

Code/name: CSFC/CANDU Spent Fuel Bundle Counter.

Nuclear material/location: Spent fuel/path from reactor discharge to spent fuel pool.

Application: Attribute test by NDA; item counting; process signals (from Geiger–Müller (GM) radiation detectors) by an electronic logic unit.

Facility equipment required: Four GM radiation detectors mounted along the path from the reactor discharge to the spent fuel pool.

Instrument description: Metal cabinet containing the bundle counter unit, battery charger unit, Geiger assemblies including cabling and the collimators, guide tubes, and detector and AC cables.

Size: Cabinet: 40 cm deep, 55 cm wide, 50 cm high.

Power supply: Batteries, AC.

Recording media: Paper.

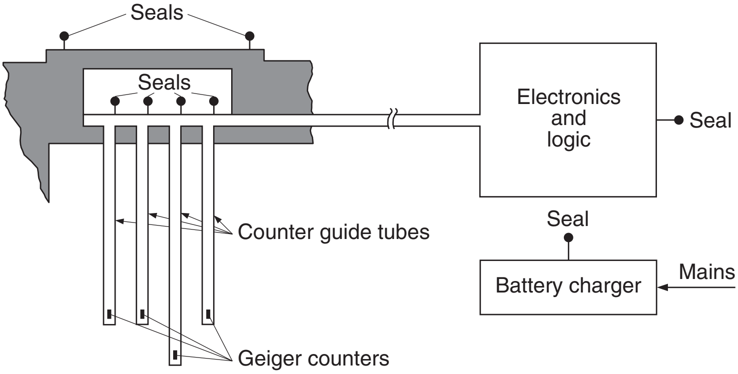


Figure: Interconnection between Geiger counters and electronics.

Code/name: HM-4/none; hand-held assay probe.

Nuclear material/location: Fresh fuel/fresh fuel storage.

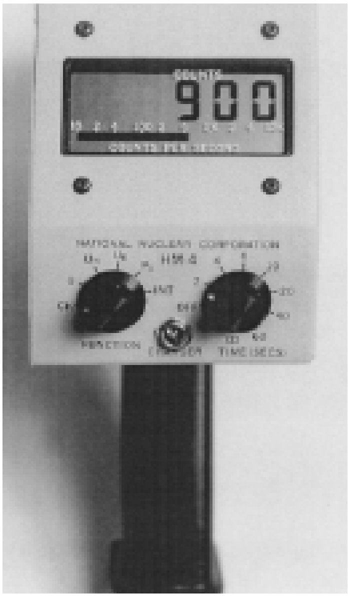
Application: Attribute test by NDA.

Facility equipment required: None; hand-held.

Instrument description: Main body containing NaI detector.

Power supply: Batteries.

Remarks: 12 hour monitoring by batteries.



Code/name: HRGS/High Resolution Gamma Ray Spectrometer.

Nuclear material/location: Spent fuel/non-routine use only.

Application: Attribute test by NDA.

Facility equipment required: None; portable.

Instrument description: Ge detector, liquid nitrogen, MCA, data processing computer, AC cable, detector cable.

Power supply: Batteries (AC for battery recharge).

Recording media: Digital media.

Code/name: HSGM/High Sensitivity Gamma Monitor.

Nuclear material/location: Spent fuel/non-routine use only.

Application: Attribute test by NDA.

Facility equipment required: None; hand-held.

Instrument description: Geiger–Müller radiation detector, data processing unit, AC cable, detector cable.

Power supply: Batteries (AC for battery recharge).

Photo: HSGM detector and data processing unit.

Code/name: ICVD/Cerenkov Viewing Device.

Nuclear material/location: Spent fuel assemblies/spent fuel pool.

Application: Attribute test by NDA; to see Cerenkov radiation generated by each spent fuel assembly.

Facility equipment required: None; hand-held; typically used from access bridge positioned over the fuel assembly being verified.

Instrument description: ICVD (shown below), carrying case.

Power supply: Batteries (2 AA)

Recording media: None

Remarks: Requires a direct view (clear water and no barrier obstructing the view) along the vertical axis of the fuel assembly. Spent fuel with very long cooling times (>18 a) and/or very low burnup (<5 MW·d/kg) defines an approximate boundary beyond which verification with the current ICVD becomes difficult.

Photo: ICVD with 105 mm lens.

Code/name: PMCG/Multichannel Analyser + GeDet.

Nuclear material/location: Spent fuel/non-routine use only.

Application: Attribute test by NDA.

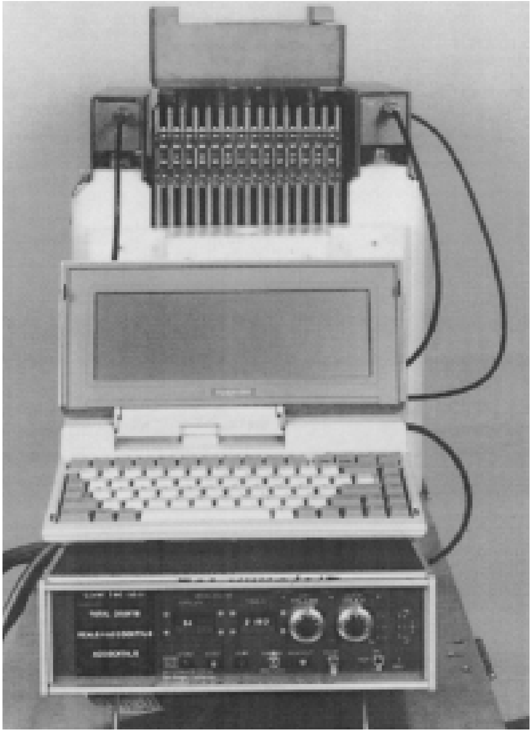
Facility equipment required: None; portable.

Instrument description: Ge detector, liquid nitrogen, MCA, AC cable, detector cable.

Power supply: Batteries (AC for battery recharge).

Recording media: Digital media.

Photo: PMCG detector and MCA.



Code/name: PNCL/Pu Neutron Coincidence Collar.

Nuclear material/location: Fresh MOX fuel assemblies/non-routine use only.

Application: Variable by NDA in attribute mode.

Facility equipment required: None, portable.

Instrument description: ^{3}He detector, MCA, PC, AC cable, detector cable.

Power supply: Batteries (AC for battery recharge).

Recording media: Digital media.

Photo: PNCL.

Code/name: SFAT/Spent Fuel Attribute Tester.

Nuclear material/location: Spent fuel assemblies/spent fuel pool.

Application: Attribute test by NDA.

Facility equipment required: Crane or hoist. Storage space should preferably be provided in the facility.

Instrument description: MCA, battery charger, NaI detector, watertight, stainless steel housing with detector, lead and copper shielding, air collimator pipes dependent on the facility, top lifting structure attached to housing specific to the facility, detector underwater cables.

Size: 1.5–2 m long, 20–30 mm diameter of air collimator pipe.

Power supply: Batteries.

Recording media: Cassette tape.

Remarks: Used for low burnup or long cooled spent fuel in ponds where the clarity of the water is poor, and in other situations where ICVD cannot be used.

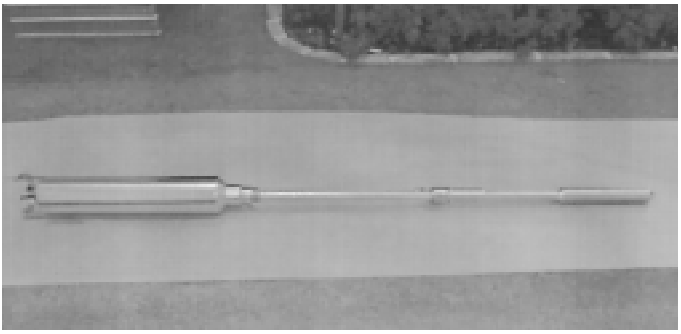


Photo: SFAT detector.

Code/name: FDET/Fork Detector.

Nuclear material/location: Spent fuel assemblies/spent fuel pool.

Application: Attribute test by NDA.

Facility equipment required: Fuelling machine (to raise spent fuel assemblies) and bridge for mounting the extension pipe (not shown). Storage space should preferably be provided for the FDET at the facility.

Instrument description: Fork detector head (gamma ray and neutron detectors), extension pipe and electronics unit (GRAND).

Power supply: Batteries/AC.

Recording media: Portable computer.

Remarks: Used for low burnup or long cooled spent fuel in ponds where the clarity of the water is poor, and in other situations where ICVD cannot be used.

Photo: FDET/fork detector head, GRAND and cable.

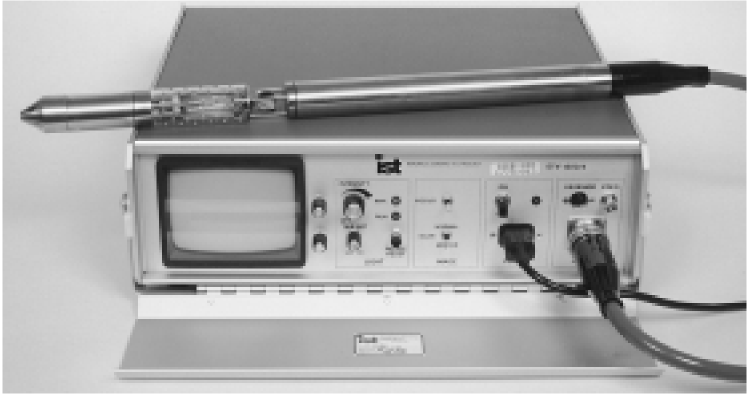
Code/name: UWTV/Underwater TV.

Nuclear material/location: Spent fuel/CANDU spent fuel pool.

Application: Spent fuel inventory check.

Facility equipment required: Portable, but requires crane to place the detector in the pool.

Instrument description: TV system with an underwater camera which has built-in lights and incorporates remote control features, detector cable and AC cable.



Power supply: AC.

Recording media: Video tape.

Photo: UWTV TV system and underwater camera.

CONTAINMENT/SURVEILLANCE AND MONITORING

Code/name: CSMS/Compact Surveillance and Monitoring System COSMOS.

Location: Reactor building, spent fuel pool.

Application: To monitor and record the movement of nuclear material (spent fuel).

Facility equipment required: Mounting equipment for permanent installation of the integrated camera and base unit.

Instrument description: An autonomous recording unit housed in a small sealed case, camera/VTR module, control module, memory module, power module, AC cable.

Size: 30 × 30 × 20 cm.

Power supply: Batteries (AC for battery recharge).

Recording media: 8 mm video tape.

Remarks: 3 months of operation (5 min interval) with batteries.

Photo: Inside of the main unit.

Code/name: EMOS/European Multicamera Optical Surveillance System.

Location: Reactor building, spent fuel pool.

Application: To monitor and record the movement of nuclear material (spent fuel).

Facility equipment required: Mounting equipment for permanent installation of the integrated camera and base unit.

Instrument description: 1 or 2 camera units, a main body containing a hard disk drive and controller, AC power cable, camera cable.

Size: Camera unit: 20 × 15 × 30 cm; main body: 45 × 50 × 35 cm.

Power supply: Batteries (AC for battery recharge).

Recording media: Hard disk, memory.

Photo: EMOS.

Code/name: GDTV/Gemini Digital Video System.

Location: Reactor building, spent fuel pool.

Application: To monitor and record the movement of nuclear material (spent fuel).

Facility equipment required: Mounting equipment for permanent installation of the integrated camera and base unit.

Instrument description: Digital camera, control unit, batteries, PC, modem, AC cable, camera cable.

Size: Body: 60 × 50 × 33 cm; base: 66 × 50 × 5 cm; camera unit: 23 × 31 × 31 cm.

Power supply: Batteries (AC for battery recharge).

Recording media: Digital media.

Remarks: Maximum camera cable length: 200 m.

Photo: GDTV.

Code/name: MIVS/Modular Integrated Video System

Location: Reactor building, spent fuel pool.

Application: To monitor and record the movement of nuclear material (spent fuel).

Facility equipment required: Mounting equipment for permanent installation of the integrated camera and base unit.

Instrument description: Four field replaceable modules: a power supply module, a control module and two recorder modules, camera unit, AC power cable, camera cable.

Power supply: Batteries (AC for battery recharge).

Recording media: Video tape, memory.

Remarks: Capacity to record 26 000 scenes, system operation during loss of AC power: 3 h (min), with the system recording at 5 min intervals; sealed video recorders are used instead of the usual video recorders.

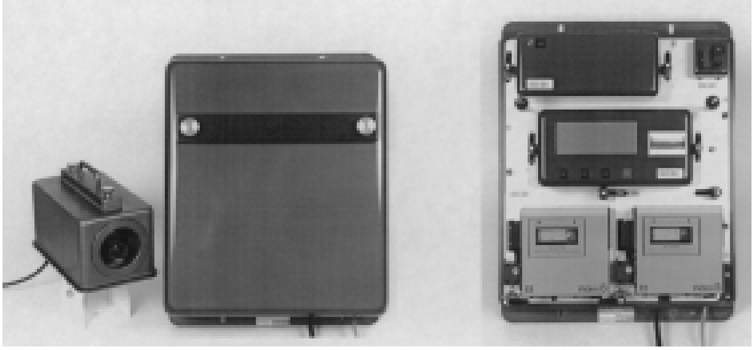


Photo: MIVS camera unit and body inside view.

Code/name: PHSR/Photo Surveillance Unit (Minolta)

Location: Reactor building, spent fuel pool.

Application: To monitor and record the movement of nuclear material (spent fuel).

Facility equipment required: Mounting equipment for permanent installation of the integrated camera and base unit.

Instrument description: Cameras with wide angle lens, timers, film, enclosure with its supporting bracket, metal seal and seal wire.

Power supply: Batteries.

Recording media: Film.

Remarks: Field of view should not include direct overhead lights or exterior windows/doors. No interference with the view of the surveillance areas. Avoid vibration and unstable temperature. Irradiation dose should be less than 30 mGy in 100 days.

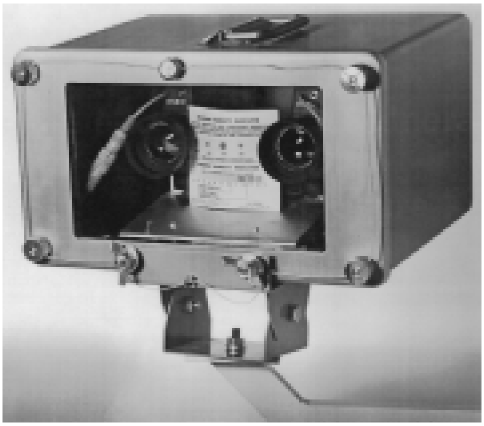


Photo: PHSR.

CONTAINMENT/SURVEILLANCE SEALS AND IDENTIFICATION TAGS

Code/name:
CAPS/Metallic seal

Application: Used to join movable segments of a containment so that access to the containment requires breaking of the seal or the seal wire.

Instrument description: Metallic double cap type seals, wire.

Power supply: None.

Remarks: The image of the unique ‘signature’ of each seal is recorded.

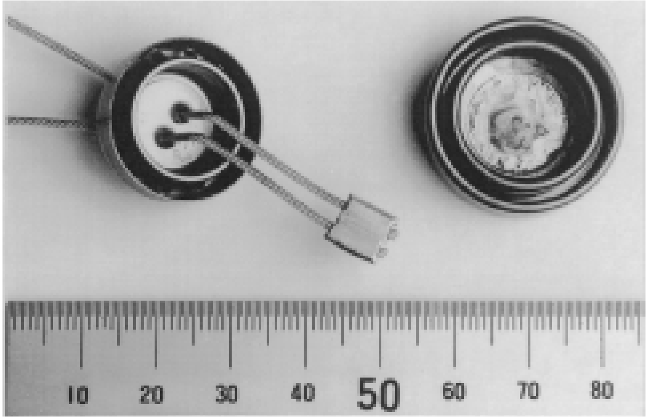


Photo: Type E metal seal.

Code/name: COBRA/Fibre optic seal

Application: Used to join movable segments of a containment so that access to the containment requires breaking of the seal or the fibre optic cable.

Instrument description: Main body, including a special cutting knife, fibre optic cable.

Power supply: None.

Remarks: The image of the unique signature of each seal is recorded by the COBRA seal verifier system (digital camera and monitor).

Photos: A COBRA seal (left) and a seal reader (right).

Code/name: ETAG/Remote location verifier.

Application: Electronic identification tag.

Instrument description: An electronic memory board installed in various surveillance/monitoring devices; a chip unit installed in the facility; connectors and connection cable.

Power supply: Batteries.

Remarks: Year long operation without battery recharge.

Code/name: ULCS/Ultrasonic seals (ARC) for CANDU fuel

Application: The ARC seal joins a cover and associated containment components to a spent fuel stacking frame. Once installed, the removal of the cover or any containment component requires breaking of the seal.

Instrument description: Seal body.

Power supply: None.

Remarks: A randomly wound coil of wire is attached to the end of a pin that is captured when an ARC seal is installed. A unique signature is obtained by examining the coil using an ultrasonic sonar technique. When an ARC seal is removed the captured pin breaks at an engineered fracture point, deforming and breaking the wire.

Photo: ULCS showing the end of the pin that is captured when the seal is installed.

Code/name: VCOS/VACOSS-s electronic seal.

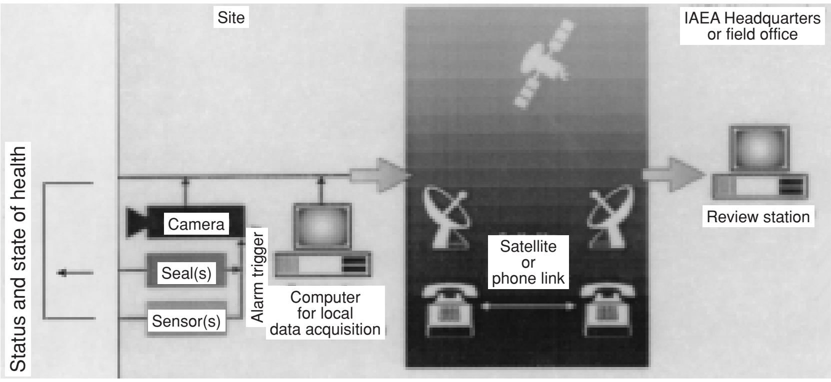
Application: Used to join movable segments of a containment so that access requires breaking of the seal or the fibre optic cable.

Instrument description: Seal unit, fibre optic circuit, monitoring device.

Power supply: Batteries.

Remarks: Maximum length of the fibre optic cable is 2000 m. Reusable. Over two years of operation without battery replacement.

Code/name: None/Remote monitoring system (simplified layout).



Code/name: DCM-14/Remote monitoring equipment — surveillance.

Instrument description: Digital image; scene change detection; image compression; image/data authentication; image/data encryption; power management; battery backup; external triggers; state of health.

Code/name: None/Remote monitoring equipment — on-site server.

Description: High capacity on-site image and data storage; communications interface; data security and access control; heavy duty power backup and management in the event of a loss of facility mains.

GLOSSARY

Terms that are relevant to design measures to facilitate the implementation of safeguards at future nuclear power plants are given here. They have been taken from the IAEA Safeguards Glossary (1987 edition), Rep. IAEA/SG/INF/1 (Rev. 1), IAEA, Vienna (1987).

NUCLEAR AND NON-NUCLEAR MATERIAL

depleted uranium. Uranium in which the abundance of the isotope ^{235}U is less than that occurring in natural uranium, e.g. uranium in spent fuel from natural uranium fuelled reactors and tails from uranium enrichment processes.

direct use material. Nuclear material that can be used for the manufacture of nuclear explosives components without transmutation or further enrichment, such as plutonium containing less than 80% ^{238}Pu, HEU and ^{233}U. Chemical compounds, mixtures of direct use materials (e.g. MOX) and plutonium contained in spent nuclear fuel also fall into this category. Unirradiated direct use material would require less processing time and effort than irradiated direct use material (contained in spent fuel).

enriched uranium. Uranium having a higher abundance of ^{235}U than natural uranium. Enriched uranium is considered a special fissionable material.

fertile material. Nuclear material which can be converted into a special fissionable material through the capture of one neutron per nucleus. There are two naturally occurring fertile materials, ^{238}U and ^{232}Th. Through the capture of neutrons followed by two beta decays, these fertile materials are converted to fissionable ^{239}Pu and ^{233}U, respectively.

high enriched uranium (HEU). Uranium enriched to 20% ^{235}U or more.

low enriched uranium (LEU). Uranium enriched to less than 20% ^{235}U.

mixed oxide (MOX). A reactor fuel consisting of a mixture of the oxides of uranium and plutonium. MOX is used for the recycling of reprocessed spent fuel (after the separation of waste) into thermal nuclear reactors (thermal recycling) and as a fuel for fast reactors. It is considered a special fissionable and direct use material.

natural uranium. Uranium as it normally occurs in nature, having an atomic weight of approximately 238 and containing minute quantities of ^{234}U, 0.7% ^{235}U and 99.3%

^{238}U. Uranium is usually supplied in raw form by uranium mines and ore processing plants as yellow cake.

plutonium. A radioactive element which occurs only in trace amounts in nature, with atomic number 94 and symbol Pu. As produced by irradiating uranium fuels, plutonium contains varying percentages of the isotopes 238, 239, 240, 241 and 242. It is considered a special fissionable and direct use material.

uranium-233. An isotope of uranium which is produced by the transmutation of ^{232}Th, and which is considered a special fissionable and direct use material.

NUCLEAR INSTALLATIONS AND EQUIPMENT

heavy water reactor (HWR). A power reactor moderated by heavy water. A prominent example is the CANDU type reactor, which is moderated and cooled by heavy water and fuelled with natural uranium. The fuel bundles, located in horizontal pressure tubes, consist of Zircaloy tubes filled with uranium oxide pellets. CANDU reactors contain large numbers of fuel bundles; they are safeguarded as item facilities. There are also HWRs that operate with a pressure vessel (similar to LWRs) and with heavy water as moderator and coolant.

item facilities. Nuclear facilities where all nuclear material is contained in identifiable items (e.g. fuel assemblies), the integrity of which remains unaltered during their residence at the facility. In such cases, IAEA safeguards are based on item accounting procedures (item counting and identification, non-destructive measurements and examination to verify the continued integrity of the item). Examples of item facilities are:

- Most power and research reactors and critical assemblies, except those fuelled with large quantities of non-identifiable units (e.g. pebbles, coupons), or liquids (e.g. molten salt);
- Item storage facilities.

light water reactor (LWR). A power reactor which is both moderated and cooled by ordinary (light) water. LWRs use massive fuel assemblies usually consisting of Zircaloy clad fuel rods containing uranium oxide pellets of low enrichment, generally less than 4% ^{235}U, or MOX having a low plutonium content (generally less than 5%). There are two types of LWR: in a boiling water reactor (BWR), the heat generated is extracted by allowing the water to boil as it passes through the core, the steam raised being passed directly to the turbine of the power generating system. In a pressurized water reactor (PWR), the reactor vessel is operated at a pressure sufficient to suppress the boiling of the water; the steam required for the turbine is obtained by passing the primary coolant water through heat exchangers.

off-load fuelled power reactor. A reactor fuelled while it is shut down and the generator(s) disconnected from the power grid. The existing off-load fuelled power reactors are item facilities.

on-load fuelled power reactor. A reactor refuelled while producing power. On-load reactors may be item or bulk handling facilities, depending on type.

DESIGN OF THE SAFEGUARDS APPROACH

conversion time. The time required to convert different forms of nuclear material to the metallic components of a nuclear explosive device. Conversion time does not include the time required to transport diverted material to the conversion facility or to assemble the device, or any subsequent period. The diversion activity is assumed to be part of a planned sequence of actions chosen to give a high probability of success in manufacturing one or more nuclear explosives, with minimal risk of discovery until at least one nuclear explosive device is manufactured. It is therefore assumed that all necessary conversion and manufacturing dummy components using appropriate surrogate materials, and non-nuclear components of the device have been manufactured, assembled and tested.

design information. “Information concerning nuclear material subject to safeguards under the Agreement and the features of facilities relevant to safeguarding such material” (INFCIRC/153, para. 8; similarly in INFCIRC/66, para. 32). The design information has to be provided by the State to the IAEA as early as possible before nuclear material is introduced into a new facility. Design information is used in preparing the safeguards approach to a particular facility, involving the form, quantity, location and flow of nuclear material being used, facility layout, and the containment features and procedures for nuclear material accountancy and control. The information is submitted to the IAEA by States using the IAEA’s Design Information Questionnaire.

detection time. The maximum time that may elapse between diversion and its detection by IAEA safeguards. According to the current guidelines, it should correspond in order of magnitude to the conversion time. Detection time is one of the factors used to establish the timeliness component of inspection goals, which is to be achieved through specified inspection and physical inventory frequencies and C/S measures.

safeguards approach. A system of nuclear material accountancy, containment, surveillance and other measures chosen for the implementation of safeguards in a given situation. The system is developed to satisfy the safeguards objective as related to that situation. In designing the system, a model safeguards approach is developed for each type of nuclear facility; this is then adapted to specific facilities for implementation — the facility safeguards approach.

significant quantity (SQ). The approximate quantity of nuclear material in respect of which, taking into account any conversion process involved, the possibility of manufacturing a nuclear explosive device cannot be excluded. The SQ is used to select accountancy verification goals. It should not be confused with critical mass; the former takes into account unavoidable losses of conversion and manufacturing processes.

timeliness goal. The adaptation of the design parameter detection time to specific conditions arising from facility practice, available equipment, workforce, etc. The timeliness goal is incorporated in various features of the inspection plan, e.g. frequency of physical inventory taking, intensity of flow verification and frequency of activities in connection with C/S measures (film evaluation, seal checking, etc.). At present the following timeliness guidelines are used:

- Within 1 month for fresh fuel containing HEU, Pu or MOX;
- Within 3 months for irradiated fuel containing HEU or Pu;
- Within 12 months for fresh fuel containing natural uranium, LEU or thorium.

Appropriate guidelines are adopted for other materials subject to safeguards agreements.

NUCLEAR MATERIAL ACCOUNTANCY

inventory verification. A basic IAEA safeguards inspection activity carried out to confirm the operator’s recorded book inventory of nuclear material present at a given time within an MBA, and thus to verify that no nuclear material has been diverted. There are two types of inventory verification, the physical inventory verification (PIV) and the interim inventory verification. The PIV follows closely or coincides with the physical inventory taking (PIT) by the operator and closes the material balance period (MBP). The basis for a PIV is an itemized inventory list prepared by the operator. The result is correlated with the physical inventory listings submitted by the State. The interim verification does not coincide with the MBP and does not necessarily include all nuclear material present. It is made for purposes of timely detection or, for example, after a failure of surveillance in order to re-establish the inventory in the area concerned.

key measurement point (KMP). "A location where nuclear material appears in such a form that it may be measured to determine material flow or inventory. 'Key measurement points' thus include, but are not limited to, the inputs and outputs (including measured discards) and storages in material balance areas" (INFCIRC/153, para 108).

material balance area (MBA). "An area in or outside of a facility such that:

(a) The quantity of nuclear material in each transfer into or out of each 'material balance area' can be determined; and
(b) The physical inventory of nuclear material in each 'material balance area' can be determined when necessary, in accordance with specified procedures, in order that the material balance for Agency safeguards purposes can be established" (INFCIRC/153, para. 110).

Design information made available to the Agency should be used: "To determine material balance areas to be used for Agency accounting purposes and to select those strategic points which are key measurement points and which will be used to determine the nuclear material flows and inventories; in determining such material balance areas the Agency shall, inter alia, use the following criteria:

(i) The size of the material balance areas should be related to the accuracy with which the material balance can be established;
(ii) In determining the material balance area advantage should be taken of any opportunity to use containment and surveillance to help ensure the completeness of flow measurements and thereby simplify the application of safeguards and concentrate measurement efforts at key measurement points;
(iii) A number of material balance areas in use at a facility or at distinct sites may be combined in one material balance area to be used for Agency accounting purposes when the Agency determines that this is consistent with its verification requirements; and
(iv) If the State so requests, a special material balance area around a process step involving commercially sensitive information may be established" (INFCIRC/153, para. 46(b)).

nuclear material accountancy. The practice of nuclear material accounting by the facility operator and the SSAC and, in addition, the verification and evaluation of this accounting system by a safeguards authority (SSAC of the IAEA), with subsequent statements of results and conclusions which make it possible to determine the degree of assurance provided by the safeguards measures. Accountancy includes the following activities:

Facility level

- — Dividing nuclear material operations into MBAs;
- — Maintaining records describing the quantities of nuclear material held within each MBA;
- — Measuring and recording all transactions that involve the transfer of nuclear material (international or domestic) from one MBA to another and changes in the amount of nuclear material present owing to nuclear production or nuclear loss;
- — Periodically determining the quantities of nuclear material present within each MBA through a physical inventory;
- — Closing the material balance over the period spanned by two successive physical inventories and computing the MUF for that period;
- — Providing for a measurement control programme to determine the accuracy of measurements and calibrations and the correctness of recorded source and batch data;
- — Testing the computed MUF against its limits of error for indications of undetected loss;
- — Analysing the accounting data to determine the cause and magnitude of mistakes in recording unmeasured losses, accidental losses and unmeasured inventory (holdup).

SSAC level

- — Preparing and submitting accounting reports to the IAEA as appropriate;
- — Ensuring that the accounting procedures and arrangements are correctly adhered to;
- — Providing for inspector access and co-ordination arrangements as necessary to enable the IAEA to carry out its verification activities;
- — Providing for independent verification by the SSAC of the safeguards performance of facility operators, as appropriate.

IAEA level

- — Independently verifying nuclear material quantities and locations using such inspection methods as examination of accounting reports, updating of the book

inventory, verification of inventory and inventory change, independent measurements, verification of the operation and calibration of instruments and other measurement and control equipment, verification of information on possible causes of MUF, shipper/receiver differences and uncertainties in the book inventory, and other activities as provided for in the safeguards agreement;
- Determining the effectiveness of the SSAC;
- Providing statements on IAEA verification activities to the State;
- Providing statements for the annual ‘Safeguards Implementation Report’ to the Board of Governors on the effectiveness of IAEA safeguards.

MEASUREMENTS AND EQUIPMENT

Cerenkov glow observation. A method for qualitative verification of irradiated nuclear fuel in storage pools. Irradiated fuel emits high energy radiation which interacts with water molecules and transfers energy to electrons, some of which acquire velocities high enough to emit a characteristic blue glow in water. Electro-optical devices have been adapted to observe this glow from above a storage pool.

neutron coincidence counter. A device which responds to prompt neutrons from spontaneous or induced fissions in a sample and distinguishes them from neutrons from other sources (such as (α, n) reactions) by separating detected events that occur closely together in time (correlated events) from those that are randomly distributed in time.

non-destructive assay (NDA). Measurement of the nuclear material content or the element or isotopic concentration of an item without producing significant physical or chemical changes in the item. It is generally carried out by observing the radiometric emission or response from the item and by comparing that emission or response with a calibration based on essentially similar items whose contents have been determined through chemical analysis. There are two broad categories of NDA:

- Passive assay, in which the measurement refers to spontaneous emissions of neutrons or gamma rays or to total decay energy;
- Active assay, in which the measurement refers to a stimulated emission (e.g. neutron or photon induced fission).

CONTAINMENT AND SURVEILLANCE

containment. Structural features of a nuclear facility or equipment which enable the IAEA to establish the physical integrity of an area or item by preventing undetected access to or movement of nuclear or other material, or interference with the item, IAEA safeguards equipment or data. Examples are the walls of a storage room or of a storage pool, transport flasks and storage containers. The continuing integrity of the containment itself is usually ensured by the use of seals or surveillance measures (especially for containment penetrations such as doors, vessel lids and water surfaces).

containment/surveillance (C/S) measures. The application of containment and/or surveillance, and important safeguards measures complementing nuclear material accountancy. The application of C/S measures is aimed at verifying information on the movement of nuclear or other material, devices and samples or on the preservation of the integrity of safeguards relevant data. In many instances, C/S measures cover the periods when the inspector is absent, and this contributes to cost effectiveness. C/S measures are applied, for instance:

- To ensure during flow and inventory verification that each item is inventoried without duplication and that the integrity of samples is preserved;
- To ensure that IAEA instruments, devices, working papers and supplies are not tampered with;
- To extend the validity of previous measurements and thereby reduce the need for remeasuring previously verified items.

The indication of an anomaly by C/S measures does not necessarily by itself indicate that material has been removed. The ultimate resolution of C/S anomalies (e.g. broken seals) is provided by nuclear material accountancy.

If any C/S measure has been, or may have to be, compromised, the IAEA shall, if not agreed otherwise, be notified by the fastest means available. Examples might be seals which have been broken inadvertently or in an emergency, or seals of which the possibility of removal after advance notification to the IAEA has been agreed between the IAEA and the operator.

optical surveillance device. A device used to provide, for later review, a visual record of activities in a defined field of view. It is used to monitor movements of material or handling of equipment under surveillance during the absence of the inspector. Optical surveillance devices are routinely used at spent fuel storage pools and storage areas and occasionally, on a temporary basis, during inventory verifications. Automatically triggered twin cameras, enclosed in a sealed, tamper indicating box, are widely used by the IAEA. The frequency of the shots is selected in accordance with the estimated time required for the activity to be monitored so that the activity is covered at least by some frames. The servicing of the camera and the evaluation of the film recovered by the IAEA inspector are planned in accordance with the film capacity of the device and timeliness requirements. Another type of optical surveillance device is the automatic closed circuit television system (CCTVS), which records on magnetic video tape or optical disk.

seal. A tamper indicating device used to join movable segments of a containment in such a manner that access to its contents without opening of the seal or breaking of the containment is difficult. General purpose metal cap seals and paper tape seals which have tamper indicating features are most commonly used by the IAEA. Ultrasonic and electronic seals with fibre optic loops are in limited use. Seals may be applied:

- On safeguarded material or equipment (in containers, vessels and storage or process locations) to maintain the continuity of knowledge of the sealed contents between inventory verifications, and during shipment of the material or equipment from one facility to another;
- On the operator's equipment (e.g. a crane) to monitor any use that would make possible the undeclared removal of nuclear material;
- On IAEA property (equipment, samples, standards, data, etc.) to prevent undetected tampering.

surveillance. The collection of information through inspector and/or instrumental observation aimed at the monitoring of the movement of nuclear material and the detection of interference with containment and tampering with IAEA safeguards devices, samples and data. The most important surveillance instruments are automatic optical devices and monitors. Surveillance may also be used for observing various operations or obtaining relevant operational data. IAEA safeguards inspectors may carry out surveillance assignments continuously or periodically at strategic points.

tampering. Interference in an unauthorized and undeclared manner to physically defeat a C/S device.

tamper indication. Physical evidence of tampering with C/S measures.

tamper resistance. Features incorporated into a device (or procedures associated with its use) intended to make tampering more difficult or reduce the probability that tampering could take place without detectable indications. IAEA C/S equipment is designed to give a high degree of tamper resistance.

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