IAEA Nuclear Energy Series

No. NF-T-3.1

Basic Principles

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International Safeguards in the Design of Facilities for Long Term Spent Fuel Management

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INTERNATIONAL SAFEGUARDS IN THE DESIGN OF FACILITIES FOR LONG TERM SPENT FUEL MANAGEMENT

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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''.

IAEA NUCLEAR ENERGY SERIES No. NF-T-3.1

INTERNATIONAL SAFEGUARDS IN THE DESIGN OF FACILITIES FOR LONG TERM SPENT FUEL MANAGEMENT

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FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

This publication, part of the IAEA Nuclear Energy Series, is one in a series of facility specific 'safeguards by design' guidance publications that are currently in preparation. The topics of these publications will include international safeguards in the design of nuclear reactors, uranium conversion plants, facilities for long term spent fuel management, reprocessing plants and enrichment plants.

This series is introductory rather than comprehensive in nature and complements the general considerations addressed in the IAEA Nuclear Energy Series publication International Safeguards in Nuclear Facility Design and Construction (No. NP-T-2.8). These publications are intended principally for nuclear facility stakeholders including vendors, designers, operators, project managers and State (or regional) authorities responsible for safeguards implementation.

A great majority of States have concluded comprehensive safeguards agreements with the IAEA pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons. The IAEA plays an independent verification role, ensuring that States adhere to their safeguards obligations as outlined in these agreements. Safeguards by design does not introduce new requirements. It simply advocates the consideration of IAEA safeguards throughout all the life cycle stages of a nuclear facility, from the initial conceptual design up to and including facility construction and into operations, including design modifications and decommissioning. Safeguards by design aims to (1) prevent safeguards requirements from unduly interfering with the smooth construction and operation of a facility; (2) avoid costly and time consuming retrofits or redesigns of facilities to accommodate safeguards; (3) minimize risks associated with licensing that may result from design changes; (4) achieve efficiencies in safeguards implementation to the benefit of the operator, the State and the IAEA; and (5) ensure the implementation of effective safeguards.

The IAEA gratefully acknowledges the assistance received through the Member State Support Programmes to the Department of Safeguards from Argentina, Belgium, Brazil, Canada, China, the European Commission, Finland, France, Germany, Japan, the Republic of Korea, the United Kingdom and the United States of America in the preparation of this publication. The IAEA officers responsible for this publication were B. Boyer and J. Sprinkle of the Division of Concepts and Planning and G. Dyck of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The IAEA works to enhance the contribution of nuclear energy to peace and prosperity around the world while helping to ensure that nuclear material is not diverted to nuclear weapons or other nuclear explosive devices. IAEA safeguards, an important part of the global nuclear non-proliferation regime, provide for independent verification by the IAEA of States' compliance with their legal obligations under safeguards agreements. This publication is part of an IAEA guidance series developed to assist facility designers and operators in considering at an early stage the safeguards activities relevant to particular nuclear fuel cycle facility types.

This publication complements the general considerations addressed in International Safeguards in Nuclear Facility Design and Construction [1] and is written primarily for designers and operators of the specific facility type described within. It is written at an introductory level for an audience unfamiliar with IAEA safeguards and has no legal status. A State may incorporate elements of this guidance into its regulatory framework, as it deems appropriate. For specific guidance on IAEA safeguards implementation, the reader can refer to Ref. [2].

Safeguards should be considered early in the design process to minimize the risk of impacts on scope, schedule or budget [3], and to facilitate better integration with other design considerations such as those relating to operations, safety and security [4, 5]. In the IAEA publication Governmental, Legal and Regulatory Framework for Safety [6], Requirement 12 (Interfaces of safety with nuclear security and with the State system of accounting for, and control of, nuclear material) states that: "The government shall ensure that, within the governmental and legal framework, adequate infrastructural arrangements are established for interfaces of safety with arrangements for nuclear security and with the State system of accounting for and control of nuclear material."

Considerations of safety, security and safeguards are essential elements of the design, construction, commissioning, operation and decommissioning stages of nuclear facilities, as discussed in publications issued by the IAEA Department of Nuclear Safety and Security. The trend is for new facilities to be built with inherent safety and security features as well as accommodations for safeguards. The publication Safety of Nuclear Power Plants: Design [7] establishes in Requirement 8, pertaining to interfaces of safety with security and safeguards, which applies to any type of facility, that: "Safety measures, nuclear security measures and arrangements for the State system of accounting for, and control of, nuclear material for a nuclear power plant shall be designed and implemented in an integrated manner so that they do not compromise one another."

Safeguards by design (SBD) is a voluntary process to facilitate the improved implementation of existing safeguards requirements,[1] providing an opportunity for stakeholders to work together to reduce the potential of unforeseen impacts on nuclear facility operators during the construction, startup, operation and decommissioning of new facilities. SBD should not be confused with the effective design of a safeguards approach, but rather it enhances the design process through the early inclusion of safeguards considerations in the management of the facility design and construction project. As such, cooperation on safeguards implementation is improved when (1) the designer, vendor and operator understand the basics of safeguards and (2) the safeguards experts understand the basics of the facility design and operations.

The particular safeguards activities conducted by the IAEA vary from one facility to another. From a design perspective, there is value in understanding the full range of potential safeguards activities and their impact on the facility design before design choices are finalized. Early planning can incorporate flexibility into the facility's infrastructure to support safeguards, accommodating technology innovations over time that may benefit the operator during the facility's life cycle. The relative ease with which safeguards can be implemented in a facility is referred to as 'safeguardability'.

Involving the design–build–operation teams in the SBD process carries the potential benefits of:

— Increasing awareness of safeguards for all stakeholders;
— Reducing inefficiencies in the IAEA's safeguards activities;

[1] It should be noted that, in States with a comprehensive safeguards agreement in force, preliminary design information for new nuclear facilities and activities and for any modifications to existing facilities must be submitted to the IAEA as soon as the decision to construct or to authorize construction, or to authorize or to make the modification, has been taken.

— Improving the effectiveness of safeguards implementation;
— Facilitating the consideration of the joint use of equipment by the operator, the State (or regional) authority responsible for safeguards implementation and the IAEA;
— Reducing operator burden for safeguards;
— Reducing the need to retrofit for installation of safeguards equipment;
— Increasing flexibility for future safeguards equipment installation.

1.2. OBJECTIVE

This publication is part of a series that aims to inform nuclear facility designers, vendors, operators and State governments about IAEA safeguards and how associated requirements can be considered early in the design phase of a new nuclear facility. SBD dialogue during early design and construction facilitates the implementation of safeguards throughout all the life cycle stages of the facility. The potential to reduce costs, avoid costly retrofits and achieve efficiencies both for the operator and for the IAEA are important drivers for the early consideration of safeguards in a nuclear facility design project.

The State (or regional) authority responsible for safeguards implementation (SRA) is the entity in the State with primary responsibility for fulfilling the safeguards obligations of the State including formal communications with the IAEA [8]. The SRA may be part of a broader nuclear authority and thus have responsibilities in addition to safeguards, such as safety or security. The SRA plays a very important role in facilitating communications among all the key stakeholders.

1.3. SCOPE

The guidance in this publication is applicable to the design and construction of long term spent fuel management facilities, such as the facility holding spent fuel containers shown in Fig. 1, except for reprocessing facilities, which will be addressed in a separate publication. It complements the general considerations addressed in International Safeguards in Nuclear Facility Design and Construction [1] and is written primarily for designers and operators of spent fuel facilities. The guidance provided herein represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

FIG. 1. Spent fuel containers.

1.4. STRUCTURE

Section 2 provides a general overview of IAEA safeguards implementation, followed by facility specific guidance in the subsequent sections. This publication includes experience gained in past efforts to incorporate safeguards requirements in the facility design, which can be useful in future efforts to build or operate nuclear facilities. Additional resources are suggested in the bibliography at the end of this publication. Reference material specific to the legal obligations undertaken pursuant to safeguards agreements can be found in Ref. [9]. It may also be useful to refer to the IAEA Safeguards Glossary [10], which can be accessed from Ref. [9].

Several terms defined within the documents that make up the legal framework of IAEA safeguards are included in the Definitions section of this publication. Additionally, Annex I provides explanations of specific safeguards terminology used in this publication.

Annex II describes safeguards considerations at the various life cycle stages of a nuclear facility. Annex III describes the identification of safeguardability issues, and Annex IV provides information on the contents of a design information questionnaire.

2. OVERVIEW OF IAEA SAFEGUARDS

A basic understanding of IAEA safeguards objectives and activities can facilitate the consideration of international safeguards in nuclear facility design and construction. A brief overview of IAEA safeguards is provided below.

2.1. IAEA SAFEGUARDS IMPLEMENTATION

Pursuant to the IAEA's authority to apply safeguards stemming from Article III.A.5 of its Statute, the IAEA concludes agreements with States and with regional safeguards authorities for the application of safeguards. These agreements are of three types: (1) comprehensive safeguards agreements (CSAs), (2) item specific safeguards agreements and (3) voluntary offer agreements. A State with any one of these agreements may also conclude a protocol [11] additional to its safeguards agreement [8]. The large majority of safeguards agreements in force are CSAs and this publication focuses on those. A State with a CSA in force undertakes to place all nuclear material in all facilities and other locations in the State, on its territory, or under its control or jurisdiction anywhere, under IAEA safeguards. The IAEA undertakes to apply safeguards on such material in accordance with the agreement, which provides for measures to protect sensitive technology and proprietary or classified information.

Under a CSA, the following three generic safeguards objectives apply. At nuclear facilities, most safeguards activities focus on addressing the first two objectives:

- To detect any diversion of declared nuclear material at declared facilities or locations outside facilities (LOFs);
- To detect any undeclared production or processing of nuclear material at declared facilities or LOFs;
- To detect any undeclared nuclear material or activities in the State as a whole.

Nuclear material accounting and the associated verification activities in the field are at the core of safeguards implementation and are the primary basis for achieving the first objective above on the non-diversion of declared nuclear material. The verification of information about the features and characteristics of a facility, known as design information verification (DIV), contributes significantly to achieving the second objective.

2.2. OVERVIEW OF SAFEGUARDS MEASURES

In general, safeguards activities are designed to verify the State's declarations about nuclear material quantities, locations and movements, and to detect indications of undeclared nuclear material or activities. Examples of techniques and measures used by the IAEA include, inter alia:

— On-site inspections by IAEA inspectors [12] including short notice random and unannounced inspections[2];
— Nuclear material accountancy, such as the review of facility records and supporting documentation [13];
— Measurements of nuclear material (e.g. weight, gamma, neutron) [14, 15];
— Unique identifiers for nuclear material items;
— Surveillance (e.g. cameras), containment (e.g. seals) and monitoring (e.g. monitoring nuclear material flows using unattended radiation measurements, monitoring of facility operational data such as pressure, temperature or power levels);
— Collection and analysis of environmental and nuclear material samples;
— Verification of facility design for features relevant to safeguards.

Additional information on the above can be found in the most recent edition of IAEA Safeguards Techniques and Equipment [15].

2.3. VERIFICATION

IAEA verification activities at a facility fall into two broad categories — verification of design information and verification of nuclear material inventories and flows. Surveillance, containment and flow monitoring are measures used in support of these verification activities. Each is discussed below.

2.3.1. Design information verification

Provisional facility design information must be submitted by the State to the IAEA when a decision is taken to construct, or to authorize construction, of a nuclear facility. Design information may be examined by the IAEA even before construction begins. Design information is updated as the design becomes more detailed [1, 8] and throughout the life of the facility to reflect changes or modifications.

Design information is submitted using a form called a design information questionnaire (DIQ); an example DIQ form containing information relevant for a research reactor can be found in Ref. [16]. Annex IV lists a summary of the type of information provided to the IAEA for the facility type addressed in this publication.

The IAEA verifies design information through on-site physical examination of the facility during the construction and all subsequent phases of the facility's life cycle (see Fig. 2). During a typical early DIV at a nuclear facility under construction, IAEA inspectors may visit the site to inspect and photograph aspects of its construction. In later visits, they may walk through the facility with detailed building plans to confirm the as-built design and to look for design features not shown on the drawings that may indicate potential for undeclared production or processing of nuclear material.

The IAEA may also verify the design and capacity of any processing equipment and systems in the facility as well as its maximum capacity. Accommodation for this requirement may be considered in the design phase. In addition, the IAEA develops an 'essential equipment' list for the nuclear facility to use in determining whether a facility can be considered decommissioned for safeguards purposes. The designers of the facility can play a valuable role in helping the IAEA to identify the equipment that is essential for operating the nuclear facility.[3]

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[2] Short notice random and unannounced inspections optimize resource allocation while maintaining safeguards effectiveness. These terms are explained in Annex I: Terminology.

[3] The IAEA *safeguards* essential equipment list is different from the *safety* essential equipment list.

2.3.2. Nuclear material accounting and verification

Under a CSA, State or regional authorities are required to report nuclear material inventories and inventory changes to the IAEA. Therefore, nuclear facilities establish nuclear material accounting systems in order to meet national and international requirements.

The IAEA verifies nuclear material inventories and flows as fundamental safeguards measures. For nuclear material accounting, one or more material balance areas (MBAs) will be established at a facility. By definition, an MBA is an area where (a) the quantity of nuclear material in each transfer into or out of the MBA can be determined and (b) the physical inventory of nuclear material can be determined. The nuclear material in an MBA is characterized as either direct use material (i.e. nuclear material that can be used for the manufacture of a nuclear explosive device without further transmutation or enrichment), indirect use material (i.e. all other nuclear material), or a combination of both. IAEA verification activities are typically more intensive for direct use material.

The IAEA also distinguishes between nuclear material in item and in bulk form. Facilities containing only nuclear material in item form are referred to as ‘item facilities’. In such facilities, the nuclear material is contained in discrete items (not designed to be opened) such as fuel rods or fuel assemblies in a typical power reactor. In ‘bulk handling’ facilities, such as fuel fabrication plants, the nuclear material is handled in loose form and can be repackaged with the possibility of combining or splitting the quantity of nuclear material in containers, and also of changing the chemical or physical form of the nuclear material. Different safeguards measures may be applied in the verification of nuclear material in item and in bulk forms. IAEA verification activities at bulk facilities are generally more intensive [13] and nuclear material samples are typically collected for analysis (see Fig. 3).

FIG. 2. IAEA design verification.

FIG. 3. Sample preparation in an IAEA laboratory.

One of the activities involved in verifying nuclear material is the evaluation of the consistency of facility records and supporting documentation with the reports submitted by the State [13]. The IAEA performs a physical inventory verification (PIV) after a facility operator has taken a physical inventory itself. The IAEA verifies the physical inventory of nuclear material in each MBA and compares its results with State reports and facility nuclear material accounting records. Key measurement points (KMPs) are established at locations where nuclear material inventory can be measured as well as at locations where nuclear material flows can be measured. Figure 4 illustrates item counting and the verification of item identification (tags) at a fresh fuel storage area in a power plant. The verification of nuclear material accountancy includes the assessment of the operator's measurement systems including the associated measurement uncertainties. Given resource limitations and the need to minimize disruption to facility operations, statistical sampling [17] is often used in nuclear material verification. Items are selected at random and verified by a number of measurement methods. These methods could include item counting, radiation and mass measurements, for example.

IAEA measurements of nuclear material are designed to meet three goals — gross, partial and bias defect detection, as described below [10]:

— 'Gross defect' refers to an item or batch that has been falsified to the maximum extent possible, so that all or most of the declared material is missing (e.g. substitution of an empty container for a full one).
— 'Partial defect' refers to an item or batch that has been falsified to such an extent that some fraction of the declared amount of material is actually present (e.g. removal of fuel pins from an assembly or some fraction of UF_6 from a cylinder).
— 'Bias defect' refers to an item or batch that has been slightly falsified so that only a small fraction of the declared material is missing (e.g. repeated removal of a very small amount of nuclear material from a flow stream).

Figure 5 shows verification measurements using handheld radiation instruments on fresh fuel in its shipping containers at a reactor, which is an example of a gross defect measurement.

Figure 6 shows measurements of irradiated fuel (irradiated direct use material) in a spent fuel storage pond. For an item facility such as a reactor, differences between the physical inventory and the accounting records are generally investigated by means other than statistical evaluation of measurement errors, e.g. by investigating the completeness and correctness of facility records. For a bulk facility, samples of nuclear material in bulk form may also be collected and analysed at IAEA laboratories.

Facility operators can support nuclear material accounting verification activities in several ways, including providing for access to nuclear material items and, once they have been verified, providing for the ability to segregate the verified items from those not yet measured. Inspectors might perform non-destructive assay (NDA) measurements with portable equipment or take samples of nuclear material from the process for destructive analysis (DA) measurements at IAEA laboratories. Ideally, the space provided for equipment storage, calibration standards and check sources, as well as the use of locations to perform measurements, should not interfere with routine plant operations.

FIG. 4. Item counting in a fresh fuel store.

FIG. 5. Verification of fresh fuel transport containers using a handheld HM-5 gamma monitor.

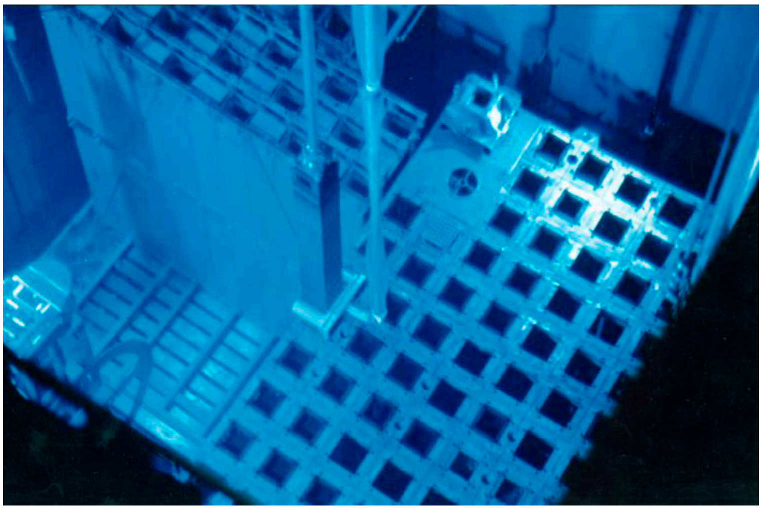

FIG. 6. Measurement of irradiated fuel in a cooling pond.

2.3.3. Surveillance, containment and monitoring

Surveillance, containment and nuclear material monitoring supplement the nuclear material accounting verification measures by providing additional means to detect undeclared access to, or movement of, nuclear material. Surveillance is the collection of optical or radiation information through human and instrument observation/monitoring. Containment refers to the structural components that make undetected access difficult. Seals are tamper indicating devices used to secure penetrations in containment thereby preventing undetected access.

During inspections, inspectors may examine optical records and data from the IAEA surveillance, containment and monitoring systems as part of verifying operator records and systems. The IAEA has several surveillance systems approved for use [15] that store optical and measurement data; include local battery backup; transmit state of health and image or other data off-site (typically to IAEA Headquarters); may be triggered by other sensors; and are sealed in tamper indicating enclosures. Figure 7 shows the interior of a tamper proof surveillance system and a typical installation.

Adequate and reliable illumination (at all hours of the day and night) is important for the effective functioning of most optical surveillance systems. Components of these systems also need to be accessible for maintenance and data retrieval. There are several ways facility operators can provide the basic support required for IAEA surveillance and monitoring systems, such as by:

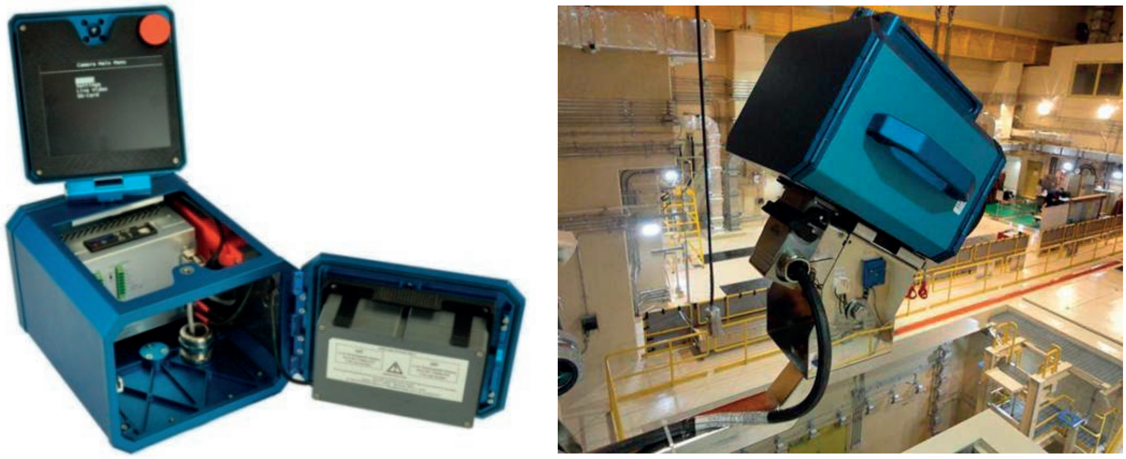

FIG. 7. A next generation IAEA surveillance system.

- — Supplying reliable power, secured access, dedicated working space and data transmission (wired or wireless) throughout the facility. Figure 8 shows a facility operator lowering an IAEA equipment rack with an overhead crane.
- — Locating data collection cabinets in easily accessible, clean areas with regulated temperature and humidity.
- — Foreseeing the impact of the operating environment on safeguards equipment (e.g. corrosion, heat).
- — Ensuring that optical surveillance systems are not blocked by equipment (e.g. cranes that move cylinders, heavy equipment or drums) and are protected from corrosion.
- — Considering a single dedicated space for electronic equipment[4] that can be access controlled by the IAEA. This space might include room for equipment, spare parts and a small office.
- — Providing sufficient access for attaching, replacing or servicing seals used by the IAEA.
- — Providing space for safeguards equipment in such a way that normal facility operation will not lead to inadvertent damage or interruption in service.
- — Labelling all installed relevant safeguards equipment (including cabling, power supplies and switches found in circuit breaker cabinets) clearly in English and the local language(s).
- — Consulting with the IAEA to facilitate the use of safeguards seals at measurement points and safeguards relevant features such as junction boxes where safeguards cables are terminated or connected.
- — Noting that seal attachment points should be part of the mechanical structure, appearing to be part of the original smooth design and not welded on after the fact, and must ensure that the attachment point cannot be removed without detection or without damaging or breaking the seal.

Maintaining the continuity of knowledge refers to the process of using surveillance, containment and monitoring to maintain the integrity of previously verified safeguards information by detecting any efforts to alter an item’s properties that are relevant to safeguards. When continuity of knowledge is maintained successfully, it can reduce the amount of re-measurement activity in subsequent inspections. Figure 9 shows an inspector using seals to maintain the continuity of knowledge during a routine inspection.

The use of unattended monitoring systems, such as a gate monitor to detect movements of spent fuel to a cooling pond, allows inspectors to focus their efforts in the field on inventory verification, investigating possible undeclared activities and detecting irregularities in operations.

Furthermore, the remote transmission of safeguards data from unattended monitoring systems can notify the IAEA when equipment needs to be serviced, provide information to help plan inspections and reduce IAEA time on-site conducting inspections, thereby reducing the impact of inspections on facility operation in addition to making safeguards implementation more effective and more efficient.

[4] Some safeguards equipment has dedicated electronics racks for signal processing, batteries, remote transmission and a data archive located remotely from the sensor in less hazardous space.

FIG. 8. A facility operator supporting the installation of IAEA equipment racks.

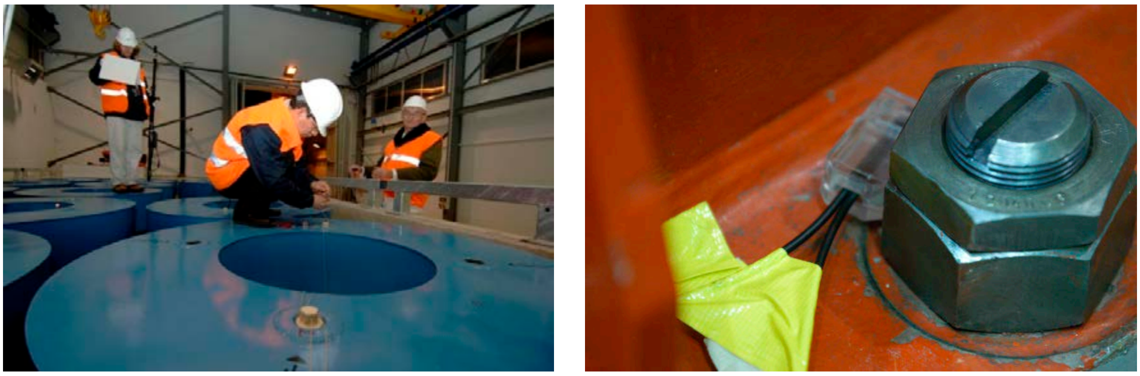

FIG. 9. Examples of seals that are used by the IAEA to maintain continuity of knowledge.

2.4. PHYSICAL INFRASTRUCTURE REQUIREMENTS FOR IAEA SAFEGUARDS ACTIVITIES

IAEA safeguards equipment requires physical space, reliable and well-regulated power supply, and infrastructure for data transmission. Even without detailed IAEA design criteria for safeguards equipment or systems (which may be only available later in the design life cycle), cabling and penetrations for IAEA equipment can be planned for in the facility design. Providing access to a stable and reliable source of power and secure data transmission capability (wired, fibre-optic or wireless) throughout a facility will eliminate the need for the most costly aspects of retrofitting for safeguards equipment systems (such as the installation of a surveillance camera, as shown in Fig. 10). Additionally, the possibility of incorporating facility equipment and the infrastructure needed to directly support IAEA verification activities into regular facility maintenance contracts could be considered. The ability to provide mounting fixtures for safeguards equipment that do not affect facility licensing or safety is desirable.

FIG. 10. Installation of a surveillance system.

2.5. FACILITY DECOMMISSIONING

Implementation of IAEA safeguards continues after a facility has been shut down and preparations for decommissioning have begun. During the initial design verification activities, the IAEA verifies the presence and characteristics of essential equipment. From the time essential equipment arrives at the facility until it is verified to have been removed or rendered inoperable, the facility is considered by the IAEA to be capable of its intended function. A facility is considered decommissioned for safeguards purposes when the IAEA has made a determination that nuclear material has been removed and the residual structures and equipment essential for its operation have been removed or rendered inoperable so that it can no longer be used to store, handle, process or utilize nuclear material [11].

2.6. FUTURE CONSIDERATIONS

Safeguards technologies continue to evolve, as does nuclear technology. The possibility to easily upgrade IAEA installed systems depends to some degree on the facility design. The electronics that support IAEA measurement hardware are changing, often in the direction of reduced physical size, modularity and increased capability. A facility design that accommodates modest changes in equipment size, shape and power requirements allows the use of newer alternatives as they become available on the market or as obsolescence removes older alternatives.

3. SAFEGUARDS CONSIDERATIONS IN SPENT FUEL MANAGEMENT

The guidance provided in this publication assumes that spent fuel is handled primarily in item form with limited repackaging activities to meet safety requirements with operating and safeguards procedures in place to address exceptions such as broken or leaking assemblies or rods and pins (e.g. the procedure that most of these exceptions are dealt with by the shipping facility). Nuclear material accountancy will remain a safeguards measure of fundamental importance and conclusions will be drawn with respect to the nuclear material under safeguards on an annual basis. The measurement of nuclear material in spent fuel and the safeguards measures for application to spent fuel management are areas of active research and development (R&D); see, for example, Refs [18–50]. In this guidance, the term 'equipment list' will be used in a general way to refer to various lists of equipment; it does not refer to a unique list.

The ease of applying IAEA safeguards measures at a facility has been described as safeguardability. A tool to assess safeguardability is summarized in Annex III [51, 52]. Perhaps the greatest benefit to a nuclear facility building project arising from SBD is the inclusion of infrastructure for safeguards equipment in design and construction.

The designer can consider the path the spent fuel takes on its way to processing (e.g. repackaging or encapsulation) and recommend optimum surveillance locations. The designer can then take these surveillance considerations into account when the facility layout and design are optimized. Specifications for the supply of electrical power, equipment space requirements and communications cabling can be discussed without knowing the exact location or height of the final equipment installation. Having an understanding of safeguards activities, a designer can plan more effectively for expected needs, such as:

- Facilitating inspection activities;
- Designing out spent fuel removal opportunities;
- Reducing potential for human error (e.g. reliable automation);
- Considering where nuclear material measurements might be made and how continuity of knowledge (CoK; defined in Section 2.3) of the measurement results could be maintained;
- Mitigating the impact of off-normal events on verification (e.g. avoiding a need to reverify a large inventory of difficult to measure material because of a loss of power);
- Modularizing or automating elements of the process to facilitate monitoring;
- Identifying where item identification might be useful;
- Identifying potential needs for buffer storage;
- Providing for reliable, stable electrical power;[5]
- Evaluating possibilities for the joint use of equipment;
- Suggesting priorities for redundancy or backup.

Provisions that can facilitate inspection activities include:

- The capability to minimize nuclear materials (or the number of items) in a material balance area (MBA) during inventory verification (e.g. minimize use of receipt storage or temporary storage);
- The use of unique identifiers for each nuclear material item;[6]
- The capability to distinguish items of different relevance to safeguards (e.g. fresh fuel, spent fuel, empty containers, control rods and non-safeguarded[7] items);
- Minimizing the radiation exposure to inspectors (and equipment);
- Access for design information verification (e.g. of containment, environmental control[8] and hot cells);
- Access for safeguards equipment maintenance;
- Minimizing potential for damage to safeguards equipment;
- Minimizing potential for loss of safeguards data;
- Clearly labelling safeguards equipment and infrastructure;
- Allocating space for safeguards cabinets and inspector offices;
- A capability for on-site remote data transmission.

The IAEA generally considers the activities in long term spent fuel management (e.g. receipt storage, encapsulation and long term disposition) as different MBAs in order to facilitate the recovery of CoK if that becomes necessary.[9] Repackaging activities and locations (e.g. hot cells) can be of greater safeguards interest than storage locations or transfers of spent fuel because of the possibility of taking an item apart and the associated possibility of diversion.

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[5] The design should take into account any needs the operator may have to cut power (e.g. for the maintenance of machines) while maintaining continuous power to safeguards equipment.

[6] The capability of making use of the identifiers might not be cost effective in some instances.

[7] In this publication, the term ‘non-safeguarded items’ refers to nuclear and non-nuclear material not subject to safeguards.

[8] Environmental control systems can include penetrations to be evaluated or monitored as potential diversion paths.

[9] When investigating a loss of CoK, one focuses most of the effort within the MBA where the loss occurred.

In the management of spent fuel, irradiated nuclear material might be considered as waste for disposal or removal by the operator. However, from a safeguards or non-proliferation perspective, the irradiated fuel containing fissile material is direct use material and often receives more verification attention than low enriched fresh fuel (which is often categorized as indirect use material). Moreover, from the operator perspective, the irradiated material is difficult and expensive to handle. Consequently, the flow of nuclear material through spent fuel management facilities can sometimes be productively considered a one way flow with minimal recycling and generation of waste. Including the consideration of safeguards in the design and construction process can:

- Facilitate a full and open dialogue among all stakeholders (e.g. the facility owner/operator, the State, the public, safety authorities, security professionals and the IAEA) regarding facility operations, safeguards and related topics;
- Minimize the impact of safeguards implementation on the operator without reducing safeguards effectiveness;
- Take advantage of each stakeholder's experience and expertise;
- Broaden the knowledge of safeguards requirements in the nuclear community;
- Improve the cost efficiency of safeguards.

Spent fuel safeguards challenges include the difficulty of drawing up statistically relevant sampling plans, making useful non-destructive assay (NDA) measurements and designing unattended safeguards approaches and systems while the operator attempts to minimize the handling and movements of spent fuel. Several Member States have contributed to R&D efforts (e.g. the Member State Support Programme (MSSP) task Application of Safeguards to Geological Repositories (ASTOR)) that included reducing the maintenance needs for safeguards equipment, especially for unattended systems [36–40].

Spent fuel repositories can have requirements by the State that any irradiated material be retrievable for a period of time, e.g. 100 years, which is much longer than a working career. Consequently, transfer of knowledge can become an issue for stakeholders. After long cooling times, the reduced radiation dose from spent fuel and the corresponding potential for reduced self-protection can become an issue of significance for both physical security and safeguards. Consideration can be given to preparing a design for the longer term, including concepts such as machine readable identification or attribute or fingerprint measurements, which are designed to still be useable if the irradiated material is retrieved at a much later date.

A few safeguards concepts of particular interest in spent fuel management are listed below:

— *Continuous inspection*: Continuous inspection refers to an inspection regime intended to maintain CoK concerning inventory and flow of nuclear material by witnessing key operations, recording measurement and operating data and by verifying information. Continuous inspection has been suggested for application to the long term management of spent fuel to provide more uniform safeguards coverage with reduced on-site inspector presence (e.g. during the one way flow of nuclear material through an encapsulation facility or into a geological repository). Continuous inspection can be more cost effective if any monitoring (e.g. radiation, seals or surveillance) is unattended and remote transmission of the data or the equipment state of health is implemented, and when the maintenance and operating costs are well managed. Stakeholders can investigate potential synergies between safety and security requirements when a continuous inspection monitoring system is considered or designed.

— *Single C/S system:* Single containment and surveillance (C/S) is a configuration in which each plausible diversion path is covered by an IAEA authorized device (e.g. a seal, a door open/closed indicator, a radiation monitor or a surveillance camera) and procedures have been established and documented for the evaluation of the results obtained from the surveillance, containment, tamper indication and monitoring devices and an examination of the associated containment. For added reliability (i.e. protection against device failure), C/S devices may have duplication or backup devices on any or all plausible diversion paths. If the surveillance, containment, tamper indication and monitoring devices are duplicated or backed up on all the diversion paths, the system can be designated a 'single C/S system with backup'. Dual C/S is expected to provide more robust coverage at a higher cost than single C/S.

— *Dual C/S system:* Dual containment and surveillance (dual C/S) is a configuration in which each plausible diversion path is covered by at least two IAEA authorized devices that are functionally independent and not subject to a common tampering or failure mode. This is normally achieved by the use of surveillance, containment, tamper indication and monitoring devices that are based on different physical principles. In addition, procedures have been established and documented for the evaluation of the results obtained from the surveillance, tamper indication and monitoring devices and an examination of the associated containment. Dual C/S systems can be considered for use whenever it is desired to reduce the periodic remeasurement activity below that required for single C/S systems. The recovery requirements of a dual C/S system can be lower than those for a single C/S system when only one mode of the surveillance, containment, tamper indication and monitoring system fails. For added reliability, additional redundancy can be considered. Implementation of dual C/S is recommended for difficult to access or difficult to measure nuclear material.

— *Difficult to access:* ‘Difficult to access’ is a designation made by the IAEA Deputy Director General for Safeguards. It can be requested for application to storage locations that are designed such that it is both (1) difficult to access the contents and (2) easy to detect attempts to access the contents. This designation is useful for nuclear material that is difficult to measure or to handle. The design features of the storage location relevant to safeguards are verified by the IAEA (e.g. the geological features of an underground repository or human-made containment features). It is important for IAEA verification to address the initial stages of construction (e.g. before the site is disturbed or concrete is poured) in order to be able to assess the absence of undeclared access tunnels or facilities located underneath the concrete. Once spent fuel has been placed in difficult to access storage, stakeholders prefer not to retrieve the fuel for any reason. Consequently, there is an effort to make all needed measurements before the spent fuel is placed into such storage and apply more stringent surveillance, containment, tamper indication and monitoring measures after the fuel is measured (e.g. dual C/S).

— *Near real time accounting:* Near real time accounting is a form of nuclear material accounting for facilities in which inventory and inventory change data are maintained by the facility operator and submitted to the IAEA on a near real time basis (e.g. daily instead of monthly or annually) so that inventory verification can be carried out more frequently with less advance notice. Near real time accounting is useful for facilities that have a large throughput of nuclear material.

— *Inventory mailbox:* An inventory mailbox is a location where the facility operator can make inventory or inventory change declarations on a frequent basis. These declarations are time stamped and are not retrievable by the operator. The mailbox may be an on-site container under IAEA control, an email address under IAEA control or other suitable arrangements. Mailboxes are often used in conjunction with near real time accounting.

— *Short notice random inspection:* Short notice random inspections are inspections performed both at short notice and at a random point in time. ‘Short notice’ is defined as an inspection for which a shorter advance notice period is provided by the IAEA than that specified under para. 83 of INFCIRC/153 (Corrected) [53]. A ‘random inspection’ is defined as an inspection performed on a date chosen randomly by the IAEA. Short notice random inspections can be difficult to implement if the time required to travel to the location after entering the State is longer than the notification time.

— *Joint use of equipment:* The joint use of equipment (where the equipment used by the IAEA is also used by the State or regional authority or by the facility operator) can be considered when the use of resources can be reduced, the burden on the operator can be reduced and safeguards effectiveness can be maintained or improved. The equipment may be owned by the IAEA, the State or regional authority or the facility operator, or provided by a third party. In these situations, the IAEA will take care to ensure that the integrity and authenticity of the data are assured and the joint use of equipment does not weaken the safeguards effectiveness or compromise the IAEA’s right to make independent measurements and observations. Joint use agreements must be approved by the IAEA Deputy Director General for Safeguards or his or her delegate.

Spent fuel management facilities are a vital part of the nuclear fuel cycle and can be expected to evolve as more experience is gained in their operation. Furthermore, IAEA safeguards will continue to evolve to address verification challenges, both with regards to facilities, and to take other nuclear activities in the State into account. SBD best practice is that stakeholders in nuclear facility design and construction maintain regular contact with State safeguards authorities in order to remain informed about developments that are relevant to safeguards.

3.1. MISUSE AND DIVERSION SCENARIOS

'Misuse and diversion' refers to the use of a safeguarded facility for the introduction, processing or production of undeclared material and/or the removal of declared nuclear material from a safeguarded facility. For existing facility designs in operation, misuse and diversion scenarios have been addressed in the safeguards approaches that are currently implemented. A design team should review their facility to ensure that they have created a facility that can best accommodate any safeguards measures without any need for retrofitting and that their facility does not contain any features that may enable misuse and diversion scenarios not foreseen in existing facilities. For more innovative designs, the designers will have to perform a more detailed analysis to identify potential misuse and diversion scenarios, possibly with the assistance of the State or regional safeguards authorities and the IAEA. Annex III and Refs [29–31, 51, 52] discuss possible analysis methods. One concept underlying IAEA safeguards as applied to the long term management of spent fuel is the question of whether the routine flow of spent fuel can be thought of as a one way flow into storage. In any event, deviations from one way flow are of safeguards interest.

One key misuse and diversion scenario appears in applying safeguards to a spent fuel management facility: diversion from declared inventories or activities. A possible undeclared activity in a spent fuel management facility might be a undeclared reprocessing facility that is collocated or near the facility. Unlike other processing facilities for nuclear material, there is little recycle and generation of scrap in spent fuel management. Consequently, it is more difficult for a potential diverter to make use of these potential diversion paths. However, there might be space for clandestine reprocessing that design information verification of the facility might detect or on-site undeclared reprocessing that could be discovered through implementation of the Additional Protocol and the use of complementary access.

The expected goals of a diverter would be to avoid detection and to require a minimum of effort to conceal the activity. A diverter's methods could include any of the following:

- Diversion from declared inventory and activities, including:
  - Failure to record and/or falsification of receipts;
  - Undeclared removal from a facility, including removal through a non-routine pathway;
  - Undeclared transfers between locations;
  - Undeclared splitting of items (declaring and moving or concealing part of the item);
  - Changing identification labels;
  - Falsifying a declaration of shipment or movement of material;
  - Substitution with similar material or surrogates;
  - Undeclared repackaging (placing less in the new container);
  - Undeclared excess loss in waste.

To address misuse and diversion paths in long term spent fuel management, the IAEA may verify, for example, the:

- Declared quantities of nuclear material;
- Presence of declared activities;
- Absence of undeclared activities;
- Absence of undeclared reprocessing capability;
- Movements of safeguarded material;
- Facility design information, including the absence of undeclared features that could facilitate diversion or facility misuse.

3.2. GENERAL GUIDANCE

From a safeguards perspective, the facility operator will perform handling, accounting and measurement of the spent fuel as part of operating and fuel management activities and the State will provide declarations regarding facility material accountancy and movements to the IAEA. The IAEA will have the task of independently verifying the declarations. In its verification, the IAEA can choose to apply statistical sampling or it can implement measures to verify each item.[10] SBD best practice is a robust process design that can accommodate any level of intensity in the application of safeguards. SBD best practice is also that the consideration of safeguards and the corresponding requirements encompass not only routine operations but also off-normal or process upset conditions. Making preparations and providing necessary facility infrastructure to recover from potential events before they happen can be cost effective compared with being unprepared when they happen.

Stakeholders can consider the integration of safeguards with the safety and security systems. These three regulatory areas address concerns regarding the nuclear material and can share common features, although they address different goals. Potential synergies between them can exist that offer improvements in effectiveness at lower cost. Careful coordination between these regulatory areas can help to minimize their impact on facility operations.

SBD best practice is the use of unique identifiers for safeguarded items to make verification by the IAEA easier. Stakeholders can consider selecting unique identifiers that have machine and human readability, even if human error cannot be ruled out. Human readability can be useful for contingency planning to mitigate machine failures. A design challenge is to find inexpensive yet robust, unique identifiers that are difficult to falsify and that function well over long time periods in a high radiation, potentially chemically harsh plant environment or under rough handling conditions (e.g. uniquely engraved three dimensional identifiers placed on fuel or storage casks by manufacturers).

The preliminary project design might start from a baseline consisting of currently available, commercial off the shelf safeguards equipment. However, when taking the long operating life expected for some of these facilities into consideration, reliable operation, flexibility in infrastructure and space allocation will become increasingly important. Component obsolescence should be expected and explicitly addressed in the design. Design choices that allow for the incorporation of improvements in equipment, safeguards measures, facility design or operations are recommended. For example, it might be reasonable to prepare for equipment obsolescence or cabling failures in facilities expected to operate for long time periods. Consideration can be given to including access to electrical power and data transmission throughout the facility to address potential future needs. Moreover, consideration can be given to sharing equipment or maintenance and to the possibility that the implementation of safeguards measures may evolve. An important lesson learned is that retrofitting for cables and making penetrations during or after construction can be much more expensive than making provision for cables and penetrations in the design.

As the experts on facility features and operations, the designer and the operator can use an understanding of safeguards objectives and measures to contribute to improving the implementation of safeguards. Some of the safeguards measures under consideration have a greater impact on facility operations than others. Recognizing that the designer and the operator are the facility experts, the IAEA relies on the State to inform it about operator or designer concerns, the relative impact of various possible safeguards activities and to assist in efforts to minimize the impacts. It is recommended that dialogue concerning safeguards issues and impacts be entered into with the IAEA so that stakeholders can develop and consider alternatives to resolve them.

Measurement of spent fuel can be difficult and has the potential to interrupt smooth facility operation. Design and operation that reduce the need for and facilitate the implementation of measurements will be beneficial to the operator. The successful maintenance of CoK to reduce the need to reverify spent fuel requires facility features (e.g. containment barriers, places to attach IAEA equipment and seals, and clear field of view for surveillance). In addition, consideration can be given to using equipment to reduce personnel exposure to radiation and to facilitate IAEA inspection and verification activities. Furthermore, the use of automated or remote monitoring that reduces human access to spent fuel handling or storage areas may simultaneously facilitate radiation worker safety, security and safeguards.

A facility layout that is easy to understand and monitor for changes (or for process upset) can benefit both the implementation of safeguards and the operation of the facility. Similarly, features to easily distinguish between fuel and non-fuel items (safeguarded and non-safeguarded items) can benefit multiple stakeholders. As removal of waste and non-radioactive material from a facility offers potential diversion paths of interest to the IAEA, these paths should be minimized and provision for monitoring them should be included in the design. Safeguards measures will be implemented to monitor all potential exit routes (e.g. ventilation penetrations, viewing ports,

[10] In general, statistical sampling is preferred as it reduces the burden on the operator, the IAEA and the State authority. However, discrepancies or a failure of a safeguards measure can be justification for a more intensive measurement effort.

elevator shafts, personnel egress/exits, radioactive and non-radioactive material shipments out of the facility) and to make activities of interest to safeguards difficult to perform without being detected (e.g. unauthorized access).

The IAEA may request additional time after some activities are completed to perform its review of the activity before the associated nuclear material is handled or processed further. For example, one cannot presume that the IAEA is ready to review remote monitoring data whenever it is sent. When an IAEA unattended system is used to provide verification data (e.g. a measurement of a nuclear material item or the monitoring of an operator activity), the IAEA may request a few working days to review the data each time it is received to be sure it is complete (e.g. no gaps), that it verifies the measurement or activity being monitored, and that no undeclared activities of interest to safeguards have occurred. This can necessitate a process design that includes buffer storage or it may offer opportunity to coordinate activities with other facility operations to design a smooth flow of work. Moreover, stakeholders should work as a team to develop concepts and assess the costs and benefits between redundancy and multiple technologies, e.g. dual C/S, dual C/S with backup, single C/S or single C/S with backup.

General features of safeguards relevance in the design include:

- Simplified nuclear material flow pathways, which are easier to monitor.
- Use of nuclear material flow monitoring systems.
- Careful inventory control, including segregation of spent fuel into batches.
- Consistency between safeguards, security and process control operational boundaries.
- Features to distinguish between routine and non-routine fuel transfers.
- Features to distinguish between fuel and non-fuel items.[11]
- Minimization of IAEA equipment and activities in contaminated or high radiation areas.
- Minimization of radiation exposure to inspectors and safeguards equipment.
- Minimization of the potential for damage to safeguards equipment or loss of safeguards data.
- Enhancement of the ability to verify the absence of undeclared activities or diversion.
- Inclusion of the IAEA equipment and activities in facility and IAEA contingency planning, e.g. for:
  - Discrepancies found in verification;
  - Off-normal operations;
  - Leaks in spent fuel packaging;
  - Obsolescence or inability to maintain components;
  - Loss of CoK.
- Access control of IAEA equipment and to the features of the facility that are relevant to safeguards.
- Arrangements for retrieval/maintenance of equipment, particularly if breakdown occurs when loaded with spent fuel.
- Access to controlled spaces for storing, handling or measuring spent fuel.
- Sharing equipment, contingent on the various stakeholders' authentication and independence needs.[12]
- Unattended operation of safeguards equipment and remote data transmission.

The installation of safeguards equipment is generally a joint undertaking. The location of the equipment will be mutually agreed by the IAEA, the operator and the State's safeguards authorities. Stakeholders can consider:

- Minimization of the effect of safeguards on plant operation by selecting locations for safeguards equipment that are accessible for inspection, monitoring and maintenance and that do not obstruct or impede plant operations;
- Planning for component obsolescence and replacement;
- Making recommendations for reliable, low-maintenance commercial off the shelf equipment and as to which spare/replacement parts might be stockpiled.

[11] SBD best practice includes the provision of training for designers and operators on how to distinguish between safeguarded and non-safeguarded items.

[12] The IAEA verifies that the data it analyses is authentic (not tampered with) and independent from possible operator manipulation.

3.2.1. Infrastructure

The facility is responsible for providing access to the facility and the infrastructure necessary to support safeguards equipment. In many cases, the facility safety regime requires that facility personnel perform equipment installation and any in situ maintenance. In this case, the IAEA should generally be present when safeguards equipment is being installed or maintained. Figure 11 shows an operator providing installation support under IAEA observation. SBD best practice is that provision be made for safeguards equipment handling and installation in the design and construction of the facility. Moreover, SBD recognizes that the techniques and methods applied for safeguards may change over the facility's operational lifetime and suggests that an infrastructure design be developed that can accommodate these changes.

When sensors are placed in high radiation or high traffic areas, the support electronics associated with those sensors can often be placed in low hazard, low traffic areas. A designer can recommend optimum locations that avoid interference with operations. Shielding, lighting, maintenance and decontamination issues can be discussed. Segregated, well labelled utilities can reduce the chance of the operator inadvertently disabling safeguards equipment. Remote data transmission capability implies that the facility will provide connections (e.g. cabling or wireless) from the safeguards sensors to the safeguards data collection and transmission equipment as well as from the IAEA transmission equipment to internet connectivity.

Safeguards equipment requires regular maintenance and replacement. This maintenance can sometimes be performed during normal facility operation if suitable arrangements are in place. Coordination with those responsible for the facility equipment installation and maintenance, including the sharing of resources, can be considered. Otherwise, maintenance can be performed by the IAEA only on equipment that has been checked for contamination after being in the nuclear facility, and that has been decontaminated if necessary.

Guidance based on lessons learned in the design and installation of infrastructure for safeguards equipment includes recommendations to:

- Provide penetrations through building structures for cabling;
- Include safeguards equipment infrastructure needs in design documents and in the design review process;
- Segregate the facility services (water, wastewater, electrical supply, compressed air, steam, helium, argon, and waste removal) from the nuclear material locations to reduce the number of facility staff who require access to those locations and the potential diversion pathways;
- Position equipment to minimize impact on operations and to reduce the opportunities for damage to the equipment;
- Include space and mounting brackets for safeguards equipment in the facility design;

FIG. 11. Receipt and installation of IAEA equipment racks.

- Provide stable electrical power (e.g. instrument quality when necessary, isolated from arc welders or other sources of noise);
- Provide backup emergency power[13] to reduce the chances of a loss of safeguards data;
- Provide adequate lighting to perform inspection activities and for the surveillance, containment and monitoring equipment;
- Provide a wireless or wired data transmission backbone;
- Facilitate access to safeguards equipment for maintenance or data retrieval;
- Consider safeguards equipment needs in the planning for installation, maintenance and refurbishment.

Designers can recommend options for environmental control when safeguards equipment requires it (e.g. space outside the processing area protected from extreme heat, humidity, radiation and contamination). Moreover, they can consider a single dedicated space for the support equipment that can be access controlled by the IAEA (except for abnormal operator access to respond to emergencies). This space can include temperature, humidity and dust control, and clean, reliable electrical power. Furthermore, future needs for space in the design optimization can be considered, e.g. for future safeguards equipment or to accommodate temporary workspace for inspectors (where temperature, lighting and noise can be held to acceptable levels).

3.2.2. Containment, tamper indicating seals, surveillance and monitoring

Measurement of spent fuel is difficult and may potentially expose personnel to radiation. Consequently, sharing of measurement equipment and results and also complementary measures are used by the IAEA to reduce its need for measurements. Complementary measures [53][14] (e.g. maintaining the CoK on information relevant to safeguards) can include containment, tamper indicating seals, surveillance and monitoring. In addition to maintaining CoK, complementary measures can be used to monitor the movement (flows) of the spent fuel or to detect undeclared access to, or movement of, the spent fuel or safeguards equipment, and also to monitor the chemical processes involved in preparing and transforming spent fuel into a final form for long term storage. They can also be applied to potential diversion paths that were not intended for fuel transport, (e.g. ventilation shafts, waste removal systems and personnel elevators). In addition, complementary measures can sometimes serve a dual function such as monitoring for radiation safety or for physical security (e.g. unauthorized access). Complementary measures are most useful when an inspector is not present. Moreover, complementary measures cannot serve their purpose without facility design features such as structural barriers, access control, segregated storage locations and fixtures for the application of tamper indicating seals. The IAEA will verify the characteristics of these facility design features before and during their use for safeguards purposes.

Well designed facility barriers:

- Limit access to portions of the facility that handle or store spent fuel;
- Have a minimum number of penetrations that require monitoring;
- Limit the movement of the spent fuel;
- Segregate fuel and non-fuel items from one another;[15]
- Segregate activities of safeguards interest from other activities;
- Serve to jointly address safety, safeguards and security concerns.

Access control can be used with facility barriers to monitor access to:

- Locations containing nuclear material;
- Processing areas;
- Control rooms or equipment.

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[13] Safeguards equipment includes limited battery backup to allow continued operation during short power outages.

[14] INFCIRC/153 (Corrected) [53] Para. 29: "To this end the Agreement should provide for the use of material accountancy as a safeguards measure of fundamental importance, *with containment and surveillance as important complementary measures*." [Emphasis added].

[15] Containment may be useful to segregate fuel and non-fuel item items (e.g. casks with tamper indication).

Sometimes the IAEA monitors access and sometimes the facility administratively limits which staff can enter monitored rooms and how often. Safeguards, safety and security staff can assess the benefits of sharing the monitoring data from access control.

When nuclear facilities are placed underground to make them more difficult to access without detection (e.g. in a geological repository), the IAEA will have an interest in verifying the integrity of the geological features considered a containment feature. The IAEA verification is not expected to duplicate all of the site characterization. It may consider use of sampling or innovative measures. As one example, stakeholders can consider the creation of a buffer zone around an underground facility that excludes surface or subsurface human activity. This can potentially facilitate the IAEA's verification that no penetration of the site (e.g. via the buffer zone) has occurred, as well as providing a safety buffer, but it might impose undue hardship on other stakeholders. Research investigating methods to monitor underground facilities and activities of safeguards relevance includes (e.g. the research reported via the MSSP ASTOR task):

- Seismic monitoring for human activities;
- Ground penetrating radar for hidden rooms;
- Underground positioning and location tools to orientate inspectors;
- Robust methods of item identification;
- Mapping with a three dimensional laser system of an active excavation site.

Segregated storage locations can be used to separate safeguarded from non-safeguarded items to help reduce subsequent safeguards verification activities (e.g. empty versus full spent fuel containers). Moreover, they can be used to separate items that have been verified from those that have not been verified and from those that pose questions arising from an incomplete verification activity).

In an item processing facility, the nuclear material items are contained in such a way that tampering with or opening an item can be easily detected. The integrity of the item is fundamental to maintaining CoK of that item. In many item facilities, the IAEA will take advantage of unique item identifiers during its verification activities. However, in a spent fuel facility with one way flow into a difficult to access location, the identifiers may not be as useful when the safeguards objective is to verify that all items go into that location. In some cases, the enclosure method for a container, such as a weld on the lid, or the chemical and radioactive signatures of its contents, creates a unique feature (e.g. an attribute) that can be used as an identifier to distinguish similar items from one another. Areas of research include examining features such as the canister closure weld or radioactive emissions in order to define unique characteristics for an item.

A well designed fixture for tamper indicating seals has the following characteristics:

- It is difficult to remove or replace without leaving evidence of tampering.
- It has no externally accessible hinges on doors or hatches.
- It is integral to the design rather than being an add-on.
- It has loops or openings through which the seal's wire or optical cable can be passed.
- It is easy to access and use.

Figure 12 shows a fibre optic tamper indicating seal being verified by an inspector. The IAEA can apply tamper-indicating seals on items while they are underwater; other concepts involve seals that are immersible and that can be verified using an underwater camera [54].

Radiation monitors respond to changes in the radiation level caused by the movement of nuclear material. Some radiation monitors are sensitive enough to respond to changes in the natural background radiation as well. The strength of the signal in a radiation monitor varies as an inverse square law based on the distance between the radiation source and the detector. Consequently, placing sensors as close as possible to the material being monitored can provide better signal to noise characteristics. However, this may make the sensor more susceptible to damage or more likely to interfere with facility operations. Design optimization finds the best balance between signal strength, signal quality and operational impacts. Another design choice can be between a more expensive sensor that distinguishes characteristics of the radiation signal and a simpler, less expensive sensor that is easier to maintain. Radiation monitors can be designed to:

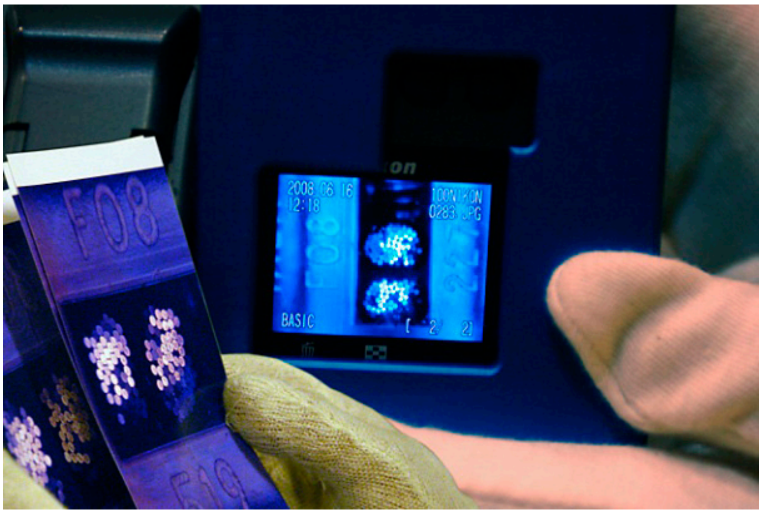

FIG. 12. Example of a fibre optic seal being interrogated.

- Indicate the presence or movement of spent fuel;
- Verify that containers are empty;
- Verify that waste contains little or no nuclear material;
- Trigger a reading from another sensor (e.g. a surveillance picture);
- Operate underwater or in low illumination areas.

In the context of monitoring nuclear material flows, radiation monitors can:

- Indicate the direction the spent fuel is moving;
- Distinguish between fresh and spent fuel;
- Distinguish between fuel and non-fuel items;
- Monitor access penetrations to verify a lack of nuclear material movement through them.

Moreover, radiation monitors can be:

- Installed outdoors or indoors;
- Installed in high radiation areas;
- Used to monitor the transfer or movement of nuclear material by any means;
- Blocked from detecting the signal by use of a radiation shield (e.g. water, lead or concrete).

Figure 13 shows the internal components of a typical radiation monitor approved for use by the IAEA, in this case a mobile unattended neutron detector system (MUND). Figure 14 shows a MUND [15] attached to a fuel transportation container. It can operate to store data using its battery during shipment of the container and then be connected to a power supply and data transmission connection upon receipt, where it can have the stored data read out remotely from an off-site location.

A potentially fruitful area of research in facility monitoring is looking into how to make better use of the operator's process monitoring and control systems installed, for example, for automated process operations for safeguards purposes. For example, can a non-sensitive subset of the operator's process monitoring data be identified (that can be shared with the IAEA) that provides assurance the facility is operating as declared? Part of the evaluation to provide an answer to this question should include the authentication of the data from sensors.[16] This data set should not overwhelm the IAEA with a large data reduction or review effort. A potential advantage to stakeholders from sharing such process data could be fewer components to maintain (e.g. shared maintenance on one set of equipment). However, maintaining the independence of the safeguards conclusions and ensuring the

[16] The IAEA must verify that the data it uses are authentic — not tampered with or altered by the operator.

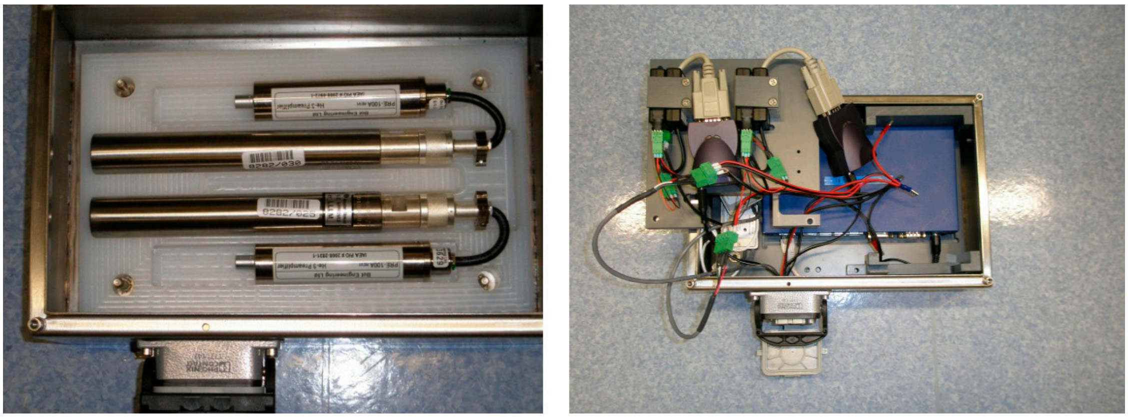

FIG. 13. Internal components for the MUND.

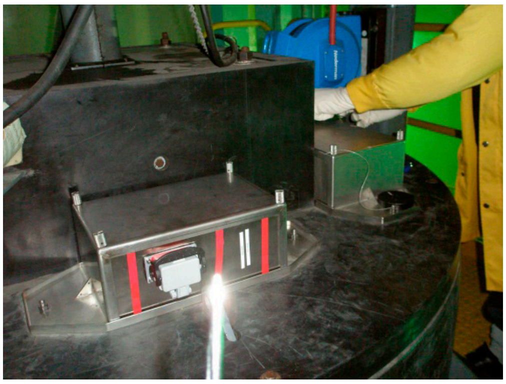

FIG. 14. MUND installed on container.

authenticity of the data for each of the stakeholders are parts of the challenge to be resolved. Designers should include safeguards considerations as part of the requirements optimization for monitoring the facility or the operations in the facility.

Radiation monitoring can be combined with other sensors. For example, the MUND displayed in Figure 14 has intrusion detection for its enclosure packaging. Furthermore, sensors can be used to transmit a signal that requests another sensor to take a reading or to perform a measurement. This type of signal is known as a trigger. Radiation monitors and seals on access penetrations can be configured to trigger surveillance when activity is detected. Each event or reading from each sensor is associated with a time stamp indicating when the event occurred. The IAEA can correlate data from multiple sensor types with operator activities using these time stamps. This has proven especially helpful to the IAEA in the review of large data sets that include a few events of interest buried in a large quantity of data of little safeguards relevance. However, protection of commercially sensitive information can potentially become a concern to be mitigated if the sensitive information leaves the site.

Design aspects that can assist surveillance, containment and monitoring measures include:

- Use of a minimal number of penetrations to be monitored in a containment structure or in hot cell fuel handling areas;
- Capability for the monitoring or measurement of all materials removed from the MBA or facility, including waste and non-radioactive material;
- Capability for monitoring possible exit routes, e.g. ventilation penetrations[17], inspection camera viewports, elevator shafts, personnel egress/exits and all shipments out of MBA or facility;
- Design of the facility layout to simplify the surveillance and monitoring system;
- Nuclear material transport routes that are easy to monitor;

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[17] For example, ventilation ducts can be split or have bends such that even the smallest fuel items cannot be moved through them.

- Provision of adequate lighting, electrical power, data transmission capability and a safe environment;
- Features to easily distinguish fuel and non-fuel items;
- Positioning of surveillance systems and limiting movements of nearby equipment so that surveillance cannot be blocked (e.g. by cranes moving objects or by scaffolding);
- Use of underwater cameras to identify or count assemblies and to follow their movement;
- Use of identification for safeguarded items that is difficult to alter without detection;
- Agreement on when individual item identification is necessary and when counting the number of items is sufficient;
- Facilitating the use of IAEA seals at features relevant to safeguards (e.g. penetrations, measurement equipment, nuclear material storage areas and junction boxes where cables are connected).

With an understanding of safeguards needs, designers can recommend simple solutions that reduce the impact on operations and minimize capital costs and maintenance.

3.2.3. Design information verification

Design information verification (DIV) objectives in long term spent fuel management include, for example:

- The verification of the facility (e.g. that the design features that are relevant to safeguards are unchanged from the declared design information);
- The verification of the facility equipment (e.g. that all activities relevant to safeguards in the facility are declared);
- The detection of any changes that would make the safeguards measures less effective.

The IAEA can choose to begin site visits before construction begins and can choose different activities to be performed during each site visit. In general terms, activities during DIV include:

- Comparing the design drawings during and after construction;
- Photographing relevant features;
- Assessing relevant features before they become difficult to access;
- Assessing completed structures for modifications relevant to safeguards;
- Comparing the declared function and capacity of the facility and equipment with the observed function and capacity;
- Assessing penetrations for the possibility of access by humans or the passage of nuclear material;
- Comparing present design with the baseline verification;
- Assessing essential equipment for undeclared modifications;
- Assessing the fixtures for IAEA seals.

At any phase of the facility's life cycle, the nuclear material storage, nuclear material flows and the facility structures supporting safeguards measures may be evaluated to gain assurance that they are as declared and to confirm they meet safeguards requirements. During any site visit, the IAEA can make use of an essential equipment list to help verify that the facility status is as declared.

With regards to the verification of design information, a design team can consider the following:

- A facility layout within which processes can be easily understood and the movements of, and activities with, safeguarded material can be easily monitored;
- Recommending how to assess the difficulty of access to locations relevant to safeguards;
- Reducing the number and size of penetrations through which nuclear material can move in containment structures or hot cell fuel handling areas;
- Providing access for design verification activities (e.g. visual inspection of hot cells, canister sealing, material flow paths and other fuel repackaging activities);
- Segregating facility locations under construction or being modified from locations containing nuclear material.

Preliminary design information must be submitted to the IAEA by the State as soon as the decision to construct or to authorize construction has been taken. However, SBD best practice is that design information be provided in preliminary form as it becomes available during the facility or process conceptual design. This can facilitate dialogue and understanding about the facility layout, the proposed operations and possible safeguards measures. This information is then updated as details become known.

The State provides detailed information to the IAEA including nuclear material types and flows, non-nuclear material types and flows, the facility's processing equipment and supporting photos, drawings and diagrams as they become available. Annexes IV–VI summarize the contents of design information questionnaires (DIQs) that are to be provided to the IAEA. The initial provision of information may be incomplete; however, it can serve to highlight gaps and questions for clarification. As these gaps and questions are addressed, it will become clear to the participants which design information is fixed, and which is still under development. Stakeholders should not be surprised if a portion of both the facility design and the safeguards measures evolve during construction.

Design modification is an expected feature of the operational phase of a geological repository, unlike other nuclear facilities. The operator excavates new drifts and tunnels, transfers nuclear material to the facility and makes the nuclear material difficult to access by backfilling tunnels. Design modification may require changes in the frequency or in the intensity of the safeguards measures applied to the facility. The IAEA may confirm that:

- The design information is correct and complete.
- The safeguards approach continues to be appropriate taking into consideration the facility design, capabilities, capacity and verification measures.
- Safeguards equipment meets requirements and is operational.
- No nuclear material has been removed.

The IAEA will continue to apply safeguards to nuclear material in a geological repository once the repository is sealed. The IAEA may adjust the safeguards activities to focus on access to the nuclear material, e.g. to verify that no access to the repository has occurred.

Areas of research interest in verifying design information for underground mining facilities as discussed during the ASTOR task include:

- Personnel location tools that do not rely on GPS;
- 3-D laser measurements applied to underground excavations;
- Ground penetrating radar;
- Passive seismic or acoustic sensor arrays;
- Satellite imagery;
- Unique identifier for nuclear material storage casks with features such that tampering, falsification or duplication of the identifier are detectable;
- Geoscientific information to demonstrate the safe and secure performance of the repository;
- Open source data collection and analysis to support DIV.

3.2.4. IAEA physical inventory verification

Physical inventory verification (PIV) in long term spent fuel management necessitates that:

- The operator and the State maintain a system of nuclear material accounting that is based on measurements to the extent feasible when limited by benefit–cost considerations.
- The IAEA independently verify the completeness and correctness of the inventory information in the reports provided by the State, as well as the facility records and supporting documentation.

The verification of the physical inventory in nuclear facilities has traditionally been performed on a yearly basis. In addition, more frequent interim inspections have been performed to obtain verification of the nuclear material for timeliness and deterrence by early detection of diversion and for material transfers such as receipts and shipments. Inventory verification activities involve inventorying all nuclear material for consistency against records and reports, performing NDA and/or DA measurements as needed, and evaluating C/S systems such that surveillance is reviewed and seals verified.

Provisions that facilitate PIV are to:

- Schedule the inventory verification when temporary storage locations are empty;
- Schedule the inventory when nuclear material movements are temporarily stopped for other reasons;
- Minimize the need for movement of safeguarded material for counting and measurement purposes;
- Segregate nuclear material from items that do not contain nuclear material (e.g. fuel assemblies from non-fuel assemblies);
- Segregate verified and non-verified items of safeguards interest.

An ability to segregate verified materials and material with potential safeguards issues under seal can simplify the subsequent verification effort.

A designer might find the following considerations useful:

- At any phase of the facility's design and operational life cycle, material receipts, shipments and static inventory as well as any safeguards data may need to be accessed for verification.
- It can be cost effective to perform any desired measurements on an item before placing it into difficult to access storage.
- Once an item has been measured by the operator and verified by the IAEA, more rigorous surveillance, containment and monitoring measures can be applied to reduce the need for remeasurement.

The above guidance assumes that nuclear material accountancy will remain a fundamental safeguards measure for verifying a State's declarations about nuclear material.

In the development of safeguards measures for spent fuel in difficult to access locations, the IAEA applies redundant surveillance, monitoring, tamper indication and containment measures[18] to reduce or eliminate the need for access to nuclear materials. These include dual C/S with backup, dual C/S and single C/S with backup and taking advantage of facility containment structures and access control.

3.2.5. Measurements of spent fuel

Stakeholders share a desire to know the correct locations and nuclear material compositions of spent fuel assemblies (e.g. the characteristics of the fuel, whether the fuel assemblies are intact or have pins removed) so that the status of the facility is verified to be intact and safe. The IAEA has the responsibility of verifying the completeness and correctness of the State's declaration of the nuclear material content of the spent fuel and nuclear activities at the facility. IAEA verification of the nuclear material content uses statistical sampling to meet a probability of detection goal dependent on the measurement uncertainties and access to the entire population of items in the facility. This sampling determines the type of measurement for each selected item with respect to gross, partial and bias defect levels of detection calculated in the sampling plan. Depending on the safeguards approach, the IAEA employs counting and tag checks of items, NDA measurements and DA measurements as appropriate and practical. With respect to spent fuel, unless there are efforts by the operator to dissemble and perform some form of post irradiation exam on the fuel during repackaging of the fuel items prior to final disposal, DA measurements would not be appropriate for repository safeguards. However, NDA techniques will be of use and need to be examined in light of the facility design and operations. A key part of the verification effort will focus on working with the best estimate of the nuclear material content of the spent fuel that can be obtained by the reactor operator when the fuel is removed from the reactor, derived from calculations of the core burnup and uranium depletion and plutonium production. What is less clear is how this information will be made readily available to subsequent stakeholders who handle the fuel or those who perform verification activities. SBD best practice is that this information be identified and the responsibility for archiving and distributing it be assigned as early as feasible so that planning for verification activities starts in the design phase.

[18] The selection of safeguards measures takes capital cost, installation and maintenance costs, and ease of use into account.

Direct measurement of the uranium or plutonium content of spent fuel is challenging [43, 49, 50]. The measurement of uranium or plutonium content in spent fuel can often be no better than ~10%, even using information from the operator, whereas removal of a single pin may constitute 1% or less of the total mass. Consequently, measures that detect the removal of one or two pins can be more rigorous than measurements of plutonium content. The IAEA can be expected to verify the operator's measurement system and results. As part of the decision about where to make these challenging measurements, SBD best practice is that consideration be given to maintaining confidence in the continued validity of the measurement results (maintaining CoK) and how to recover from a loss of that CoK.

This guidance assumes that the majority of the spent fuel is in intact, non-leaking assemblies, but provision must be made for exceptions. When inspectors are not present, IAEA review of spent fuel verification activities may require up to a few working days before the item is released for further handling or processing (e.g. the IAEA may request access to the specific fuel item for three working days, until the review of the measurement and remote monitoring data can be completed at headquarters). Once the content of the spent fuel has been verified by the IAEA, measures can be applied to reduce the need to repeat verification activities, including surveillance, containment, monitoring, access control and tamper indicating seals.

Because of the difficulty and high cost of implementing the current techniques and limitations on measuring the quantity of plutonium directly, verification of spent fuel constitutes an active area of R&D [43–50]. The opinion held by some at the time of writing was that the best attended verification measurement method approved by the IAEA for use in spent fuel ponds was based on Cerenkov viewing devices (ICVD and DCVD) [15, 28] that verify that the fuel has been irradiated and, with CoK, the IAEA can assume that the fuel has not been tampered with since it was removed from the core and that it contains all plutonium and uranium declared. Cerenkov viewing essentially then verifies spent fuel nuclear material indirectly by assuming an irradiated fuel assembly is an intact fuel assembly that was irradiated as declared by the operator. On the other hand, the best unattended method approved for use is based on the fork detector (FDET) [15, 50]. The FDET can, through gamma and neutron measurements of the spent fuel, assess the declared burnup of the fuel essentially providing an indirect but far more quantitative verification of the uranium and plutonium content of spent fuel. Alternatives such as the irradiated fuel tester (IRAT), the safeguards MOX python (SMOPY) and the spent fuel attribute tester (SFAT) [15] are considered better in some situations. However, research efforts on methods to verify spent fuel offer promise for improvement [43, 49, 50]. SBD best practice is that any facility that includes spent fuel verification in its operations consider preparing for the possibility that an improved measurement alternative will become available (e.g. consider the associated spent fuel handling implications, space allocation, electrical power and communications cabling).

Verification of spent fuel with an FDET requires movement of the assemblies into the detector. In addition, the handling of the FDET or provision of a fixture to hold it in place can be considered. Figure 15 shows an FDET in use as a fuel assembly is being moved by the operator underwater towards the measurement position, shown in the inset in the lower right corner of the figure.

Verification of spent fuel in wet storage using a Cerenkov viewing device requires that the water be optically clear, the pond surface still and that the lighting not have interfering wavelengths or cause interfering reflections. The viewing device must be precisely positioned over each assembly to be verified. Access is needed directly above each assembly and the capability to attach the viewing device, essential for the DCVD, attach the viewing device to spent fuel pool bridge or other suitable structures or to brace it against stout structures such as bridge handrails. Provision for protection against personnel dropping miscellaneous components (e.g. pens and paper, the viewing device itself, eyeglasses belonging to the inspector or personnel radiation detectors) into the spent fuel pond should be considered.

Figure 16 shows IAEA personnel using the operator's bridge crane during Cerenkov glow verification measurements [15] above the spent fuel pond. Figure 17 shows an example of the glow observed from irradiated fuel.

Unattended measurements with the FDET and secure remote transmission of results to the IAEA may:

- Be used with mailbox declarations and a near real time accounting regime [28, 33];
- Offer more flexibility in the scheduling of facility operations;
- Reduce the on-site presence of the IAEA;
- Need a more complicated system or software with increased maintenance needs;
- Place limitations on the use of other measurement techniques.

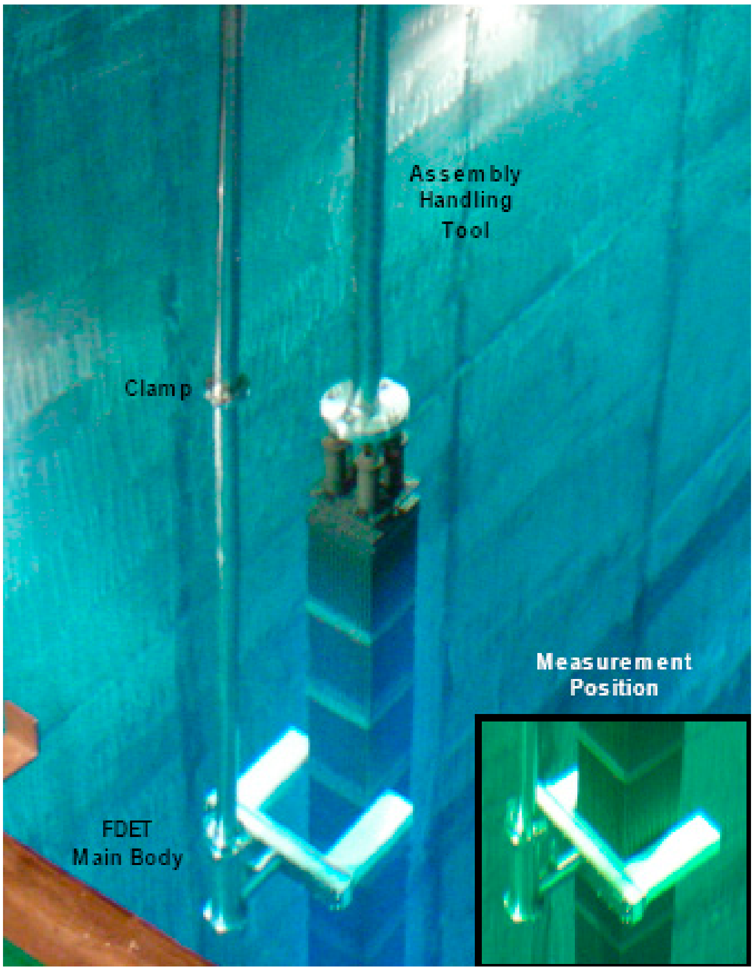

FIG. 15. FDET being used for spent fuel verification measurements.

FIG. 16. IAEA use of operator equipment during spent fuel verification.

It can be challenging to agree on the best location and time in the spent fuel management process for measurements; one possibility is at the reactor shortly after discharge, and another is just before encapsulation or placement into storage. Potential topics for discussion when comparing alternative measurement locations include:

- The number of sets of equipment (e.g. when multiple sites or facilities are involved);
- The quantity of surveillance, containment and monitoring equipment;

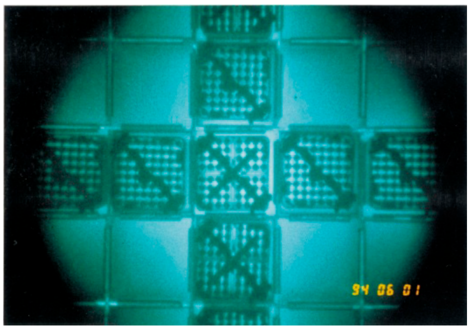

FIG. 17. Example of the Cerenkov glow observed from irradiated fuel.

- The impact on the efficient operation of different facilities;
- The ease of IAEA access to different facilities (e.g. facility safety training and escorting requirements);
- The need for temporary buffer storage;
- The need for a dedicated location for verification or operator measurements that is isolated from other fuel assemblies;
- The relative impacts of provision for IAEA access to pond activities versus IAEA access to encapsulation activities;
- The sharing of equipment, subject to stakeholders' authentication concerns;
- The sharing of maintenance support (note that some facility safety regimes limit non-facility-staff activities inside the facility);
- The control of access to measurement or verification equipment and locations;
- The capability of distinguishing between fuel and non-fuel items;
- The capability of verifying empty transfer or shipping containers.

Considerations and lessons learned in spent fuel measurements include the following:

- Spent fuel verification requires operator support and equipment.
- The operator will prefer to minimize the handling and movement of spent fuel (e.g. to minimize dose to staff and inspectors and to integrate measurements with the other facility fuel handling operations).
- The IAEA will endeavour to minimize the impact on the operator's schedule (e.g. avoid being on the critical path in facility operations).
- The IAEA will decide on the sampling plan (e.g. how many and which items must be verified).
- A capability to segregate verified items from unverified items is desirable.
- A capability to easily verify positions of containers that do not contain nuclear material is desirable.

It is generally accepted that significant effort will be made to maintain CoK following spent fuel measurements to reduce the need for subsequent measurements. Options to consider during contingency planning for recovery from a loss of CoK include:

- Partitioning a storage area into subsections using segregation and seals on partitions to reduce the magnitude of any reverification effort;
- The possible use of attribute or fingerprint baseline measurements for items to enable subsequent rapid item identification;
- Alternative measurement techniques;
- The use of statistical sampling and calculations as part of some safeguards measures.

Other miscellaneous considerations regarding safeguards measurements include the following:

- In most cases, each spent fuel assembly constitutes an item to be measured or verified and contingency planning is necessary for the exceptions (e.g. broken or leaking assemblies, pieces of fuel).

- Waste can be generated in small quantities and as it is a potential diversion path, the IAEA may choose to verify that waste does not contain nuclear material.
- Waste measurements generally yield better results in locations with relatively low background radiation isolated from movements of items that might contain nuclear material.
- NDA measurements usually benefit from shielding and segregation from similar items that can cause problems with background variations impacting the results. Access and scheduling for the maintenance of IAEA equipment can be coordinated with the facility's schedules.
- Space, procedures, facility personnel and equipment will be needed for decontaminating IAEA equipment after use in the spent fuel pond.
- A water quality treatment system might be installed and maintained in a spent fuel pond for several reasons, one of which can be the long term operational capability of the IAEA equipment and verification activities.

3.3. SPECIFIC ACTIVITIES AND LOCATIONS

Sections 3.3.1–3.3.7 provide guidance for specific activities and locations in long term spent fuel management and share lessons learned from previous implementations of IAEA safeguards.

3.3.1. Transfers of spent fuel

It is a generally accepted principle that nuclear material is more vulnerable to diversion while it is being transported between sites or facilities. This section addresses the safeguards considerations for (1) on-site movements of spent fuel, and (2) transfers between sites that occur outside the facility safety and security boundaries.

These two scenarios can be addressed quite differently by security and safeguards personnel. However, in both cases, coordination between these regulatory areas can be beneficial. Safety, security and safeguards have overlapping interests regarding spent fuel transfers. All three regulatory disciplines want to verify that all the spent fuel gets transferred completely and correctly, i.e. no spent fuel is lost or diverted. Consequently, transfers between sites that take longer than expected can become issues of interest for safeguards, and also for safety and security. Efficient coordination between these regulatory regimes can be challenging. Transfers of spent fuel within a facility are often performed with automated equipment and without human access to the fuel, making use of flow monitoring as a verification measure attractive to the IAEA for these transfers. For transfers between sites, verification of containment and tamper indicating seals, as well as a comparison of the shipment and receipt records from the two facilities, are likely to be implemented.

Transfers of spent fuel can require extensive monitoring effort on the part of the IAEA unless it implements an automated continuous inspection scheme or unannounced inspections. Early consultation between stakeholders, including working groups and field trials, if necessary, can result in an improved design. Moreover, early and sustained involvement of the operator is important for successful implementation of safeguards [3, 20–23, 32, 33, 41, 42].

Since spent fuel is hazardous and is handled remotely with shielding and specialized equipment, the aim is to minimize the handling of fuel. Therefore, measurement activities are often combined with transfer activities to reduce the amount of handling that is required. Stakeholders can take into account the fact that, after cooling for as little as 25–50 years the radiation hazards from spent fuel and the need for shielding can be substantially reduced, depending on the reactor and fuel types, and the intensity of physical security measures might therefore be increased [55].

The two primary issues of interest to safeguards during the transfer of spent fuel are determining:

- How much nuclear material was transferred;
- That all the transferred nuclear material has been received.

The safeguards measures usually applied to address these issues aim to maintain CoK on the material flow movements and material quantities. Safeguards measures include unattended radiation or surveillance monitoring, application of tamper indicating seals or devices, confirming the integrity of facility features such as walls and barriers that assist in containment, and even the use of human surveillance and monitoring when needed. Stakeholders can assess the benefits and costs of seals, surveillance and radiation monitoring to reduce the need for on-site inspector presence. In addition, unannounced inspections, remote monitoring (transmission of data or state of health information off-site) and mailbox declarations can be part of the discussions to reduce IAEA impact on operations, increase deterrence of diversion by early detection, maintain CoK and provide for means for reverification of material where CoK has been lost.

Safeguards considerations and issues include efforts to:

- Minimize the time performing the transfer;
- Design a simple transfer route that is easy to monitor and control, with minimal opportunities for diversion;
- Coordinate transfer schedules with the IAEA, subject to security limits or concerns (e.g. loading, movement or opening of casks);
- Share equipment;
- Adjust the location where IAEA seals are applied to meet safeguards technical objectives while accommodating operational needs [32];
- Assess possibilities for item identification [33, 40] or process monitoring [56, 57].

3.3.2. Wet storage of spent fuel

It is assumed in this guidance that the spent fuel has been irradiated sufficiently in the reactor to become a radiation safety hazard that requires special handling. Immediately after removal from the reactor, spent fuel is generally stored in water to provide both biological shielding and cooling. The storage is usually situated close enough to the core to minimize handling, but sufficiently out of the way to avoid interference with other activities.

The spent fuel pool in Fig. 18 has a water treatment system to control the water chemistry. The chemistry is controlled to reduce corrosion of the spent fuel or any equipment in the water, and also to facilitate observation of the spent fuel assemblies, including any identification markings. Observation of the Cerenkov glow requires water clarity in both the ultraviolet and visible light spectra as well as an undisturbed water surface. In addition, when fuel is stored in open containers and in a single layer, it can facilitate use of Cerenkov radiation as a safeguards measure.

In the annual PIV, the IAEA will verify the State declaration of the spent fuel pond contents using statistical sampling plans to create an inspection plan including item identification, item counting, NDA measurements and examination of facility records. Discrepancies between the records and the physical inventory might require additional activities in order to resolve them. The inspectors can carry out measurement verification activities, e.g. with a Cerenkov viewing device (ICVD or DCVD) [15, 28] or an FDET [15], depending on the technical objectives for the State and facility. Figure 19 shows the use of the DCVD to observe irradiated fuel from a wet

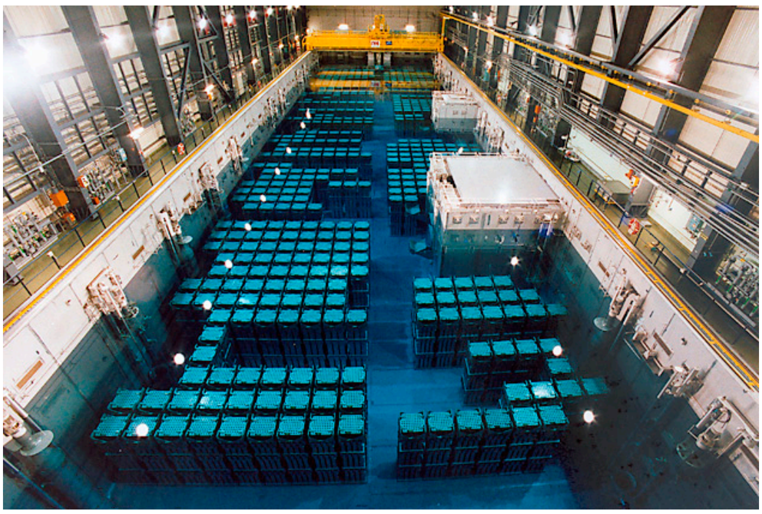

FIG. 18. Spent fuel in a wet storage facility.

FIG. 19. DCVD in use in spent fuel wet storage.

storage hall bridge crane. Between annual PIVs, the entire spent fuel cooling pond area might be under optical surveillance and the transfer channels in a reactor facility between the reactor core and the pond can be sealed or monitored, and in away from reactor storage or wet or dry storage, transfer hatches or doorways for the movement of spent fuel casks can also be sealed or monitored, as part of maintaining CoK. Arrangements can be planned with the IAEA in advance for fuel transfers into or out of ponds in all cases.

Surveillance measures (e.g. cameras and radiation detectors) can be applied to the spent fuel pond and the surrounding area to maintain CoK on the verified spent fuel and to monitor any nuclear material movements. Cooling pond covers with barriers and tamper indicating seals that indicate whether the pond or the spent fuel has been accessed can be installed over areas of the pond that are not subject to regular use. Designers can recommend optimum locations for sensors (e.g. optical surveillance, radiation or transfer channel open/closed indicators) that reduce impact on operations, protect equipment from damage and minimize costs.

Design features for spent fuel wet storage areas that assist in the implementation of safeguards are:

- Providing a location with an unobstructed view of activities involving nuclear material that is suitable for the installation of surveillance equipment;
- Room lighting whose spectrum does not interfere with the characteristics of Cerenkov glow detection[19] and that avoids direct reflections that impede camera viewing;
- Inspector access to the cooling pond bridge crane and a fixture for attaching safeguards equipment;
- Spent fuel storage racks that permit unobstructed viewing straight at the top of each fuel assembly with its identifier visible (e.g. for viewing of the Cerenkov glow);
- Spent fuel storage racks configured in a single layer to facilitate safeguards activities;
- Provisions for verifying and sealing the fuel in the lower layer(s) if fuel storage is in more than one layer;
- An indexing system to facilitate the identification of specific fuel assembly locations from the crane controls;
- As few openings as possible in the building structure through which it is possible to transfer spent fuel, with arrangements to allow for their sealing or surveillance (e.g. personnel access doors, fuel transfer channels, ventilation openings);
- Penetrations and supplementary barriers that use size, shape and bends to restrict what can pass through them (e.g. to obstruct 3 m long fuel assembly passage);
- A minimum number of personnel access points into the area, subject to safety constraints;

[19] The IAEA can provide spectral information about Cerenkov viewing devices.

- Control of the water clarity and surface stability to facilitate visual inspection of the fuel assemblies in their storage positions and viewing of the Cerenkov glow.

Lessons learned from previous implementations include the following:

- A pond cooling water return route designed to prevent viewing distortions caused by thermal turbulence near the fuel assemblies should be considered.
- Provide adequate working space on the bridge for inspectors and equipment (illustrated in Fig. 19).
- Provide capability to quickly locate and access any fuel assembly selected by the IAEA statistical sampling plan for identification or measurement.
- Provide for the raising or temporary isolation of assemblies in special cases (e.g. long cooled fuel, low burnup fuel or those locations that are not accessible for verification activities).
- Configure the fuel transfer layout to also facilitate the verification of fuel transfers out of the spent fuel pond (e.g. by remote monitoring).
- If such an area is required, consider a design for the disassembly and repair area that facilitates surveillance or radiation monitoring, including monitoring of all possible movements of assemblies and rods into and out of the area.
- Consider provisions for inspection of closed containers located within the spent fuel pond and for maintaining the relevant CoK.
- Providing space in the pond and within facility for storing shielded containers capable of containing spent fuel to facilitate fuel movements, access for operators and inspectors, and verification measures.
- A hoist can be necessary for an underwater camera used to item count and identify spent fuel.
- Underwater storage locations can be required for safeguards equipment used underwater.

As mentioned previously, safeguards measures for, and measurements of, spent fuel are active areas of research and development. Periodic improvements in authorized techniques (e.g. IRAT, SFAT, SMOPY, ICVD, DCVD, FDET) can be expected. The potential for advances is sufficiently good that SBD best practice is that stakeholders assess the R&D efforts in measurement capabilities and process monitoring (e.g. through professional societies or international standards organizations) [37, 41–49].

3.3.3. Dry storage of spent fuel

Once the intensity of the decay heat produced by spent fuel has diminished, some operators may select dry storage of the spent fuel. Dry storage of spent fuel might allow greater latitude in the placement of physical barriers. Figure 20 shows an outdoor dry storage facility for spent fuel. Some dry storage has been covered by a

FIG. 20. View of a spent fuel dry storage facility.

shed or placed inside an unheated building for additional protection from the impacts of weather, which may also be beneficial for safeguards equipment.

Spent fuel in a dry storage facility can be designated by the IAEA Deputy Director General for Safeguards as difficult to access [13, 33]. As part of such a designation, the IAEA will perform DIV to confirm that access to the irradiated fuel is difficult. Moreover, the IAEA can apply more rigorous surveillance,[20] containment, tamper indication and monitoring measures to the difficult to access storage, e.g. dual C/S or dual C/S with backup. Figure 21 shows the installation of an unattended monitoring system on a modular air cooled storage MACSTOR-200 facility for the storage of Canadian deuterium uranium reactor (CANDU) spent fuel.

Before the spent fuel is placed into difficult to access storage, stakeholders can perform additional activities (e.g. the best possible measurement) in order to remove any need to retrieve the fuel. The desire to eliminate the need for retrieval for any reason is a common interest shared between IAEA safeguards and the State's safety, safeguards, security and environmental protection professionals. Designers can supply advice to these stakeholders regarding technical issues, costs, benefits and mean time between failure estimates for the proposed design choices.

It is generally understood that power reactor and research reactor spent fuel will be verified by the IAEA before being transferred to dry storage. If spent fuel has been previously verified and has remained under successful safeguards measures, a second verification before placement into dry storage is generally not required.

In some situations, a gross defect measurement has been acceptable for fuel assembly types that cannot be easily disassembled (e.g. welded assemblies). For fuel assembly types that can be easily disassembled (e.g. that are not welded), a partial defect measurement has been applied to detect possible pin diversion, using the best available method approved for inspection use. No absolute metric has been set for spent fuel verification measurement quality; rather, the best available measurement method [14, 15, 20] is performed. SBD best practice is that a facility design take into consideration where the best possible measurement method may be performed as well as the possibility that the optimum facility or safeguards measurements may change over the lifetime of the facility.

Between the measurement and the placement into dry storage, CoK can be maintained by continuous inspector presence, surveillance, containment and monitoring measures, or a combination of these measures. Dual C/S or dual C/S with backup is generally preferred to reduce the possibility of loss of CoK and to reduce the need for on-site inspector presence.

Once in the dry storage facility, storage casks can be placed under dual C/S or dual C/S with backup to reduce or eliminate the need to open the cask for safeguards reasons. The surveillance, containment and monitoring measures can be applied to each cask separately and can also ensure the immobilization of each cask. Furthermore, additional surveillance, containment, monitoring and tamper indicating measures can be considered for application

FIG. 21. IAEA inspector installing unattended monitoring on MACSTOR-200 facility.

[20] The use of cameras may be more cost effective inside structures that provide protection from the weather.

to the facility or site, possibly shared with the physical security system. When access to the identification is possible, a means to permanently identify each storage cask without compromising its long term safety case can be considered for incorporation into the cask design.

3.3.4. Encapsulation of spent fuel

Encapsulation refers to the placement of the spent fuel into robust engineered barriers designed to protect against leakage during long term disposal. This section assumes the encapsulation plant is in a separate facility or separate MBA from the reactors or spent fuel storage installations from which it receives shipments and from the repository to which it ships filled disposal canisters. Moreover, this section assumes that the operator's measurements occur before the nuclear material is encapsulated and that, following that measurement, the IAEA's verification emphasis will be on maintaining CoK. Figure 22 illustrates a conceptual design of copper canister encapsulation for the geological disposal of spent fuel.

From a safeguards perspective, a typical encapsulation plant can have areas for different activities, such as the following:

- Spent fuel transport cask receiving and storage area;
- Spent fuel assembly handling area for transferring spent fuel assemblies from transport casks to disposal canisters;
- Handling area for permanently closing, decontaminating and quality control of the disposal canisters;
- Disposal canister storage area where the closed canisters are stored;
- Disposal canister shipping area.

The spent fuel assembly handling area will provide the last opportunity to easily handle individual assemblies, so it is of increased interest to safeguards and will be monitored carefully. Moreover, a spent fuel assembly handling

FIG. 22. Cut-away model of a canister for encapsulating spent fuel in a geological repository.

area might include temporary storage for transport casks, disposal canisters, complete assemblies, individual fuel pins and broken fuel. The handling capabilities and the variety of material types and containers in an area with fuel assembly handling and repackaging capabilities complicate the safeguards verification activities. One safeguards concern is how to verify when transport casks and disposal canisters are empty. Overhead surveillance with a capability to view the interiors of the empty containers might be considered to facilitate this safeguards activity.

Stakeholders can clarify in the design discussions with the IAEA and the State what is considered an item (e.g. fuel assembly, fuel pin or spent fuel canister) in the different areas of the encapsulation plant.

SBD best practice is that an encapsulation facility design takes into consideration the possibility that the operator may change or that IAEA measurement technologies may evolve and improve over the operational lifetime of the facility. Infrastructure flexibility, the available space and measurement locations can all be considered by the stakeholders. The spent fuel assembly handling area can be considered as a location for use by the IAEA to verify the spent fuel assemblies. However, this area might not have sufficient space or operational flexibility to easily accommodate verification activities. The optimum compromise may be to perform measurement and verification activities before the assemblies reach this location. In either case, after spent fuel assemblies have been verified, redundant or dual C/S measures are important to reduce the possibility of loss of CoK. If spent fuel verification is performed in the spent fuel handling area, consideration can be given to a reliable low-maintenance unattended measurement system coupled with surveillance, containment and monitoring measures to monitor the loading of disposal canisters with spent fuel assemblies and the permanent closure of the disposal canister.

Where it is possible to access the disposal canister to read the identification, a means to permanently identify each disposal canister without compromising its long term safety case can be evaluated and potentially incorporated into the canister design. Validating canister identification using specific attributes (e.g. weight, temperature profile, radiation signature or surface microstructure) is an area of active R&D and is discussed in e.g. Refs [33, 40].

Safeguards activities at an encapsulation plant can also include verifying nuclear material flow, detecting undeclared activities, monitoring non-safeguarded items to verify that they do not contain spent fuel, and retrieving data from and maintaining IAEA equipment. The safeguards measures can be included as the facility develops its detailed schedules and the layout of equipment is defined in more detail.

Safeguards considerations for spent fuel encapsulation plants include:

- That the IAEA may request a few days to review verification or measurement results for quality control (this might require securing an item to preclude further processing or handling until the IAEA review is complete);
- IAEA verification of waste measurements and minimizing waste in the facility operation;
- Permanent unique identification of a disposal canister that does not compromise its long term safety;
- That compliance with facility safety and security requirements may affect opportunities to perform safeguards activities;
- Surveillance, containment and monitoring measures being applied between annual PIVs to provide knowledge regarding the activities that occur between verifications;
- Maintaining CoK on the spent fuel from the verification measurement until the fuel is placed successfully into long term, difficult to access disposal.

IAEA activities can include:

- Verification of spent fuel receipts;
- Unattended monitoring of the nuclear material flows;
- Verification that items declared as not subject to safeguards (e.g. waste, non-nuclear material) contain no safeguarded material;
- Servicing and maintenance of IAEA equipment with minimal disruption to facility operations;
- Verification and servicing of tamper indicating seals;
- Observation and surveillance of the spent fuel handling areas and monitoring of the operations;
- Verification of waste measurements;
- Observation of the disposal canister handling and shipping areas;
- Verification of disposal canister shipments.

Important questions raised by an operator and designer in an encapsulation design and build project included the following:

- Can the PIV be timed so that all nuclear material is easily available for verification?
  - Can the operator empty buffer storage and move closed disposal casks into a difficult to access disposal location?
  - Is there a need for temporary storage space?
  - Is a capability to segregate and seal groups of safeguarded items required?
  - Is there segregated storage for spent fuel transport casks?
- When should the shipping cask tamper indicating seal and the CoK be verified, upon receipt or before opening?
- How can it be verified that transport casks are empty?
- Does unattended measurement or monitoring imply that the operator handles fuel assemblies or tamper indicating seals in the absence of IAEA personnel? If so, what administrative limits on this activity are expected?
- Does visual observation of an item require access or can the item be viewed by camera?
- Does visual observation of an item include reading of the item identification?
- In a storage room with unshielded disposal containers, how might the IAEA perform a PIV in a high radiation area?

3.3.5. Geological disposal of spent fuel

Long term geological disposal of spent fuel in excavated mines[21] is under consideration in several States. Since the application of safeguards will continue for nuclear material in these locations, it should be considered in harmony with the State's need for spent fuel to be managed and disposed of in a way that ensures long term safety, security and environmental protection with minimal maintenance. Challenges for the implementation of safeguards at geological repositories include:

- Maintaining safeguards effectiveness with minimal use of resources;
- Maintaining CoK on the safeguarded materials, including during their transport;
- Taking a long term perspective commensurate with the facility timescales;[22]
- Transferring knowledge as staff retire, are promoted or move on;
- Preparing for the eventual obsolescence of safeguards equipment;
- In some States, taking into account the legal requirement to maintain retrievability for a certain period of time;
- Preparing for technological innovation.

A geological repository consists of above ground areas and below ground areas. Both potentially contain material and activities of safeguards interest. In many cases, the below ground areas do not have a declared capability to open spent fuel disposal canisters. The IAEA can be expected to verify the lack of such capability during the preoperational and operational phase of the repository (e.g. when underground access is feasible). Both above and below ground areas can also have activities that are not of safeguards interest. Careful segregation of the activities that are of interest to safeguards from those that are not can facilitate the implementation of safeguards. For a repository, the general safeguards concept can be to verify design and operations below ground and to verify nuclear material flows and inventories in the above ground areas.

A generally accepted principle for the geological disposition of spent fuel is that the public and the State will benefit from having access in the long term to the best possible information about the radioactive material destined for disposal. Spent fuel disposal in geological repositories is subject to safeguards by the IAEA in accordance with the applicable safeguards agreements. Safeguards for such material remain in force as long as the safeguards agreement remains in force. This section assumes that the safeguards measurements of the spent fuel have taken

[21] Geological disposal in boreholes has not been considered in this guidance.
[22] The radiation safety issues and the attractiveness of the nuclear material evolve as the isotopes decay.

place before the spent fuel is safely and securely packaged and transferred for geological disposal. Consequently, the verification emphasis will be on maintaining the CoK on the safeguarded material from the time the measurements verify the State's declaration until such time as safeguards are no longer applied to this material.

DIV of a geological repository is intended to confirm the design of the repository and to detect possible undeclared activities. DIV may include:

- Evaluating design information provided by the State;
- Mapping or surveying excavations to detect undeclared tunnels, shafts or access routes [58];
- Monitoring for activities in a three dimensional exclusion buffer zone surrounding the geological repository volume;
- Verifying the geological features relevant to safeguards (e.g. that make access difficult);
- Verifying the absence of equipment for retrieval or reprocessing;
- Identifying locations where spent fuel could be removed from containers or processed;
- Assessing ventilation, personnel and vehicle access shafts to determine whether they could be used to retrieve nuclear material;
- Reviewing satellite or geoscientific information about the site or the surrounding area.

The IAEA can be expected to make inquiries about the geological features of the site and to perform verification activities with regard to the resulting information.[23]

These activities can include verifying that adjacent facilities or activities are not related to the repository and do not have the potential to accidentally or intentionally create possible access to the repository. Joint use of geoscientific monitoring equipment can be considered, subject to stakeholder constraints. The IAEA has experience in performing DIV during heavy construction and can explain to the designer and operator which characteristics are of safeguards relevance and what is the necessary precision to which various characteristics need to be known (e.g. tunnel and drift dimensions and locations). Verification procedures for on-site visits can be discussed in advance with the State and operator and conform to the State's safety and security regulations.

A fundamental constraint likely to become more important as time goes by is the efficiency with which effective safeguards can be maintained on materials in repositories. If, as might be expected, the use of geological repositories for spent fuel becomes more prevalent, more efficient use of remote and unattended monitoring can be expected if their maintenance and operating costs continue to improve. A fundamental characteristic of safeguards interest in verification activities is that the flow of nuclear material into the geological repository is generally one way. This situation can be used to facilitate the implementation of remote and unattended monitoring; however, it does not reduce the obligation of the IAEA to detect undeclared retrieval. Any retrieval of nuclear material from the repository is expected to be preceded by formal notification to the IAEA and the introduction of additional safeguards measures to address the retrieval activity. If retrieval might become necessary (e.g. in a safety or environmental emergency), designers and operators can include safeguards authorities and the IAEA in the planning and preparations for such retrieval.

Communication between the operator, the IAEA and the safeguards authority to address issues will be necessary to implement an effective safeguards system that also meets the safety, security and environmental protection goals of the repository.

States may choose to place non-safeguarded radioactive material (e.g. vitrified high level waste) in their repository in addition to spent fuel. Some safeguards measures may need special design or may be incapable of distinguishing between safeguarded and non-safeguarded radioactive material. Design consideration can be given to segregating the safeguarded and non-safeguarded material in handling, transfer paths and disposal locations to mitigate any associated safeguards issues.

A widely accepted principle for addressing the long term safety of radioactive waste and spent fuel in a geological repository is that the isolation systems should be passive in nature and that an active monitoring programme is therefore unnecessary. However, some States may choose to apply institutional controls or monitoring for societal or other reasons (e.g. to protect future generations from inadvertently breaching the repository and releasing the contents). In accordance with the safeguards agreements for material on which safeguards have not been terminated, there remains an obligation to implement a safeguards regime that is capable of detecting

[23] See Annex VI for more information regarding expectations for geological repository design information.

the possible diversion of the nuclear material. The design challenge is to meet this obligation in a cost effective manner. Consideration can be given to unattended modes of operation, remote data transmission off-site and a capability to function for long periods in a potentially harsh environment with minimal maintenance. As part of this consideration, the designer can take into account that all penetrations into the repository through which nuclear material can possibly be moved can be monitored by the IAEA. The designer can include adequate space for equipment installation and infrastructure connections. Figure 23 shows radiation based portal monitors installed on both sides of a heavy duty vehicle roadway. It is important to consider protection for equipment from possible damage caused by heavy vehicle traffic.

Another concern is that the facility lifetime is expected to be very long, spanning multiple generations. Consequently, flexibility to accommodate technological innovation can be an important design consideration. Furthermore, a design that can address the obsolescence of safeguards equipment as well as its maintenance will be of value.

A designer for a geological repository for spent fuel can take into consideration the length of the facility lifetime. SBD best practice is that flexible infrastructure and space allocation be considered for the implementation of safeguards equipment. Safeguards issues of particular interest for geological repositories are:

- Verification of the design information as it evolves;
- Verification that all declared nuclear material goes into the repository;
- Verification that no nuclear material is retrieved from the repository without a declaration;
- Verification that no nuclear material handling or processing facilities exist underground (e.g. to make smaller, easier to handle packages or to purify nuclear material);
- Maintaining an accurate accounting of the nuclear material inventory in the repository.

The primary safeguards objective in geological repositories is the detection of diversion. In order to help ensure the applied safeguards are effective and efficient, the IAEA prefers to begin consultations with stakeholders in advance of design. Early consultations can be coordinated by the State or regional safeguards authority to include:

FIG. 23. Radiation portal monitors placed at a repository entrance.

- Sharing the characteristics of the undisturbed repository site with the IAEA;
- Providing information on the safeguards objectives and legal basis to the designer;
- Providing information on possible safeguards measures to the designer;
- Providing preliminary design and process information to the IAEA;
- Providing periodic updates as the safeguards and facility designs evolve.

With a basic understanding of other stakeholders' objectives, alternatives that improve a design can be discussed. A designer can be aware that various tools are being assessed for applicability (e.g. geophysical techniques, environmental sampling, remote monitoring and satellite imagery) and have been reported on in professional society meetings, the joint MSSP ASTOR project and national R&D programmes [41, 42]. It is expected that some safeguards measures currently under development will become approved for use in the coming decades. Changes in the facility operations can also be expected as experience is gained in encapsulation and disposal operations. Experience with other facility types suggests that an optimum safeguards approach will be facility specific. Liaison between the operator, State/regional safeguards authority and the IAEA will be crucial in order to implement an effective safeguards system that also meets the safety and security goals of the repository. The frequency and intensity of the safeguards measures that are applied can be expected to change throughout the indefinite lifetime of the repository because of changes in the attractiveness of the used fuel, stakeholder activities relevant to safeguards and changes in technology.

Three phases in the life cycle of a geological repository can be identified for the consideration of safeguards:

- A preoperational phase preparing for the receipt of spent fuel;
- An operational phase with handling of spent fuel;
- A post-closure phase after completion of disposal activities.

3.3.5.1. Preoperational phase

The preoperational phase includes all activities that occur before nuclear material arrives at the disposal facility. In the preoperational phase, it can be expected that much of the detailed design information will be preliminary or will develop over decades.[24] Frequent communication can help stakeholders stay up to date with the changing information and understand the next activities scheduled to be performed.

During the preoperational phase, the activities that occur before the spent fuel is involved include:

- Site characterization;
- Underground exploration and access construction (especially if planned to be used as access during the operational phase);
- Definition of a buffer zone (e.g. exclusion zone) around the repository;
- How to verify the absence of activity in that buffer zone;
- Initial construction of the repository, above and below ground.

During this phase, on-site DIV visits by the IAEA may be performed to verify that the construction is consistent with the declared design, e.g. that there are no undeclared tunnels or drifts or undeclared equipment (e.g. hot cells for opening spent fuel or processing equipment for chemical separations). It is expected that design information will be preliminary during the early preoperational phase, yet it is still of great use to the IAEA. Annex VI is a summary of information in an IAEA design information questionnaire for a geological repository. Figure 24 shows DIV activities in the preoperational stage of a geological repository, before nuclear material is brought to the site.

When construction activities are under way, more frequent updates of design drawings and schedules are helpful. Some of the communication can be informal (e.g. consider the use of video conferences, email and telephone in addition to face to face meetings). The IAEA will make a reasonable effort to minimize its impact on construction, but it must verify that the facility is being built as declared. The stakeholders should take into account

[24] For example, the location of drifts or tunnels in a mined repository may be adjusted based on the locations of cracks or the rate of water seepage in some areas.

FIG. 24. DIV activities during the preoperational stage of the geological repository.

the challenges of keeping the design information up to date and also the difficulties of independent verification in the harsh underground working environment[25] while the facility is being excavated. An inspector must be prepared to review the information relevant to safeguards on-site and the facility must be prepared to adequately support the inspector and the safeguards equipment. Cooperation and coordination are key elements for the successful management of the project.

Clear definition of expectations and the information required by each stakeholder can assist all involved in understanding one another's needs. For example, a designer/operator might request clarification regarding the use of an approved IAEA measure (e.g. the three dimensional laser range finder (3DLR) [15]). A designer/operator can reasonably expect that the design verification activities at an active excavation site will not be as rigorous as those at a nuclear reactor.

During portions of the repository preoperational phase, the geological information and site monitoring data might accumulate more rapidly and in larger amounts than at other safeguarded facilities. The underground construction planning, the understanding of the repository layout and the existing condition of the facility or site might change daily, while the operational time for collection, archiving and review of the design data might be longer (e.g. weekly). Stakeholders can consider meeting frequently to address this issue.

3.3.5.2. Operational phase

The operational phase includes the receipt of spent fuel and emplacement in the repository and also the backfilling. Since parts of the facility may be in use for disposal while other parts are under construction, more frequent inspections may be useful at times to verify the activities.

During the operational phase, the main activities of safeguards interest are:

- Construction of additional drifts or tunnels;
- Receipt of nuclear material;
- Emplacement of nuclear material;
- Backfilling of disposal drifts and vaults with non-safeguarded material;[26]
- Backfilling of all other drifts, tunnels and shafts with non-safeguarded material.

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[25] Mining is a hazardous occupation due to the possibility of tunnel collapse, underground fire or lack of oxygen.

[26] Verifying the absence of spent fuel in the large volume of mining rubble and material that comes out of the repository has the potential to be a significant safeguards effort.

During this phase, the implementation of safeguards can be facilitated by a design and by facility operations that offer a clear segregation of the mining and construction activities and locations from the nuclear material handling and disposal activities and locations. This segregation can facilitate the implementation of safety and security functions as well as of IAEA safeguards. Clear definition of expectations, schedules and information required by each stakeholder can facilitate IAEA verification and reduce its impact on operations.

The IAEA might choose to verify the design and capacity of the spent fuel handing and processing equipment and systems, for example, to improve its understanding of facility operations and to verify the absence of undeclared activities.

The spent fuel is expected to arrive on-site in externally clean packages, but with radiation safety issues (high external dose), potentially 'safeguards sealed' with measures that maintain CoK on the package contents. CoK on the package contents can usually be maintained by material accounting techniques (e.g. verifying number of packages, using unique identifiers and verifying records of package contents) supported by surveillance, containment and monitoring. The surveillance, containment and monitoring are expected to verify that:

- All spent fuel that arrives on-site goes into the repository;
- There is no undeclared retrieval of spent fuel.

Once nuclear material is being transferred into the repository, all openings that could potentially be used for undeclared removal of nuclear material will be monitored. During operations, frequent movements of personnel, equipment, transport vehicles and excavation spoils that require monitoring can occur. The IAEA may use statistical sampling in its monitoring activities and may vary the sampling rate. At openings with containment structures (e.g. fan housings), tamper indicating seals may be applied by the IAEA. At openings where no radioactive material should be present, simple radiation monitors can be used. At openings where radioactive material is expected, radiation monitors can be designed to detect both the presence of radiation and the direction of movement of the radioactive item. At openings where both safeguarded and non-safeguarded material move, design features to facilitate the IAEA's independently distinguishing between these material types would be useful. The application of design features to assist the IAEA in these activities can also benefit operations by reducing the impact of safeguards measures on routine operation and by supporting operational needs.

DIV activities are expected to be a principal safeguards measure applied to the underground space of the repository. Frequent updates to the as-built drawings and facility operation schedules can be expected and might be verified by on-site inspections. Statistical sampling plans can be used to adjust the frequency and duration of inspections. Other considerations of safeguards interest are as follows:

- Separating the receiving, storing and handling areas for non-safeguarded material (e.g. bentonite, excavated rubble, and health and safety equipment) may reduce verification activity in those areas.
- DIV activities can be expected to address the structures and facility operations above ground as well as those below the surface and to verify that essential equipment continues to be as declared.
- To minimize the impact on routine operations, it is best practice that PIV activities be scheduled when no nuclear material items are in the encapsulation process or buffer storage (e.g. in staging areas preparing for, or in the elevators used to transport items into the repository).
- Redundancy, reduced maintenance and reliability are all important design requirements in the systems that maintain CoK.

Some States may require a pre-closure, post-operational phase when all waste has been emplaced but the above ground facilities are still available for observation. SBD best practice is that the project management include such activities in long term safeguards and project planning.

3.3.5.3. Post-closure phase

At a geological repository containing spent fuel, the post-closure phase begins after all the nuclear material is emplaced, the repository has been backfilled with buffer material[27] and sealed, and surface activities related to

[27] In some formations, e.g. salt, closure may occur more quickly or with minimal human assistance.

the geological repository have been completed and have ceased. It is generally accepted that the safe post-closure phase of a geological repository should not be reliant on continuing, active, institutional control after its closure. However, both the need to keep society aware of the potential for release of hazardous material and the need to apply IAEA safeguards [59] may necessitate inspection or monitoring in the long term.

Some States may choose to begin the post-closure phase with a period of institutional control that may or may not include an engineered ability to monitor the contents of the facility and an ability to retrieve the waste or spent fuel packages. The IAEA would take these features into account when it specifies the safeguards measures. If a State decides to open a closed repository, revised safeguards measures under a new safeguards approach would be negotiated with the IAEA as one of the preliminary steps.

After backfilling all drifts, tunnels, shafts and boreholes and removal of the surface facilities, the IAEA may consider reducing the safeguards measures to those which give assurance that no intrusion to the repository occurs that could result in the retrieval of nuclear material. The IAEA will retain the right of access. Since reverification of the nuclear material in the repository is expected to be very expensive, if not impossible, redundancy, diversity and robustness should be considered in the selection of safeguards measures as well as minimizing the associated maintenance costs. If in use, the safeguards application of geophysical methods and satellite imagery techniques may continue. In the post-closure phase, a design goal is that all safeguarded nuclear material is inside the difficult to access repository and that only PIV activities that verify the lack of nuclear material or activities in the above ground areas and in the buffer zone around the repository would be considered.

Spent fuel disposed of in geological repositories is subject to safeguards in accordance with the applicable safeguards agreement. Safeguards for such material are maintained after the repository has been backfilled and sealed, and for as long as the safeguards agreement remains in force. The safeguards applied should enable credible assurances regarding the non-diversion of the nuclear material in the repository.

3.3.6. Modification of existing facility

This section considers safeguards activities when facility modifications occur during the facility's operational use. Industrial facilities can require modification during their operational lifetimes for many reasons, including obsolescence, taking advantage of improvements in technology or reaching the end of a component's operational life. In the special case of geological repositories, design modification can be considered an integral part of the operational phase and is addressed in Section 3.3.5. Design modification may require changes in the safeguards measures or in the intensity of measures applied to the facility. It may require installation of an upgraded NDA and a surveillance, containment and monitoring system in the facility. The designer can be consulted regarding space allocation, mounting brackets and cabling for installation of the safeguards equipment.

Information for facility modifications shall be submitted to the IAEA prior to starting the modification work to reduce the possibility of delays or misunderstanding. Ideally, nuclear material should be accessible for verification during the entire period of the facility modification. Otherwise, specific compensatory safeguards measures can be negotiated in advance with the IAEA. For example, the order in which the modifications are carried out might affect the need for additional safeguards measures (e.g. whether nuclear material can be moved out of a location to other locations before starting modifications on it, or whether temporary containment barriers might need to be erected).

CoK should be maintained during facility modification. Additional temporary surveillance, containment and monitoring systems may be useful during the modification activities, particularly if features relevant to safeguards are affected. Planning and a good design can offer flexibility for adjustments and avoid retrofits or other issues.

In the design modification of an operating nuclear facility, the designer should take into consideration that safeguards equipment should not be tampered with, blocked, obstructed or disconnected during the facility modification process.

3.3.7. Decommissioning

The application of safeguards at a facility continues after it has ceased operations with nuclear material. When the IAEA has made a determination that a facility has been decommissioned for safeguards purposes, inspections are no longer performed at that location. With respect to decommissioning for safeguards purposes, the designer can consider facilitating safeguards activities such as verifying that:

- Nuclear material has been removed from the facility;
- Waste containing nuclear material has been removed from the facility;
- Essential equipment has been removed or rendered inoperable.

The designer can also consider that the IAEA and State authority will agree on the disposition (e.g. decontamination, disposal, return to the IAEA) of any IAEA installed equipment.

In the context of international safeguards, following the removal of all nuclear material, a facility is considered to be decommissioned when equipment essential for its operation has been removed or rendered inoperable. For each facility under safeguards, the IAEA develops a list of equipment that is essential for the declared activities of the facility, called a safeguards essential equipment list.[28] During the time from when essential equipment arrives at the facility to when it is verified to have been removed from the site[29] or verified to be inoperable, the facility can be considered by the IAEA as available for use and the IAEA can choose to apply safeguards measures.

The designer of a facility is well positioned to help the IAEA create its essential equipment list, which can be part of the preliminary information provided to the IAEA at an early stage of the design process and subsequently revised, as necessary. Portable equipment can be of less interest to safeguards than large pieces of equipment that are difficult to move or install. Activities relevant to safeguards can be discussed with the IAEA before decontamination and decommissioning activities begin.

Examples of safeguards essential equipment are [59]:

- Welding equipment for permanently closing a spent fuel disposal canister lid;
- Equipment for opening welded spent fuel disposal canisters;
- Equipment to move the spent fuel shipping containers upon receipt;
- Equipment to move spent fuel disposal canisters;
- Specialized tools for handling or sealing inserts for the disposal canister;
- Equipment and hot cells to move spent fuel between containers;
- Spent fuel storage ponds;
- Equipment to move spent fuel assemblies;
- Hoists and vehicles for transferring spent fuel;
- Spent fuel transportation casks.

For a geological repository after closure, the operator will clean up, dismantle and decommission the above ground facilities. But since there will still be nuclear material at the facility (i.e. underground), the facility will not be regarded as decommissioned and safeguards will continue to be applied. SBD best practice is that stakeholders take a long range project management perspective, including the consideration of related fuel cycle facilities, to address the issues surrounding decommissioning a portion of the geological repository site activities.

[28] The safeguards essential equipment is different from the safety essential equipment.
[29] The IAEA may request the verification of the fate of the equipment.

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Annex I

TERMINOLOGY

Like any technical field, IAEA safeguards has its own lexicon and applies specialized meanings to many words in common everyday usage. This annex offers simple definitions for terminology used in the field; many, but not all of the terms, are used in this publication.

NUCLEAR AND NON-NUCLEAR MATERIAL

direct use material. Nuclear material that can be used for the manufacture of nuclear explosives components without transmutation or further enrichment.

hold-up. Nuclear material deposits remaining in and about process equipment, interconnecting piping, filters and adjacent work areas.

in-process inventory. Nuclear material in the bulk processing areas of the plant that is not considered to be in storage. Hold-up is sometimes included in the in-process inventory.

irradiated direct use material. Direct use material that contains a substantial amount of fission products (e.g. plutonium in spent fuel).

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

mixed oxide. A mixture of the oxides of uranium and plutonium.

scrap[1]**.** Rejected nuclear material removed from the product stream, containing nuclear material that is economic to recover and recycle.

unirradiated direct use material. Direct use material that does not contain fission products.

waste.[1] Rejected nuclear material in concentrations or forms that do not permit economic recovery and that is designated for disposal.

NUCLEAR INSTALLATIONS AND EQUIPMENT

bulk handling facility. A facility where nuclear material is held, processed or used in bulk form.

item facilities. Nuclear facilities where all nuclear material is contained in identifiable items (e.g. fuel assemblies), the integrity of which remains unaltered during the time they are at the facility.

reprocessing plant. An installation for the chemical separation of nuclear material from fission products, using irradiated fuel as the feed material. Once purified, uranium and plutonium may be converted to oxides as the product material.

safeguards essential equipment list. A list of equipment, systems and structures essential for the declared operation of a facility. *Safeguards* essential equipment is often different from *safety* essential equipment.

[1] The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-proliferation of Nuclear Weapons, INFCIRC/153/Corr., IAEA, Vienna (1972).

accountancy. The practice of nuclear material accounting as implemented by the operator and the State as well as the activities by the IAEA to independently verify the completeness and correctness of the information in the facility records and the reports provided by the State to the IAEA.

additional measures. Measures taken to augment the traditional safeguards approach to address timeliness goals that can include, for example, process monitoring, environmental sampling, continuous inspection presence and access to all operator staff.

attended monitoring. A mode of non-destructive assay or surveillance, containment, monitoring and tamper indicating measures, or a combination of these, that requires inspector presence for operation.

authentication. Measures providing assurance that genuine information has originated from a known source (sensor) and has not been altered, removed or replaced.

continuity of knowledge. Assurance that the safeguards relevant data (e.g. identity and integrity of the item, item contents or flow and inventory of nuclear material) remains valid.[2]

declarations. Information submitted to the IAEA by a safeguards authority.

design information. A comprehensive description of the facility and its operation relevant to safeguards submitted to the IAEA by a State.

destructive assay. Measurement of the nuclear material content, or the elemental or isotopic concentration of an item, that produces significant physical or chemical changes in the item and generates waste.

diversion pathway assessment. A comprehensive analysis of the pathways within a facility where nuclear material could be diverted from the process.

inventory mailbox. A location where the facility operator can make inventory or inventory change declarations on a frequent basis. The mailbox may be a container on-site under IAEA control or an email address under IAEA control. See definition for **near real time accountancy**.

mailbox. An IAEA controlled location where an operator makes frequent declarations. (See mailbox declaration.)

mailbox declarations. A situation where the operator makes (typically) daily declarations of the nuclear material received, shipped or processed into an IAEA controlled location. (See **short notice random inspections** and **near real time accounting**.)

material balance period. Term used to refer to the time between two consecutive physical inventory takings.

near real time accountancy. A form of nuclear material accountancy for bulk handling material balance areas in which itemized inventory and inventory change data are maintained by the facility operator and made available to the IAEA on a near real time basis so that inventory verification can be carried out and material balances can be closed more frequently than, for example, at the time of an annual physical inventory taking by the facility operator.

non-destructive assay. Measurement of the nuclear material content, or the elemental or isotopic concentration of an item, without producing significant physical or chemical changes in the item.

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[2] Usage illustrated in the IAEA Safeguards Glossary, but not defined.

nuclear material accountancy. The practice of nuclear material accounting by the facility operator and, in addition, the verification and evaluation of this accounting system by a safeguards authority and/or the IAEA.

physical inventory verification. Also known as an inventory verification. An IAEA safeguards inspection activity involving a physical nuclear material inventory within an MBA carried out to verify the operator's book inventory of nuclear material present at a given time within that MBA.

remote monitoring. A technique whereby safeguards data from equipment installed in a facility and operating unattended are transmitted off-site via communications networks for review and evaluation.

safeguards approach. A set of nuclear material accountancy, containment, surveillance and other measures chosen by the IAEA for the implementation of safeguards in a given situation.

safeguards authority. The State's primary coordinating body responsible for ensuring the effective implementation of IAEA safeguards. This term is replacing 'safeguards regulatory authority' in normal usage.

short notice random inspection. An inspection performed at a facility or location outside a facility both on short notice[3] and randomly[4] that makes falsification more difficult and uses safeguards resources more effectively and efficiently. Short notice random inspections are often used in conjunction with mailbox declarations.

state of health. Data that describe the operational state of an instrument or other hardware.

trigger. An electronic signal, usually from a sensor, to request that another sensor take a reading or perform a measurement.

unannounced inspections. An inspection performed at a facility or a location outside a facility for which no advance notice is provided by the IAEA to the State before the arrival of IAEA inspectors.

unattended monitoring. Non-destructive assay or containment and surveillance measures, or a combination, that operates for extended periods without inspector intervention.

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 an item or with IAEA safeguards equipment or data.[5]

difficult to access. A designation that can be applied by the IAEA Deputy Director General for Safeguards to nuclear material (typically spent fuel) that is placed in long term storage which is not designed for easy access or retrieval, e.g. welded containers that are buried below ground or placed in securely closed, heavy concrete vaults.

dual containment and surveillance system. Each credible diversion path is covered by at least two IAEA authorized devices which are functionally independent (e.g. a seal, monitor or surveillance camera) and not subject to a common tampering or failure mode.

seal. A tamper indicating device used to join movable segments of containment in such a manner that access to the contents without opening of the seal or breaking of the containment is difficult.

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[3] An inspection for which less advance notice, e.g. 24 hours, is provided by the IAEA to the State than that provided for under para. 83, ibid.

[4] An inspection performed on a date chosen randomly.

[5] This definition differs from that generally used in safety.

single containment and surveillance system. Each credible diversion path is covered by an IAEA authorized device, e.g. a seal, monitor or surveillance camera.

surveillance. The collection of information through inspector and/or instrumental observation aimed at the monitoring of the movement of nuclear material or the detection of interference with containment and tampering with IAEA safeguards devices, samples and/or data.

tampering. Interference in an unauthorized and undeclared manner to physically defeat a containment and surveillance device.

MISCELLANEOUS

INFCIRC. A document circulated by the IAEA in order to provide information on matters of general interest to all its Member States.

safeguardability. The degree of ease with which a nuclear energy system or facility can be effectively and efficiently placed under international safeguards.

Annex II

SAFEGUARDS CONSIDERATIONS IN FACILITY LIFE CYCLE STAGES

Safeguards implementation is relevant to each stage of a facility's life cycle. While safeguards implementation potentially has a small impact on project cost and schedule when considered early in the design process, failure to consider it can result in a much larger impact than necessary, both on construction and operation. Figure II–1 depicts the life cycle stages of a facility in a simplified form, and potential safeguards aspects at each stage are discussed below. The State (or regional) authority responsible for safeguards implementation (SRA) is the official contact with the IAEA and should always be included in the dialogue when the IAEA is involved. When the designer and the operator are from different States, each may deal with a different State authority. Once a location in a State is selected for the nuclear facility, the corresponding SRA will be the official contact with the IAEA.

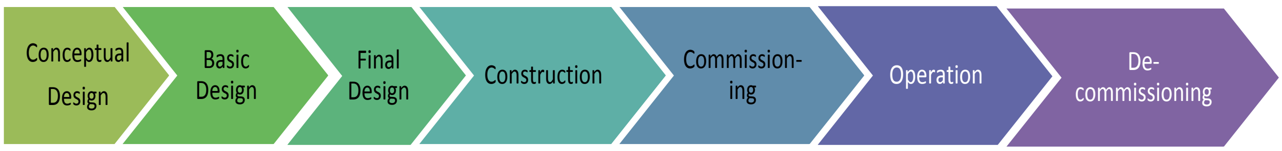

FIG. II–1. Facility life cycle stages.

II–1. CONCEPTUAL DESIGN

The conceptual design stage is the project planning period, the earliest design stage in which preliminary concepts for safeguards measures might be discussed. This stage may contain the following steps:

- A designer or operator assists the SRA to provide the IAEA with early design information.
- The IAEA examines the design information and may perform an evaluation of the operational process for features relevant to safeguards and identify possible safeguards measures for consideration.
- The IAEA prepares a preliminary safeguards approach and begins discussions with the SRA.
- The designer, operator, SRA and IAEA identify and mitigate potential safeguards risks in the conceptual design process.

II–2. BASIC DESIGN

In the basic design stage, the subsystem designs are under way and basic facility design details are available, including proposed safeguards equipment and locations. During this stage:

- The IAEA makes a preliminary definition of MBAs and key measurement points and refines the safeguards approach.
- Discussions are held to consider how the design can be optimized to meet operational and safeguards goals, including physical infrastructure for safeguards instrumentation and equipment.
- Design information is updated and provided by the SRA to the IAEA and design information examination continues.

II–3. FINAL DESIGN

By the final design stage, the detailed facility design is complete; dimensions, equipment and planned operations are known, allowing for confirmation that the various systems will meet specified requirements. During this stage:

— The IAEA continues design information verification.
— Stakeholders review the detailed facility design.
— Stakeholders confirm that planned safeguards equipment will meet specified requirements under expected plant conditions.
— Design information is updated and provided by the State to the IAEA.

II–4. CONSTRUCTION

During the construction stage, the facility is constructed according to the specifications. Any necessary changes to the facility design or the planned safeguards equipment are assessed to ensure that they will not compromise safeguards performance. During this stage:

— The IAEA continues design information verification.
— SRA, IAEA and operator cooperate to install and test safeguards equipment.[1]

II–5. COMMISSIONING

During the commissioning stage, the final systems testing and licensing activities are under way. During this stage:

— The IAEA continues design information verification.
— The first nuclear material is introduced to the facility and may be used to calibrate safeguards equipment.
— The safeguards equipment and instruments are tested.
— The operator confirms the facility measurement and sampling equipment are adequate for reporting to the State.
— The operator tests facility systems.

II–6. OPERATION

The operation stage begins when the operator starts up the facility,[2] tests all systems and begins routine operation. During this stage:

— The IAEA continues design information verification and reviews the facility and associated systems.
— The IAEA performs inspections, e.g. verifies facility nuclear material accounting system, records and measurement systems.
— The IAEA confirms the operability and function of safeguards equipment, calibrates equipment, cooperates with SRA and the operator to troubleshoot any issues.

During routine operation, the IAEA performs safeguards activities as summarized in Section 2 of this publication. Operating and maintenance activities may include repair and replacement of equipment.

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[1] During construction, safeguards equipment can be confirmed to be functional without nuclear material in the facility, whereas operational status includes all necessary aspects for routine operation (e.g. calibration, positioning and certification), including operation of the equipment with nuclear material present.

[2] The safeguards equipment should be certified for use before nuclear material is introduced into the facility.

II–7. DECOMMISSIONING

In the decommissioning stage, the operator takes the facility out of operation and begins cleanup and dismantlement. During this stage:

— The IAEA continues design information verification and inspections.
— The IAEA verifies the removal of nuclear material and removal or disabling of essential equipment.
— The IAEA may make a determination regarding the decommissioned status of the facility, for safeguards purposes.

Annex III

IDENTIFYING SAFEGUARDABILITY ISSUES

This annex gives an example of a facility safeguardability assessment approach.[1] It can be used as a structured approach to understanding and identifying potential safeguards issues. If an operator is building or modifying a standardized facility design for which a well understood safeguards approach exists, an analysis of safeguardability may not be needed. However, it may be possible to make existing safeguards tools and measures more efficient with slight modifications to the design, configuration or operating procedures.

A greater effort to assess facility safeguardability might be warranted for facilities that include novel design features or facilities that present particular safeguards challenges. Innovative designs that are different from those for which IAEA safeguards approaches have been established can present safeguards challenges that could be considered by the designer, who could help mitigate these issues or help accommodate innovative safeguards tools and measures to address them. In this case, the facility design team might benefit from the inclusion of safeguards expertise.

Safeguards issues can arise from design differences (as compared with existing facilities under IAEA safeguards) that:

— Use different isotopic, chemical or physical forms of the nuclear material;
— Create additional or alter existing diversion paths;
— Create different nuclear material categories for measurement;
— Alter nuclear material flows or pathways;
— Increase the difficulty of design information examination and verification;
— Impede the IAEA's capability to verify that diversion has not taken place;
— Create a new or alter an existing potential for the facility to be misused.

The following screening questions may be helpful in assessing safeguardability of a facility design, particularly as compared with a design of a similar facility which has an established safeguards approach.

[1] BARI, R.A., et al., Facility Safeguardability Assessment Report, Pacific Northwest National Laboratory Report, PNNL-20829, Pacific Northwest National Laboratory, Oak Ridge, TN (2011).

TABLE III–1. FACILITY SAFEGUARDABILITY ASSESSMENT

Facility safeguardability assessment screening questions	
1. Does this design differ from the comparison design/process in ways that have the potential to create additional diversion paths or alter existing diversion paths?	Yes/No
1.1. Does this design introduce nuclear material of a type, category or form that may have a different significant quantity or detection time objective than previous designs (e.g. mixed oxide rather than low enriched uranium, irradiated vs. unirradiated, or bulk vs. item)?	Yes/No
1.2. Does this design layout eliminate or modify physical barriers that would prevent the removal of nuclear material from process or material balance areas (e.g. circumvent a key measurement point)?	Yes/No
1.3. Does this design obscure process areas or material balance area boundaries making containment/surveillance or the installation of measurement and monitoring equipment more difficult?	Yes/No
1.4. Does this design introduce material that could be effectively substituted for safeguarded material to conceal diversion?	Yes/No
2. Does this design differ from the comparison design in a way that increases the difficulty of design information examination and verification by IAEA inspectors?	Yes/No
2.1. Does the design incorporate new or modified technology? If so, does the IAEA have experience with the new or modified technology?	Yes/No
2.2. Are there new design features with commercial or security sensitivities that would inhibit or preclude IAEA inspector access to equipment or information?	Yes/No
2.3. Do aspects of the design limit or preclude inspector access to, or the continuous availability of, essential equipment for verification or testing?	Yes/No
2.4. Are there aspects of the design that would preclude or limit IAEA maintenance of continuity of knowledge during the life of the facility?	Yes/No
3. Does this design or process differ from the comparison design or process in a way that makes it more difficult to verify that diversion has not taken place?	Yes/No
3.1. Does this design lessen the efficiency of physical inventory taking by the operator or the effectiveness of physical inventory verification by the IAEA?	Yes/No
3.2. Does this design impair the ability of the operator to produce timely and accurate interim inventory declarations or of the IAEA to perform timely and accurate interim inventory verification (IIV)?	Yes/No
3.3. Does this design impede timely and accurate inventory change measurements and declarations by the operator and verification by the IAEA?	Yes/No
3.4. Does this design impede the introduction of or reduce the usefulness of other strategic points within the material balance area?	Yes/No
4. Does this design differ from the comparison design in ways that create new, or alter existing, opportunities for facility misuse or make the detection of misuse more difficult?	Yes/No
4.1. Does this design differ from the comparison facility/process by including new equipment or process steps that could change the nuclear material being processed to a type, category or form with a lower significant quantity or detection time objectives?	Yes/No
4.2. If the comparison facility safeguards approach employs agreed upon short notice visits or inspections, measurements or process parameter confirmations, would this design preclude the use of, or reduce the effectiveness of, these measures?	Yes/No
4.3. Do the design and operating procedures reduce the transparency of plant operations (e.g. availability of operating records and reports or source data for inspector examination or limited inspector access to plant areas and equipment)?	Yes/No

Annex IV

DESIGN INFORMATION QUESTIONNAIRE INFORMATION FOR SPENT FUEL STORAGE FACILITIES

The following information is written at an introductory level for an audience unfamiliar with IAEA design information questionnaires. It has no legal status. Official templates are available from the IAEA.

Spent fuel storage facility design information questionnaire information includes at least the following:

- Name of the facility (including any usual abbreviation).
- Location and postal address.
- Owner.
- Operator.
- Description of main features.
- Purpose.
- Status (planned, under construction or in operation).
- Construction schedule dates (if not in operation).
- Normal operating mode (days only, two-shift, number of days per annum, etc.).
- General facility layout (including routes followed by nuclear material).
- Site layout (including other buildings, roads, railways and rivers).
- Names and/or title and address of responsible officers (for nuclear material accounting and control and contact with the IAEA; if possible, include organizational charts).
- Storage facility details:
  - Facility description for each storage area;
  - Design capacity;
  - Anticipated annual receipts and inventory, nuclear material description and flow.
- Containers handled at the facility:
  - Description of containers;
  - Description of container contents.
- Nuclear material description and flow:
  - Physical (mechanical) form and dimensions (for the fuel elements/assemblies expected for storage), (attach drawings);
  - Chemical form (indicate chemical composition or main alloy constituents);
  - Uranium enrichment range and plutonium content;
  - Range of weight of nuclear material;
  - Cladding material;
  - Means of nuclear material identification;
  - Types of containers, packaging;
  - Radiation level at nuclear material location;
  - Other nuclear material at the facility not already specified (quantity, form and location);
  - Schematic flowsheet for nuclear material.
- Handling of nuclear material:
  - Description of each nuclear material storage area;
  - Design range of inventories of nuclear material in each storage area;
  - Method of positioning nuclear material in storage;
  - Routes and equipment used for movement of nuclear material;
  - Frequency of receipt and shipment;
  - Shielding.
- Protection and safety measures:
  - Basic measures for physical protection of nuclear material;
  - Specific health and safety rules for inspection compliance.
- Nuclear material accounting and control system description:

  - The nuclear material accounting system;
  - The method of recording and reporting accounting data and establishing material balances;
  - The procedures for account adjustment after inventory and corrections of mistakes;
  - Receipts (including shipper/receiver differences and subsequent account corrections);
  - Shipments (including waste).
- Physical inventory details:
  - Procedures;
  - Measurements and measurement errors;
  - Operational records and accounting records, including method of adjustment or correction and place of preservation and language;
  - Features related to containment and surveillance measures.
- Other information (that the operator considers relevant to safeguarding the facility).

Annex V

DESIGN INFORMATION QUESTIONNAIRE FOR ENCAPSULATION PLANTS

The following information is written at an introductory level for an audience unfamiliar with IAEA design information questionnaires. It has no legal status. Official templates are available from the IAEA.

Encapsulation plant design information questionnaire information includes at least the following:

- Name of the facility (including any usual abbreviation).
- Location and postal address.
- Owner.
- Operator.
- Description of main features.
- Purpose.
- Status (planned, under construction or in operation).
- Construction schedule dates (if not in operation).
- Normal operating mode (days only, two-shift, number of days per annum, etc.).
- General facility layout (including routes followed by nuclear material).
- Site layout (including other buildings, roads, railways and rivers).
- Names and/or title and address of responsible officers (for nuclear material accounting and control and contact with the IAEA; if possible, include organizational charts).
- Spent fuel encapsulation plant details:
  - Facility description (pertaining to the measurement, control and accounting of nuclear material);
  - Process description;
  - Design capacity (quantities of nuclear material in metric tonnes);
  - Anticipated annual throughput;
  - Important items of equipment for processing nuclear material, if any.
- Nuclear material description and flow:
  - Main types of nuclear material and accountability units to be handled in the facility;
  - Physical (mechanical) form, cladding and overall dimensions of spent fuel assemblies or CANDU bundles;
  - Physical (mechanical) form, overall dimensions and capacity of disposal canisters;
  - Physical form and overall dimensions of other types of containers and packaging;
  - Means of item identification;
  - Range of initial weights of heavy metal and initial enrichments of uranium in fuel assemblies;
  - Range of spent fuel burnup, cooling times and Pu contents of fuel assemblies;
  - Means of batch identification, batch size, flow rate and campaign period;
  - Range of radiation levels in nuclear material storage and process areas;
  - Range of radiation and heat levels at exterior of transport and disposal containers;
  - Frequency of receipt and shipment (batches/units per month);
  - Other nuclear material in the facility and its location, if any;
  - Schematic flowsheet for nuclear material;
  - Nuclear material flow quantities for each nuclear material handling area;
  - Design range of inventories of nuclear material in each storage and process area.
- Nuclear material handling container and packaging description:
  - Description of containers and packaging in which nuclear material is received;
  - Description of containers and packaging in which nuclear material is shipped (inner container and over-pack container);
  - Range of radiation and heat levels at exterior of storage and transport packages and disposal canisters;
  - Description of each nuclear material storage and process area (including range of radiation levels in nuclear material storage and process areas);
  - Shielding;
  - Methods and means of handling and transport of nuclear material;

    - Transportation routes followed by nuclear material.
- Plant maintenance:
    - Normal plant maintenance;
    - Plant and equipment decontamination;
    - Plant startup and shutdown procedures.
- Protection and safety measures:
    - Basic measures for physical protection of nuclear material;
    - Specific health and safety rules for inspector compliance.
- Nuclear material accounting and control system description:
    - Description of the nuclear material accounting system;
    - The method of recording and reporting accounting data and establishing material balances;
    - The procedures for account adjustment after inventory and corrections of mistakes etc. under the following headings:
        - General;
        - Receipts (including method of dealing with shipper/receiver differences and subsequent account corrections);
        - Shipments (including waste).
- Physical inventory details:
    - Procedures;
    - Measurements and measurement errors;
    - Operational records and accounting records;
    - Including method of adjustment or correction and place of preservation and language.
- Features related to containment and surveillance measures.
- Other information (that the operator considers relevant to safeguarding the facility).

Annex VI

DESIGN INFORMATION QUESTIONNAIRE FOR GEOLOGICAL REPOSITORIES

The following information is written at an introductory level for an audience unfamiliar with IAEA design information questionnaires. It has no legal status. Official templates are available from the IAEA.

Geological repository design information questionnaire information includes at least the following:

- Name of the facility (including any usual abbreviation).
- Location and postal address.
- Owner.
- Operator.
- Description of main features.
- Purpose.
- Status (planned, under construction or in operation).
- Construction schedule dates (if not in operation).
- Normal operating mode (days only, two-shift, number of days per annum, etc.).
- General facility layout (including routes followed by nuclear material).
- Site layout (including other buildings, roads, railways and rivers).
- Names and/or title and address of responsible officers (for nuclear material accounting and control and contact with the IAEA; if possible, include organizational charts).
- Geological repository facility description:
  - Information on the host geology of the geological repository (including geological stratification; geochemistry; geophysics; identification of radionuclides found in the repository environment; and evidence and conclusions on the integrity of the host rock);
  - Description of restricted zone and other controlled areas established around the repository;
  - Geological repository characterization activities;
  - Information on the design of the geological repository underground area;
  - Information on design of the surface areas;
  - Information on access for personnel and materials; provision of utilities, areas for receipt and storage of non-nuclear materials;
  - Hoist and transport vehicle capacity;
  - Information on the presence of nearby mines and other nearby excavation activities (including identification of structures that might conceal an entrance to excavations).
- Process description:
  - This should include all above ground and underground facility operations; ramp, tunnel and shaft excavation; canister, material and backfill transport; backfilling and tunnel closure; and including nominal schedule of excavation, emplacement and backfilling.
  - Design capacity.
  - Anticipated annual disposal rate.
  - Monitoring system for excavation activities.
  - Other monitoring systems (including safety monitoring).
  - Other equipment (including testing and experimental equipment).
- Monitoring system for excavation activities.
- Other monitoring systems (including safety monitoring).
- Other equipment (including testing and experimental equipment).
- Nuclear material description and flow:
  - Types of nuclear material and other radioactive material in the facility;
  - Types of accountability units to be handled in the facility;
  - Appearance, means of identification and overall dimensions of accountability units;
  - Number of fuel assemblies or other radioactive material per disposal container;
  - Number of disposal containers per transport container;

- Range of weight of nuclear material per disposal canister;
- Frequency of receipts;
- Frequency of transfers underground and emplacement of disposal containers;
- Range of radiation levels and temperatures at surface of containers;
- Schematic flowsheet for nuclear material;
- Design range of inventories of nuclear material in each storage area.

— Facility operation and handling of nuclear material:
- Transport and disposal container description;
- Shielding;
- Methods and means of transfer of nuclear material;
- Transportation routes followed by nuclear material;
- Description of each nuclear material storage area;
- Method of positioning of nuclear material in storage area (emplacement);
- Description of each nuclear material emplacement area.

— Maintenance:
- Above ground and underground maintenance activities;
- Protection and safety measures and basic measures for physical protection of nuclear material;
- Specific health and safety rules for inspector compliance.

— Nuclear material accounting and control system description:
- The nuclear material accounting system;
- The method of recording and reporting accounting data and establishing material balances;
- Source data identification;
- The procedures for making adjustments;
- The physical inventory procedures, frequencies and methods;
- Possible verification method for irradiated nuclear material;
- Receipts, transfers between MBAs and shipments;
- Operational records and accounting records;
- Means of long term preservation of records;
- Features related to monitoring, containment and surveillance measures.

— Other information (that the operator considers relevant to safeguarding the facility).

ABBREVIATIONS

3DLR	three dimensional laser range finder
ASTOR	Application of Safeguards to Geological Repositories
CANDU	Canadian deuterium uranium reactor
C/S	containment and surveillance
CoK	continuity of knowledge
CSA	comprehensive safeguards agreement (based on INFCIRC/153 (Corrected))
DA	destructive analysis
DCVD	digital Cerenkov viewing device
DIQ	design information questionnaire
DIV	design information verification
FDET	fork detector irradiated fuel measuring system
HEU	highly enriched uranium
ICVD	improved Cerenkov viewing device
IRAT	irradiated fuel tester
KMP	key measurement point
LEU	low enriched uranium
LOF	location outside of a facility
MBA	material balance area
MOX	mixed oxide fuel
MSSP	Member State Support Programme for IAEA Safeguards
MUND	mobile unattended neutron detector
NDA	non-destructive assay
PIV	physical inventory verification
R&D	research and development
SBD	safeguards by design

SFAT	spent fuel attribute tester
SMOPY	safeguards MOX python
SRA	State or regional authority responsible for safeguards implementation

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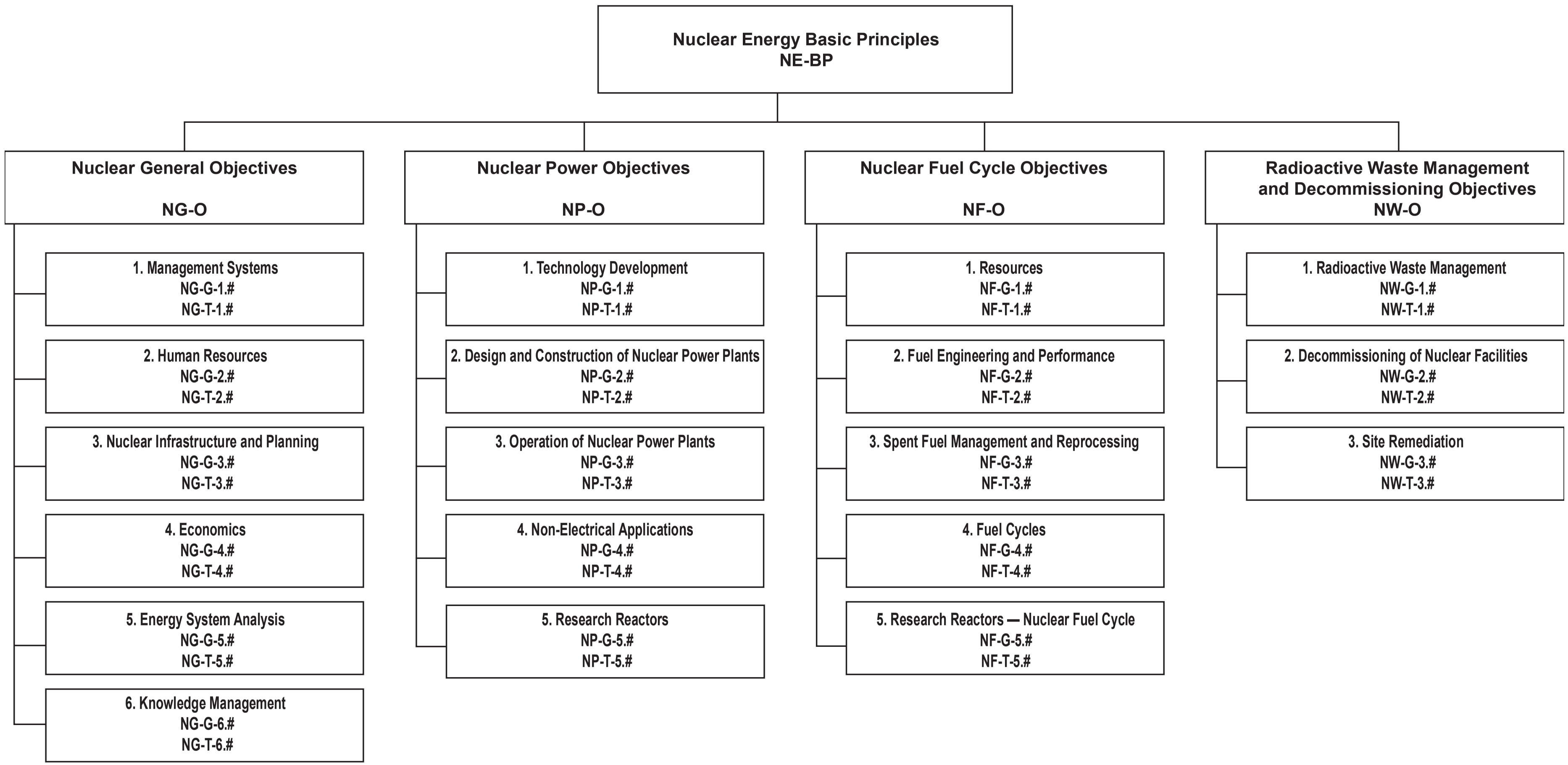

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