IAEA Nuclear Energy Series

No. NF-T-3.2

Basic Principles

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International Safeguards in the Design of Reprocessing Plants

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INTERNATIONAL SAFEGUARDS IN THE DESIGN OF REPROCESSING PLANTS

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

IAEA NUCLEAR ENERGY SERIES No. NF-T-3.2

INTERNATIONAL SAFEGUARDS IN THE DESIGN OF REPROCESSING PLANTS

INTERNATIONAL ATOMIC ENERGY AGENCY
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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 of spent nuclear fuel[2] reprocessing plants, such as the one shown in Fig. 1. This publication is intended to support the consideration of safeguards in the design of reprocessing plants. It is directed primarily at reprocessing plant designers and operators.

1.4. STRUCTURE

Section 2 provides a general overview of IAEA safeguards implementation, followed by facility specific guidance in Section 3. 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].

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] In this publication, no distinction will be made between spent fuel, used fuel and irradiated fuel.

FIG. 1. Aerial view of Sellafield Limited, including the Thermal Oxide Reprocessing Plant (THORP).

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[3];
— 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 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

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

FIG. 2. IAEA design verification.

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.[4]

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).

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

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

FIG. 3. Sample preparation in an IAEA laboratory.

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

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

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

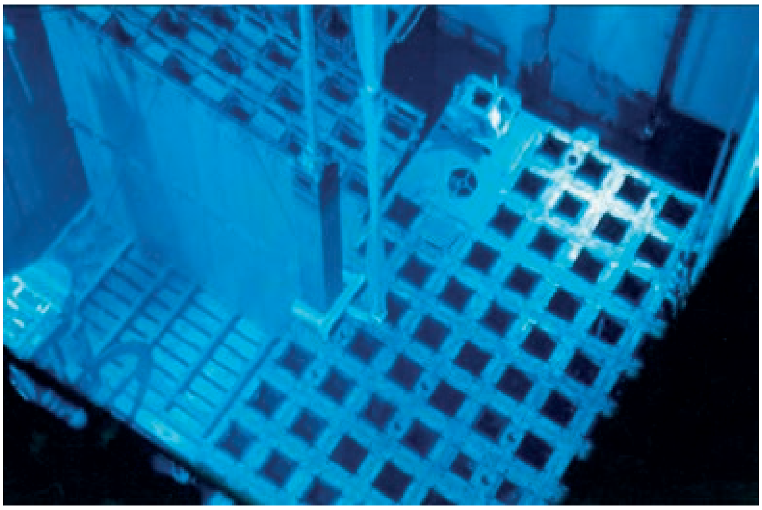

FIG. 6. Measurement of irradiated fuel in a cooling pond.

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.

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:

- 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[5] 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.

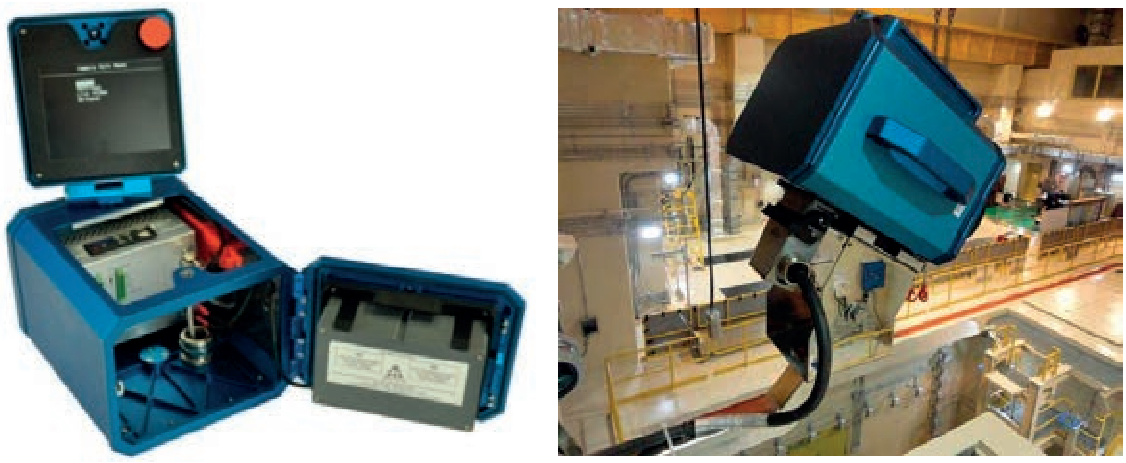

FIG. 7. A next generation IAEA surveillance system.

[5] 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.

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.

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

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.

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.

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.

FIG. 10. Installation of a surveillance system.

3. SAFEGUARDS CONSIDERATIONS IN REPROCESSING

Performing accountancy verification based solely on measurements at a large reprocessing facility on the scale that is applied to small facilities would require huge resources from both the operator and the IAEA. Therefore, in order to reduce costs, measures additional to traditional accountancy measurements are applied. Safeguarding a spent fuel reprocessing facility presents challenges [18–24] due to the:

— Size and complexity of the facility;
— Poor knowledge of the input nuclear material values;[6]
— Inaccessibility of the spent fuel owing to health and safety measures;
— Bulk nature of the nuclear material processing.

Reprocessing facilities can be designed to facilitate IAEA verification. In particular, careful design of the facility system for nuclear material control and accounting can provide for accurate and timely declarations to the IAEA with minimal effort and can facilitate the resolution of discrepancies.

The ease of applying IAEA safeguards to a facility has been described as safeguardability. Major points to consider when assessing safeguardability are listed in Annex III, which draws on Refs [25–27]. The assessment of the safeguardability of an innovative design is expected to be more productive than an assessment of a design operating under a known safeguards approach, since the latter has already undergone assessment by the IAEA. Some factors to question when building a reprocessing plant with the goal of enhancing its safeguardability are [18]:

— What is the local availability of technical support services (e.g. electrical, mechanical)?
— Will the plant safety and security arrangements be able to accommodate IAEA short notice or unannounced random inspections?
— What might facilitate the implementation of safeguards measures?
— What will be the expected education and experience levels and training requirements for the operator and safeguards staff?

Ideally, the consideration of safeguards begins when the conceptual design begins. Most plant designs allow for flexibility in the operational modes that can potentially be optimized to take nuclear material accounting and its verification into account. International standards are available that offer guidance on nuclear facility design and construction, as well as on operations. The conceptual design of the nuclear material accounting system can be coordinated with designing the plant concept of operations [28–35]. When not only the physical design and layout but the operational parameters are examined in parallel with the safeguards measures, the opportunity exists to ensure that safeguards and operations integrate appropriately and that they will function together smoothly when processing material.

At an early stage in the design, IAEA safeguards can be considered in general terms that are not overly prescriptive. Guidance that describes the safeguards issues, rather than prescribing how to address them, can be more useful to facility designers and operators. Moreover, dictating specific technology solutions for facility safeguards is challenging since the variability in facility design and State specific factors limit ‘one size fits all’ solutions. However, early in the safeguards dialogue, it can be useful to include information regarding measurement equipment sizes, accuracy and precision, the supporting infrastructure and additional safeguards measures. For example, while it may not be feasible to identify an exact camera location until later in the design process, the safeguards authorities can inform the designer which activities are proposed to be monitored with surveillance. In addition, with knowledge of the safeguards concerns, a designer can assess the path the nuclear material follows on its way through processing and suggest potential surveillance locations. The documenting of specifications for the supply of electrical power, space for equipment and cabling for communications can begin without knowing the exact location or height above the working level(s) of the final installation; the design for bringing the infrastructure into the room can precede determining the sensor’s location. The proposed locations for safeguards equipment can be expected to change as stakeholders come to a better understanding of each other’s constraints. SBD advises

[6] The shipper’s values based on calculations can be a significant source of uncertainty, especially for research reactor fuel.

that the potential locations for safeguards equipment be suggested during the conceptual design phase and then be reconsidered as the design of the facility evolves.

The goals of SBD include defining the design requirements for safeguards early in the project in collaboration with the IAEA and preparing for the IAEA and other inspectorates to have sufficient access and flexibility to implement requirements. However, the safeguards goals cannot be accomplished well without a clear understanding by the IAEA of the operational process and the nuclear material composition. With an understanding of IAEA activities, the inclusion of safeguards in the design and construction process can:

- Facilitate a full and open dialogue between stakeholders regarding facility design and operations, safeguards, and related topics;
- Include provisions for protecting the operator's proprietary and restricted information that do not create 'blind spots' in the facility that limit verification by the IAEA;
- Take advantage of each stakeholder's experience and expertise;
- Reduce the impact of safeguards measures on the operator without reducing their effectiveness;
- Improve the cost efficiency of safeguards and facility operations;
- Facilitate accomplishing safeguards activities safely and expeditiously.

In addition, consideration can be given to minimizing the radiation exposure to inspectors and instrumentation, to facilitating routine maintenance or repairs and to providing infrastructure. Sensitive design information that must remain in the control of the facility owner/operator (e.g. engineering drawings) should be identified early. Arrangements for inspector access to the information can be established, such as storage of the information in an on-site operator controlled area under IAEA tamper indicating seals. It is generally expected that the IAEA will require operator support for the installation, operation and maintenance of equipment.

It is generally understood that the IAEA would like to minimize impact on the operator and the operator would like to minimize the handling and movement of nuclear material. Consequently, designs are preferred that incorporate safeguards activities smoothly with the other operations that involve nuclear material. Keeping design documentation up to date benefits several stakeholders. For example, design documentation can be required for IAEA design verification as well as for licensing by the State. Finally — noting that prevention is better than detection — a goal of SBD is to minimize risk by designing out safeguards related vulnerabilities.

A designer can keep general safeguards considerations in mind, such as:

- Performing all relevant IAEA activities before permanently closing process areas to make access difficult;
- Reducing the opportunities for the undeclared removal of nuclear material;
- Reducing the potential for human error;
- Reducing the potential for loss of safeguards data;
- Mitigating the consequences of off-normal events;
- Modularizing or automating of processes to facilitate safeguards activities;
- Including features that minimize or eliminate inventory remaining outside locations that are easy to measure after clean out or during interim inventory taking;
- Minimizing the need for inspectors to revisit the site for clarification of information collected during previous visits;
- Making recommendations for the joint use of equipment;
- Making recommendations for reliable, low maintenance equipment;
- Allocating space for safeguards cabinets and inspector office space;
- Providing reliable power and a data transmission backbone for safeguards systems;
- Suggesting where redundancy or backup may be beneficial.

Moreover, a designer can recommend tools (e.g. three dimensional design drawings and mechanical strength assessments) that facilitate improving the design.

Both the technology for and the measurements used in reprocessing are areas of active research [22, 23, 36–42]. Research and development (R&D) on the reprocessing of irradiated nuclear fuel has been carried out with wet and dry processes, with the plutonium uranium redox extraction (PUREX) wet process being a process that has been scaled up to commercial level. While this publication will use the PUREX process as an example, much of the guidance applies to any processing of irradiated nuclear fuel. The different chemical processes that have been proposed to separate the plutonium, uranium, minor actinides and fission products might impact the safeguards measures in different ways (e.g. the presence of minor actinides in the product can impact which measurement techniques can be applied or the resulting measurement uncertainty). This should be taken into account. Advanced reprocessing schemes with varying degrees of technical maturity have been investigated [40], often with the intent of better understanding intrinsic barriers to proliferation (e.g. not separating the minor actinides) [43]. However, it is generally understood that intrinsic barriers have limited international safeguards value; any State with the technical capability to use these processes can be expected to have the capability to modify them [43]. In addition, stakeholders should take into account that there can be a trade-off between the difficulty of misuse and the ease of applying safeguards — according to the size and capacity of the facility and process as well as the type of the spent fuel to be reprocessed. SBD advises including the consideration of safeguards as an integral part of R&D on separations technology.

The facility MBA structure can be useful to segregate the facility into regions with different safeguards issues and different resolution procedures [13, 44]. SBD advises that stakeholders address the MBA and measurement issues early in the conceptual design process. For example, four MBAs might be assigned in a reprocessing plant for safeguards purposes. One MBA might be for the spent fuel receipts and head end, one can be assigned for the main processing areas, another for waste handling and the fourth MBA might be used for the nuclear material products. The receipts and head end MBA can then be used to evaluate the input shipper–receiver difference. The processing MBA can be used to verify the changes in chemical form and composition the nuclear material undergoes in processing. The issues involving waste (e.g. routes, treatments and storage) are usually addressed in a separate MBA, as they might be challenging. Placing the nuclear material products in a separate MBA allows for shipper–receiver differences to be isolated from the other facility activities. More complex MBA structures could treat U, Pu or (if present) mixed oxide (MOX) conversion as separate MBAs.

The IAEA may suggest the use of an on-site laboratory (OSL) that it staffs and controls, to facilitate more timely measurement results as well as to reduce the impact on the operator of the preparation and shipping of IAEA samples. Such a laboratory would require space and infrastructure to be supplied by the operator. If present, the IAEA OSL would be considered a separate MBA in a separate facility under safeguards.

Activities of interest to safeguards in reprocessing include:

- The shipment of nuclear material to the facility;
- The storage of nuclear material in the facility as well as the flows in and out of storage;
- The movement of nuclear material between MBAs;
- Changing the chemical or physical form or the composition of the nuclear material;
- The separation of elements;
- Process recycle or recovery;
- Generating, storing and disposing of waste;
- Nuclear material retention in process locations (e.g. hold-up, in-process inventory or spills);
- Packaging the product material;
- The shipment of nuclear material from the facility.

One consequence to safeguards due to the large capacity of a bulk handling facility arises from the fact that uncertainties in the measurement results tend to be a certain percentage of the measured value (e.g. 1–2% when sampling; homogeneity and other contributions to the uncertainty are included). Therefore, larger facility throughputs are associated with larger absolute uncertainties in the measurements, which contribute to larger absolute uncertainties in the material balance evaluation. Rather than perform more measurements and more frequent material balance verification to address this, an operator might implement additional measures (e.g. IAEA monitoring of the operator's process, short notice random inspections, unannounced inspections and mailbox declarations). The design of the facility can facilitate such additional measures through the automation of the process and the remote transmission of safeguards data. Properly implemented, this can result in a reduced need for routine access by the operator or inspector to locations that contain nuclear material. Specifications for these additional measures might be agreed to relatively late in the construction phase. Consequently SBD advises developing a flexible design that can accommodate additional measures.

The measuring and monitoring used in IAEA safeguards might rely on the same type of sensors, but with important differences in their approaches to calibration, measurement control, authentication and independence (e.g. monitoring generally requires less frequent calibration and measurement control activities). In short, a measurement provides a quantitative result with an associated uncertainty, while monitoring provides a qualitative result that may not have a reported associated uncertainty. Measurements and monitoring are discussed in more detail below. While measurements have historically been used to support nuclear material accounting and monitoring has been used to assess whether the facility is operating correctly and to maintain continuity of knowledge (CoK), R&D continues to build on the initial success of combining the two in a more formal fashion [45–48]. A more rigorous combination is expected to result in more effective safeguards with a lower cost. Based on experience in other chemical processing fields, experts have suggested there should be additional benefits from additional PM. However, issues of commercial sensitivity, independence from operator control and a concern over a possible negative impact on operation warrant further development, testing and evaluation. SBD advises that stakeholders monitor the R&D results for PM, as well as the R&D regarding the joint use of resources and equipment, for advances that can benefit the design of the facility. The greatest challenges in the implementation of safeguards applied to reprocessing are to reduce the effort required to accomplish the safeguards objective and reduce the impact of safeguards on operations.

3.1. MISUSE AND DIVERSION SCENARIOS

Safeguards objectives at a reprocessing plant include verifying that there is:

— No diversion of declared nuclear material;
— No misuse occurring through the processing of undeclared feed;
— No undeclared separation of alternative nuclear materials.

Many misuse and diversion scenarios can be addressed by nuclear material accountancy [13–15, 19–23, 32, 33]. However, safeguards accountancy measures might have limitations due to measurement uncertainties, the large nuclear material throughput or the need for significant resources to implement them. Consequently, monitoring for undeclared processing and separations as well as the application of containment and surveillance (C/S) are important additional measures. The potential for misuse of the facility using undeclared feed can be addressed by a combination of design verification and nuclear material flow verification, supplemented by ensuring that all nuclear material in the plant is measured and reported.

Measures that increase the transparency[7] of facility operations, making operations easier to understand and misuse more difficult to hide, as well as that facilitate the verification of nuclear material and operational status include [20, 21]:

— IAEA use of remote viewing of hot cells [28];
— The permanent installation of tank calibration systems that the IAEA can verify [44–52];
— Improvements in the design of the accountancy vessels to facilitate accurate measurement of the contents (e.g. taking into consideration internal structures, homogenization, temperature fluctuations, environmental controls and sampling systems);
— Clear separation of and well defined waste handling and treatment areas;
— Installation of independent inspectorate owned and controlled systems [39, 53–59];
— Support for inspector access to safeguards relevant operating information [46–48];
— Provision for the joint evaluation of facility sampling systems by the IAEA, State and operator (e.g. evaluate the possibility of evaporation, tamper vulnerability or access control) [19, 20, 33, 53–55, 58, 59].

[7] Transparency implies that inspectors can readily understand what activities are underway and whether they are part of normal operations.

3.2. GENERAL GUIDANCE

Safeguards concepts that have been used to reduce the impact of safeguards activities on the operator at reprocessing facilities include:

- An OSL to provide faster turnaround for the reporting of results [53–55, 59];
- Independent and authenticated solution measurement and monitoring systems for in-process hold-up and transfers [45–52, 60–66];
- Unattended NDA measuring and monitoring systems for spent fuel receipts and transfers, hold-up in the powder processes, powder product measurements and transfers and waste streams [15, 35, 41, 67–69];
- A near real time accounting (NRTA) system that provides frequent and timely operator declarations to the IAEA [70];
- Less frequent, but shorter notice random and unannounced inspections that can provide added assurance that the operations are as declared [10, 42, 62, 71, 72].

The following sections include guidance and lessons learned relating to various safeguards activities and measures as well as opportunities for improvement.

3.2.1. Infrastructure to support safeguards

The facility is responsible for providing the infrastructure to support safeguards equipment as well as access to the facility by the IAEA. In many cases, the facility safety regime requires that facility personnel perform equipment installation and maintenance. In this case, the IAEA will generally request to be present when safeguards equipment is being installed or maintained. Figure 11 shows the operator providing installation support under IAEA observation. SBD advises that the safeguards equipment be included in the facility planning for equipment installation.

When planning for IAEA equipment installation a number of considerations can come into play:

- For sensors 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 locations that avoid interference with operations.
- Shielding, lighting, maintenance and decontamination can be discussed prior to installation.
- Segregated, well labelled utilities for the safeguards equipment can reduce the chance of the operator inadvertently disabling safeguards equipment.

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

— Remote data transmission capability inside the facility implies that the facility will be requested to provide connections (e.g. cabling or wireless) from the safeguards sensors to the safeguards data collection and transmission equipment.[8] SBD advises that stakeholders address the quantity of data to be transmitted early in the design considerations. There can be a huge difference in size between infrequent signals that indicate whether instrumentation is functioning correctly (commonly referred to as SOH information) and cameras that send high resolution pictures.
— The intensity and subset of the measures applied in safeguards may change over the facility's operational lifetime. SBD advises the infrastructure design be able to accommodate changes that occur as the overall design evolves.

Safeguards equipment requires regular maintenance or replacement. This maintenance can sometimes be performed during normal facility operation if suitable arrangements are in place. Coordinating these activities with the facility equipment installation and maintenance, including the sharing of resources, can be desirable. When safeguards equipment is removed from the facility for maintenance or replacement, the IAEA will normally request the facility to provide services (e.g. to check equipment for contamination and decontaminate it if necessary).

Guidance based on lessons learned [19–23, 39] in the design and installation of infrastructure for safeguards equipment includes the suggestion to:

— Plan penetrations through building structures for safeguards cabling (note that in the joint use of equipment, the IAEA may request a separate signal cable or extra cables);
— Document the IAEA and operator safeguards equipment infrastructure needs and review them periodically during design and construction (e.g. when the facility or safeguards design evolves);
— Segregate the facility services (e.g. 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 locations containing nuclear material;
— Label all safeguards equipment (including cabling, power supplies and switches) and its associated infrastructure clearly to avoid inadvertent interruptions;
— Recommend locations for safeguards equipment that minimize impact on operations, provide a benign environment and reduce the opportunities for damage to the equipment;
— Include mutually agreed upon space and mounting brackets for safeguards equipment in the facility design;
— Facilitate access to safeguards equipment for maintenance or data retrieval;
— Provide adequate lighting to perform inspection activities as well as for surveillance, containment and monitoring activities;
— Provide a data collection location protected from extreme temperature, humidity and dust for video surveillance and flow monitoring systems;
— Take into account operator needs to cut power (e.g. for the maintenance of machines) while maintaining continuous power to safeguards equipment;
— Supply dedicated circuits for safeguards equipment;
— Provide stable electrical power (e.g. instrument quality where necessary as well as isolated from arc welders or other sources of electrical noise);
— Provide backup emergency power to reduce the chances of a loss of safeguards data.

Safeguards equipment often has instrumentation racks for signal processing electronics, batteries, and data archive and storage located remotely from the sensor in less hazardous space than the sensor requires. This equipment is installed in IAEA supplied cabinets. SBD advises the consideration of dedicated, IAEA access controlled space (except for operator access to respond to emergencies) for safeguards electronic equipment. Moreover, SBD advises being prepared to accommodate minor changes in the size of the equipment over the life of the facility (e.g. when obsolescence occurs, the possible replacements might be a different size). Designers can recommend options for environmental control when required. Furthermore, they may recommend locations for office space for inspectors (where temperature, humidity, lighting and noise can be held to acceptable levels).

[8] The cable and conduit might be specified by or provided by the IAEA and subsequently verified after installation.

3.2.2. Design information examination and verification

Large bulk processing nuclear facilities require significant resource commitment and planning in order to implement a safeguards approach. Nuclear reprocessing facility designs and operations are particularly complicated, difficult to describe succinctly and challenging to review. It is generally understood that the early provision of preliminary design information to the IAEA offers an opportunity to reduce interruptions to the project schedule [1, 3, 4, 73–75]. SBD advises that clear indication be included in the provision of information that identifies which information is provisional or likely to be changed. In most cases, it is not practical for the IAEA to verify the construction and operation of the entire facility or site; the imposition on the operator and the resource requirements would be too large. Consequently, it is generally expected that the IAEA will apply random sampling to the less important structures, equipment and operations [17, 74] and will select a different subset from the possible verification activities during each site visit [73]. SBD advises that the design and design implementation plan accommodate this variation.

The IAEA generally carries out an examination of the design information each time it is provided or revised. Activities carried out by the IAEA during the design information examination (DIE) serve to determine that all relevant descriptive and technical information has been provided that would support the development, implementation or updating of safeguards measures [73]. The design information is examined, or re-examined, to evaluate whether:

— The design information provided is complete and consistent;
— Additional information is needed for amplification or clarification;
— Generic or facility specific safeguards measure should be applied or updated;
— Specific equipment for accountancy verification and C/S measures is required;
— Sufficient information is available to establish or update a facility specific list of essential equipment, including systems and structures;
— Sufficient information was provided for the preparation or update of the facility attachment and inspection procedures;
— The design information was provided in a timely manner;
— Sufficient information was provided to develop or update the DIE/DIV plan and procedures.

Initial DIVs are performed during the construction and commissioning phases for new facilities and as soon as a CSA has entered into force for a State with existing facilities. The purpose of the initial DIV is primarily to provide assurance that the facility matches the design. Periodic DIVs are performed throughout the lifetime of the facility per arrangements specified in the DIE/DIV plan or when safeguards significant modifications are made. Periodic DIVs confirm the continued validity of the design information relevant to the implementation of safeguards. When modifications or changes in design information relevant to safeguards occur, such modifications or changes are verified to establish a basis for the adjustment of the safeguards approach and procedures. In summary, the design information is verified in order to:

— Confirm the correctness and completeness of the design information;
— Obtain additional design and/or design related information through visual and technical measures and through discussions with the State and facility operator;
— Contribute to the design, implementation and evaluation of the safeguards measures;
— Provide assurance that no undeclared activities or operations are taking place;
— Verify that the safeguards relevant facility design features are unchanged from the declared design information (e.g. no added material flow features such as additional pipes);
— Verify that all safeguards relevant equipment and operational activities in the facility are declared;
— Detect any changes throughout the lifetime of the facility that would make the safeguards measures less effective.

The challenge for stakeholders is how to assist the IAEA in performing the verification activities at lowest cost and with sufficient rigour, including how to support IAEA activities on-site and how to answer questions about documentation. Early provision of design information allows the IAEA to begin planning resources and developing facility specific implementation plans. On-site visits can be useful even before the site preparations for a new facility begin. The IAEA uses photography to support visual observations and written reports over lengthy periods of time, including observations during concrete pours for foundations, walls and ceilings. In early DIV visits, the IAEA may verify site characteristics or the preparations for construction. In later visits during construction, the IAEA may carry out a number of different verification activities (e.g. take dimensional measurements, trace pipe runs, identify penetrations and pipes through containment walls and use various means to document equipment and areas that will not be available at a later time) and might access and examine the construction site perusing detailed building drawings to confirm that the design features observed are those documented on the drawings.

SBD advises that facility modifications be assessed as to whether they can introduce additional diversion paths that were not considered in the safeguards implementation. If part of the nuclear facility is being constructed or modified while another part is in operation with nuclear material, the operator can segregate the two parts with access control to simplify the IAEA verification task. Clearly segregating locations undergoing construction from those undergoing routine inspections with physical barriers facilitates implementing the safeguards measures as well as facility operations and safety practices.

IAEA design verification activities continue throughout the operational lifetime of the project, starting with the examination of the preliminary design information and continuing until the facility is decommissioned for safeguards purposes. An inspector can request access to process, waste, mechanical and hot cells before they are permanently closed, authorized for use and potentially become contaminated in order to perform design verification and/or to install safeguards equipment and/or tamper indicating devices. Following this, stakeholders can put procedures in place to ensure that undeclared access does not disrupt the assurance of CoK on the design verification. Subsequent DIVs might include verifying that the containment remains a viable barrier without any new penetrations. There can be occasions following the initial DIV of these cells and the application of seals to the entrances, when the installation and commissioning engineers require access for additional work and modifications. In this case, arrangements can be made for the safeguards inspector to be present to observe the work and to reactivate any tamper indicating measures following the completion of the work.

Items and activities of interest during design verification typically include:

— Tanks or process vessels that have the capacity to contain large inventory of U or Pu;
— Pipework for material flows relevant to safeguards;
— Process control instrumentation and associated pipework and/or wiring;
— Data handling processes, particularly related to the facility’s nuclear material control and accounting;
— Validation of process models and calibrations;
— Sample taking systems including systems for transfers to the analytical laboratory;
— Reagent storage and recycle (e.g. nitric acid and tributyl phosphate);
— Ventilation systems associated with process or storage areas.

SBD advises that stakeholders evaluate the possibility for some design verification to be done off-site (e.g. for equipment before delivery to the site) and whether some is required before nuclear material is introduced (e.g. the interior of hot cells) or perhaps even before low hazard surrogates (e.g. depleted uranium) are introduced for the initial commissioning steps. In such cases, it should be understood the equipment might still require DIV activities after installation to assure that no design or operating changes have been introduced.

It can be difficult to maintain CoK on previously verified structures, as the equipment and piping in large bulk handling facilities can be difficult to understand. Consequently the IAEA might apply specialized tools, e.g. a 3D laser rangefinder (3DLR) [15, 74, 75] that can be used to highlight changes that have occurred since the previous scan. Figure 12 shows a 3DLR scanning through an enclosure window. Figure 13 shows a previously obtained reference image of a glove box, the verification image and an image showing the differences highlighted in red.

Other equipment useful for IAEA DIV activities includes:

— A portable manometer systems for vessel volume calibrations;
— A ground penetrating radar to detect hidden structures;
— Endoscopes to detect pipework branching in non-accessible areas;
— Acoustic tools.

FIG. 12. IAEA design verification using a 3D laser rangefinder.

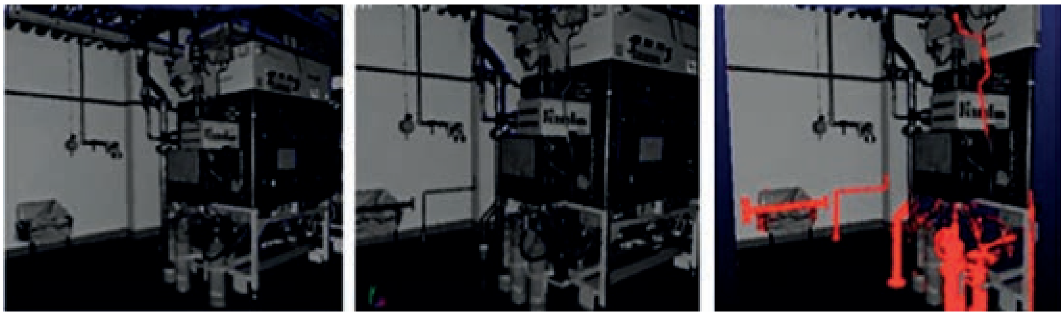

FIG. 13. A three dimensional laser rangefinder reference image (left), verification image (centre) and an image with the differences highlighted (right).

Designers, vendors or facility operators might know of and suggest alternative technologies to facilitate design verification.

3.2.3. Nuclear material accountancy

Nuclear material accountancy is a safeguards measure of fundamental importance; it is implemented to satisfy the requirements of safeguards agreements, to verify declarations and to resolve verification questions and discrepancies[9]. It is generally understood that:

— The operator will have a comprehensive system for the accounting for and control of nuclear material that includes procedures, records and measurement equipment;
— The IAEA will verify the operator's measurements and records using a variety of measures including statistical sampling, independent measurements and the review of records;

[9] A 'discrepancy' is an IAEA term that encompasses inconsistencies between or in measurement results, records, reports and other safeguards measures.

— Nuclear material accounting can help the operator achieve more efficient facility operation (e.g. higher throughput at lower cost).

Smaller uncertainties in the measurements of the nuclear material [15, 17] improve the safeguards verification but can be expensive or difficult to achieve. While easier to determine, both volume and weight need to be accompanied by a concentration measurement to determine the quantity of nuclear material in the container or vessel. Designers of reprocessing facilities can therefore include measurement systems, their locations and associated infrastructure in design considerations to facilitate implementation by both the operator and the IAEA.

Designers can play an important role in suggesting measurement locations and associated infrastructure, as well as in minimizing the impact of measurement activities on facility operations.

To reduce on-site inspector presence and to verify that operations are as declared when inspectors are not present, the IAEA may install unattended measurement and monitoring systems. Opportunities may exist for the joint use of measurement systems. If so, SBD advises that the joint use of measurement systems be part of the early design discussions.[10]

SBD advises that stakeholders agree on the sharing of resources for the design, procurement, installation, calibration, operation and maintenance of safeguards equipment. Measurement system stakeholders can include the owner/operator, the vendor, State and/or regional safeguards authorities and the IAEA as well as various subcontractors. It is important for the IAEA and State inspectorates to have an opportunity to both be present during the commissioning and calibration of operator and inspectorate measurement systems. SBD advises that a designer take into consideration that the procedures for operating a measurement system will include calibration, measurement control and maintenance activities. A measurement control programme provides information on the performance of measurement systems, including documentation of the measurement uncertainties [14, 31–33, 35, 45, 49–52, 76–83]. These measurement support activities generally require dedicated, access controlled space for the storage of the operator's calibration materials, check sources and records. Furthermore, the IAEA may require IAEA controlled space in the facility for similar items. SBD advises the allocation of space and time for these activities be considered while designing the flow of nuclear material through the facility.

3.2.3.1. Operator's nuclear material accounting system

IAEA safeguards require that the facility operator have a system based on measured or calculated values to support the operator's records and the State's declarations concerning nuclear materials. It is expected that the operator will implement measurement systems that conform with international standards [31–33, 35, 76–83], that meet international target values (ITV) [14] and meet facility requirements for safety, ease of use, and security [6, 84–86]. Moreover, it is expected that the design and operation of the plant will be such that:

— The nuclear material is in a measurable form at inventory and flow measurement points;
— The amount of nuclear material contained in the process area can be minimized and collected in a few locations for measurement during the taking of the annual physical inventory;
— The plutonium inventory distribution can be established and declared throughout the facility for interim inventory taking;
— The accounting activities minimize reliance on estimation or stream averages.

Independent verification of calculated values for spent fuel nuclear material masses and isotopic fractions (e.g. from research reactors) has been challenging to accomplish in the past. To better segregate this challenge and separate it from other issues, SBD advises that a separate MBA be defined in the facility — an MBA used to handle nuclear material shipments and to determine input accountability values.

The operator's system of nuclear material accounting and control can include sampling, destructive assay measurements, NDA measurements, in-process measurements, the use of portable equipment and dedicated measurement locations shielded from process interference (e.g. radiation background or large temperature fluctuations). SBD advises that the operator be prepared to provide technical justification of the applicability of the method and of the associated uncertainties for all measurement methods that are used and for the results

[10] Retrofitting of IAEA authentication measures into off the shelf equipment can be difficult and expensive.

obtained from those methods, including estimations and stream averaging. In order to get the best results from measurements, subject matter experts can be consulted for assistance in both the design and the implementation of the measurement methods. It is generally agreed that determining a good quality measured value for spent fuel is not yet feasible or cost effective. Consequently, measurement of spent nuclear fuel is an active area of R&D. SBD advises stakeholders be informed regarding the facility, State and IAEA requirements regarding measured values and CoK — noting that the requirements may seem to be inconsistent and therefore may need clarification. Stakeholders should also be informed regarding recent improvements from the R&D.

SBD advises that facility operating procedures and systems provide for timely submittal of nuclear material flow and inventory declarations to the safeguards authorities, including relevant source data. Furthermore, the operator's systems and procedures can be designed to provide previously agreed to operating information such as schedules, operational status and information about process upsets. To facilitate this provision, the operator's nuclear material accounting reporting system might require near real time access to operating and in plant accounting information.

3.2.3.2. IAEA sampling capabilities

Both the operator and the IAEA typically draw samples in reprocessing plants for high accuracy measurements. The drawing of IAEA verification samples generally necessitates maintaining traceability (e.g. where, when and how the sample was drawn); strict controls on access to the samples, sampling equipment and transfer lines; and secure storage for the safeguards samples, including archival samples. Many of these needs might also be relevant to the operator's samples. In some instances multiple samples are mixed, then split for multiple labs to perform comparative analyses with a part being archived in case questions arise about the results. SBD advises the plant design include authenticated and access controlled capability for drawing, handling, storing and shipping of samples — taking into account the multiple stakeholder requirements.

The independent analysis of samples of the nuclear material by the IAEA is an important safeguards measure to assure that declarations are correct. Although unattended measurement systems can be preferable for minimizing IAEA impact on operations, independent and representative measurements may be required by the IAEA:

— To offset the higher uncertainties associated with unattended measurement systems;
— For authentication of the unattended measurement systems;
— For use where in-line measurements are not possible;
— As part of a quality assurance/quality control (QA/QC) programme.

The IAEA's requirement for independent, authenticated, representative samples can be taken into consideration when designing and installing the facility's sampling system [17, 59]. The IAEA can be expected to periodically observe sample drawing procedures, to verify the homogeneity of the samples and to assess the uniformity of the bulk material that the sample is drawn from. IAEA safeguards verification samples will usually be transported to an off-site analytical laboratory or to an OSL. In some instances a few samples may go to the operator's laboratory for IAEA analysis, while others may be archived for later use. As part of a QA/QC programme, comparison between the analytical results from different labs on splits from one sample may be carried out to evaluate measurement quality.

Sampling systems and their effects on the quality of the samples can be assessed during plant design. One can take into consideration factors such as tamper indication, evaporation, homogenization of the bulk material and the sampling location in the vessel, as well as the capability for sampling multiple vessels. Stakeholders can address the requirements for joint use, operator owned sampling systems. Operator sampling systems jointly used by the State and the IAEA can be designed to provide transparent[11] operations, sample traceability, low vulnerability for possible tampering, provision for authentication, and flexibility in the drawing and scheduling of samples [19, 21–23, 42, 54, 55, 59]. Procedures that ensure the integrity of empty and full sampling vials are also important. The sampling system should be capable of tracking empty sample vials from their introduction into the system, including transfer to the process sampling location, their filling and their return to inspector control, with high assurance that a quality, representative sample has been obtained.

[11] In this context, 'transparent' implies that the inspector can clearly understand the process function and connections in the plant as well as the difficulty of misuse in such a process.

In view of the large number of samples expected to be taken at large scale reprocessing plants, SBD advises the consideration of dedicated inspector controlled OSL for large plants.

3.2.3.3. IAEA on-site laboratory

In the early 1990s various stakeholders concluded that sampling of material from process vessels for DA would be required to meet the safeguards objectives at large scale reprocessing plants. Based on experience, they also concluded that transport of the samples to off-site laboratories should be avoided for reasons of safety, cost and timeliness. It was therefore decided by the then European Community to establish laboratories on the sites of Sellafield and La Hague [53, 55–57]. Sample measurement methods were selected using the criteria of highest possible measurement accuracy and minimum resource consumption. Following the recommendations of the Large Scale Reprocessing Plant (LASCAR) international forum [87], the OSL at the Rokkasho Reprocessing Plant is jointly operated by the Japanese authority Nuclear Material Control Centre and the IAEA to provide analytical services for safeguards samples [22, 23, 54, 58]. The OSL deals with a variety of samples typical to a reprocessing plant, including mixed U/Pu solutions originating from various stages of the chemical process, pure product solutions of uranium and plutonium, and highly radioactive waste solutions.

Stakeholders can consider whether an OSL would be for IAEA use alone or for joint use with another stakeholder. Although an OSL might require a large financial and human resource commitment, it can provide the following benefits for the operator:

— Reduced resource requirements for the preparation of inspection samples;
— Reduced paperwork and handling associated with shipping inspection samples;
— Reduced handling of inspection samples;
— Reduced overall cost and impact to operations.

An OSL can offer the following benefits for the inspector:

— Timely analytical results that meet international target values [14], or that are of equal quality to those of the IAEA’s network of analytical laboratories [82, 83];
— An ability to handle liquid samples (of high activity), as opposed to the smaller, dried samples typically sent off-site;
— An ability to recycle waste (e.g. remnants from analysis or excess of sample) back into the process;
— Improved control of inspector samples and reduced chance of tampering;
— An ability to archive samples locally;
— A reduction in the number and cost of shipping samples off-site.

If an OSL is not part of the safeguards concept, the alternatives potentially include use of the operator’s laboratory for sample preparation and use of the operator’s measurement equipment. Use of the operator’s laboratory and staff for IAEA safeguards requires additional security and authentication measures for the handling of samples and the conducting of the measurements as well as additional facility resources.

3.2.3.4. Inventory that is difficult to measure

Difficult to measure inventory can include:

— Nuclear material outside the expected locations or vessels;
— Heterogeneous or otherwise difficult to sample materials;
— Nuclear material that is flowing during an interim inventory verification (IIV) and from which representative samples cannot be easily taken;
— Highly radioactive material that is difficult to handle in the laboratory;
— Material that is difficult to analyse because of the matrix (the constituents other than uranium or plutonium);
— Materials for which no calibration standard is available.

Several terms with similar meanings are commonly used by the nuclear industry when addressing inventory that is difficult to measure. When there is a lack of agreement on the terminology, confusion can result. The following offers a definition of such terms:

— 'Difficult to measure' inventory usually describes the measurement challenge, not where the nuclear material is located.
— 'Hold-up' is generally defined based on where the material is located (e.g. nuclear material retained within process equipment or process areas following normal operations), not whether the material in question is easy to measure.
— 'In-process inventory' describes nuclear material in the process equipment, that under ideal circumstances will pass through the equipment during operation, leaving negligible hold-up.
— 'Unmeasured inventory' can include hold-up as well as in-process inventory and is sometimes possible to measure.

If hold-up, in-process inventory or unmeasured inventory happens to be large, the annual PIV can be facilitated by performing non-destructive measurements with portable equipment or by running the process without feed to clear the nuclear material out of the process equipment as much as possible.[12] If large quantities still remain, disassembly of equipment and physical cleanout of the nuclear material may be an expensive but necessary alternative for recovery of the material for measurement. Some chemical forms encountered in these activities may require stabilization or special handling or packaging for safety or to facilitate measurement. In preparing for physical inventory or to facilitate nuclear material accounting in general, SBD advises consideration of design features to reduce difficult to measure inventory (e.g. cleanout and consolidation) as well as consideration of a capability for the stabilization and measurement of the extracted material. Designers can include provision for any additional equipment, storage or infrastructure that might be required.

SBD advises that nuclear material inventory in locations that are difficult to measure (e.g. pipes, pumps, evaporators, calciners, furnaces, separators and hoppers) should be minimized [29, 30], in particular for inventory taking. An ability to accumulate the majority of in-process nuclear material in a few locations better suited for measurement (e.g. in calibrated tanks) greatly facilitates inventory taking (e.g. requires fewer resources and less time). To minimize opportunities for measurement challenges, facility design should be optimized in terms of footprint, layout and simplicity. For example, designs can avoid long distances between buildings with piping that is difficult to access. Since a facility cannot completely avoid unmeasured inventory in process areas, algorithms might be developed and tested to estimate the inventory has a reasonable inventory and throughput allowing for measurements to have acceptably low uncertainities between cleanouts. In general, these algorithms must be periodically verified, including by the use of cleanouts and measurements of the recovered material. SBD advises that the design minimize the need to periodically disassemble equipment for a thorough cleanout of the nuclear material.

Experience has shown that the bulk processing of nuclear material will include locations, equipment and times when material does not flow smoothly through the process (e.g. during process upsets). This can lead to residual material in unexpected and difficult to measure locations.

Other aspects of design relating to difficult to measure inventory include:

— Features and layout that facilitate the draining of pipes, vessels and pumps [25, 26];
— The construction of scale-model test equipment to support the development of algorithms;
— Estimating holdup from engineering design drawings (accurate as-built drawings are required);
— Provision for cleanout, stabilization and packaging of the material;
— Confirming estimated and measured holdup values, including heels, during commissioning and start up (witnessed and verified by the IAEA).

[12] It is generally not cost effective to clean out process equipment routinely for IIVs.

Difficult to measure waste streams are often candidates for consideration in the resolution of inventory differences or material unaccounted for. Design considerations to facilitate this consideration include the ability to:

— Segregate clean waste from waste that is potentially contaminated;
— Segregate discarded office paperwork from process waste;
— Measure liquid and gaseous flowing waste streams;[13]
— Segregate waste into categories for measurement [28–35].

A design for waste measurements can include:

— Infrastructure that minimizes impact on operations (e.g. space for operator or IAEA equipment with environmental controls, radiation shielding, instrument quality power and data communications);
— Access for the IAEA to review waste stream activities;
— Access and space for IAEA measurement activities;
— Preparation for the IAEA to review and verify waste stream measurement activity.

3.2.3.5. Flowsheet verification

A capability for the separation of other fissionable actinides (neptunium and americium) from the spent fuel, referred to as alternative nuclear material (ANM), can be of interest to the IAEA. The implementation of flowsheet verification [41] can provide assurance that the process is being operated as declared and that no additional separations are taking place. Implementation of flowsheet verification requires the operator (via the State) to declare the expected flow routes of the agreed ANM and its expected elemental ratios with uranium and plutonium in selected process locations. Flowsheet verification usually involves randomly analysing safeguards samples for the agreed ANM element. Additional random samples may be required from locations not routinely sampled. However, this sampling is usually done with a low frequency. SBD advises that stakeholders clarify the separation capabilities of the process for neptunium and americium and understand whether provision for additional safeguards measures should be made in the facility design.

3.2.4. Process monitoring

Accountancy verification based solely on measurements at a large reprocessing facility would be resource intensive so, to reduce costs, measures additional to traditional accountancy measurements are used. These include monitoring and C/S, including the use of tamper indicating devices.

Process monitoring (PM), as discussed earlier, is a safeguards measure that monitors material, processes and equipment (nuclear and non-nuclear) through independent and/or shared operator measurements relevant to safeguards [62–65]. It is usually implemented in continuous and unattended mode, with data being stored locally, transmitted to a central on-site location, or transmitted to IAEA Headquarters [66]. PM systems may incorporate many types of sensors, both quantitative and qualitative, and may include surveillance systems. The data collected may come in a variety of forms. Three general categories of remotely transmitted safeguards data are:

— SOH information for individual or all components of a measurement or monitoring system that confirms that the system is functioning properly or provides an indication of malfunction or tampering;
— Summary data that provide relevant information for the preparation of inspection activities;
— Detailed data that provide information to be used in deriving safeguards conclusions.

When the IAEA considers the implementation of safeguards for a reprocessing facility, there are number of challenges that can benefit from the use of PM. In large facilities PM may be used to provide added assurance to accountancy verification measures or to maintain CoK of nuclear material as it moves through a process or during transportation. The majority of process operations in a reprocessing facility are opaque from an inspector's

[13] Continuous qualitative measurements might be more useful for waste streams than more accurate measurements of samples drawn from the streams infrequently.

perspective, making it difficult or impossible to apply direct IAEA verification methods to the nuclear material. Additionally, the physical form of the nuclear material changes, it is subject to complex processes with large throughputs and it has radiation levels that preclude access by IAEA inspectors.

The following safeguards challenges have been positively impacted by the use of PM and the information it provides:

— CoK of DIV and the detection of design changes;
— CoK of in-process flows, nuclear material transport and storage;
— The optimization of sampling and measurement plans;
— Assurance of high uncertainty measurements increased;
— Support for NRTA methods;
— The determination of in-process inventory hold-up and un-measurable inventory;
— The timely detection of process disruptions and equipment malfunction;
— Assurance that facility operations and parameters are as declared;
— Use of measurement data and operating information when scheduling of short notice and non-notice random inspection activities;
— Intrusiveness of methods on facility operations;
— Effort of inspection.

PM systems may be either independent systems, owned and controlled by the IAEA, or owned by the facility operator or the State with IAEA authentication measures applied to enable the joint use of the systems. As previously stated, these systems are normally operated in a continuous and unattended mode, and data may be collected locally or transmitted to IAEA Headquarters or to one of the IAEA field offices. The PM data are collected, analysed and used in conjunction with other IAEA data and information.

In the case of the joint use of a PM system with the operator and/or State, SBD advises planning for special measures be put in place from the early phases of design to assure that the data collected are authentic. Other considerations when designing and installing PM systems for safeguards use are:

— Reliability (e.g. a mean time of 150 months between failures);
— Robustness (harsh environment, radiation field, temperature, humidity, shock resistant);
— High measurement sensitivity;
— Diagnostics in the field;
— Data retrieval and servicing access;
— Remote transmission of safeguards relevant data and/or the equipment SOH.

An important component of the operator's process control and monitoring system is the continuous provision of information regarding the locations and movements of nuclear material throughout the plant. This component can assist the operator's nuclear material accounting office in preparing accurate and timely inventory declarations. In addition, it can potentially assist with IAEA verification activities. If PM is selected for use as a safeguards measure, systems owned and controlled by the State and/or IAEA would only be used for monitoring the process, with no process control capabilities assigned to the IAEA. However, in most cases there would be a mixture of authenticated operator systems and independent IAEA systems.

During the design phase of a facility, an important area for discussion and potential development in implementing IAEA safeguards is how to make better use of the operator's PM systems [19, 20, 62–66, 70] either as systems for joint use or as a complementary measure. Advantages of sharing some of the data between the operator and the inspectorate would be shared costs, reduced space required and fewer components to maintain. One important issue to be considered is the identification of a set of the operator's PM data that would provide assurance the facility is operating as declared for sharing with the IAEA. This would involve issues such as the protection of proprietary information on the operator's side and authentication of the data on the IAEA side. It may not be necessary to apply authentication measures to every sensor if the data can be correlated with data from other independent or authenticated sensors. A second important issue is that the quantity of data obtained from PM should not overwhelm the IAEA with a huge effort in data reduction and review.

Examples of PM systems that have been used in reprocessing facilities:

— Solution measurement and monitoring system;
— Radiation monitoring system;
— Plutonium inventory measurement system;
— Radiation and surveillance system.

3.2.4.1. Solution measurement and monitoring system

The purpose of the solution measurement and monitoring system (SMMS) is to measure and monitor the levels, volumes and densities in selected process vessels of a reprocessing plant [52, 61]. It uses high accuracy pressure measurement devices in selected process vessels. IAEA owned and controlled instruments have independent pressure transducers connected directly to the pneumatic dip tube lines that are installed in the vessels. Alternatively, less independent (but authenticated) IAEA systems split the signal from the operator's transducer.

The SMMS includes high accuracy electromanometers, interface hardware and environmentally controlled computers (e.g. Fig. 14) for local data collection, evaluation of SOH information, data buffering and authentication of data which is transmitted to an inspector station for final data collection and evaluation.

Data from the SMMS are collected and processed by solution monitoring software used routinely by inspectors, which includes configuration, preprocessing and evaluation functions. It automatically analyses the data from the pressure sensors, temperature sensors and neutron detectors. In its monitoring mode, it detects events in a series of data, which it compares with a reference signature; it raises alarms when differences are detected. It can also calculate the volume transferred out of a vessel and into another vessel and correlate the information between sender and receiver vessels. The SMMS provides the inspector with a high level graphical user interface (Fig. 15).

3.2.4.2. Radiation monitoring systems

Radiation monitors are designed to respond to changes in the radiation levels caused by the movement of nuclear material. Some radiation monitors are sensitive enough to also respond to changes in 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 can provide better signal to noise response. However, that 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,

FIG. 14. Solution measurement and monitoring system electromanometer.

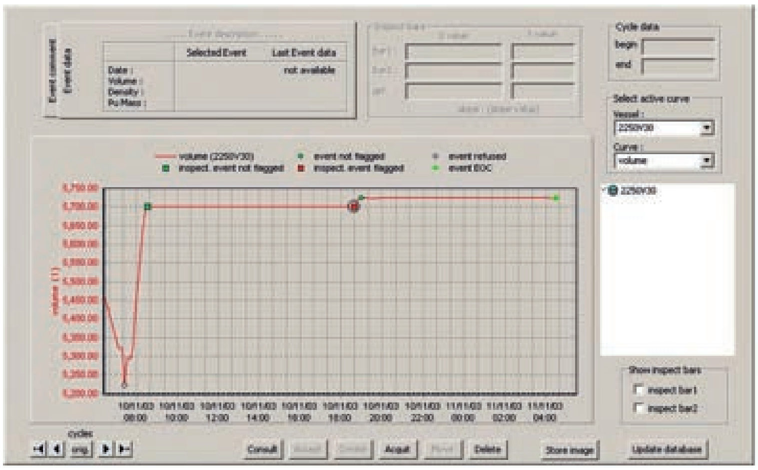

FIG. 15. Solution measurement and monitoring system graphical output.

signal quality and operational impact. Another choice can be choosing between a more expensive sensor (that distinguishes characteristics of the radiation signal to provide more information or that has a wider dynamic range) and a simpler, less expensive sensor that is easier to maintain.

Radiation monitors can be designed to:

— Indicate the presence or movement of nuclear material;
— Verify that containers are empty;
— Verify that waste contains little or no nuclear material;
— Indicate the direction in which the nuclear material is moving;
— Distinguish between fresh and spent fuel;
— Distinguish between nuclear and non-nuclear items;
— Trigger a reading by another sensor (e.g. request a surveillance picture be taken);
— Be triggered by another sensor (e.g. measure radiation associated with the detection of motion by detecting changes in the ambient radiation field);
— Operate underwater or in low illumination areas.

Moreover, radiation monitors can be:

— Installed outdoors or indoors;
— Installed in high radiation areas;
— Used to monitor vehicles or items.

When radiation monitors are implemented, SBD advises considering measures to mitigate opportunities to shield radiation monitors from the signals relevant to safeguards.

3.2.4.3. Plutonium inventory measurement system

The plutonium inventory measurement system is a distributed total neutron counting system (Fig. 16) jointly used by the operator, State regulatory authority and the IAEA in a MOX conversion process [60]. Authentication measures have been implemented so that it can be used by the IAEA to reach independent conclusions. This installed unattended system provides:

— A monitoring function that enables the continuous tracking of process material as it moves through the process (Fig. 17). The near real time nature of the plutonium inventory measurement system permits the safeguards authorities to monitor plant activities around the clock and to maintain CoK over the process material being fed into the conversion process. This tracking and monitoring also provides the operator with reassurance that the plant is functioning correctly and process disruptions are not occurring.

— An inventory measurement function that gives a snapshot view of the inventory within the plant and the distribution of that inventory during IIV. The system is used both for the operator to declare such inventories (in conjunction with book accountancy and other methods) and by the inspector to verify that the data declared by the operator are correct.
— A means of confirming that the plant has been effectively cleaned out of all process material prior to performing the annual PIV.

The system determines the overall count rate at each of the 142 ^{3}He neutron detectors (Fig. 18). The software then determines the number of neutrons emitted from each inventory item (vessels, glove boxes, etc.). These neutron emissions are then converted into an equivalent mass of plutonium for each item. This yields a determination of the distribution of nuclear material throughout the process.

3.2.4.4. Radiation and surveillance system

Some applications benefit from having both radiation monitors and surveillance measures. Figure 19 shows a camera and radiation detector PM assembly designed to fit as a cylindrical insert into a facility shielding wall. It is used to monitor the process activities behind the wall. Figure 20 is a drawing of the internal components of

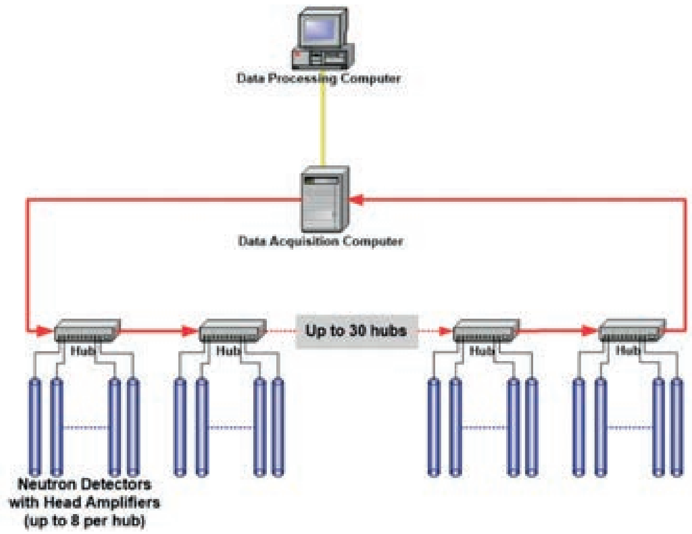

FIG. 16. Plutonium inventory measurement system.

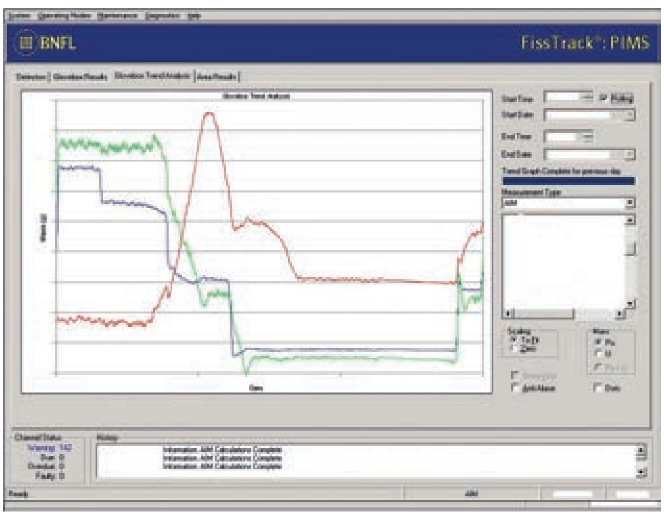

FIG. 17. Plutonium inventory measurement system graphical user interface [88].

the assembly. The camera viewing angle can be configured as wide angle or normal, the radiation detector can be for neutrons, gamma radiation or both, and the unit can include an internal radiation shield to protect sensitive electronics from damage. This design allows for maintenance to be performed on the IAEA equipment without requiring personnel access inside the shielded area. Furthermore, it reduces the radiation levels the equipment is exposed to, thereby reducing the need for maintenance or replacement of parts owing to radiation damage.

3.2.5. Containment and surveillance measures

The implementation of a safeguards approach based on nuclear material accountancy can be complemented with the use of C/S measures. C/S can be applied to maintain the CoK on previously verified facility or equipment design features or on nuclear material. It can also be applied to monitor potential diversion paths that were not intended for nuclear material transport (e.g. ventilation shafts, waste removal systems, maintenance hatchways

FIG. 18. Plutonium inventory measurement system ^{3}He neutron sensor enclosures on glove boxes.

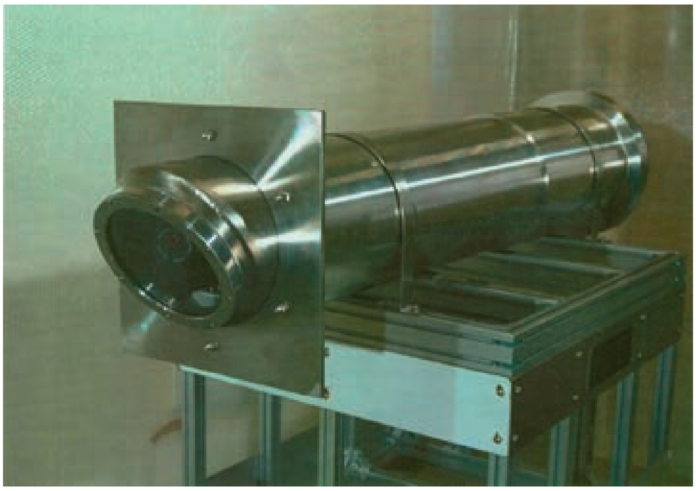

FIG. 19. A hot cell wall insert containing a camera and radiation sensors.

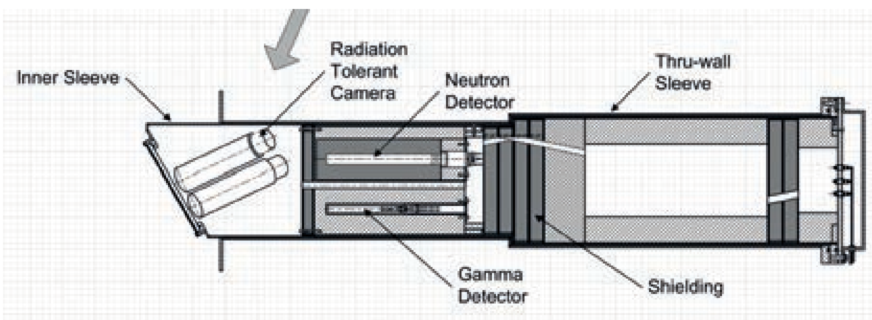

FIG. 20. Diagram of a hot cell wall insert containing a camera and radiation sensors.

or personnel elevators). These safeguards measures are particularly useful during times when inspectors are not present in the facility.

C/S measures cannot serve their purpose without facility features such as structural barriers, access control, segregated storage locations and fixtures for the application of tamper indicating seals. If used for safeguards purposes, the IAEA will verify the characteristics of these facility design features before and during their safeguards use, typically on an irregular basis.

Well designed facility barriers have the following characteristics:

— They serve to jointly address safeguards, safety and security concerns;
— They segregate activities or materials of safeguards interest from other activities or materials;
— They limit the movement of nuclear material;
— They limit access to locations where nuclear material is handled or stored;
— They segregate nuclear and non-nuclear items;
— They have a minimal number of penetrations that require monitoring.[14]

3.2.5.1. Containment and seals

Access control can be used with facility barriers (containment) to monitor human or equipment access to locations containing nuclear material, processing areas and control rooms, or to safeguards relevant equipment. Safeguards, safety and security stakeholders can assess the benefits of sharing the access control and monitoring systems or data [89].

A well designed fixture for tamper indicating seals on containment:

— Is difficult to remove or replace without leaving evidence of tampering;
— Has no externally accessible hinges on doors or hatches;
— Is integral to the design rather than giving the appearance of being an add-on or modification;
— Has loops or openings through which to pass the seal’s wire or optical cable;
— Is easy to access and use.

Figure 21 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 which can be verified using an underwater camera [90].

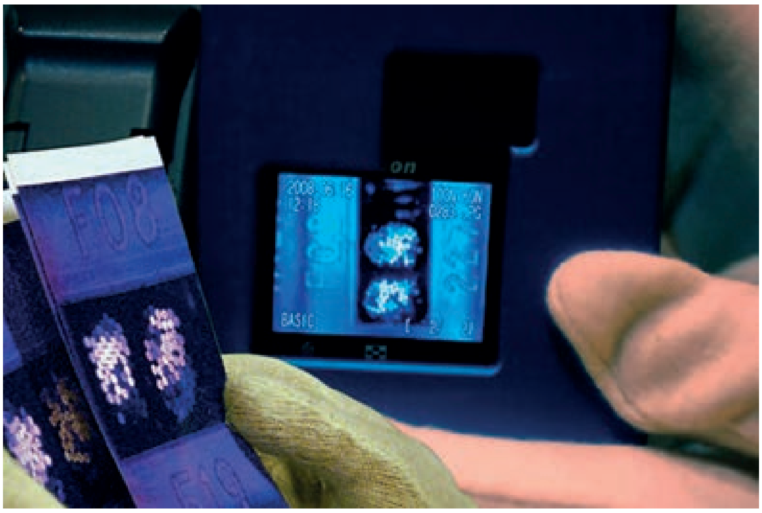

FIG. 21. A fibre optic seal being interrogated.

[14] Penetrations which are too small for people or nuclear material items to pass through are generally not of interest to safeguards.

3.2.5.2. Surveillance

IAEA surveillance by humans or equipment requires the provision of adequate, reliable lighting[15] and electrical power by the facility. The data retrieval from IAEA surveillance equipment can be performed remotely or by inspectors or technicians accessing the equipment. Authentication of unattended surveillance systems is usually accomplished by some combination of tamper indication on the camera body and electronics, data encryption and/or multiple sensors which monitor each other. Regular access by inspectors or technicians to maintain the system should be expected. The IAEA is experienced with implementing remote SOH monitoring for surveillance equipment, subject to prearrangements with the State and the facility [66] as well as the application of surveillance underwater and in hot cells. In addition, it has used remote transmission of surveillance data to enable a reduction of inspection cost and effort as well as a less intrusive inspection regime.

Design considerations for containment, tamper indicating measures, surveillance and monitoring include whether:

— All possible exit routes (e.g. ventilation penetrations, elevator shafts, personnel egress/exits and all shipping and receiving doorways) can be monitored;
— All material brought into or removed from the MBA or facility can be monitored and/or measured, including waste and non-radioactive material;
— The facility layout simplifies the use of a surveillance and monitoring system;
— There is a minimum number of penetrations to be monitored in containment structures or hot cell fuel handling areas;
— Nuclear material transport routes are easy to monitor;
— Movements of shielded containers can be monitored;
— Features of nuclear and non-nuclear material items can be easily distinguished.

SBD advises that designers understand early in the design process (and revisit as necessary) when individual item identification is necessary (including the use of unique, difficult to alter identification for each item) and when counting the number of items is sufficient for the purposes of safeguards. In addition, designers can facilitate the use of IAEA seals at features relevant to safeguards (e.g. penetrations, measurement equipment, nuclear material storage areas and junction boxes where cables relevant to safeguards are connected). The use of identification on safeguarded items that is difficult to alter without detection as well as easily readable by both humans and the surveillance/monitoring system might be challenging to implement but will better serve both safeguards and operational needs. Additionally, the selection of the surveillance and monitoring system's sensor locations as well as limits on the movements of nearby equipment can make it more difficult for the activities or materials of importance to safeguards to be blocked from view (e.g. by cranes moving objects or the location of temporary scaffolding). With an understanding of the safeguards needs, designers can recommend simpler solutions that reduce the impact on operations and that will minimize capital costs and maintenance.

3.2.6. System and data authentication

Confidence that the State or operator cannot modify or use knowledge of the safeguards system and data to defeat the implementation of IAEA activities is an important concept for the successful implementation of safeguards. An IAEA approved standard of authentication and encryption can confirm that sensor data to be used for safeguards purposes has originated from the appropriate source and has not been altered, deleted or substituted [91].

Opportunities may exist for the joint use of measurement systems, in which case, attention can be given to IAEA and State requirements regarding independent and/or authentic measurement results. SBD advises that joint use systems incorporate tamper indication and authentication measures into their design rather than add such features after they have been purchased. Experience has shown that failure to incorporate authentication requirements prior to equipment purchase can significantly increase the cost and possibly even preclude the use of the equipment. Information security requirements can be identified early to understand their potential impact and to facilitate their incorporation into the facility design, operating procedures and equipment.

[15] The IAEA has experience with infrared surveillance systems (used where necessary) as well as optical.

Examples of security and/or authentication methods include:

— Tamper-indicating enclosures, camera surveillance, motion sensors and IAEA approved conduit;
— Portable cable testers and pressure gauges (e.g. to detect undeclared connections);
— Varying levels of password control and delayed access to certain data for the operator or State;
— Cross-correlation of data from a number of sources;
— Short notice random inspections to the site by inspectors (for observations or measurements);
— Locations in the facility under IAEA access control.

3.2.7. Data collection and evaluation systems

Modern reprocessing facilities make use of IAEA data collection and evaluation systems to reduce the burden on facility and IAEA personnel [70, 92]. Large facilities may have many sensors in an MBA, some of which can make readings as often as every minute. When inspectors retrieve or review this data monthly or quarterly, the resulting quantities of data can be quite large. SBD advises that designers take into consideration measures to facilitate the secure transmission of data from attended and unattended measurement, containment, tamper indication, surveillance and monitoring equipment to a central database, either in the inspector's on-site office, to IAEA Headquarters or to a regional office.

When off-site transmission of inspector data or equipment SOH is anticipated, SBD advises addressing security considerations as a team effort early in the project.

A decision worth drawing stakeholder's attention to early in the design process is whether transmission of SOH information off-site will be sufficient, when transmission of the results of data analysis are necessary and when raw data should be transmitted off-site; note that the decision may be different for different sensors. With the potential to generate gigabytes of raw data, when and where to perform data reduction is an important decision. Concerns about data sensitivity and its protection can usually be addressed more effectively earlier rather than later in the design process. As in many facility design questions, there can be a trade-off between higher capital expenditures up front and higher maintenance and operating costs during the subsequent facility operations. This trade-off can be complicated when various costs are borne by different stakeholders. SBD advises lifecycle costs for all stakeholders be considered as a group to mitigate this issue.

Joint use versus sole use of equipment is both a cost and a control issue. One potential solution is for two data collection and evaluation systems to share sensor data. When sharing of data occurs, the IAEA can take advantage of review and preliminary evaluation of data in an automated and real time mode to improve the planning and performance of its activities. Design specifications for the integration of the operator's nuclear material accounting system and the inspector's data collection and evaluation systems can be included as an integral part in the parallel development of the safeguards approach and the concept of operations for the facility. In which case, SBD advises that interface and control documentation be specified and documented. However, to reduce the potential for interference with plant operations or tampering with either system, SBD also advises that physical connections between the inspector and operator data systems be minimized. It might be that an independent data transmission network for the IAEA is a good design solution, as that can be part of the approach to data authentication. All network and supporting power connections (including circuit breakers) related to IAEA equipment can be marked to avoid unintentional interruption during facility operations or maintenance. In addition to data received from attended and unattended systems, analytical results from IAEA verification samples can be incorporated into the inspector's system so that they are received in a timely manner.

3.2.8. Lessons learned

Experience with implementing safeguards at reprocessing plants has been accumulated, documented and assessed over many years [18–21, 87, 93, 94]. With the passage of time and the gaining of experience, both the facilities and challenges for safeguards have grown in size. Lessons learned for the implementation of safeguards have been summarized in this publication. It is evident that R&D opportunities remain, both in the concepts for and approaches to safeguards as well as in equipment R&D.

Beyond being of fundamental importance for international safeguards, SBD advises consideration be given to the fact that nuclear material accounting values provide information used for criticality safety, process operations, worker health and safety and physical security [6, 21, 22, 62, 84, 85, 95–100].

SBD notes that integration across project requirements has the potential to facilitate a formalized approach to verifying 'operations as declared' by the operator. The increased integration of nuclear material safeguards with operational systems is expected to lead to greater safeguards effectiveness and reduced impact to facility operations. Moreover, similar potential for positive benefit exists for the integration of safeguards with safety and physical security objectives.

Experience with the knowledge transfer process as personnel retire has not been optimal in the nuclear industry (as in other industries). One reason might be the reduced number of new nuclear facilities beginning operations. A lesson learned from facilities that began operating before 1990 is that the hold-up of nuclear material in process equipment can easily become a major issue (e.g. Refs [21, 22, 28–32, 98–100]). Resolution of this issue can require an extensive measurement campaign or a disassembly and cleanout before the facility can resume routine operations. Another valuable lesson learned is that planning and preparation for safeguards can never start too early in the life cycle of a nuclear facility [18, 20].

3.3. SPECIFIC ACTIVITIES AND LOCATIONS IN A REPROCESSING PLANT

Regular access to the reprocessing plant site by an inspectorate is an important safeguards measure. Access may be scheduled on a regular basis and it may occur with reduced or no advance notice. The selection of safeguards activities to be performed during each access visit can be affected by results from unattended monitoring, as well as by observations during the actual visit or those from an earlier visit. Safeguards measures with the potential to enhance IAEA effectiveness at reprocessing plants include:

- Enhanced PM;
- Replacement of the 'traditional' IIV with a high frequency random sampling or measurement plan for in-process material;
- Inspector access to additional operator records on a short notice basis.

It is generally understood that the IAEA will be informed in a timely fashion of facility maintenance activities and modifications to the plant design or operations that could impact safeguards implementation. In areas of the plant where human access is not expected during operations or limited access is planned (e.g. enclosed trenches and process cells with high radiation levels), IAEA design verification can be facilitated prior to restricting access. For example, in high radiation areas, a design can include containment features that allow inspectors to seal reusable penetrations. Additionally, provision can be made for the continuing verification inside difficult to access locations by remote viewing devices, access to the locations during maintenance periods or by robots, or by using other remote means to increase assurance that no changes are made to features relevant to safeguards.

The building of models prior to installation in the plant can be useful for both training operators and familiarizing inspectors with certain vessels; familiarization can facilitate better understanding of the design, the operation and the measurement characteristics of accounting vessels, high-inventory vessels and equipment that is difficult to measure (e.g. evaporators and separators). Models can assist in the optimization of internal structures for calibration, the testing of homogenization, understanding the interplay between systems and the effect of environmental controls or lack thereof, and the validation of the sampling system. Access to the model demonstration or test facility can be beneficial for the designer, the operator, the State and inspectors.

SBD advises that consideration be given in the design process to requirements for the periodic recalibration and calibration checks on inventory vessels and tanks; the requirements can require use of specialized equipment, certified standards or non-facility personnel. The installation and use of permanent calibration systems, as well as standardized procedures, during the initial calibration of selected vessels can result in more controlled and reproducible conditions during recalibration activities, thus potentially reducing the cost of the recalibration.

Plant operations can have a large impact on the ease of use and understanding of the nuclear material accounting system; operations conducted in an appropriate manner can facilitate safeguards verification activities. Access to monitor process and batch operations can facilitate verification. Batch transfers between vessels, where and when possible, can facilitate the verification of in-process inventory and inventory changes in an operating plant. The amount of nuclear material hold-up in piping can be better controlled if vessels and tanks are properly drained between batches (e.g. appropriate drainage capability can be a design requirement) and if the overall facility design provides clear boundaries for inventory measurements and declarations.

Consideration can also be given during the design process to locations where nuclear material rework and chemical recycling occurs; safeguards can be easier to implement when these auxiliary locations are available for verification by inspectors, their function and design are easily understood and their contents are possible to measure accurately. The potential for misuse or undeclared use of these auxiliary processes is of interest to safeguards. Therefore, access to these areas for an inspector or a surveillance system can increase confidence that the facility is being operated as declared. SBD advises reducing the potential for radiation exposure, simplifying egress, providing viewing windows in containment, making any processing equipment readily identifiable and simplifying the interconnecting pipework.

Measurement of waste generally becomes an issue of interest when addressing process losses or material unaccounted for. Liquid and solid waste handling and treatment areas can be clearly segregated and defined in the plant, and the plant operations can include a waste tracking and measurement system that records the origin and disposition of potentially contaminated waste. Stakeholder documentation can include waste sorting, packaging and measurement requirements.

Additional considerations for specific activities or locations in a reprocessing plant are:

— Spent fuel storage;
— Head end operations;
— Chemical processing;
— Product storage;
— Decommissioning.

3.3.1. Spent fuel storage area

Activities of interest to safeguards in the receiving and spent fuel storage MBA in reprocessing plants generally include the receipt of the spent fuel assemblies (SFAs) from power reactor sites, storage of the SFAs prior to processing and transferral of the SFAs to the head end area. The storage capacity at a reprocessing facility can be considerably larger than at a reactor site (e.g. for product control and operational reasons) and transfer operations into and out of it might be automated or remotely controlled. SBD advises the consideration of the safeguards verification activities for the nuclear material receipts and transfers be included in the design of automated or remotely controlled transfer operations as well as considering CoK activities in the design of any large or segmented storage capacity (e.g. consider the ability to segregate items from the main inventory, to monitor items with surveillance or to seal part of the inventory with tamper indication).

It is generally agreed that determining a high quality accountability value for spent fuel is not yet feasible or cost effective. Consequently, the shipper’s value is used in the accounting records and redundant measures to maintain CoK are applied until the fuel has been processed sufficiently to be amenable to measurement. The shipper’s value is generally based on calculations that are sensitive to the reactor operating characteristics and history, with few opportunities to benchmark the calculation results. Consequently, since measurement capability for the spent fuel is not readily available, additional safeguards measures are necessary in this MBA and the measurement of spent nuclear fuel is an active area of R&D.

The safeguards measures applied to spent fuel storage are typically based on item accounting and the use of multiple and independent NDA, C/S and monitoring measures to maintain CoK from receipt at the facility through the transfer to the head end operations area until a measurement can be made. Designers can help by doing the following:

— Minimizing the processing and handling of the spent fuel before a measurement can be made;
— Suggesting a process flow where safeguards activities that require time to perform do not adversely affect operations;
— Suggesting designs where safeguards issues that require time to resolve do not adversely impact operations;
— Enabling a system that functions routinely without inspector on-site intervention;

— Suggesting automation include remote readout regarding position and/or identification of the assemblies;
— Suggesting a design where only a single path is available for transfer of the spent fuel assemblies to the head end operations area.

Since opportunity for improvement exists in both fuel handling and measurements, R&D can be expected to be pursued and the design community can also contribute useful, innovative ideas for the implementation of safeguards.

3.3.2. Head end operations area

Of interest to safeguards, the head end operations area involves a transition from item accounting (of the assemblies or pins) to bulk material accounting procedures. While it is preferable to verify the shipper's value before processing the spent fuel in any way (e.g. removal of cladding), this may not be feasible or cost effective. At the time this publication was written, the input accountability tank was the first location in an aqueous reprocessing facility where a cost effective, high quality, quantitative measurement of nuclear material could occur. In the PUREX process, dissolution of assemblies occurs in heavily shielded cells under C/S and monitoring measures that maintain CoK of the nuclear material content, inventory changes and the design information (e.g. the shielded cell containment and the process steps). SBD advises the systematic labelling of components and pipes in the head end to facilitate IAEA comparison of the physical plant to the engineering drawings during DIVs. After dissolution, the volume and/or weight of the resulting solution is typically measured in a specially designed and calibrated accounting tank and combined with a measurement of concentration. Better measurement results can be obtained when calibration, homogeneity control (mixing), the sampling process and engineering studies of the measurement are considered in the vessel or tank design.

Measurements of the contents of the dissolved fuel solutions are important as they are the basis of accounting for the nuclear material quantity processed in the facility. Difficulties in accounting for undissolved solids, incomplete dissolution and large variation in the burnup of the spent fuel have been experienced in liquid sample measurements as well as issues with mixing to obtain homogeneity. SBD advises the design process consider ways to reduce such effects. Determining the nuclear material content of the hull and end piece waste is important. Experience has shown that incomplete dissolution may occur in the end pieces.

In aqueous processing, SFAs are typically processed in batches. Batch dissolution offers better opportunity for measurements and comparison with the shipper's values than continuous dissolution. In a continuous dissolution, demonstrating homogeneity of the solution for drawing samples can add processing time and a comparison with the shipper's accounting values for each assembly can only be carried out when the head end area is cleaned out at the end of a process campaign. In batch dissolution, SBD advises minimizing the number of assemblies in each batch in order to facilitate addressing shipper–receiver differences for individual assemblies.

3.3.3. Chemical processing area

The measurements conducted in the head end accounting tank are used as the input measurements for the chemical processing area. Of interest to safeguards, in the chemical processing area, is the separation of plutonium and uranium from the fission products and the purification and packaging of the final products. These industrial chemical processes require monitoring by the operator to ensure that optimal conditions are maintained, the process continues to operate in a safe manner and that the process yields products of the desired quality. Automation in the process area, where possible, can help to demonstrate single pathway flow for the nuclear material. Moreover, joint use equipment can help simplify the design and thereby facilitate verification of single pathway flow. SBD suggests automation and joint use be considered in order to increase operational efficiency as well as to simplify the containment features. Instruments commonly used in PUREX reprocessing can include:

— NDA instruments to monitor flows and inventories of uranium and plutonium;
— DA measurements to provide on-line monitoring of process conditions;

— PM and control to measure and control aspects of plant operation such as temperatures, pressures, flow rates and vessel (or tank) levels.[16]

In reprocessing plants the removal of samples from the process for off-line analysis is generally applied with measures to uniquely identify and track the samples. When a joint use OSL is employed, a two person team (one person from the IAEA and one person from the operator) can be necessary to maintain the authentication of the IAEA samples until analysis is complete and reported. Facilitating occasional inspector access to process areas is a useful factor to be considered in plant design (e.g. mitigating issues with proprietary technology). In addition, enhanced PM in conjunction with a NRTA system that minimizes as well as incorporates limits on the variation in the quantity of in-process inventory can also be considered. The quantity of nuclear material in any waste should be measured before the waste leaves the MBA. SBD recommends that the ability to track, segregate and measure waste be included as part of the facility design requirements.

Intermediate and final products of the chemical processing are loaded into containers with tamper indicating seals, thus making the transition from bulk to item processing feasible for these samples as well as facilitating the associated measurements. The output measurements for the chemical processing area can be carried out by weighing, NDA and chemical analysis of samples taken from the product material before the product is loaded into containers. Provision should be considered in the design for periodic verification of the calibration, measurement control and/or recalibration on vessels and equipment relevant to safeguards, especially those for product measurement. Containers are typically placed into storage while they wait for the analytical results where C/S and monitoring measures maintain CoK on the measured items. The application of unique, human and machine readable[17] identifiers for nuclear material containers facilitates both facility accounting and IAEA verification.

3.3.4. Product storage area

For safeguards purposes, a plutonium product storage area can involve a transition from bulk processing to item processing. In reprocessing, the output measurements from the process MBA usually provide the measured values for the storage MBA. While relying mostly on C/S and monitoring measures, the IAEA can also use measurements to verify nuclear material items in storage.

Containment features of product storage facilities can be enhanced by limiting the number and dimensions[18] of penetrations for access and by providing fixtures and infrastructure for the implementation of C/S and monitoring measures. These measures potentially include seals on doors or ventilation grates, surveillance cameras, sensors for detecting door openings, radiation sensors to measure or to detect movement of items, and systems to integrate data from different types of devices. Verification and maintenance of these safeguards measures generally requires inspector access, and facility safety rules might limit the frequency or length of access. In many cases, movement of the containers is automated, remotely operated and visually monitored to minimize the need for human access to the product. Safeguards systems can permit unattended verification of item transfers and can thereby provide more efficient safeguards while being less intrusive. Designers can recommend ways to reduce the impact of these safeguards measures on storage area operations. Facility designers and operators can help to reduce the impact of safeguards by implementing robust item handling systems and high quality measurement systems.

3.3.5. Decommissioning

The application of safeguards to a facility continues after operations with nuclear material have ceased. Changes in the activities relevant to safeguards can be discussed with the IAEA before decontamination and decommissioning activities begin. Stakeholders can consider how to facilitate the following activities:

— Verifying nuclear material has been removed from the facility;
— Verifying waste containing nuclear material has been removed from the facility;

[16] The operator's PM instrumentation is often based on standard chemical processing equipment and techniques adapted to the highly radioactive environment.

[17] Experience has shown that human readable capability is a prudent contingency measure for sample identifiers.

[18] Openings too small to provide an alternate pathway for people and items do not require application of safeguards measures.

— Verifying safeguards essential equipment[19] has been removed or rendered non-functioning[20];
— Returning useable equipment belonging to the IAEA.

In the context of international safeguards, following the removal of nuclear material, a facility is considered to be decommissioned only when equipment essential for its operation has also been removed or rendered inoperable. For most facilities 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. Designers are well suited to help the IAEA create this list, which can be part of the preliminary design information provided to the IAEA at an early stage of the design process and subsequently revised, as necessary.

During the time from when essential equipment arrives at the facility to when it is verified to have been removed from the site or to be inoperable, the facility can be considered by the IAEA as available for use and the IAEA can apply safeguards measures. Examples of safeguards essential equipment are [101]:

— Storage ponds for spent fuel;
— Equipment to move spent fuel;
— Equipment to declad or chop spent fuel;
— Equipment and hot cells to process spent fuel;
— Plutonium conditioning, conversion and concentration equipment;
— Uranium conditioning, conversion and concentration equipment;
— Plutonium product packaging or handling equipment.

3.4. NEXT GENERATION TECHNOLOGY

Several next generation chemical processing methods (flowsheets) have been proposed for the reprocessing of spent nuclear fuel [39, 102]. One justification offered for this R&D on processing methods is to increase throughput and decrease processing time. These justifications have the possibility of making the application of safeguards more difficult. Consequently, SBD advises the parallel consideration of potential safeguards measures during R&D on next generation technology [103–106]. In particular, a novel technology might create nuclear material forms and compositions for which measurement techniques are not well understood. Moreover, as there is less experience in applying safeguards to next generation technology, SBD advises planning for a more conservative, flexible set of safeguards measures. As part of responding to the lesson learned that planning and preparation for safeguards can never start too early [18, 20], SBD suggests including dialogue with safeguards and measurement experts as part of the technology R&D process.

Features of relevance to safeguards in next generation technology include any feature which alters the applicability or usefulness of previously accepted safeguards measures [106]. For example:

— Lack of an input accountability tank from which a homogeneous sample can be drawn;
— Batch processing as compared with continuous (solution) flow;
— Smaller physical size;
— Ability to process short cooled fuel with higher radiation levels;
— Additional front end preprocessing or back end postprocessing;
— Processes that may yield different material forms or product purities from those currently in use;
— Inclusion of other transuranics or incomplete removal of fission products in the processed product;
— Safety differences (e.g. the high temperatures, radiation levels and inert atmosphere in electrochemical processing can be a safety concern, making access or in-line measurements challenging);
— Difficulty establishing process parameters and understanding variations in process stability.

[19] The safeguards essential equipment can be different from the safety essential equipment.

[20] In safety parlance, different definitions of ‘operable or inoperable’ can apply: ‘functioning’ implies good working order but the calibration and final documentation is not approved, ‘operable’ implies that it meets licensing requirements (is calibrated and certified) and ‘functional and approved for use’ implies that all required documentation is approved and in place. ‘Non-functioning’ implies the equipment is not useable, irrespective of the calibration and approval documentation.

Although it might be a goal of the technology R&D, it cannot be assumed that the stability of a next generation process will be easy to maintain or that process upsets will be unlikely. Instability or process upsets can require more operator interaction with the process in the process areas, making misuse easier to accomplish and more difficult to detect. Process manipulation to change the product composition might be easier to disguise and process losses might be not well understood. On the other hand, technology that allows less flexibility in adjusting product purity and throughput can make it simpler to apply safeguards. In addition, at least initially, process hold-up can be expected to be large and heterogeneous until operational experience is acquired; hold-up might not be amenable to the existing measurement capability. PM might be useful in mitigating these issues. The use of neutron monitoring supplemented by means to measure the curium/plutonium ratios and chemical forms has been proposed [107, 108] as well as other sensor types. However further R&D is necessary to test and evaluate these proposed measures.

If the next generation process yields different material forms or product purities that require measurement, measurement capabilities will need to be developed. The presence of measurement interferences due to other isotopes can be a cause of measurement bias, increased measurement uncertainty or possibly cause an inability to perform measurement with some techniques. Some of the new product forms may not be clearly defined in the IAEA material categories. SBD advises that R&D be pursued on these issues in parallel while the next generation technology is developed, not deferred until later. When NDA or DA methods are not well established, in addition to R&D on the methods, there can also arise a need to develop calibration standards and measurement control materials that ultimately might require secure storage space in the facility [77–79, 109–111]. Sampling errors can be hard to assess or mitigate if the homogeneity of samples drawn from the bulk material is in question. The combination of heterogeneous waste forms with measurement interferences can be expected to compound the measurement challenge. Furthermore, larger measurement uncertainty can lead to requiring additional safeguards measures to mitigate the potential for a larger inventory difference.

The following measures have been considered for addressing these issues:

— Improving knowledge of the feed material (the input spent fuel content);
— Enhancing use of PM;
— Using neutron monitoring innovatively, supplemented by other measurements;
— Using in-line or at-process-line instruments;
— Monitoring waste streams (process upsets can send the desired product into the waste stream);
— Modelling and simulation to improve measurement calibration or quality;
— Monitoring transuranic ratios;
— Monitoring the salt chemistry/composition (e.g. in electrochemical processing).

While consideration of alternate processing technologies can be motivated in part by attempting to increase proliferation resistance, it should be understood that all such technologies (wet or dry) still require robust safeguards and security measures [42, 112]. Any State or facility operator that can use such technologies can be assumed to possess the capability to operate them for various purposes. Moreover, intrinsic barriers such as high radiation from the product material might offer increased proliferation resistance but can also present challenges to traditional nuclear material accounting and safeguards verification activities [112, 113].

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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. More complete explanations as well as translations of these terms into eight languages can be found in the IAEA Safeguards Glossary[1].

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. 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. 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.

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safeguards Glossary, International Nuclear Verification Series No. 3, IAEA, Vienna (2002).

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.

NUCLEAR MATERIAL ACCOUNTANCY

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) remain 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 declarations.**)

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 inspection** 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.

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

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.

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 a material balance area carried out to verify the operator's book inventory of nuclear material present at a given time within that material balance area.

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 inspection. 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.

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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 of 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).

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

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

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 a containment in such a manner that access to the contents without opening of the seal or breaking of the containment is difficult.

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.

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 material balance areas 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.

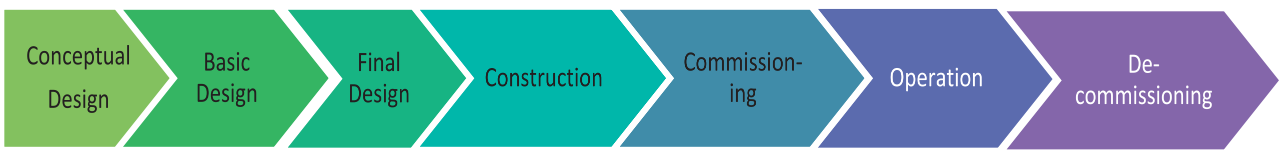

FIG. II–1. Facility life cycle stages.

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.
— The 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 into the facility and may be used to calibrate safeguards equipment.
— The safeguards equipment and instruments are tested.
— The operator confirms that 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, and cooperates with the SRA and the operator to troubleshoot any issues.

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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, 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.

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.

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 screening questions in Table III–1 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, Rep. PNNL-20829, Pacific Northwest National Laboratory, Richland, WA (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 REPROCESSING

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.

A reprocessing plant design information questionnaire includes at least the following:

- Facility name, location, address, owner, operator, status and purpose;
- Facility description, including general flow diagrams;
- Process description, including modifications of chemical and physical form;
- Design capacity (per year);
- Anticipated annual throughput;
- Important items of equipment using, producing or processing nuclear material;
- Descriptions of all nuclear material, scrap and waste materials;
- Waste treatment system(s);
- Other nuclear materials (other than uranium, thorium or plutonium as defined by the IAEA);
- Schematic flow sheets for nuclear material activities;
- Details for each nuclear material handling area (including nuclear material forms and amounts, handling or processing activities, and storage);
- Inventory details (e.g. in-process; feed, product and tails storage; scrap; waste and recycle);
- Nuclear material handling details (e.g. containers, packaging, storage areas);
- Plant maintenance, decontamination, cleanout details;
- Protection and safety measures (including specifics for inspectors);
- Detailed description of nuclear material accountancy and control (e.g. shipping, receiving, inventory taking, measurement systems, measurement errors, overall limit of measurement error, procedures, measured discards, waste, unmeasured losses, containment and surveillance measures, key measurement points, use of batch or stream averages, material unaccounted for, expected hold-up, in-process inventory, intermediate product, etc.);
- Other information that the operator considers relevant to safeguards.

ABBREVIATIONS

3DLR	three dimensional laser rangefinder
ANM	alternative nuclear material
C/S	containment and surveillance
CoK	continuity of knowledge
CSA	comprehensive safeguards agreement
DA	destructive assay
DIE	design information examination
DIQ	design information questionnaire
DIV	design information verification
DNLEU	depleted, natural or low enriched uranium
HEU	high enriched uranium
IIV	interim inventory verification
KMP	key measurement point
LEU	low enriched uranium
LOF	location outside a facility
MBA	material balance area
MOX	mixed oxide
MUF	material unaccounted for
NDA	non-destructive assay
NRTA	near real time accounting
OSL	on-site laboratory
PIV	physical inventory verification
PM	process monitoring
PUREX	plutonium uranium redox extraction
QA	quality assurance
QC	quality control
R&D	research and development
SBD	safeguards by design
SFA	spent fuel assembly
SMMS	solution measurement and monitoring system
SNRI	short notice random inspection
SOH	state of health
SRA	State or regional authority responsible for safeguards implementation[1]

[1] In some States, the safeguards authority and the regulatory authority are separate entities.

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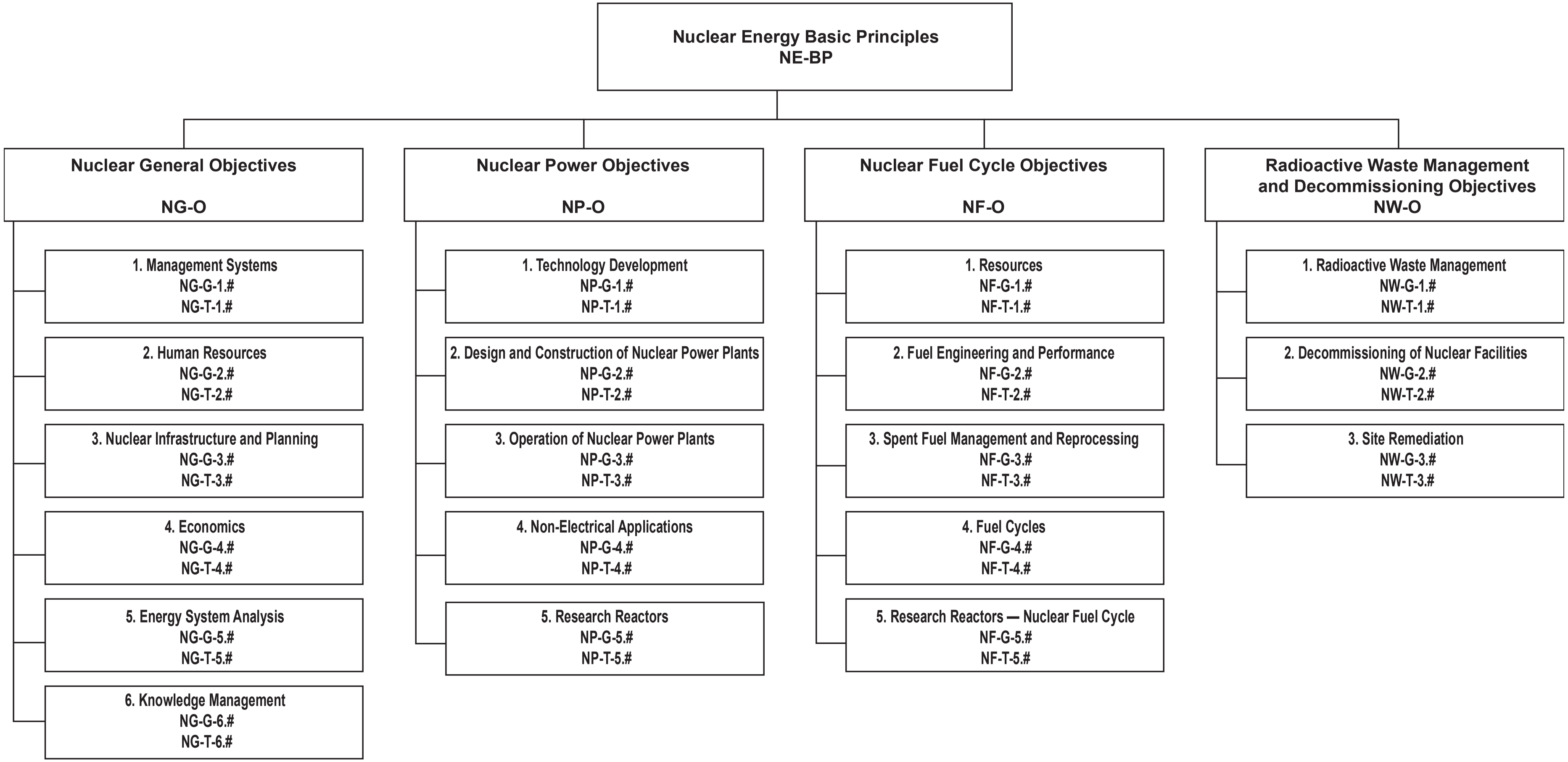

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