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No. NF-T-4.7

International Safeguards in the Design of Fuel Fabrication Plants

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IAEA NUCLEAR ENERGY SERIES PUBLICATIONS

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INTERNATIONAL SAFEGUARDS IN THE DESIGN OF FUEL FABRICATION PLANTS

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IAEA NUCLEAR ENERGY SERIES No. NF-T-4.7

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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.

EDITORIAL NOTE

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CONTENTS

1. INTRODUCTION 1

1.1. Background 1
1.2. Objective 2
1.3. Scope 2
1.4. Structure. 3

2. OVERVIEW OF IAEA SAFEGUARDS 3

2.1. IAEA Safeguards implementation 3
2.2. Overview of safeguards measures 4
2.3. Verification 4
  2.3.1. Design information verification. 4
  2.3.2. Nuclear material accounting and verification 5
  2.3.3. Surveillance, containment and monitoring 7
2.4. Physical infrastructure requirements for IAEA safeguards activities 9
2.5. Facility decommissioning 10
2.6. Future considerations. 10

3. SAFEGUARDS CONSIDERATIONS IN FUEL FABRICATION 10

3.1. Design information verification. 12
3.2. Nuclear material accounting and verification 12
  3.2.1. Nuclear material flows. 13
  3.2.2. Nuclear material accounting considerations 14
  3.2.3. Material balance area structure 15
  3.2.4. Physical inventory verification 16
  3.2.5. Non-destructive assay measurements 16
  3.2.6. Receipts and shipping 18
  3.2.7. Bulk processing operations 19
  3.2.8. Product (fuel assembly) storage. 20
  3.2.9. Summary of design considerations to enhance nuclear material accounting and verification 21
3.3. Containment, surveillance and process monitoring. 22
3.4. Decommissioning 22

4. CONSIDERATIONS RELATED TO FUEL VARIATIONS 23

4.1. Natural uranium fuel 23
4.2. Mixed oxide (MOX) fuel. 23
4.3. HEU fuel 25
4.4. Next generation technology. 25

REFERENCES 27

BIBLIOGRAPHY 29

ANNEX I: TERMINOLOGY 31
ANNEX II: SAFEGUARDS CONSIDERATIONS IN FACILITY LIFE CYCLE STAGES 35
ANNEX III: IDENTIFYING SAFEGUARDABILITY ISSUES 38

ANNEX IV: DESIGN INFORMATION QUESTIONNAIRE INFORMATION FOR FUEL FABRICATION PLANTS 40

DEFINITIONS 43

ABBREVIATIONS 47

CONTRIBUTORS TO DRAFTING AND REVIEW 49

STRUCTURE OF THE IAEA NUCLEAR ENERGY SERIES 52

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;

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[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

This guidance is applicable for the design and construction of nuclear fuel fabrication facilities, such as the Springfields facility in the United Kingdom shown in Fig. 1. The guidance provided herein represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

FIG. 1. Springfields fuel fabrication plant.

1.4. STRUCTURE

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

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

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

2. OVERVIEW OF IAEA SAFEGUARDS

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

2.1. IAEA SAFEGUARDS IMPLEMENTATION

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

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

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

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

2.2. OVERVIEW OF SAFEGUARDS MEASURES

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

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

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

2.3. VERIFICATION

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

2.3.1. Design information verification

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

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

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

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

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

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

2.3.2. Nuclear material accounting and verification

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

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

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

FIG. 2. IAEA design verification.

FIG. 3. Sample preparation in an IAEA laboratory.

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

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

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

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

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

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

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

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

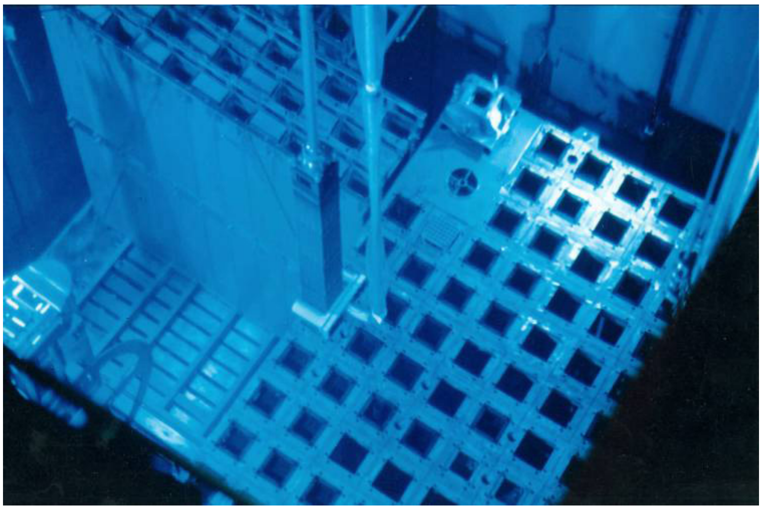

FIG. 6. Measurement of irradiated fuel in a cooling pond.

2.3.3. Surveillance, containment and monitoring

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

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

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

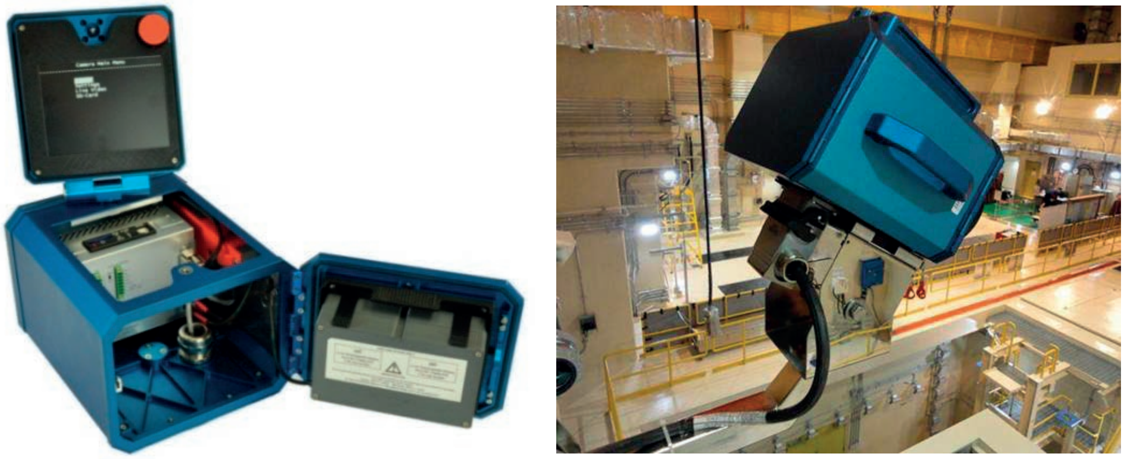

FIG. 7. A next generation IAEA surveillance system.

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

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

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

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

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

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

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

2.4.   PHYSICAL INFRASTRUCTURE REQUIREMENTS FOR IAEA SAFEGUARDS ACTIVITIES

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

FIG. 10. Installation of a surveillance system.

2.5. FACILITY DECOMMISSIONING

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

2.6. FUTURE CONSIDERATIONS

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

3. SAFEGUARDS CONSIDERATIONS IN FUEL FABRICATION

This section uses the fabrication of low enriched uranium (LEU) fuel as a baseline example for providing guidance, much of which is applicable to other fuel types (specific guidance for these is provided in Section 4). This guidance does not prescribe a specific safeguards approach for fuel fabrication facilities but rather highlights conceptual elements.

IAEA safeguards are designed to meet certain objectives that pertain to the diversion of nuclear material, the misuse of facilities or to undeclared activities. Examples of possible misuse and diversion scenarios relevant to depleted, natural and low enriched uranium (DNLEU) fuel fabrication plants are described in Table 1 with potential concealment methods and the safeguards measure(s) to address each one.

TABLE 1. DIVERSION STRATEGIES, CONCEALMENT METHODS AND SAFEGUARDS MEASURES

Diversion strategy	Concealment method	Safeguards measure
Removal of uranium in bulk form	Failure to record receipts	Transit matching between shipper and receiver
	Understating amount received	Weighing and sampling a random selection of received containers for analysis
	Reporting inflated MUF	Statistical analysis
	Inflated measurement uncertainty	Verification of reported uncertainties
	Substitution of enriched U with natural or depleted U	Shipper/receiver analysis, applying containment and surveillance (C/S), use of NDA measurements and DA
	Borrowing material from other facilities	Simultaneous or random inspections, verify all receipts
	Using hollow or low density pellets	Weighing, NDA measurements and sampling
	Reporting a false loss	Verification of records and estimate process losses
Removal of fuel rods or assemblies	Altering the assembly serial number, substitution with dummy	Inspection of seals, verifying receipts at facility, NDA measurements, item counting
	False declaration of shipment	Verification of records and transit matching with receiver
	Substitution of enriched U rods or assemblies with natural or depleted uranium	Application of C/S, use of NDA measurements
	Borrowing assemblies from other facilities	Simultaneous or random inspections and verification of all receipts
Removal of nuclear material from rods or assemblies	Stating nominal values	Weighing and NDA measurements
Diversion of scrap	Inflation of amount transferred or shipped	IAEA verification of records and receipts at recovery facility
	Reporting inflated processing loss	Establishing reasonable process losses
Undeclared feed	Failure to record receipts	Transit matching between shipper and receiver and verification of operating records

Acquisition path analysis highlights the diversion, misuse and clandestine activity scenarios that safeguards seek to detect and deter. For new designs, any stakeholder can perform such an analysis to identify possible scenarios that could be addressed, potentially in collaboration with safeguards authorities, the IAEA or both. For existing designs currently under safeguards, misuse and diversion analysis will have been performed and documented. Annex III and Ref. [18] discuss methods for performing such analyses.

Safeguardability is a term that refers to the relative ease of applying safeguards to a nuclear facility [18]. Practical examples of design features to increase the safeguardability of a fuel fabrication plant are discussed in the following sections and include, inter alia:

- Easy to read, unique identifiers for nuclear material items;

- A minimum number of penetrations in the containment structures that require monitoring or seals;
- Provision for seals and other tamper indicating devices;
- Use of near real time accounting, mailbox declarations and short notice random inspections (SNRIs);
- Use of process and area radiation monitoring;
- Layout of the plant to reduce the number of surveillance systems;
- Maximizing segregation between different parts of the facility by using access control barriers;
- The capability to easily distinguish fuel and non-fuel items;
- Minimizing waste and nuclear material hold-up in the process;
- Access control to locations used for the receipt, storage and measurement of nuclear items.

3.1. DESIGN INFORMATION VERIFICATION

The IAEA performs DIV before concrete for a new facility is poured, and continues performing DIV throughout all the life cycle stages of the facility (see Annex II for more information about safeguards activities at each life cycle stage). At any phase of the facility’s design and operational life cycle, the material flow and measurement systems may be examined during DIV to gain assurance that they are as declared, confirm that they meet requirements and verify that there are no undeclared design changes. During DIV at a fuel fabrication plant, the IAEA may perform a variety of activities, such as the:

- Verification of process or containment design through comparison of design drawings with actual construction, and assessment of containment structure, process capacity or declared function and capabilities;
- Preparation of an essential equipment list for safeguards which may include specifications, descriptions and guidance on how to verify whether each piece of equipment is useable[5] or not;
- Verification of the usability of essential equipment and assessing its throughput or capacity;
- Examination of a subset of the essential equipment, including clearly identifying excess or redundant capacity in order to facilitate IAEA understanding of the plant’s operating capacity;
- Comparison of the as-is building design with the description of operations;
- Checking the operations inside selected buildings for consistency with declared operations;
- Assessment of whether the site and general building design could support undeclared nuclear operations;
- Assessment of possible indicators of undeclared nuclear activities or material, including collection and analysis of environmental samples;
- Obtaining of additional safeguards relevant, design related information (e.g. up-to-date, as-built drawings for IAEA use).

3.2. NUCLEAR MATERIAL ACCOUNTING AND VERIFICATION

Verification of nuclear material accountancy is a fundamental part of any safeguards approach. In a fuel fabrication plant, material is normally received in item form and subsequently processed in bulk (loose) forms, such as powder, liquid or gas. One point of safeguards interest is whether the plant is physically segregated into areas that handle nuclear material in bulk form and those where material is handled as discrete items. The design team can consider barriers to prevent mixing of material forms in these areas. Verification in the bulk processing areas usually involves IAEA measurements (both non-destructive and DA), while counting of the items (sometimes with verification of item IDs) might be sufficient for nuclear material in item form. In some cases, statistical sampling will be used instead of 100% verification. Where continuity of knowledge can be maintained using containment and surveillance (C/S) methods, previously verified items may not need to be re-verified.

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[5] From the safeguards misuse or diversion perspective, ‘useable equipment’ implies equipment that is operable and does not necessarily require calibration, certification or licensing, or procedures to be followed.

3.2.1. Nuclear material flows

Figure 11 shows the flow of nuclear material through a typical fuel fabrication process. In normal operations, the flow of nuclear material to and from the fabrication plant creates large additions to, and subtractions from, the nuclear material inventory in the MBA. In many cases, these flows are larger than the in-process inventory over a material balance period. In addition, nuclear material flow rates in a fuel fabrication plant often fluctuate. The high throughput, accompanied by the changing forms of the nuclear material during processing, complicates the IAEA's verification task. Another important consideration is that scrap, waste and hold-up is generated in relatively large quantities in solid, liquid and airborne forms, which are difficult to measure and are often recycled in the plant. These measurements typically increase the uncertainty associated with calculating the MUF. For example, the collection and measurement of the nuclear material contained in the scrap from the pellet grinding process is important for IAEA verification.

Figure 12 shows a simplified process flow diagram for producing uranium fuel. Uranium can be received at the plant in various forms, which are converted to oxide, purified and stored until needed for pellet fabrication. After fuel pellets have been fabricated and quality control checks have been passed, the pellets are assembled into fuel rods, which are then assembled into fuel assemblies. Each of these processing areas generates scrap, waste and hold-up, some of which is recycled to recover the uranium and reintroduce it into the process.

While the first two process areas involve the storage and handling of material in bulk form — with changes in material form and quantity and the generation of scrap, waste and hold-up — the third (assemblies) involves

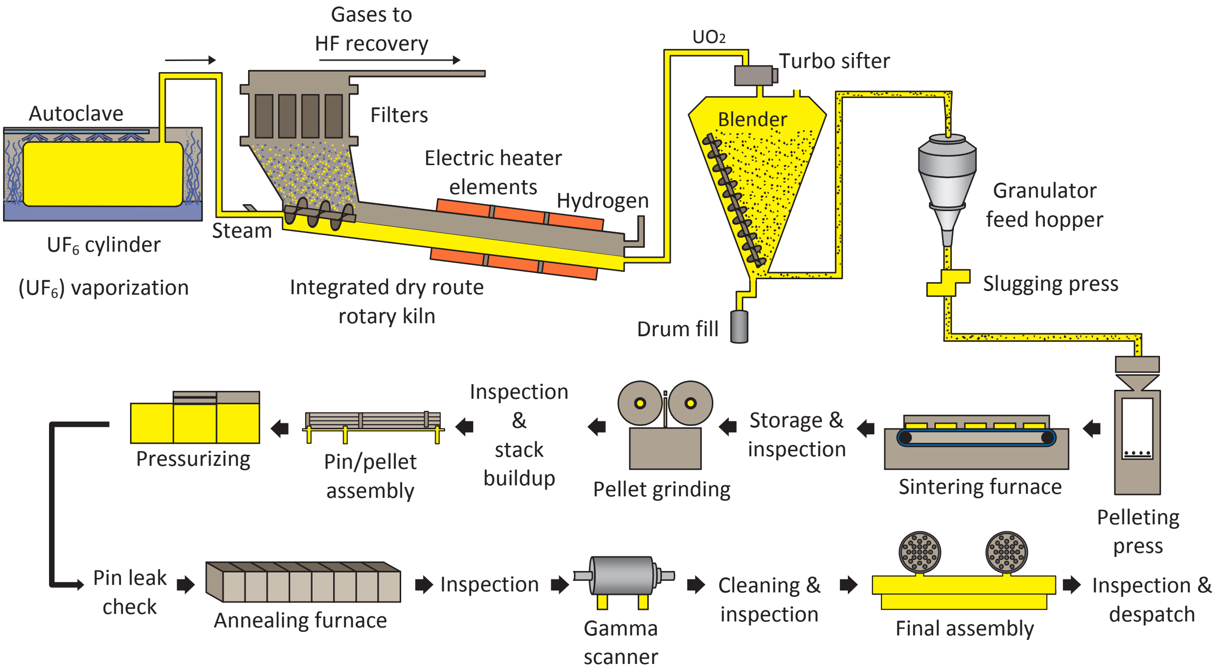

FIG. 11. The fuel fabrication process.

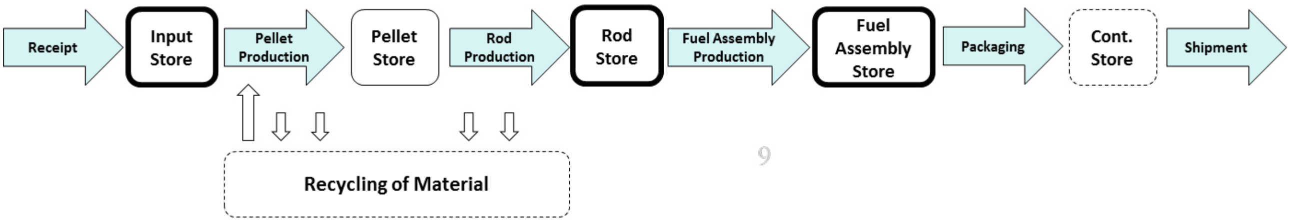

FIG. 12. Simplified fuel fabrication process flow.

no changes in the form of the nuclear material items, but repackages items into groups. In some cases the nuclear material is customer (not facility) owned and batches for different customers are controlled separately. Segregation of different enrichment streams is also important both for the operator and for safeguards verification. Cleanouts between campaigns using different enrichments generate waste with mixed enrichment. For economic reasons, an operator minimizes such waste material and segregates it from unmixed material. This also assists nuclear material accountancy because nuclear material in the mixed enrichment waste needs to be measured, which can be difficult and result in large uncertainties. Designers can take IAEA verification needs into consideration when laying out the recycling processes and prepare simple material flow paths that facilitate the selection of optimum measurement points.

Each main process area applies methods of quality control that generate samples for analytical laboratory tests. Both the operator and the IAEA benefit from a reliable sample tracking system including measurement results and disposal of residues. A design that segregates each process area with containment facilitates the monitoring of material movement between areas.

3.2.2. Nuclear material accounting considerations

The amount of bulk nuclear material present at different stages of the process is determined by weighing and volume determination, combined with measurements of concentration and isotopic composition, or sampling[6] for DA using IAEA off-site laboratories. On-site IAEA measurements will likely require dedicated on-site space in a low radiation location. Provision of additional shielding to reduce the background radiation may be required.

Bulk processing of material involves accumulation of material residues in the process equipment, which is known as nuclear material hold-up and can be considered part of the in-process inventory. Hold-up is notoriously difficult to control or quantify. In the case of a fabrication plant that manufactures reactor fuel of different enrichments and therefore operates in campaigns, process hold-up is often cleaned out between campaigns. Lack of a rigorous cleanout can be a source of error in the inventory determination and can lead to the undesired mixing of material. Design features to minimize hold-up (e.g. smooth internal surfaces, no sharp corners or bends and minimal interior surface area) or to collect it in measureable form will benefit both operators and the safeguards authorities [19].

All measurement results have inherent uncertainties. As a result, the material unaccounted for (MUF), which is computed from the material balance components (i.e. beginning inventory, increases, decreases and ending inventory based on measured values), is usually not zero and its magnitude and variability depend on the uncertainties of the measurement systems [13–15]. The amount of nuclear material that goes into scrap, waste[7] or hold-up[8] will affect the magnitude and uncertainty of the MUF. Designing a process to minimize scrap, waste and hold-up will benefit both the operator and the safeguards authorities.

Larger amounts of non-product streams cost the operator money and can create challenges for safeguards with the associated increased MUF. In facility bulk handling areas, a material balance evaluation based on error propagation and statistical analysis can be useful to help decide whether the MUF declared by the operator can be explained by legitimate measurement error. The same is true when considering the shipper/receiver difference (i.e. the difference between the shipping facility's and receiving facility's measured values for each item), the validity of which is assessed using the shipper's and receiver's measurement system uncertainties. The design team can consider safeguards nuclear material accounting verification requirements in the design optimization, such as:

- A compact layout of the process area glove boxes and material transport to reduce the amount of nuclear material in the process, the size and complexity of the ventilation ductwork, the number of pieces of equipment and the chance of nuclear material hold-up in the process;
- Planning nuclear material transport routes so that C/S or flow monitoring systems can clearly distinguish between routine and non-routine nuclear material transfers, as well as between nuclear and non-nuclear items.

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[6] The IAEA must verify that the samples it analyses are representative of the bulk material they are drawn from. The design team can consider the value of engineering studies to ensure this, e.g. to evaluate how long mixing should be performed for or where is best to draw the sample from.

[7] Scrap and waste are discussed in Annex I: Terminology.

[8] Hold-up is discussed in Annex I: Terminology and in ASTM C1217 [19].

3.2.3. Material balance area structure

For some fuel fabrication facilities, three MBAs are used — a receiver MBA (items), a process MBA (which will involve MUF calculations) and a product storage MBA (items); see Fig. 13. This structure segregates shipper/receiver differences from processing losses and isolates product measurement results from processing measurement uncertainties. A single MBA for the whole plant may be used together with sufficient KMPs to account for flow and inventory, so that shipper/receiver differences and facility MUF can be identified separately. KMPs are generally located in nuclear material storage areas and at nuclear material transfer paths.

Figure 14 shows one possible concept for the safeguards information flow in a fuel fabrication plant. The IAEA may place equipment in the plant or make use of operator equipment to support safeguards activities. References [9, 20] give additional information about IAEA inspection activities.

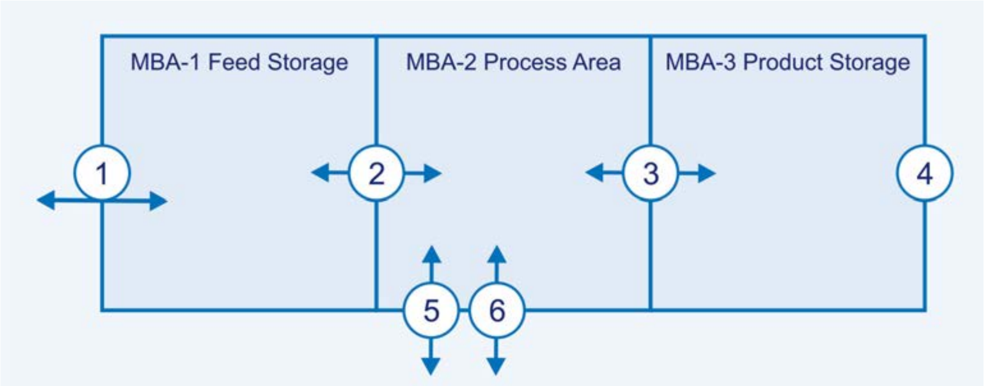

FIG. 13. Possible MBA and KMP structure at fuel fabrication facility. The KMPs are indicated by circles. Key: KMP 1: Receipt (and shipment, if necessary) of nuclear material feed; KMP 2: Transfer of nuclear material between MBA-1 and MBA-2; KMP 3: Transfer of nuclear material between MBA-2 and MBA-3; KMP 4: Shipment of nuclear material product (generally fuel assemblies); KMP 5: Receipt and shipment of high grade nuclear material (if necessary); KMP 6: Transfer and shipment of solid waste and analytical samples.

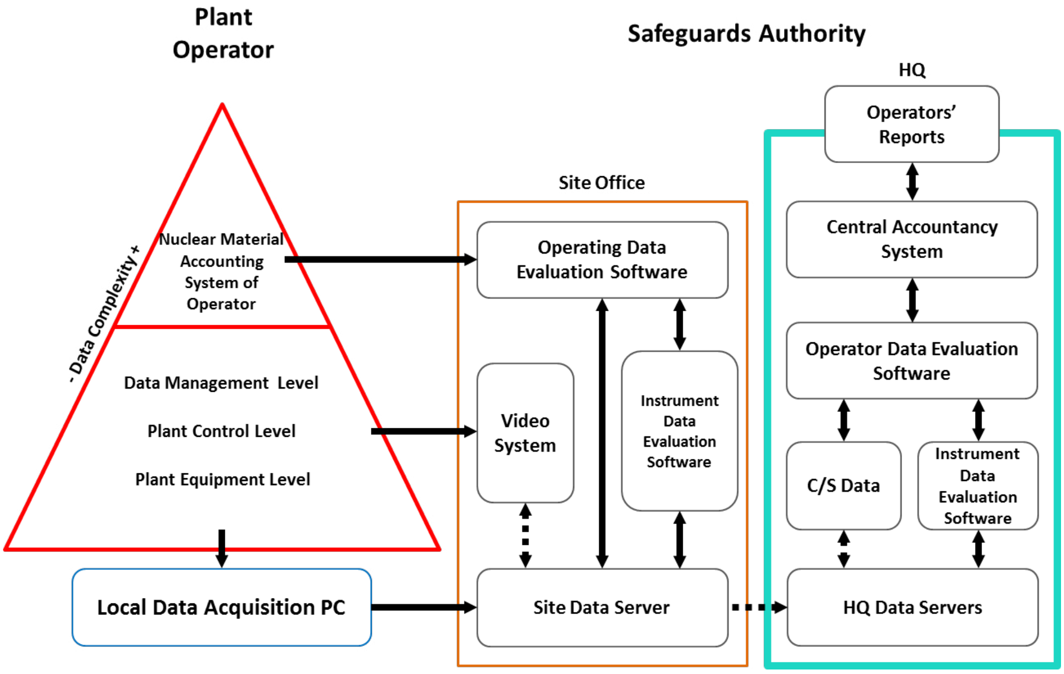

FIG. 14. Possible safeguards information flow for a modern fuel fabrication plant.

3.2.4. Physical inventory verification

The PIV in a fuel fabrication plant is usually performed on a yearly basis, whereas material flow (increases and decreases in the material balance equation) is often verified during periodic interim inspections (occurring between the more intensive annual PIVs) or SNRIs. During interim inventory verification or PIV at a fuel fabrication facility, IAEA activities may include:

- Verification of material in bulk form by sampling and DA at IAEA laboratories;
- Measurement of pellets, fuel rods and assemblies using NDA equipment (see Fig. 15);
- Evaluation of the quality and functioning of the operator's measurement system;
- Review of facility records and supporting documentation;
- Verification of the quantity of in-process nuclear material, including verification of stock and process vessels and their contents;
- Verification of material in item form by container identification and attribute (gross defect) measurement;
- Verification of domestic and international transfers of nuclear material such as feed material (these items may need to be temporarily stored while awaiting verification prior to removing an IAEA seal);
- Drawing samples for DA measurements by the IAEA;
- Evaluation of C/S measures;
- Verification of design information.

FIG. 15. An IAEA inspector performing measurements on fuel assemblies.

3.2.5. Non-destructive assay measurements

IAEA inspectors typically use NDA[9] equipment for the verification of the facility operator's measurement equipment and results. These activities can include the verification of the facility's nuclear material values using

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[9] NDA measurements are discussed in Annex I: Terminology.

the inspectors' NDA measurements, taking nuclear material samples for laboratory analysis and comparison of observed nuclear material characteristics with the facility's declarations. Verification of the quality of the operator's measurement system can be based on statistical evaluation of the measurement data, paired comparison between the results of the operator's and the IAEA's analyses of samples, or the analysis of IAEA certified standards using facility equipment. The facility designer or operator may be requested to provide the facility measurement system specifications and qualification test results [13–15].

Depending on the nature of the nuclear material, measurements can include ^{235}U enrichment using gamma ray detection, bulk uranium assay using neutron measurements, active length measurements using a handheld assay probe and weighing using scales or balances [12]. For uranium fuel assemblies, the uranium neutron collar, shown in Fig. 16, can be used in combination with active length measurements (obtained, for example, using the HM-5 handheld assay probe [12] as shown in Fig. 17) to verify the total amount of ^{235}U in a fuel assembly. The collar, along with the associated radiation check sources and computer, might need to be kept at the facility in space controlled by the IAEA. C/S can be used to secure IAEA equipment at the facility or to segregate nuclear material during an inspection before, during and after verification activities. Furthermore, the IAEA may also require on-site

FIG. 16. Uranium neutron collar being used to measure ^{235}U content in a fuel assembly [15].

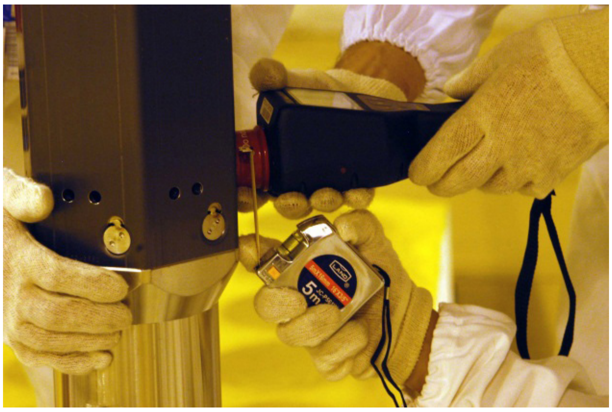

FIG. 17. HM-5 handheld assay probe measurement of active length of fuel assembly [15].

storage for NDA calibration standards, such as well characterized fuel rods or pellets, access to which is controlled by the inspectorate in order to preserve the continuity of knowledge of their characteristics.

Neutron and gamma NDA measurement systems will have specific requirements for sample and detector geometry, collimation and shielding. They will require an instrument-quality power supply, and typically operate best within specific temperature and humidity ranges and in stable, low radiation locations. Some equipment will require cooling prior to use, and battery charging. Liquid nitrogen may be needed for this purpose. Environmental control could be considered for safeguards equipment stored on-site in an accessory cabinet, for example, by allowing such a cabinet to be installed outside the processing area and protected from extreme temperature, radiation, humidity and dust or contamination, in a location easily accessible by IAEA personnel.

From lessons learned, general guidance to consider in the design of facility infrastructure to support IAEA measurement equipment includes:

— Providing penetrations through building structures for the cabling for safeguards equipment in order to avoid ad hoc drilling through walls and supports.
— Isolating the service infrastructure (electrical supply, backup electrical supply, water, compressed air, steam, helium, argon and waste removal) from the nuclear material areas to reduce the number of facility staff who require access to these areas.
— Protecting safeguards equipment from unintentional damage (e.g. preventing its misuse as a stepladder or table and positioning it to avoid contact with passing traffic).
— Designing storage for nuclear material items to facilitate verification without handling. Ease of verification can include unattended monitoring for movement of radioactive items, C/S of IAEA equipment and provisions for sealing part of the storage areas to reduce the need to re-verify fuel assemblies and other nuclear material items.

3.2.6. Receipts and shipping

Nuclear material received by a fuel fabrication plant can include UF_6 or feed powder, pellets and even individual pins. The nuclear material might arrive without seals applied and be put into the feed storage. For DNLEU fuel fabrication plants, the use of SNRIs has become typical for verifying receipts. The operator regularly informs the safeguards authorities about the receipts and shipments, normally on the same day they occur. The operator can be invited to share the planned schedule for these transfers with the IAEA in advance. In combination with a mutually agreed minimum retention time before the material can be used as feed, all material flows have a chance to be selected and verified in the IAEA sampling plan. In this case, the facility layout should include sufficient segregated storage capacity. On arrival at the facility for a SNRI, the inspectors will notify the operator which nuclear material has been selected for verification activities.

The safeguards activities performed for verification of receipts and shipping can include:

— Item counting and identification;
— Weighing;
— NDA measurements[10] using gamma and neutron equipment;
— Investigation of shipper/receiver differences;
— Checks of accounting records and source documents;
— Sampling for DA.

When verification activities include inspector measurements, an access controlled space that is shielded from radiation fluctuations caused by movements of nuclear material and electrically isolated from other noisy facility operations (e.g. arc welding or induction furnaces) is desirable to reduce the effects on the measurement results. The alternative — restricting movements of nuclear material or other plant operations during an IAEA measurement campaign — can have a negative impact on facility operations.

Figure 18 shows preparations for moving a container of uranium oxide in a storage room and Fig. 19 shows the loading of a large UF_6 container onto a vehicle.

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[10] Verification of item accounting often uses qualitative, attribute measurements.

FIG. 18. *Handling activities in a uranium storage facility.*

FIG. 19. *UF_6 cylinder transfer.*

Design features for the shipping/receiving area of a facility that can assist in the implementation of safeguards are:

- A minimum number of access points to the shipping/receiving area, each with suitable arrangements to allow for radiation monitors, sealing, surveillance equipment, or a combination of these;
- The capability to support remote and unattended monitoring [20–23];
- The use of integrated information systems to allow for detailed follow-up to resolve questions about accounting records, measurements or nuclear material items;
- Sufficient segregated storage for material retained pending safeguards activities.

3.2.7. Bulk processing operations

The transition of nuclear material from ‘item’ to ‘bulk processing’ affects the safeguards measures. In general, DNLEU facilities allow for easy access to the material in question. This facilitates both the application of safeguards and the potential for diversion. Safeguards measures can include measurement activities at multiple points within the facility. Measurements might be applied to some fraction of the nuclear material each time the bulk material is repackaged or changes form. Unattended measurement instrumentation at these points can help the safeguards authorities carry out the verification activities with reduced inspector presence on-site and reduced impact on facility operations.

Another aspect that makes bulk processing different from item processing is the accumulation of nuclear material hold-up in process equipment and in enclosed volumes, sometimes referred to as ‘in-process material’. Facility designs that minimize hold-up [15] are beneficial to both operations and safeguards. Customized measurement equipment is sometimes used to measure the in-process nuclear material in order to reduce both measurement uncertainties in the results and the frequency of cleanouts. The design team can inquire among the other stakeholders whether such equipment is necessary and whether it may be shared.

Bulk processing operations and features that are of interest to safeguards include:

- The heels (remaining nuclear material) in empty UF_6 cylinders;
- Changes to chemical and physical form, e.g. purification, homogenization, blending, pellet pressing and sintering, pellet grinding and pin loading;
- Changes in packaging;
- Splitting or combining of items;
- Containerizing, storing and labelling of intermediate products;
- Nuclear material control and accounting between storage and process areas;
- Quality assurance samples (including the sampling procedures and the handling or processing of samples).

The safeguards activities to be performed for verification of bulk processing are typically:

- Item counting and identification (similar to that applied in item processing);
- Sampling randomly selected items for weighing;
- Sampling randomly selected items for non-destructive measurements;
- Drawing small samples from randomly selected items and subsequently transferring the samples to a laboratory for DA;
- Reviewing results of any C/S measures;
- Reviewing remote and unattended monitoring data.

3.2.8. Product (fuel assembly) storage

The radiological hazard related to DNLEU fresh fuel assemblies is low and no biological shielding is needed (unless uranium recycled from used reactor fuel is used) making the assemblies easily accessible to inspectors and to the operator. The product fuel assembly storage might be under C/S measures in order to ensure continuity of knowledge and reduce re-verification during the PIV. In many cases, it can be helpful to seal part of the inventory to reduce the need for subsequent re-verification.

Information needed by the IAEA (lists of items on the inventory, for example) can be made available in electronic format and can contain details about the items in storage, including their IDs, location and content (e.g. nuclear material characteristics such as elemental mass, isotopic distribution and chemical form). Providing this information prior to the IAEA’s arrival on-site visit can reduce the impact of inspections on facility operations. Figure 20 illustrates IAEA inventory verification measurements in fuel assembly storage.

From a safeguards point of view, it would be convenient to design the storage system and to schedule operations in the product fuel assembly storage area in a manner that controls and minimizes unnecessary access and activities. Safeguards friendly designs allow for fuel assembly storage that is access controlled, with monitored entry and exit of items and personnel. This helps to maintain continuity of knowledge of the contents and thus to minimize re-measurement requirements. Design features for fuel assembly storage areas that assist in the implementation of safeguards are:

- Placement of utilities and infrastructure in separate rooms with separate access control.
- Allowing a minimum number of access points to the fuel assembly storage area, with suitable arrangements to allow for measurements, sealing, surveillance or a combination of these.

FIG. 20. Verification activities in a fuel assembly storage area.

- Layout of the fuel assembly storage that allows inspectors to verify and progressively seal groups of fuel assemblies as they are placed into storage without affecting the continuity of knowledge of the assemblies already in storage.
- Adequate space and lighting between assemblies (as shown in Fig. 20) that allow inspectors to read the identifiers on fuel assemblies and to conduct NDA measurements, specifically:
  - Provision for the use of IAEA portable NDA equipment;
  - Arrangement of fuel within the storage area that minimizes the necessity for moving fuel to verify specific assemblies;
  - For special cases (e.g. anomalies), provision of the capability for the quarantine of such assemblies under IAEA seal;
  - Provision of ladders or other personnel lifting devices;
  - Placement of identifiers at heights visible from the ground.

3.2.9. Summary of design considerations to enhance nuclear material accounting and verification

From lessons learned, practical examples of design features that may be considered in order to enhance nuclear material accounting verification for fuel fabrications plants include:

- Dynamic nuclear material accounting, mailbox declarations, SNRIs and near real time monitoring systems for the production process.
- Those providing a capability to measure or verify nuclear material content in every location where it changes form or every time it moves between process areas facilitate its control and improve process knowledge. However, for practical reasons, the number of such locations should be minimized. In some cases, a partial determination (e.g. weight) is sufficient; in others, a full analysis might be required (e.g. final product certification). Designers can solicit input from the operator, the State authority and the inspectorate for information about measurements and the potential for sharing equipment or space.
- Those reducing the need to remove material from the process except for product and waste.
- Those integrating any quality control equipment for nuclear material or its containers into the main fabrication line to reduce the need (or opportunity) to remove nuclear material as samples.
- Dedicated equipment for estimating the quantity of nuclear material in-process. Better estimation of in-process quantities can also help in planning for recovery and cleanout of that material.
- Provisions for periodic cleanouts in preparation for inventory taking in order to reduce the amount of nuclear material left in-process as hold-up.

- Measures to improve in-process powder recovery and to minimize hold-up or to collect it in measureable form [15].
- Pre-filters at the glovebox end of the ventilation ductwork that can be removed and measured non-destructively, so that nuclear material hold-up in the post-filter ductwork can be reduced.
- Unique identifiers for nuclear material items and containers with machine readability. For contingency or as a backup, human readability is useful. A potential challenge is to identify inexpensive, difficult-to-duplicate identifiers that function well in a higher radiation or chemically harsh environment or under rough handling in the plant environment.

3.3. CONTAINMENT, SURVEILLANCE AND PROCESS MONITORING

Historically, the application of C/S measures in fuel fabrication using indirect use material has been limited. Advances in monitoring and process control technology potentially offer an opportunity for a more efficient use of C/S measures. Also, considering SBD, designers can weigh the costs and benefits of modularizing the process, using a smaller number of standardized containers, limiting access to parts of storage areas and using simpler nuclear material transport paths. The operator's (automated) process control and process monitoring information offer the potential to provide improved assurance to both the IAEA and the operator that the facility is operating as declared. In addition to reducing the possibility of mixing process streams inappropriately, automated process control can reduce the need for human access to the process areas.

Facilities that make extensive use of automated processing of nuclear material or that process material with higher safeguards sensitivity can consider using continuous unattended monitoring. The resulting data might be made available to the inspectorate using remote transmission off-site to conserve resources for both the operator and the IAEA. Automatic transmission of selected operators' process data (via secure communication channels) might lead to a further reduction of personnel necessary at the facility and enhance safeguards implementation. Moreover, remote transmission can reduce process interruptions caused by safeguards activities.

C/S measures can be applied to conserve safeguards resources at either end of a shipment or receipt. In these cases, additional activities involving applying or cutting seals by the operator or the IAEA and the review of C/S data by the IAEA might be needed. From lessons learned, general guidance to consider in the application of containment, surveillance and monitoring is to:

- Consider use of unattended or remote monitoring, or both, of the storage, measurement and movement of nuclear material;
- Minimize the number of penetrations in the containment and other structures through which movement of nuclear material is possible;
- Consider where surveillance in the facility might benefit both the plant operator and the IAEA;
- Consider the sharing of equipment, contingent on the various stakeholders' authentication and independence needs;[11]
- Ensure that optical surveillance systems cannot be blocked by pieces of equipment (e.g. cranes moving large objects or scaffolding put in place for facility modification);
- Facilitate the use of IAEA seals by including robust barriers and secure attachment fixtures at KMPs and in the designs for safeguards relevant features (e.g. feed, scrap, waste and product storage areas and also at junction boxes where safeguards cables are terminated or connected);
- Understand that proper sealing requires certain tamper proof design features, e.g. externally inaccessible hinges on doors and integrated fixtures for the seal wire or cable loop.

3.4. DECOMMISSIONING

As mentioned earlier, safeguards continue well after a facility has been shut down and nuclear material has been removed. The IAEA makes a determination as to when the facility has been decommissioned for safeguards

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[11] The IAEA verifies that the data it analyses are authentic (not tampered with) and independent of possible operator manipulation.

purposes, requiring, inter alia, that all safeguards essential equipment has been removed or rendered unusable. Examples of essential equipment at a fuel fabrication facility are:

- UF_6 feed station;
- Powder processing equipment;
- Pellet pressing equipment;
- Sintering furnaces;
- Grinding, polishing and inspection equipment;
- Rod loading and welding equipment;
- Fuel assembly manufacturing tools and equipment.

4. CONSIDERATIONS RELATED TO FUEL VARIATIONS

This section discusses variations from DNLEU fuel fabrication. Differences in fuel fabrication that are relevant to safeguards include the enrichment and chemical form of the nuclear material and the size and shape of its product. In addition to the considerations discussed in Section 3, designers and engineers can consider how the IAEA safeguards implementation details described below might affect the facility design and construction.

4.1. NATURAL URANIUM FUEL

IAEA safeguards verification for natural uranium fuel fabrication can be less intensive than for LEU fuel fabrication. This can lead to a reduction in inspection frequency and effort. From a design perspective, the potential IAEA approach, instrumentation and measures are similar to those applied to LEU plants. Figure 21 shows a view of a CANDU fuel bundle made using natural uranium.

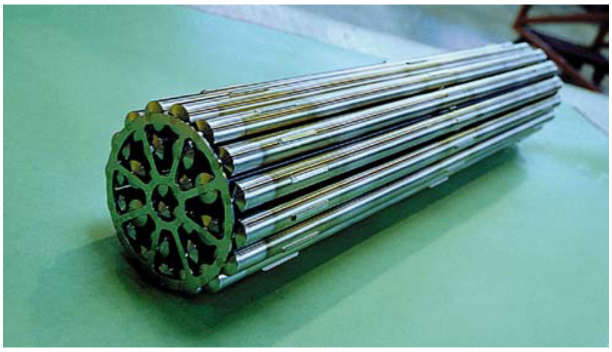

FIG. 21. Natural uranium CANDU fuel bundle.

4.2. MIXED OXIDE (MOX) FUEL

The greatest technical challenge for safeguarding a fuel fabrication facility concerns direct use material. Any high enriched uranium (HEU), ^{233}U or plutonium will have the shortest timeliness goal and smaller significant quantities of interest than DNLEU. A designer can consider segregation of this material with barriers, and limiting access to reduce the area that will be subject to more stringent safeguards attention. The safeguards approach at a mixed oxide (MOX) fuel fabrication plant can be significantly more intensive than that at a DNLEU one, given the greater safeguards significance of the direct use material. In particular, some safeguards activities may occur monthly rather than annually.

In general, DNLEU facilities allow for easy access to nuclear material, whereas for MOX facilities, the process operations are carried out under robust health and safety containment. Criticality safety concerns limit the handling of MOX material to smaller quantities and physical dimensions, resulting in more items to track and measure. Plutonium has higher radiotoxicity; it is generally handled with higher containment standards and multiple safety systems to better address off-normal operations and emergencies. Most MOX fabrication is performed in glove boxes with an inert gas atmosphere and shielding. This can limit access to the nuclear material for verification activities and special equipment may be required to perform verification measurements.

Verification activities at MOX facilities can include additional nuclear material accountancy and C/S measures. This makes the use of unattended verification and remote monitoring systems more relevant. The additional verification effort can include more detailed verification of receipts and shipments and also of in-process nuclear material, more careful determination of residual material left in processes or glove boxes (hold-up), and improved measurement of scrap and waste streams, all performed with greater precision than that required at DNLEU facilities.

Designers can create a compact process layout to minimize hold-up of nuclear material. To facilitate cleanout, more attention can be paid to saving and recycling waste, and greater sharing of sampling and quality control measurements can be recommended.

Automated systems offer potential advantages for ensuring product quality and safety. Consideration of safeguards early in the design of these systems can facilitate verification activities while reducing operational impacts. In a high throughput MOX fuel fabrication plant, the use of near real time accounting may be investigated in order to provide added assurance that the facility is operating as declared. A near real time accounting system enables periodic sequential analysis of material flow and inventory data in addition to the typical yearly material inventory evaluation that is applied to LEU fuel cycle facilities. The quality of these analyses is highly dependent on the uncertainties associated with the operator's measurements. Moreover, the deployment of such a system can create additional reporting requirements for the operator and State. This should be offset by a reduced IAEA presence on-site when everything is working smoothly. Designers can assist in proposing the optimum use of equipment and resources for the system, including a significant reduction in, or elimination of, the need to enter any information manually more than once.

Designers can assist in planning by considering the following aspects related to safeguards activities:

— More frequent inventory verification can be expected. IAEA inspectors might perform monthly interim inventory inspections; alternatively, under some conditions, random interim inspections might be conducted several times a year.
— Secured vaults and automated storage are often used for MOX items and may require use of more rigorous sealing methods, redundant safeguards equipment or both.
— Unattended NDA systems can help to verify MOX material flows and quantities; these systems might be designed to transfer data remotely to IAEA offices for verification analysis.
— Greater use of C/S measures is typical in MOX facilities. Multiple sensors[12] and cameras may be used to monitor or detect changes in the various storage areas in order to ensure continuity of knowledge and to minimize re-verification efforts. Designers can consider how best to provide flexible infrastructure to support IAEA equipment.
— The use of bag-in bag-out operations in glove boxes (which requires manual intervention and potentially enables the spread of contamination and diversion of direct use material) can be reduced to the extent practical for operations.
— The quality control equipment for the nuclear material can be integrated into the main fabrication line glove boxes to reduce the need to remove nuclear material as samples from the main process line.
— C/S and measurement equipment can be shared.

Effective design planning to accommodate the above activities can reduce the need for retrofits.

Glovebox hold-up measurement has historically been an attended measurement performed by the IAEA or operator with portable equipment during interim and PIV activities. Figure 22 shows a new unattended mode glovebox neutron counter with two slab neutron detectors supported by a blue framework on the outside of a

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[12] In this context, sensors can include motion sensors, door switches, radiation sensors and seals.

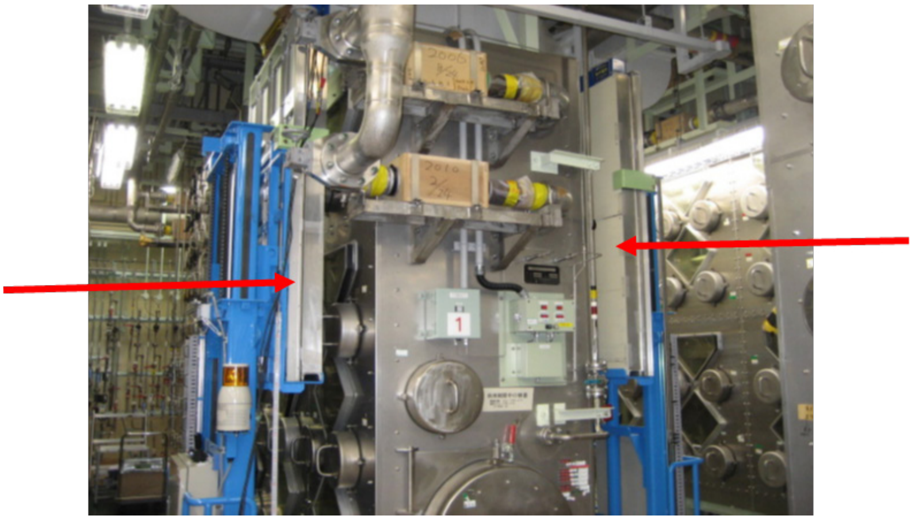

FIG. 22. Unattended mode glovebox neutron measurement equipment indicated by red arrows and supported by a blue framework.

glovebox. Facility designers can coordinate with instrument designers for this type of safeguards equipment or, potentially, can help develop improved automated systems. Provision of space and infrastructure for safeguards equipment can be part of the design requirements addressing the glovebox volume and room size.

Another nuclear material accounting activity the IAEA may perform at MOX fuel fabrication facilities is verifying the content of scrap. The plutonium scrap multiplicity counter [12] is an example of an NDA instrument used for such a purpose.

4.3. HEU FUEL

As with MOX, the IAEA safeguards approach at an HEU fuel fabrication plant can be significantly more intensive than that at a DNLEU plant, given the greater safeguards significance of the direct use material. The accounting verification can require more and better quality measurements as well as higher sample sizes for inventory verification. Criticality safety concerns generally limit nuclear material handling to smaller quantities, containers and process equipment, resulting in more items for safeguards to monitor. The safeguards approach will be similar to that applied to MOX fuel, discussed in Section 4.2, except for the radiotoxicity concerns — access to HEU material is less restrictive than access to MOX material for occupational exposure reasons.

4.4. NEXT GENERATION TECHNOLOGY

IAEA and industry guidance for next generation technology recommend the incorporation of more features to accommodate safety, safeguards and security requirements [5]. They also recommend consideration of how such requirements might share common goals and also of the resources to address them. Fuel fabrication technology will develop as industrial processes and new fuel requirements evolve and the associated safeguards can also be expected to evolve.

Monitoring of the process or operational transparency can make more extensive use of the plant operator's process instrumentation as an additional safeguards confidence building measure. Data authentication measures to address the desired independence of the IAEA's use of the operator's control instrumentation and the use of limited independent sensor duplication are areas of current research and development (R&D). If nuclear material movements are performed without human access, and if access to nuclear material storage locations is similarly limited, remote monitoring of the movements by reliable, redundant systems may have the potential to reduce the frequency and intensity of on-site inspections.[13] The design team can consider improving the automated tools used to collect and review data from multiple sensors, including a review of signal authentication. Moreover, the design team can also consider improving the infrastructure that supplies reliable power and connects sensors to electronics, computer systems and off-site inspector review stations.[14] Designers representing any stakeholder can help to eliminate common mode failure paths (e.g. accidentally turning off the wrong circuit breaker or local power switch) and suggest suitable levels of redundancy in safeguards equipment.

Metallic fuel may be more widely used in the future. Different instruments may be required to measure this fuel because of the differing material properties and fuel design, but, in general, the overall safeguards approach is expected to be similar to that for oxide fuel fabrication. While there are no commercial reactors currently using metallic plutonium fuel, there are fast reactor concepts that might use it. Some of these include other radioactive components, e.g. minor actinides, which could affect the ease of verification measurements or the quality of the measurement results. The inclusion of other radioactive material could require that access to the nuclear material be restricted and that new instrumentation for quantitative measurements be developed. The other potential safeguards measures will be similar to those applied to MOX fuel facilities that are discussed above.

Tristructural-isotropic (TRISO) or similarly coated particles are fuel concepts undergoing R&D. Some of these fuel types can present a challenge to traditional safeguards approaches in that individual fuel items do not carry identification, so stringent material flow controls are needed, not only in the bulk processing part of the facility, but also in the product store. On the other hand, some of the proposed TRISO fuel fabrication processes do not involve grinding and its associated generation of scrap and hold-up. Dedicated instrumentation and the application of unattended monitoring might be useful to address these fabrication processes. In the case of fuel in the form of a pebble, the nuclear material masses are typically quite low. This means a large number of pebbles would have to be diverted to reach a significant quantity, but it also makes monitoring more challenging.

Thorium is characterized in safeguards as indirect use nuclear material. Thorium based fuels require the addition of enriched uranium or plutonium in the initial fuel loading in order to start the fission process. Moreover, the use of thorium in a reactor creates ^{233}U, which has the same safeguards considerations as plutonium. Similar to MOX fabrication, thorium based fuel fabrication might be performed in a controlled environment for safety reasons (high gamma radiation fields). This introduces complexity for verification while reducing opportunities for unauthorized access to the nuclear material [20]. Higher levels of automation can be considered to limit the necessity for manual intervention, thereby helping to address health and safety concerns. Increased automation can also reduce staffing requirements; consequently, fewer people would require access to the nuclear material areas. In general, a fuel fabrication plant for thorium based fuel might have similar safeguards features to that of a MOX plant as one consequence of this automation and restricted access.

Fuel fabrication facilities are an essential part of the nuclear fuel cycle and will continue to develop as industrial processes adapt to a competitive fuel market and advances in reactor technology. Similarly, IAEA safeguards will continue to evolve to address new verification challenges presented by new technology and the changing political environment. The State, the IAEA and other stakeholders working together in the design and construction process for new facilities can help ensure that the most cost effective and efficient safeguards can be implemented, to the benefit of all.

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[13] At the time of writing, it is not anticipated that the IAEA will reduce its requirement for on-site access to declared nuclear facilities to less than annual frequency.

[14] Experience suggests costs are lower when authentication requirements are considered early in equipment development.

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Annex I

TERMINOLOGY

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

NUCLEAR AND NON-NUCLEAR MATERIAL

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

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

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

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

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

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

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

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

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

NUCLEAR INSTALLATIONS AND EQUIPMENT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

CONTAINMENT AND SURVEILLANCE

containment. Structural features of a nuclear facility or equipment which enable the IAEA to establish the physical integrity of an area or item by preventing undetected access to or movement of nuclear or other material, or interference with an item or with IAEA safeguards equipment or data.[5]

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

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

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

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

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

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

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

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

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

MISCELLANEOUS

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

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

Annex II

SAFEGUARDS CONSIDERATIONS IN FACILITY LIFE CYCLE STAGES

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

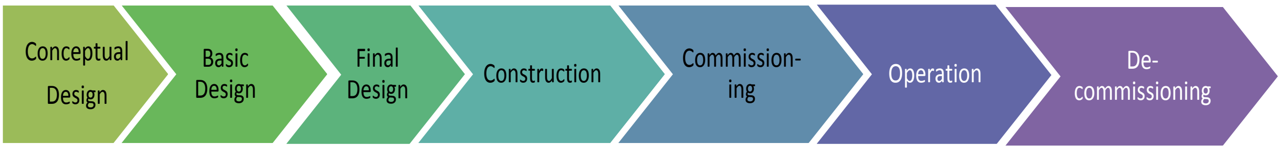

FIG. II–1. Facility life cycle stages.

II–1. CONCEPTUAL DESIGN

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

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

II–2. BASIC DESIGN

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

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

II–3. FINAL DESIGN

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

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

II–4. CONSTRUCTION

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

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

II–5. COMMISSIONING

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

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

II–6. OPERATION

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

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

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

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

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

II–7. DECOMMISSIONING

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

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

Annex III

IDENTIFYING SAFEGUARDABILITY ISSUES

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

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

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

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

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

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

TABLE III-1. FACILITY SAFEGUARDABILITY ASSESSMENT

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

Annex IV

DESIGN INFORMATION QUESTIONNAIRE INFORMATION FOR FUEL FABRICATION PLANTS

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

Fuel fabrication facility design information questionnaire information includes at least the following:

- Facility name, location, address, owner, operator, status, purpose, etc.
- Officers responsible for the facility.
- Facility status — planned, under construction, in operation, decommissioned.
- Facility and site layout.
- Facility description, including general flow diagrams, storage areas, and feed, product and waste points.
- Process description, indicating type of conversion or method of fabrication, including the modification of chemical and physical forms.
- Design capacity (principal products per year).
- Anticipated annual throughput (including growth projections if applicable).
- Important items of equipment using, producing or processing nuclear material.
- Nuclear material description and flow (for feed, intermediate product and product):
  - Accountability units to be used;
  - Chemical and physical forms including drawings with dimensions;
  - Throughput, U enrichment ranges, Pu contents;
  - Batch size and flow rates;
  - Storage and plant inventory;
  - Frequency of shipments;
  - Frequency of receipts.
- Feed material.
- Product material.
- Scrap material:
  - Sources;
  - Chemical and physical form;
  - Estimated U enrichment ranges and Pu content ranges;
  - Estimated quantities per year, storage periods;
  - Generation rates;
  - Storage inventory and maximum capacity;
  - Method and frequency of recycling.
- Waste material:
  - Sources;
  - Chemical and physical form;
  - Estimated U enrichment ranges and Pu content ranges;
  - Estimated quantities per year, storage periods;
  - Generation rates;
  - Storage inventory and maximum capacity;
  - Method and frequency of disposal.
- Waste treatment system.
- Other nuclear material in the facility, including location.
- Flow sheets.
- Types, forms, enrichment range, Pu content (range), flow rates (ranges) of nuclear material in each nuclear material handling and storage area.
- Recycling processes (include diagrams).
- In-process, feed and storage inventory.

- Nuclear material inventories and flows in other areas.
- Container information, including packing and storage description.
- Methods and means of transfer of nuclear material.
- Transportation routes followed by nuclear material (include drawings).
- Shielding for storage and transfer.
- Maintenance, decontamination and cleanout plans:
  - Methods to ensure vessels are empty;
  - Tools and accessories used for cleanout.
- Plant startup and shutdown procedures.
- Basic physical protection measures.
- Specific health and safety rules for inspector compliance.
- Nuclear material accountancy and control:
  - System description;
  - Ledger format, operational records and accounts;
  - Form (electronic, paper, microfilm);
  - Procedures for making adjustments;
  - Procedures for making measurements;
  - Procedures for measurement control;
  - Receipts;
  - Procedure for shipper/receiver differences;
  - Shipments (products, waste, measured discards);
  - PIV including procedures, frequency, measurement method details, cleanout;
  - Retained waste;
  - Unmeasured losses.
- Features related to C/S measures.
- Description of measurement points, items being measured, possibility to use for PIV, sampling procedures, measurement instruments, precision and accuracy of measurement, calibration details, measurement control details.
- Overall limits of error (shipper/receiver differences, book inventory, physical inventory, MUF).
- Optional information the operator considers relevant to safeguards.

DEFINITIONS

Several terms are defined in INFCIRC/153[1] and INFCIRC/540[2] and a subset of these are provided below for convenience. The IAEA Safeguards Glossary[3] provides definitions of other safeguards terms as well as translations of safeguards terms into eight languages.

adjustment. An entry into an accounting record or a report showing a **shipper/receiver difference** or **material unaccounted for.**

annual throughput. The amount of **nuclear material** transferred annually out of a **facility** working at nominal capacity.

batch. A portion of **nuclear material** handled as a unit for accounting purposes at a **key measurement point** and for which the composition and quantity are defined by a single set of specifications or measurements. The **nuclear material** may be in bulk form or contained in a number of separate items.

batch data. The total weight of each element of **nuclear material** and, in the case of plutonium and uranium, the isotopic composition when appropriate. The units of account shall be: (a) grams of contained plutonium; (b) grams of total uranium and grams of contained uranium-235 plus uranium-233 for uranium enriched in these isotopes; and (c) kilograms of contained thorium, natural uranium or depleted uranium. For reporting purposes, the weights of individual items in the **batch** shall be added together before rounding to the nearest unit.

book inventory (of a material balance area). The algebraic sum of the most recent **physical inventory** of that **material balance area** and of all **inventory changes** that have occurred since that **physical inventory** was taken.

closed down facility or closed down location outside facilities. An installation or location where operations have been stopped and the **nuclear material** removed but which has not been decommissioned.

decommissioned facility or decommissioned location outside facilities. An installation or location at which residual structures and equipment essential for its use have been removed or rendered inoperable so that it is not used to store and can no longer be used to handle, process or utilize **nuclear material**.

effective kilogram. A special unit used in safeguarding **nuclear material.** The quantity in effective kilograms is obtained by taking: (a) for plutonium, its weight in kilograms; (b) for uranium with an **enrichment** of 0.01 (1%) and above, its weight in kilograms multiplied by the square of its **enrichment;** (c) for uranium with an **enrichment** below 0.01 (1%) and above 0.005 (0.5%), its weight in kilograms multiplied by 0.0001; and (d) for depleted uranium with an **enrichment** of 0.005 (0.595) or below, and for thorium, its weight in kilograms multiplied by 0.00005.

enrichment. The ratio of the combined weight of the isotopes uranium-233 and uranium-235 to that of the total uranium in question.

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

[2] Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540/Corr.1, IAEA, Vienna (1998).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safeguards Glossary, 2001 Edition, International Nuclear Verification Series No. 3, IAEA, Vienna (2002).

facility. (a) A reactor, a critical facility, a conversion plant, a fabrication plant, a reprocessing plant, an isotope separation plant or a separate storage installation; or (b) any location where **nuclear material** in amounts greater than one **effective kilogram** is customarily used.

high enriched uranium. Uranium containing 20% or more of the isotope uranium-235.

inventory change. An increase or decrease, in terms of **batches,** of **nuclear material** in a **material balance area;** such a change involves one of the following: (a) an increase, which may be: (i) import; (ii) domestic receipt, which is a receipt from another **material balance area,** a receipt from a non-safeguarded (non-peaceful) activity or a receipt at the starting point of safeguards; (iii) nuclear production, i.e. the production of special fissionable material in a reactor; or (iv) de-exemption, i.e. reapplication of safeguards on **nuclear material** previously exempted therefrom on account of its use or quantity; (b) a decrease, which may be: (i) export; (ii) domestic shipment, i.e. shipments to other **material balance areas** or shipments to a non-safeguarded (non-peaceful) activity; (iii) nuclear loss, i.e. loss of **nuclear material** due to its transformation into other element(s) or isotope(s) as a result of nuclear reactions; (iv) measured discard, i.e. **nuclear material** which has been measured, or estimated on the basis of measurements, and disposed of in such a way that it is not suitable for further nuclear use; (v) retained waste: **nuclear material** generated from processing or from an operational accident, which is deemed to be unrecoverable for the time being but which is stored; (vi) exemption, i.e. exemption of **nuclear material** from safeguards on account of its use or quantity; and (vii) other loss, for example, accidental loss (that is, irretrievable and inadvertent loss of **nuclear material** as the result of an operational accident) or theft.

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

location outside facility. Any installation or location, which is not a **facility**, where **nuclear material** is customarily used in amounts of one **effective kilogram** or less.

location specific environmental sampling. The collection of environmental samples (e.g. air, water, vegetation, soil, smears) at, and in the immediate vicinity of, a location specified by the IAEA for the purpose of assisting the IAEA to draw conclusions about the absence of undeclared **nuclear material** or nuclear activities at the specified location.

material balance area. An area in or outside of a **facility** such that: (a) the quantity of **nuclear material** in each transfer into or out of each material balance area can be determined; and (b) the **physical inventory** of **nuclear material** in each material balance area can be determined when necessary, in accordance with specified procedures, in order that the material balance for IAEA safeguards purposes can be established.

material unaccounted for. The difference between **book inventory** and **physical inventory.**

nuclear material. Any source or any special fissionable material as defined in Article XX of the IAEA Statute[4]. The term source material shall not be interpreted as applying to ore or ore residue. Any determination by the Board under Article XX of the Statute after the entry into force of this agreement that adds to the materials considered to be source material or special fissionable material shall have effect under this agreement only upon acceptance by the State.

physical inventory. The sum of all the measured or derived estimates of **batch** quantities of **nuclear material** on hand at a given time within a **material balance area,** obtained in accordance with specified procedures.

shipper/receiver difference. The difference between the quantity of **nuclear material** in a **batch** as stated by the shipping **material balance area** and as measured at the receiving **material balance area.**

source data. Those data, recorded during measurement or calibration or used to derive empirical relationships, that identify **nuclear material** and provide **batch data.** Source data may include, for example, weight of compounds, conversion factors to determine weight of element, specific gravity, element concentration, isotopic ratios, relationship between volume and manometer readings and relationship between plutonium produced and power generated.

strategic point. A location selected during examination of design information where, under normal conditions and when combined with the information from all the strategic points taken together, the information necessary and sufficient for the implementation of safeguards measures is obtained and verified; a strategic point may include any location where key measurements related to material balance accountancy are made and where containment and surveillance measures are executed.

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[4] The Statute of the IAEA, IAEA, Vienna (1956), as amended up to 1989. Article XX:

"1. The term "special fissionable material" means plutonium-239; uranium- 233; uranium enriched in the isotopes 235 or 233; any material containing one or more of the foregoing; and such other fissionable material as the Board of Governors shall from time to time determine; but the term "special fissionable material" does not include source material.

"2. The term "uranium enriched in the isotopes 235 or 233" means uranium containing the isotopes 235 or 233 or both in an amount such that the abundance ratio of the sum of these isotopes to the isotope 238 is greater than the ratio of the isotope 235 to the isotope 238 occurring in nature.

"3. The term "source material" means uranium containing the mixture of isotopes occurring in nature; uranium depleted in the isotope 235; thorium; any of the foregoing in the form of metal, alloy, chemical compound, or concentrate; any other material containing one or more of the foregoing in such concentration as the Board of Governors shall from time to time determine; and such other material as the Board of Governors shall from time to time determine."

ABBREVIATIONS

C/S	containment and surveillance
CSA	comprehensive safeguards agreement
DA	destructive assay
DIQ	design information questionnaire
DIV	design information verification
DNLEU	depleted, natural and low enriched uranium
HEU	high enriched uranium
KMP	key measurement point
LEU	low enriched uranium
LOF	location outside a facility
MBA	material balance area
MOX	mixed oxide fuel
MUF	material unaccounted for
NDA	non-destructive assay
PIV	physical inventory verification
R&D	research and development
SBD	safeguards by design
SNRI	short notice random inspection
SRA	State or regional authority responsible for safeguards implementation

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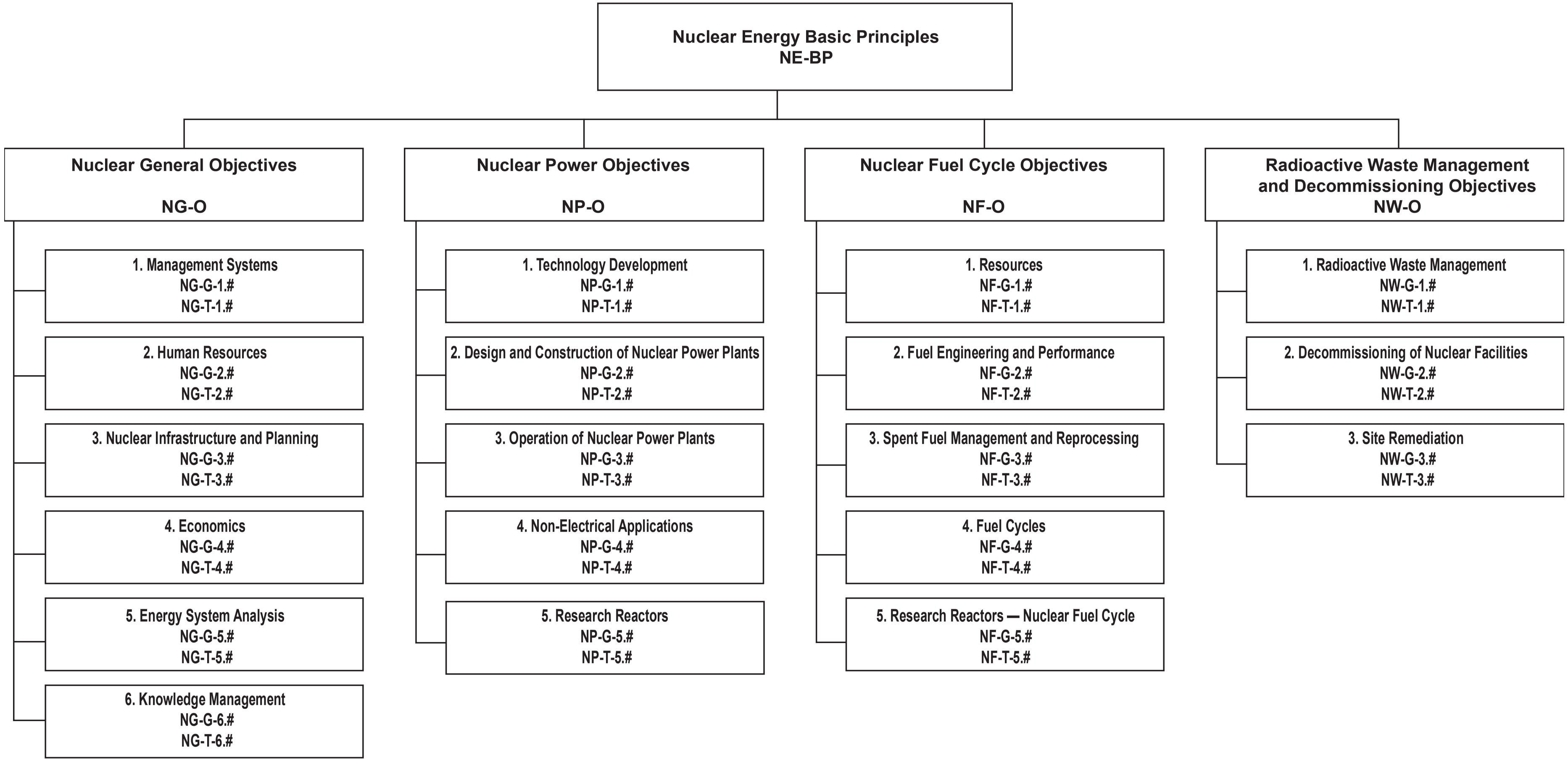

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