IAEA Nuclear Energy Series

No. NF-T-4.10

Basic Principles

Objectives

Guides

Technical Reports

International Safeguards in the Design of Enrichment Plants

IAEA

International Atomic Energy Agency

IAEA NUCLEAR ENERGY SERIES PUBLICATIONS

STRUCTURE OF THE IAEA NUCLEAR ENERGY SERIES

Under the terms of Articles III.A and VIII.C of its Statute, the IAEA is authorized to foster the exchange of scientific and technical information on the peaceful uses of atomic energy. The publications in the **IAEA Nuclear Energy Series** provide information in the areas of nuclear power, nuclear fuel cycle, radioactive waste management and decommissioning, and on general issues that are relevant to all of the above mentioned areas. The structure of the IAEA Nuclear Energy Series comprises three levels: **1 — Basic Principles and Objectives**; **2 — Guides**; and **3 — Technical Reports**.

The **Nuclear Energy Basic Principles** publication describes the rationale and vision for the peaceful uses of nuclear energy.

Nuclear Energy Series Objectives publications explain the expectations to be met in various areas at different stages of implementation.

Nuclear Energy Series Guides provide high level guidance on how to achieve the objectives related to the various topics and areas involving the peaceful uses of nuclear energy.

Nuclear Energy Series Technical Reports provide additional, more detailed information on activities related to the various areas dealt with in the IAEA Nuclear Energy Series.

The IAEA Nuclear Energy Series publications are coded as follows: **NG** — general; **NP** — nuclear power; **NF** — nuclear fuel; **NW** — radioactive waste management and decommissioning. In addition, the publications are available in English on the IAEA Internet site:

http://www.iaea.org/publications/index.html

For further information, please contact the IAEA at PO Box 100, Vienna International Centre, 1400 Vienna, Austria.

All users of the IAEA Nuclear Energy Series publications are invited to inform the IAEA of experience in their use for the purpose of ensuring that they continue to meet user needs. Information may be provided via the IAEA Internet site, by post, at the address given above, or by email to Official.Mail@iaea.org.

INTERNATIONAL SAFEGUARDS IN THE DESIGN OF ENRICHMENT PLANTS

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

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

IAEA NUCLEAR ENERGY SERIES No. NF-T-4.10

INTERNATIONAL SAFEGUARDS IN THE DESIGN OF ENRICHMENT PLANTS

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019

COPYRIGHT NOTICE

All IAEA scientific and technical publications are protected by the terms of the Universal Copyright Convention as adopted in 1952 (Berne) and as revised in 1972 (Paris). The copyright has since been extended by the World Intellectual Property Organization (Geneva) to include electronic and virtual intellectual property. Permission to use whole or parts of texts contained in IAEA publications in printed or electronic form must be obtained and is usually subject to royalty agreements. Proposals for non-commercial reproductions and translations are welcomed and considered on a case-by-case basis. Enquiries should be addressed to the IAEA Publishing Section at:

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
www.iaea.org/publications

© IAEA, 2019

Printed by the IAEA in Austria
December 2019
STI/PUB/1865

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: International safeguards in the design of enrichment plants / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2019. | Series: IAEA nuclear energy series, ISSN 1995–7807 ; no. NF-T-4.10 | Includes bibliographical references.
Identifiers: IAEAL 19-01268 | ISBN 978–92–0–104419–8 (paperback : alk. paper)
Subjects: LCSH: Nuclear facilities — Design and construction. | Nuclear industry — Security measures. | Nuclear nonproliferation. | Uranium enrichment.
Classification: UDC 621.039.3 | STI/PUB/1865

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

This publication has been edited by the editorial staff of the IAEA to the extent considered necessary for the reader's assistance. It does not address questions of responsibility, legal or otherwise, for acts or omissions on the part of any person.

Although great care has been taken to maintain the accuracy of information contained in this publication, neither the IAEA nor its Member States assume any responsibility for consequences which may arise from its use.

Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

The use of particular designations of countries or territories does not imply any judgement by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.

The IAEA has no responsibility for the persistence or accuracy of URLs for external or third party Internet web sites referred to in this book and does not guarantee that any content on such web sites is, or will remain, accurate or appropriate.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

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

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

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

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

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

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

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

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

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

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

1.2. OBJECTIVE

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

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

1.3. SCOPE

The information presented here is applicable to the design and construction of commercial uranium enrichment plants,[2] such as the plant shown in Fig. 1. This publication is intended to support the consideration of safeguards in parallel with other considerations during the design and construction process. It is directed at the baseline case of gaseous centrifuge enrichment plants; however, the information can be applied in general to other methods of isotope separation (e.g. diffusion, electromagnetic, laser). The scope encompasses the receipt of feed material in various chemical forms and the on-site storage of intermediate and final products. The guidance provided herein represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

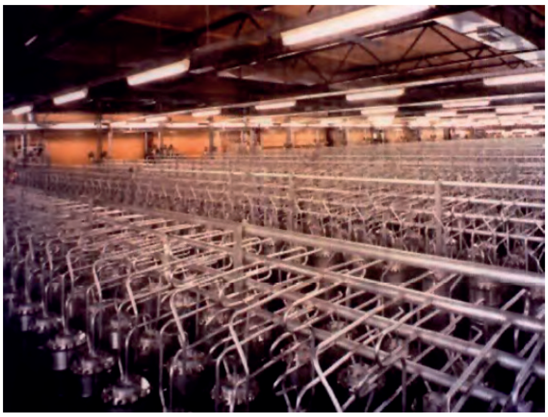

FIG. 1. Centrifuges and piping connections in a commercial uranium enrichment plant.

[2] Sometimes referred to as isotope separation facilities.

1.4. STRUCTURE

Section 2 provides a general overview of IAEA safeguards implementation, followed by facility specific guidance in Section 3. This publication includes experience gained in past efforts to incorporate safeguards requirements in the facility design, which can be useful in future efforts to build or operate nuclear facilities. Additional resources are suggested in the bibliography at the end of this publication. Reference material specific to the legal obligations undertaken pursuant to safeguards agreements can be found in Ref. [9]. It may also be useful to refer to the IAEA Safeguards Glossary [10], which can be accessed from Ref. [9].

Annex I provides explanations of specific safeguards terminology used in this publication. Annex II describes safeguards considerations at the various life cycle stages of a nuclear facility. Annex III describes the identification of safeguardability issues, and Annex IV provides information on the contents of a design information questionnaire.

2. OVERVIEW OF IAEA SAFEGUARDS

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

2.1. IAEA SAFEGUARDS IMPLEMENTATION

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

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

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

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

2.2. OVERVIEW OF SAFEGUARDS MEASURES

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

— On-site inspections by IAEA inspectors [12] including short notice random and unannounced inspections[3];
— Nuclear material accountancy, such as the review of facility records and supporting documentation [13];
— Measurements of nuclear material (e.g. weight, gamma, neutron) [14, 15];
— Unique identifiers for nuclear material items;
— Surveillance (e.g. cameras), containment (e.g. seals) and monitoring (e.g. monitoring nuclear material flows using unattended radiation measurements, monitoring of facility operational data such as pressure, temperature or power levels);
— Collection and analysis of environmental and nuclear material samples;
— Verification of facility design for features relevant to safeguards.

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

2.3. VERIFICATION

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

2.3.1. Design information verification

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

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

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

The IAEA may also verify the design and capacity of any processing equipment and systems in the facility as well as its maximum capacity. Accommodation for this requirement may be considered in the design phase. In addition, the IAEA develops an 'essential equipment' list for the nuclear facility to use in determining whether a facility can be considered decommissioned for safeguards purposes. The designers of the facility can play a valuable role in helping the IAEA to identify the equipment that is essential for operating the nuclear facility.[4]

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

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

FIG. 2. IAEA design verification.

2.3.2. Nuclear material accounting and verification

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

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

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

One of the activities involved in verifying nuclear material is the evaluation of the consistency of facility records and supporting documentation with the reports submitted by the State [13]. The IAEA performs a physical inventory verification (PIV) after a facility operator has taken a physical inventory itself. The IAEA verifies

FIG. 3. Sample preparation in an IAEA laboratory.

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.

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.

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

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

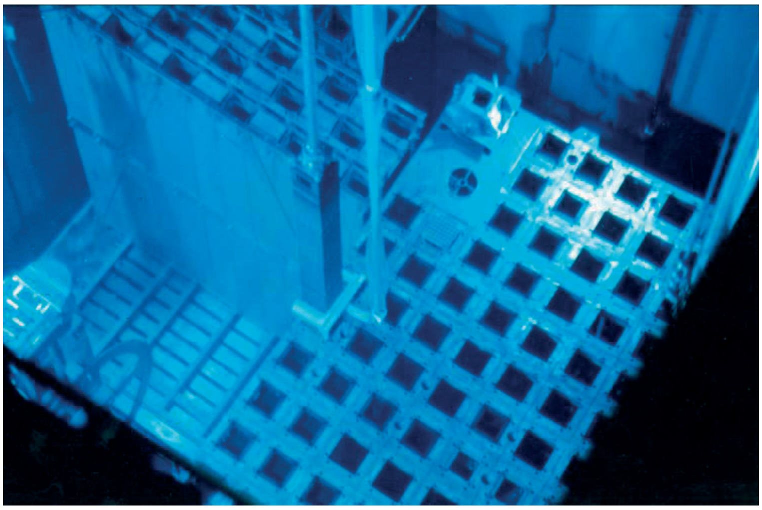

FIG. 6. Measurement of irradiated fuel in a cooling pond.

There are several ways facility operators can provide the basic support required for IAEA surveillance and monitoring systems, such as by:

— Supplying reliable power, secured access, dedicated working space and data transmission (wired or wireless) throughout the facility. Figure 8 shows a facility operator lowering an IAEA equipment rack with an overhead crane.
— Locating data collection cabinets in easily accessible, clean areas with regulated temperature and humidity.
— Foreseeing the impact of the operating environment on safeguards equipment (e.g. corrosion, heat).
— Ensuring that optical surveillance systems are not blocked by equipment (e.g. cranes that move cylinders, heavy equipment or drums) and are protected from corrosion.
— Considering a single dedicated space for electronic equipment[5] that can be access controlled by the IAEA. This space might include room for equipment, spare parts and a small office.
— Providing sufficient access for attaching, replacing or servicing seals used by the IAEA.
— Providing space for safeguards equipment in such a way that normal facility operation will not lead to inadvertent damage or interruption in service.
— Labelling all installed relevant safeguards equipment (including cabling, power supplies and switches found in circuit breaker cabinets) clearly in English and the local language(s).
— Consulting with the IAEA to facilitate the use of safeguards seals at measurement points and safeguards relevant features such as junction boxes where safeguards cables are terminated or connected.
— Noting that seal attachment points should be part of the mechanical structure, appearing to be part of the original smooth design and not welded on after the fact, and must ensure that the attachment point cannot be removed without detection or without damaging or breaking the seal.

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

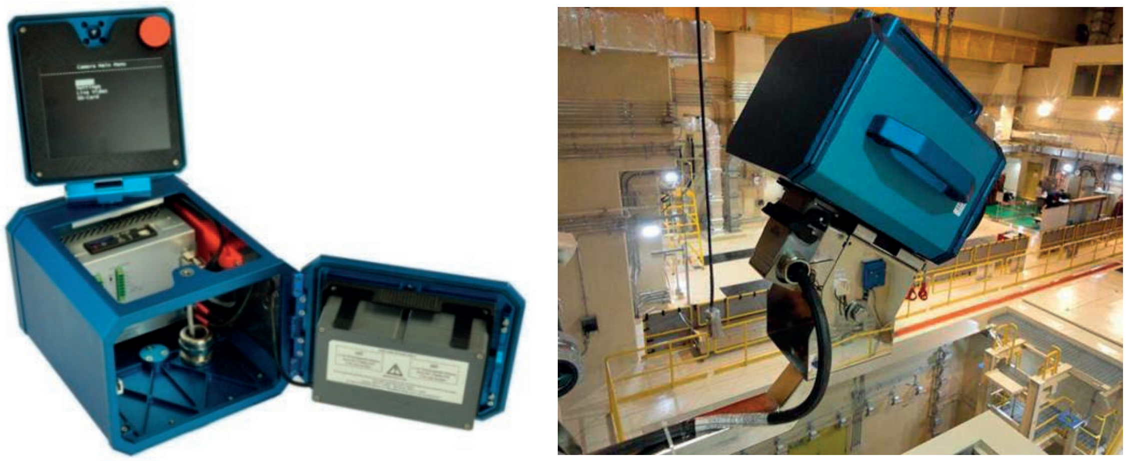

FIG. 7. A next generation IAEA surveillance system.

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

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.

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

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

2.4. PHYSICAL INFRASTRUCTURE REQUIREMENTS FOR IAEA SAFEGUARDS ACTIVITIES

IAEA safeguards equipment requires physical space, reliable and well regulated power supply, and infrastructure for data transmission. Even without detailed IAEA design criteria for safeguards equipment or systems (which may be only available later in the design life cycle), cabling and penetrations for IAEA equipment can be planned for in the facility design. Providing access to a stable and reliable source of power and secure data transmission capability (wired, fibre-optic or wireless) throughout a facility will eliminate the need for the most costly aspects of retrofitting for safeguards equipment systems (such as the installation of a surveillance

FIG. 10. Installation of a surveillance system.

camera, as shown in Fig. 10). Additionally, the possibility of incorporating facility equipment and the infrastructure needed to directly support IAEA verification activities into regular facility maintenance contracts could be considered. The ability to provide mounting fixtures for safeguards equipment that do not affect facility licensing or safety is desirable.

2.5. FACILITY DECOMMISSIONING

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

2.6. FUTURE CONSIDERATIONS

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

3. SAFEGUARDS CONSIDERATIONS RELATED TO ENRICHMENT PLANTS

This section addresses safeguards considerations specific to the design, construction and operation of enrichment plants. Figure 11 shows an inspector performing safeguards verification activities in a uranium hexafluoride (UF_6) storage area at an enrichment plant. The Hexapartite Safeguards Project developed the initial model safeguards approach for gas centrifuge enrichment plants (GCEPs) [18]. More recently, attention has been given to the usefulness of additional measures for application to GCEPs [19–21] to provide strength in depth, to address technology developments and weaknesses in the Hexapartite Safeguards Project model approach, and to address resource limitations.

In particular, since misuse of an enrichment plant could have the aim of converting low enriched uranium (LEU) to high enriched uranium (HEU), and as some facilities can potentially accomplish this conversion in a shorter time, it must be recognized that the time needed to produce a significant quantity of nuclear material of safeguards interest could be less than previously considered. Figure 12 shows an example of the design of a GCEP plant. The diagram shows a generic layout with a natural uranium feed (yellow) and enriched uranium product (red) and depleted uranium tails (green) stations as well as halls containing centrifuges in the left building. The right building shows product storage and stations for blending different product enrichments to create the desired customer enrichments. Such a plant would have areas for the storage of feed cylinders received and awaiting feeding as well as for tails storage. A GCEP plant may ship tails for re-enrichment to natural levels or deconversion from UF_6 to U_3O_8 for safer storage of the depleted uranium, or the plant may hold them for years while awaiting a final disposition strategy.

Nuclear facilities address the need for nuclear material control and accounting by operations as well as the conduct of associated inspections by national and international authorities. To optimize these aspects of the design, it is helpful for enrichment facility designers to have a basic understanding of safeguards measures and the objectives they are intended to address [1, 21]. In summary, the safeguards measures for commercial GCEPs include an annual PIV and interim inspections to verify the operator’s declared flows and inventories of nuclear material. In addition, the IAEA applies limited frequency unannounced access to the cascade halls in order to detect changes in the enrichment cascade configuration, to detect the introduction of additional valves or UF_6 withdrawal points and to make NDA measurements as well as, in some cases, to obtain DA or environmental samples. The aim is to achieve 100% coverage of the process flow (i.e. all receipts and shipments available for verification) and to actually verify at least 20% of the flow using random selection. Moreover, additional interim or unannounced inspections could be performed to achieve a higher sampling rate. The Hexapartite Safeguards Project model approach also includes design verification and containment and surveillance (C/S) measures as well as sampling and other measurements of the nuclear material. Both total uranium and ^{235}U material balances are evaluated.

FIG. 11. An IAEA inspector undertaking verification activities in a UF_6 cylinder storage area.

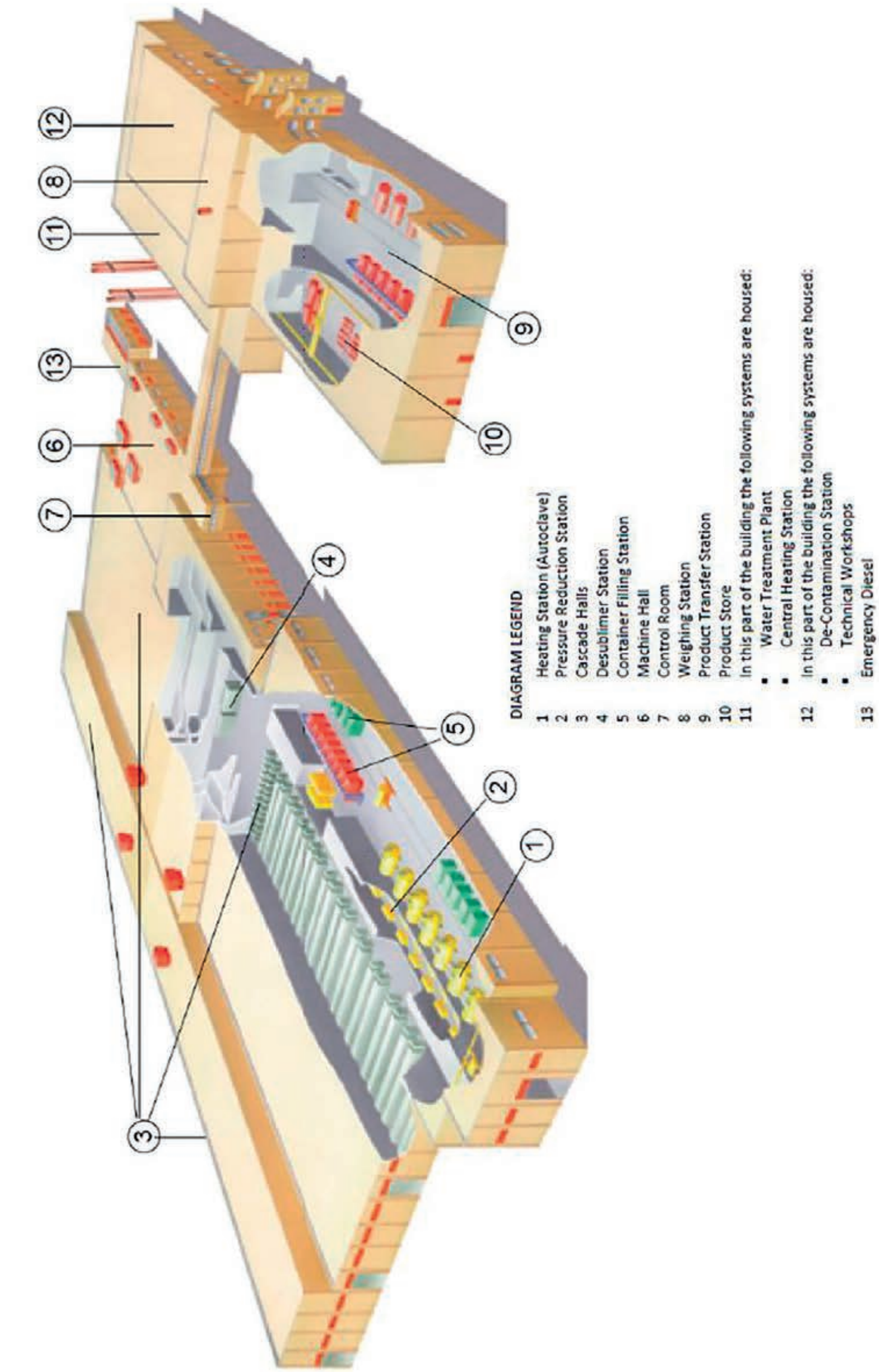

FIG. 12. An example of the design of a GCEP.

As experience has been gained with the implementation of GCEP safeguards, additional safeguards measures have been developed [20–22]. These measures include activities to guard against the introduction of undeclared feed and withdrawal (F/W) stations or undeclared cylinders as well as adding flow and enrichment measurements from in-line equipment. Moreover, environmental sampling has been in use since 1996 to detect higher than declared enrichments inside cascade halls. Use of a short notice random inspection or unannounced inspection with a mailbox approach can require fewer inspection days per year to achieve the same verification requirements [23–25]. Use of authenticated operator's equipment (e.g. precision balances or load cells) can significantly improve the accuracy achievable in the material balance evaluation.

Although the baseline case discussed here uses GCEPs as an example, much of the information in this publication can be applied to any isotope separation technology. In this publication, the term 'IAEA safeguards equipment' will be used to represent various lists of equipment. It does not imply one unique list.

The primary safeguards objectives at an enrichment plant are the timely detection of:

— The diversion of significant quantities of natural, depleted or low enriched UF_6 from the declared flow through the plant, and the deterrence of such diversion by the risk of early detection;
— The misuse of the facility in order to produce undeclared product (at the normal product enrichment levels) from undeclared feed and the deterrence of such misuse by the risk of early detection;
— The misuse of the facility to produce UF_6 at enrichments higher than the declared maximum, HEU in particular, and the deterrence of such misuse by the risk of early detection.

These diversion and misuse activities could potentially be facilitated by:

— False reporting of operator measurements (e.g. in the reporting of material unaccounted for (MUF) or shipper–receiver difference (SRD));
— Improperly calibrated instrumentation used for weighing, measuring product flow rates, etc.;
— The introduction of undeclared feed into the plant;
— The production of uranium of higher than the declared enrichment;
— The production of an excess quantity of enriched uranium using declared feed material (either natural uranium or depleted tails) fed clandestinely into the process with the enriched uranium withdrawn and shipped clandestinely;
— False reporting of waste measurements;
— Tampering with IAEA equipment;
— Process upset or off-normal activities;
— False reporting of material loss.

Practical examples of design features to increase the 'safeguardability' of the facility are discussed in the following sections. These include:

— Easy to read, unique identifiers for nuclear material items (e.g. radiofrequency identification (RFID) tags);
— A minimum number of penetrations in the process containment;
— Easy access for design verification (e.g. access to piping and valves);
— Visible pipes and ductwork connecting all F/W stations;
— Provision for attaching seals and other tamper indicating devices;
— Provision for application of surveillance equipment;
— The application of near real time accountancy and process monitoring (PM);
— Plant layout (including containment barriers to facilitate segregation of material) that makes mixing, substitution or inappropriate transfers more difficult;
— Accurate measurements of in-process material and measured discards;
— A well defined and practical change control process to track any physical changes to the plant or changes to operating procedures or policies;
— Controlled access to locations for the receipt, storage and measurement of nuclear material;
— Provision of a detailed operational programme (in advance).

In addition, a designer can recommend ways to:

— Facilitate inspection activities;
— Protect sensitive, classified or proprietary information;
— Mitigate issues of safeguards relevance that might arise during off-normal (unusual) events;
— Minimize the impact of safeguards activities on routine facility operation.

In the conceptual design stage, SBD advises that safeguards be considered using general guidance that is not overly prescriptive. Guidance that describes the safeguards issues, rather than prescribing how to address them, may be more readily used by the facility designers to seek an optimum solution for all stakeholders. Moreover, dictating specific technology solutions might be unrealistic owing to variability in facility or State specific factors. Safeguards concepts that have been applied successfully to other types of bulk processing facilities that could be explored further for application to enrichment plants include on-site laboratories, near real time accountancy and PM.

Once an enrichment plant has been built, it can be challenging to retrofit or modify it in order to accommodate IAEA equipment. Therefore, required IAEA monitoring equipment should be incorporated in the original plant design. The need for subsequent adaption of the process equipment to accommodate sampling or measurement of the nuclear material should be avoided.[6] For example, facilitating access to the process floor while maintaining the protection of sensitive information, the retrofitting of a process vessel to allow in-line measurement of the uranium enrichment, the installation of flow monitoring equipment for chemically hazardous streams or the replacement of rudimentary instrumentation with higher accuracy instrumentation can be difficult and expensive. The IAEA will make use of the physical inventory list and inventory change reports (e.g. a listing of receipts, shipments and movements of UF_6 cylinders) in its verification activities. The IAEA may choose to verify some or all of the information relevant to safeguards concerning a specific UF_6 cylinder (e.g. tare weight, gross weight, fill times, re-batching, uranium mass, enrichment, purity and concentration, a review of source documentation). In addition, a review of calibration records for weighing and sampling equipment may be completed. Figure 13 shows an inspector weighing a randomly selected UF_6 cylinder.

The design of cylinder storage areas should address the need to be able to quickly locate any cylinder selected by the IAEA from the inventory list as well as the capability to easily move stored items to scales for weighing, while keeping any IAEA applied seals accessible and protected from damage. The IAEA should have the capability to use portable IAEA load cells safely with the site lifting devices. The main and most accurate method of weighing cylinders is for the IAEA to be able to use the operator's accountancy scales. The operator must make provisions for independent verification of the scale's calibration such as the use of sealed check weights. The handling of cylinders in outdoor storage areas should be addressed in ways that minimize the uncertainties inherent to weighing under different environmental conditions. In addition, the design of the project can consider the use of automation

FIG. 13. An inspector weighs randomly selected cylinders on the operator's accountancy scale to verify UF_6 weight.

[6] The design team can consider engineering studies to ensure that samples will be representative of the material from which they are drawn, for example, how long mixing should be performed or from where the sample is best drawn.

when handling UF_6 cylinders in order to reduce handling errors. The operators should also be willing to incorporate advances in technology such as the World Nuclear Transport Institute's standardized format and application method for a global identifier for UF_6 cylinders [26] that would ease cylinder identification, accounting and authentication of the identity of a specific unique cylinder.

One component of IAEA activities at enrichment plants that has been challenging to address historically involves access to the production halls for comparing the operator's design information with observations of the facility and activities. Activities in the cascade hall can be grouped into those the inspector performs, those the inspector can observe and those that should be concealed to protect sensitive, classified or proprietary information. Segregating activities and visual barriers can help address the various constraints. Inspectors observe the cascade hall to confirm the absence of undeclared F/W operations, the absence of undeclared or undocumented pipes leaving the cascade area and the absence of any reconfiguration of the declared process piping. To aid visual inspections, a site might have well defined inspection routes to protect proprietary enrichment technology from view, yet provide inspectors with visual access to the necessary piping. Items to consider for inspection routes include:

— Avoiding non-accessible process equipment and piping;
— Minimizing ingress and egress openings to the processing areas;
— Locating sampling points in areas accessible to inspectors;
— Avoiding the need for facility portable equipment in processing areas the inspector might visit;
— Maintaining an uncluttered facility.

Entry and exit points for material flowing into or out of the process should be kept to a minimum to minimize the number of pathways along which the diversion of material or introduction of undeclared feed could occur.

3.1. DESIGN INFORMATION EXAMINATION AND VERIFICATION

The provision of design information that has high commercial sensitivity to the IAEA should be minimized [27].[7] The use of shrouding (e.g. curtains or covers) can only be considered when concealment of sensitive or proprietary information cannot be adequately addressed by restricting IAEA access to the location. Sensitive design information which must remain in the control of the facility owner/operator should be identified early in the process. Arrangements for inspector access to such information must be established and agreed upon, e.g. storage of the information in an on-site State/operator controlled area under both IAEA and State seals.

The IAEA will perform design information examination and, if required, request clarification or additional information to resolve questions. It can use the design information to develop and to adjust its safeguards activities. The IAEA can perform DIV before concrete for a new facility is poured (e.g. to verify site characteristics or concrete forms), and will continue performing verification activities, perhaps on an intermittent basis, throughout the life cycle of the facility (see Annex II for more information about safeguards activities at each life cycle stage). During DIV at an enrichment plant, the IAEA may perform a variety of activities, such as:

— Requesting and reviewing additional information relvant to safeguards and related to design;
— Comparing process and containment design with actual construction;
— Verifying an absence of new F/W stations or piping reconfiguration;
— Verifying the usability of essential equipment[8] and assessing its throughput or capacity;
— Verifying the quality of the operator's measurement system;
— Assessing whether the site and general facility design could support undeclared nuclear operations;
— Assessing possible indicators of undeclared nuclear activities or material, including analysis of environmental samples.

[7] INFCIRC 153 (Corrected) allows a State to establish a special material balance area around a process step involving commercially sensitive information.

[8] The safeguards essential equipment list is defined in Annex I: Terminology.

GCEPs, as with other enrichment technologies, tend to involve large buildings with complex process pipework. The application of safeguards to a GCEP is facilitated if the IAEA can understand the piping network (verify the design) through visual inspection. This understanding should include all valves and flanges that could potentially be used for F/W of UF_6. Flexibility in the GCEP design might facilitate operations but can make IAEA verification of the operating configuration more difficult. SBD advises considering a design that optimizes both the operating and verification functions. In addition, the design of the processing facility can minimize locations for the nuclear material hold-up, which is in the interest of both the operator and IAEA. If UF_6 piping must pass through inaccessible spaces, the designer can consider including access panels to facilitate the design verification. The access panels can have tamper indication (e.g. optical or magnetic switches or sensors) that provide an alarm reported to the IAEA in the event that an access panel is opened. The header piping through these areas should be continuous and should not incorporate valves or the capability to withdraw process gas or to introduce material to the cascade. The IAEA will likely require mounting brackets, reliable power receptacles and cable connections if they install surveillance cameras within the confined space to verify a lack of design changes.

3.2. NUCLEAR MATERIAL ACCOUNTANCY

Nuclear material accountancy is a safeguards measure of fundamental importance that includes both the operator's accounting system and the IAEA's verification of that accounting system; it is implemented to satisfy the requirements of safeguards agreements, to verify declarations by the State and to resolve verification questions and discrepancies[9]. In enrichment plants, IAEA verification of the nuclear material accounting balance is performed for both the total uranium and the isotope ^{235}U. In some facilities a separative work unit balance is also performed by making generic separative work unit balance calculations for comparing the declared uranium and ^{235}U mass balances against designed plant separative work unit capacity. As the declared purpose of the facility is to alter the isotopic composition, independent verification of the declared isotopic composition throughout the plant is an important safeguards measure.

It is generally understood that:

— Nuclear material accounting and control can facilitate more efficient facility operation (e.g. facilitate higher throughput at lower cost or detect process upsets).
— The operator will have a system for the accounting for and control of nuclear material that includes procedures, records and measurement equipment.
— The inspectors will verify the operator's measurements and records using a variety of measures including statistical sampling [17], independent measurements and the review of records.

Other factors related to nuclear material accounting are that:

— The verification of domestic and international transfers of nuclear material can impact the verification of the facility's accounting.
— Treaty obligations on the feed material may require segregation into batches.
— Drawing samples from the feed stream or product stream may result in shipping the samples off-site for analysis.

Safeguards activities can include:

— Confirmation of the absence of borrowed nuclear material from other locations or facilities;
— Review of the operator's input into an 'inventory mailbox' [23–25, 28];
— Use of a randomized inspection scheme;
— Follow-up activities (e.g. additional measurements, review of records) to address discrepancies and anomalies.

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

Ideally for safeguards, the operator's measurement system will quickly and accurately determine the amount of uranium in the facility when the plant is running and collect this uranium inventory information in a central location. Design features that facilitate the IAEA's implementation of safeguards verification of accounting include the following:

— Access to nuclear material sampling areas with adequate space for installing IAEA equipment and for checking IAEA seals;
— The ability to monitor sample withdrawal into sample containers, including provisions to uniquely identify and maintain control of each sample;
— Secure storage on-site for IAEA sample containers under IAEA (or shared) seals or locks until shipment to a laboratory for analysis;
— Sufficient spacing and shielding for NDA measurement systems, including any shielding to minimize the impact of background radiation on the measurements.

Implementing SBD allows facility systems and operating procedures to provide for the timely submittal of nuclear material flow and inventory measurement results to the safeguards authorities. In addition, the operator's systems and procedures can be designed to provide previously agreed operating information, such as schedules, operational status and information about process upsets. To facilitate this, the operator's nuclear material accounting reporting system might require near real time access to operating and in-plant accounting information. Designers and operators can consider that IAEA inspections include interim inspections performed throughout the material balance period. Although PIV only occurs annually, interim inspections at enrichment plants are usually carried out on a monthly basis and/or unannounced inspections are carried out on a random basis several times per year. Designers should be aware that as part of interim verification activities, IAEA inspectors may need access to in-process areas such as the F/W stations and cascade halls.

UF_6 has a propensity to lead to process hold-up when exposed to air in-leakage. When a new facility begins to operate with nuclear material, process hold-up begins to occur as new, clean surfaces become passivated[10] or otherwise coated during their initial contact with the potentially corrosive nuclear material. Moreover, in routine operation, the nuclear material can collect in low points, crevices and other accumulation points in equipment, piping and ductwork. This nuclear material hold-up can be difficult to locate and to measure. Minimizing the amount of nuclear material in process locations that are difficult to measure reduces the uncertainty in the total inventory. In order to accurately determine the material balance for the facility, it is necessary to clean as much nuclear material hold-up out of the process as is practical before taking the physical inventory. The design can minimize hold-up by reducing sharp corners, irregular surfaces and dead ends in the process equipment, by sloping equipment toward drains or cleanout points, by preparing the internal surfaces to minimize coating by nuclear material and by minimizing the amount of surface area exposed to nuclear material. Where nuclear material hold-up cannot be reduced, NDA techniques can usually be applied to quantify the hold-up [29–31].

Once a GCEP reaches stable operation in enrichment and material throughput, it is uneconomic to halt the process for the taking of physical inventory. SBD advises consideration of the cost and benefits of a real time process measurement system in addition to measures to reduce and control process hold-up. During the annual physical inventory, while the plant continues routine operations, the IAEA might observe the switch out of cylinders from the F/W stations with cylinders that are already verified, to allow those in use at the time of the inventory to also be verified. Alternatively, it might make use of F/W station load cell measurements.

The MBA structure for the enrichment facility can help segregate measurement issues related to processing from those related to shipping and receiving — which can be useful in simplifying the resolution of any issues that might arise. The use of physical barriers (containment) to limit access can facilitate this segregation. In enrichment facilities, the IAEA might designate MBAs for:

— The receipt and shipment of nuclear material;
— In-process nuclear material;
— Analytical, weighing and sampling activities;
— Waste and other material.

[10] Passivation — the treatment or coating of a metal surface that renders it resistant to further corrosion and less reactive.

Receipt and shipment areas usually include a storage area for the feed cylinders that contain nuclear material to be introduced into the process and for the tails cylinders containing residue from the process. Sometimes, product cylinders are stored in the same location. If so, SBD advises that an ability to segregate previously verified cylinders be a design consideration. The solid and gaseous residual uranium remaining in a transportation cylinder after extraction of UF_6 is a safeguards concern. The periodic recertification of cylinders may also result in revised tare weights for the cylinders. Consequently, safeguards considerations should be part of the container recertification process.

The in-process areas include F/W stations, enrichment cascade halls and possibly laboratory spaces (e.g. those used to analyse samples taken from the process). In routine operation, the material flow in an enrichment plant during a material balance period greatly exceeds the in-process nuclear material inventory. Consequently, emphasis is placed on the verification of the reported feed and the reported product and tails quantities (i.e. receipts and shipments, respectively). It should be noted that tails may be shipped off the site for deconversion from UF_6 into U_3O_8 or re-enrichment to natural uranium enrichment levels. Furthermore, as noted above, at a number of enrichment plants, tails are being used as feed for enrichment to natural or even low enriched uranium levels. Material flows not only include the natural uranium feed into the enriched uranium product and tails out of the facility, but can also include plant UF_6 samples, intermediate product and recycle materials from cold traps and the heels of natural uranium in empty feed cylinders. Verification that these flows are as declared and within the expected isotopic range of the declaration is another safeguards measure.

Declarations by the State to the IAEA are required on an annual basis for the physical inventory of nuclear material in the facility, while inventory change reports can be required more frequently (e.g. monthly). In near real time accountancy with the use of a mailbox, the operator generally reports inventory changes (in an irretrievable fashion) as soon as possible to the mailbox (e.g. within a day of filling or disconnecting a cylinder) and holds the cylinder in a predefined location for a predefined time in case the IAEA sampling plan identifies that cylinder for verification. A key component in an effective and efficient material accounting system can be the use of a reliable, automated, tamper resistant process for tagging and monitoring the location and status of UF_6 cylinders. Clearly identified reserved areas can be used for cylinders due for verification, such as: just delivered, coming out of the process area or ready for shipment outside the facility. Positioning one or more scales near the aforementioned reserved areas could support efficient safeguards activities.

In general, the use of an automated cylinder monitoring system can reduce the risk of false or incorrectly reported cylinder tare weights, the diversion of nuclear material, the concealment of excess production, the utilization of undeclared cylinders and the misrepresentation of cylinder contents. An automated system could include the ability to monitor the movement of UF_6 cylinders throughout the entire facility, which could provide more effective accounting and control for operations as well as for safeguards purposes.

Facility designers and operators can play a key role in supporting IAEA nuclear material accountancy activities by:

- Providing IAEA personnel with training and refresher briefings regarding facility access rules and routine operations;
- Assisting with the collecting, packaging and transport of samples of nuclear material for IAEA analysis;
- Minimizing the radiation and chemical hazard exposure for the inspectors and equipment;
- Making a clear separation, with labelling, between IAEA and facility infrastructure and equipment.

3.3. MEASUREMENT SYSTEMS AND ISSUES

The IAEA safeguards system requires that the facility operator have a measurement system to support the operator's records and the State's declarations to the IAEA concerning nuclear material quantities and inventory changes. SBD advises that the facility be capable of providing timely reports of all inventory changes after the changes occur. To support this reporting, it is expected that the operator will implement measurement systems that conform to international standards [13, 15, 32–34], that meet international target values [14] and that meet facility requirements for safety, ease of use and security [6, 7, 35–39]. Moreover, it is expected that the design and operation of the plant will be such that:

— The nuclear material is in a measurable form at inventory and flow measurement points.
— The amount of nuclear material contained in the process area will be minimized during the taking of the annual physical inventory.
— The facility accounting system minimizes reliance on estimation or stream averages.

All measurement results have inherent uncertainties. Smaller uncertainties in the measurements of the nuclear material [14, 29, 33, 34, 40, 41] can improve verification but might be expensive or difficult to obtain. The operator's measurement equipment is generally optimized to provide excellent results for the facility materials. Consequently, the joint use of this measurement equipment can be a cost effective way to improve verification. While easier to determine, volume and weight need to be accompanied by a concentration and enrichment measurement in order to determine the quantity of nuclear material. In addition, measurement of the isotopic composition is necessary to determine the amount of ^{235}U in the uranium.

The independent DA by the IAEA of samples drawn from the nuclear material in the facility is an important safeguards measure. Although unattended in-line NDA measurement systems might reduce the IAEA impact on operations, independent and representative DA measurements may be required by the IAEA:

— As part of the sampling plan;
— For authentication of an unattended measurement system;
— For use where in-line NDA measurements are not possible;
— As part of a quality assurance/quality control programme.

At an enrichment plant, the IAEA sampling plan generally identifies a smaller number of more intrusive and time consuming but more accurate bias defect DA measurements combined with a larger quantity of less intrusive and faster but less accurate measurements.

Upon the receipt of feed cylinders at the facility, the operator inspects and weighs the UF_6 cylinders to ensure that they comply with regulations and to determine SRD. When the feed and product cylinders are to be verified by inspectors, accessibility to the cylinders in the shipping area as well as a capability to segregate verified cylinders from unverified cylinders can be facilitated in the design. IAEA measurements using scales or load cells might be used to verify declarations. In addition, inspectors might perform NDA measurements on the cylinders with portable equipment to determine uranium content or enrichment. In other cases, samples for DA might be taken.

In enrichment plants, both the operator and the IAEA typically draw samples for measurements. Standard operating procedures for sample collection and preparation should be developed and implemented to ensure representative samples are collected. Samples may be taken from process lines, UF_6 cylinders or other containers. The drawing of IAEA verification samples generally requires maintaining traceability (e.g. where, when and how the sample was drawn); strict controls on access to the samples, sampling equipment and (possibly) transfer lines; as well as secure storage for the safeguards samples, including storage of archival samples. The IAEA can be expected to observe sample drawing procedures periodically to verify the quality of the sample and to assess the uniformity of the bulk material that the sample is drawn from. The homogeneity of the bulk material from which the samples are drawn can be an issue. Routine homogenization of UF_6 cylinder contents can help reduce heterogeneity in the cylinder contents (this is generally done by the operator to obtain an accurate DA sample). In some instances, multiple samples are drawn and then mixed, to be split for comparative analyses at multiple certified laboratories (with a part being archived in case questions arise). Sampling systems and their effects on the quality of the samples can be assessed during plant design. SBD advises that the plant design and operation include authenticated and access controlled capability for drawing, handling, storing and shipping of samples, taking into account the multiple stakeholder requirements (e.g. process constraints such as cooling time for heated containers). Moreover, an on-site laboratory under IAEA control could significantly reduce the impacts of preparation for shipping and the shipping of samples off site for analysis.

The IAEA conducts NDAs on take-off header pipes to independently confirm the absence of HEU in the piping. As part of this verification activity, it is necessary for the IAEA to be able to trace the take-off header pipe from the measurement location back to the cascade. The IAEA has approved both the portable (cascade

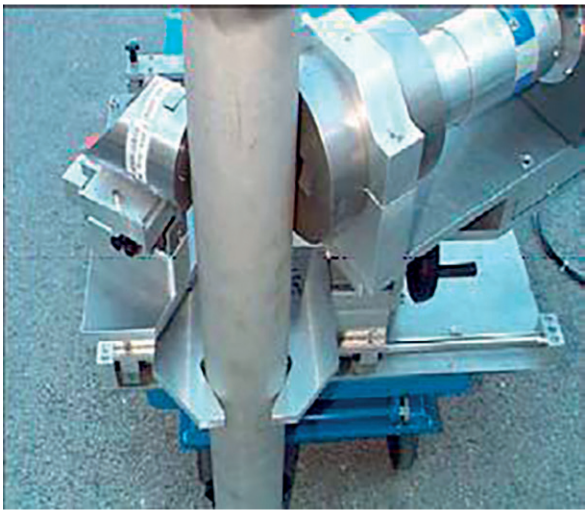

FIG. 14. Cascade header enrichment monitor system.

FIG. 15. Continuous enrichment monitor system.

header enrichment monitor — CHEM, shown in Fig. 14) and installed (continuous enrichment monitor — CEMO, shown in Fig. 15) NDA equipment for routine use[11] [15, 42]. R&D to improve the quality and reliability of these measurements is also under way [43–48] to improve and replace both types of monitor. In addition, the IAEA has a capability, at some facilities, to collect gas samples directly from the cascade for independent analysis. SBD advises that all sample related piping be visually traceable and that the facility include the ability for the IAEA to receive duplicate samples when the operator uses on-line mass spectrometers.

PIV is performed by the IAEA on a yearly basis immediately following the physical inventory taking performed by the facility operator.[12] In addition, material flows are verified during interim inspections as well as during a PIV. The potential measurement targets include NDA of cylinders, piping and cold traps as well as sample collection for DA. An evaluation based on error propagation and statistical methodologies indicates whether the MUF declared by the operator could be due to legitimate measurement error. In addition, historical MUF trend analysis helps the IAEA assess whether the uncertainties are random or if a measurement bias (or a diversion) may be causing a trend. A similar analysis can be applied to the SRD whose validity is assessed on the basis of both the shipper's and receiver's measurement uncertainties. A design to both minimize and accurately measure process

[11] Some approved equipment cannot be used in all facilities as it requires specific design characteristics, e.g. minimum pipe diameter. The URENCO facility at Capenhurst in the United Kingdom removed the CEMO and is awaiting a replacement technology.

[12] In Euratom GCEP facilities, physical inventory taking can be carried out jointly with the operator.

losses (scrap, waste and hold-up) benefits safeguards, improves the operator's efficiencies and simplifies nuclear material verification activities.

Weighing is an important verification measure at enrichment plants. Inspectors can select a subset of containers or cylinders for independent weighing using either the operator's scales or IAEA equipment.[13] To verify the accuracy of the operator's scales, inspectors may present certified weight standards for the operator to weigh. Such standards may be stored at the facility under IAEA tamper indicating seals. After weighing cylinders or containers, the IAEA may apply seals to them in order to be able to verify that the contents have not changed. For sealed containers, during subsequent inspection visits, the IAEA will focus its verification on containers without seals or on containers where seals have been compromised. To facilitate weighing activities, it is advised that:

— The stored containers or cylinders be accessible and easily moved to scales for weighing;
— The containers or cylinders be designed such that seals can be applied and any fixtures for the seals are not obviously welded on finished containers after the fact;
— Seals be accessible and protected from accidental damage;
— Certified scales with appropriate accuracies be available for weighing items.

It is important for the IAEA and State inspectors to have the opportunity to be present during the commissioning and calibration of operator and inspectorate measurement systems and to have the opportunity to reverify the systems. For example, the inspectors can use sealed check weights to check the calibration of load cells and scales. SBD advises that a designer take into consideration that procedures for operating a measurement system will include calibration, measurement control and maintenance activities [33, 34, 40, 41, 49–53]. These measurement support activities generally require dedicated, access controlled space for the storage of the calibration materials and check sources for the operator's measurement systems. Furthermore, the IAEA may require IAEA controlled space in the facility for similar items.

To reduce on-site inspector presence and to verify that operations are as declared when inspectors are not present, the IAEA has an interest in installing unattended measurement and monitoring systems [48, 54, 55]. Opportunities may exist for the joint use of these systems; if so, SBD advises that the joint use be an early design discussion as the retrofitting of IAEA authentication measures into commercial off the shelf equipment can be difficult and expensive.

3.4. MONITORING MEASURES

Although nuclear material accounting is the keystone of IAEA verification activities at a facility, the IAEA applies measures beyond IAEA accountancy, including PM, to provide additional information about a facility's operational parameters.

PM is a safeguards measure that monitors material, processes and equipment (nuclear and non-nuclear) through independent and/or shared safeguards-relevant operator measurements [56–60]. PM systems can incorporate many types of sensor, both quantitative and qualitative, and can include surveillance systems. In large facilities, PM can be used to add assurance to the verification of the accounting system or to maintain continuity of knowledge on nuclear material as it moves through a process or during transportation. It can be implemented in continuous and unattended mode, with data being stored locally, transmitted to a central on-site location or transmitted to IAEA headquarters [61–64].

During the design phase of a facility, one area for discussion and development in implementing IAEA safeguards is how to make better use of the operator's PM systems [65] either for joint use or as a complementary measure. Advantages of sharing some of the data between the operator and the inspectorate could be shared costs, less space required and fewer components to maintain. An important issue to be addressed is establishing the set of suitable and available operator's PM data for sharing with the IAEA. This decision must address issues such as the protection of proprietary information (the operator's perspective) and authentication of the data (the IAEA perspective). It may not be necessary to apply authentication measures to every sensor. If the operator data corroborate another authenticated data source, it shows that the operator data give additional confidence that the

[13] IAEA approved equipment includes alternatives to scales (e.g. load cells) [15].

plant is operating as declared. Another important issue to address is that the quantity of data obtained from PM should not overwhelm users with a substantial effort to reduce and review it. PM can be useful in reducing the impact of the safeguards measures on routine operations with relevant data. As one example, PM and surveillance can be applied to detect potential misuse of the F/W area, monitoring the inventory changes as nuclear material is fed into or withdrawn from the enrichment cascade. UF_6 cylinder portal monitors have been investigated that provide independent verification of the cylinder identity [63, 64], gross weight, uranium mass and ^{235}U mass. If necessary, an IAEA inspector could review such data in the presence of site personnel to mitigate proprietary information concerns of the removal of plant data off-site.

3.5. CONTAINMENT AND SURVEILLANCE

C/S measures can be used to verify movements of nuclear material or to verify the integrity of previously verified material (to maintain ‘continuity of knowledge’ regarding the contents of previously verified items) as well as to verify the integrity of IAEA equipment. In IAEA usage, C/S includes tamper indication of equipment, cables, images and data [66]. Surveillance cameras can be implemented using a close-up lens or at a distance from the item or activity being monitored. For example, surveillance measures can be applied to UF_6 cylinder F/W stations or tamper indicating seals can be applied to storage locations or to verified containers. Suitably located surveillance techniques can also be used to monitor for modifications to the enrichment cascade. Otherwise, means to apply tamper indicating devices[14] such as seals to detect access to the cascades or to the process piping might be necessary. This application of tamper indicating devices can facilitate confirming the absence of misuse when bringing cascade halls into initial service or during their removal from service, as well as facilitate confirming that only verified cylinders are connected to F/W stations.

C/S measures are more easily designed and applied when facility features such as structural barriers, access control, segregated storage locations and fixtures for the application of tamper indicating seals exist. Before relying on C/S measures for safeguards purposes, the IAEA will verify the characteristics of these facility design features relevant to safeguards before (and during) their safeguards use.

Well designed facility barriers should have the following characteristics:

— They segregate activities or materials of safeguards interest from other activities or materials.
— They limit the movement of nuclear material.
— They limit access to locations where nuclear material is handled or stored.
— They serve to jointly address safeguards, safety and security concerns.
— They segregate nuclear and non-nuclear items.
— They have a minimal number of penetrations that require monitoring.[15]

Tamper indicating seals might be applied to verified feed, product or scrap material, cylinders awaiting sampling, IAEA sample cabinets, the IAEA equipment locker or unused equipment. Fixtures that readily facilitate seal application are the following:

— Are highly difficult to remove or replace without leaving evidence of tampering;
— Have no externally accessible hinges on doors or hatches;
— Are integral to the design rather than giving the appearance of being an add-on or modification;
— Have loops or openings through which a tamper indicating seal’s wire or optical cable can be passed;
— Are easy to access and use and are protected from accidental damage.

Ingress and egress openings to the F/W area for personnel and equipment can be under surveillance, alarmed or sealed to detect unauthorized access. The device may be chosen depending on the frequency of access or difficulty of observation with cameras, all taking into account operator concerns for protecting sensitive information.

---

[14] Tamper indicating devices are used to join movable segments of a containment structure in a manner such that access to the contents without opening the tamper indicating device or breaking the containment is difficult.

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

3.6. LESSONS LEARNED

The implementation of safeguards at enrichment plants has evolved [20–26]. Lessons learned include:

- Intensive dialogue with the IAEA on specific safeguards measures can facilitate their implementation.
- Early consideration of safeguards along with the other disciplines that make use of the measurements of nuclear material can result in lower project risk.
- Early consideration of safeguards can allow for more useful input from designers and operators.
- Automated monitoring of the operator's process can improve the effectiveness of safeguards at lower cost and reduced inspector on-site presence.
- Segregation of activities the IAEA can monitor from those of a proprietary nature in different work areas can facilitate on-site visits.
- Segregation of the decontamination and dismantling of process components from F/W areas can simplify verification.
- Process hold-up of nuclear material can result from leaks in systems running below atmospheric pressure that are difficult to detect.
- The retention of specialist knowledge as subject matter experts retire has not always been optimal.

3.7. DECOMMISSIONING

The IAEA makes a determination that a facility has been decommissioned for safeguards purposes after it verifies both that all safeguards essential equipment has been removed or rendered unusable and that all nuclear material has been removed. The safeguards essential equipment list includes equipment essential for the operation of the enrichment facility, and the definition of this list can begin in the preliminary DIQ. Some examples of safeguards essential equipment at enrichment plants [67] are the following:

- Production rate limiting equipment;[16]
- Centrifuges (in a centrifuge facility), diffusers (in a diffusion facility), high powered magnet supplies (in an electromagnetic facility) or lasers (in a laser facility);
- Vacuum pumps;
- Cold and chemical traps;
- Specialized power supplies;
- Process cylinder cooling units;
- Process heating systems;
- Analytical mass spectrometers.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in Nuclear Facility Design and Construction, IAEA Nuclear Energy Series No. NP-T-2.8, IAEA, Vienna (2013).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safeguards and Verification (2017), https://www.iaea.org/topics/safeguards-and-verification

[3] BLANCHARD, B., System Engineering Management, 4th edn, Wiley, New York (2008).

[4] BJORNARD, T., BEAN, R., DURST, P.C., HOCKERT, J., MORGAN, J., Implementing Safeguards-by-Design, Rep. INL/EXT-09-17085, Idaho National Laboratory, Idaho Falls, ID (2010).

[5] OKKO, O., HONKAMAA, T., KUUSI, A., HÄMÄLÄINEN, M., "New nuclear power reactors to Finland: Safeguards, security and safety considerations in design", Proc. 33rd Conf. Budapest, 2011, European Safeguards Research and Development Association, Ispra, Italy (2011).

[16] This equipment allows the IAEA to routinely verify that equipment that limits production has not been modified.

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards No. GSR Part 1 (Rev. 1), IAEA, Vienna (2016).
[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, IAEA Safety Standards No. SSR-2/1 (Rev. 1), IAEA, Vienna (2016).
[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols, IAEA Services Series No. 21, IAEA, Vienna (2016).
[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Assistance for States, https://www.iaea.org/topics/assistance-for-states
[10] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safeguards Glossary, 2001 Edition, International Nuclear Verification Series No. 3, IAEA, Vienna (2002).
[11] 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).
[12] BOYER, B., SCHANFEIN, M., "International safeguards inspection: An inside look at the process", Nuclear Safeguards, Security, and Non-proliferation, DOYLE, J. (Ed.), Elsevier, Oxford (2008) Ch. 5.
[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Material Accounting Handbook, IAEA Services Series No. 15, IAEA, Vienna (2008).
[14] ZHAO, K., PENKIN, M., NORMAN, C., BALSLEY, S., International target values 2010 for measurement uncertainties in safeguarding nuclear materials, ESARDA Bull. **48** (2012) 3–24.
[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Safeguards Techniques and Equipment: 2011 Edition, International Nuclear Verification Series No. 1 (Rev. 2), IAEA, Vienna (2011).
[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Forms and Templates, https://www.iaea.org/safeguards/assistance-for-states/guidance-and-assistance/forms-and-templates
[17] JAECH, J.L., RUSSELL, M., Algorithms to Calculate Sample Sizes for Inspection Sampling Plans, STR-261 (Rev. 1), IAEA, Vienna (1991).
[18] MENZEL, J., Safeguards approach for gas centrifuge type enrichment plants, JNMM **12** 4 (1983) 30.
[19] BEDDINGFIELD, D., Process Monitoring at GCEP Facilities — Data Validation Topics, Rep. LA-UR-15-27508, Los Alamos National Laboratory, NM (2015).
[20] LAUGHTER, M., et al., Implementing Safeguards by Design at Gas Centrifuge Enrichment Plants, NGSI-SBD-006, Oak Ridge National Laboratory, TN (2012).
[21] COOLEY, J., et al., "Model Safeguards approach and innovative techniques implemented by the IAEA at gas centrifuge enrichment plants", Proc. 48th INMM Annual Mtg Tucson, AZ, INMM, Deerfield, IL (2007).
[22] GORDON, D., et al., "IAEA verification experiment at the portsmouth gaseous diffusion plant", Proc. 39th INMM Annual Mtg Naples, FL, INMM, Deerfield, IL, 1998 (1998).
[23] FISHBONE, L., et al., "Field test of short-notice random inspections for inventory-change verification at a low-enriched-uranium fuel-fabrication plant", Safeguards Technical Report STR-302/ISPO-371, IAEA, Vienna (1995).
[24] ARONSON, A., GORDON, D., The Mailbox Computer System for the IAEA Verification Experiment on HEU Downblending at the Portsmouth Gaseous Diffusion Plant, Rep. BNL-52605/ISPO-411, Brookhaven National Laboratory, New York (2000).
[25] TSVETKOV, I., et al., Implementation of short notice random inspections (SNRI) at Japanese low enriched uranium (LEU) bulk facilities — The experience gained and inspectorate perspective, IAEA-SM-367/8/05, presented at the IAEA Safeguards Symposium, Vienna, 2001.
[26] WORLD NUCLEAR TRANSPORT INSTITUTE, WNTI Standard — UF6 Cylinder Identification, Version 1, WNTI, London (2017).
[27] The Structure and Content of Agreements Between the IAEA and States Required in Connection with the Treaty on the Non-proliferation of Nuclear Weapons, INFCIRC/153 (Corrected), IAEA, Vienna (1972).
[28] BENJAMIN, R.M., "Implementation of an integrated safeguards approach for transfers of spent fuel to dry storage at multi-unit CANDU generating stations", IAEA-CN-148/113, paper presented at the IAEA Safeguards Symposium: Addressing Verification Challenges, Vienna, 2006.
[29] ASTM INTERNATIONAL, Standard Test Method for Nondestructive Assay of Special Nuclear Material Holdup Using Gamma-Ray Spectroscopic Methods, ASTM C 1455, ASTM International, West Conshohocken, PA (2014).
[30] ASTM INTERNATIONAL, Standard Guide for Nondestructive Assay of Special Nuclear Material (SNM) Holdup Using Passive Neutron Measurement Methods, ASTM C 1807, ASTM International, West Conshohocken, PA (2015).
[31] SPRINKLE, J., Jr., et al., Holdup Measurements under Realistic Conditions, Rep. LA-UR-97-2612, Los Alamos National Laboratory, NM (1997).
[32] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Measurement Management Systems — Requirements for Measurement Processes and Measuring Equipment, ISO 10012:2003, ISO, Geneva (2003).
[33] ASTM INTERNATIONAL, Standard Guide for Qualification of Measurement Methods by a Laboratory within the Nuclear Industry, ASTM C 1068, ASTM International, West Conshohocken, PA (2003).

[34] ASTM INTERNATIONAL, Standard Guide for Preparation of Working Reference Materials for Use in Analysis of Nuclear Fuel Cycle Materials, ASTM C 1128, ASTM International, West Conshohocken, PA (2001).
[35] McLAUGHLIN, T., et al., A Review of Criticality Accidents — 2000 Revision, Rep. LA-13638, Los Alamos National Laboratory, NM (2000).
[36] INTERNATIONAL ATOMIC ENERGY AGENCY, Objective and Essential Elements of a State's Nuclear Security Regime, IAEA Nuclear Security Series No. 20, IAEA, Vienna (2013).
[37] INTERNATIONAL ATOMIC ENERGY AGENCY, Use of Nuclear Material Accounting and Control for Nuclear Security at Facilities, IAEA Nuclear Security Series No. 25-G, Vienna (2015).
[38] WORLD INSTITUTE FOR NUCLEAR SECURITY, Material Control and Accountancy in Support of Nuclear Security, WINS Best Practice Guide 4.4, WINS, Vienna (2011).
[39] CARNEGIE ENDOWMENT FOR INTERNATIONAL PEACE, Nuclear Power Plant Exporters' Principles of Conduct,Carnegie Endowment for International Peace, Brussels (2014).
[40] ASTM INTERNATIONAL, Standard Guide for Establishing Calibratrion for a Measurement Method Used to Analyze Nuclear Fuel Cycle Materials, ASTM C 1156, ASTM International, West Conshohocken, PA (2018).
[41] ASTM INTERNATIONAL, Standard Guide for Establishing a Measurement System Quality Control Program for Analytical Chemistry Laboratories Within the Nuclear Industry, ASTM C 1210, ASTM International, West Conshohocken, PA (2018).
[42] WHICHELLO, J., LEBRUN, A., "The role of advanced instrumentation in support of safeguards implementation at enrichment plants", Proc. 11th Workshop on Separation Phenomena in Liquids and Gases, St. Petersburg, Russian Federation, 2010 (2010).
[43] IANAKIEV, K., et al., "Advanced technology for enrichment monitoring in UF6 gas centrifuge enrichment plants", paper presented at IAEA Safeguards Symposium, Vienna, 2010.
[44] IANAKIEV, K., et al., "Field trial of LANL on-line advanced enrichment monitor for UF6 GCEP", Proc. 53rd INMM Annual Mtg Orlando, FL, 2012, INMM, Deerfield, IL (2012).
[45] BAKER, S., DEKKER, B., FRIEND, P., IDE, K., "The introduction of a continuous enrichment monitor for safeguards applications in centrifuge enrichment plants", Proc. ESARDA Symp. Aachen, European Safeguards Research and Development Association, Ispra, Italy (1995).
[46] MILLER, K., et al., "Joint field trial considerations for UF6 cylinder assay technologies at an enrichment facility", Proc. 55th INMM Annual Mtg Atlanta, GA, 2014, INMM, Deerfield, IL (2014).
[47] ELY, J., et al., "On-Line Enrichment Monitor (OLEM): Supporting safeguards at enrichment facilities", e-poster presented at IAEA Safeguards Symposium Vienna, 2014.
[48] VELDHOF, R.J.G., MEYERING, A., ALBRIGHT, R., KORBMACHER, T., "Overview of conducted field trials at URENCO: An operator perspective", Proc. Symp. on International Safeguards: Linking Strategy, Implementation and People, 2014 (2015).
[49] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, General Requirements for the Competence of Testing and Calibration Laboratories, ISO 17025:2005, ISO, Geneva (2005).
[50] ASTM INTERNATIONAL, Standard Guide for the Selection, Training and Qualification of Nondestructive Assay (NDA) Personnel, ASTM C1490, ASTM International, West Conshohocken, PA (2014).
[51] AMERICAN NATIONAL STANDARDS INSTITUTE, ANSI Standard N15.36 Nondestructive Assay Measurement Control and Assurance, ANSI, New York (2013).
[52] ASTM INTERNATIONAL, Standard Guide for Preparing and Interpreting Precision and Bias Statements in Test Method Standards Used in the Nuclear Industry, ASTM C1215, ASTM International, West Conshohocken, PA (1992).
[53] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Determination of the Characteristic Limits (Decision Threshold, Detection Limit and Limits of the Confidence Interval) for Measurements of Ionizing Radiation: Fundamentals and Application, ISO 11929:2010, ISO, Geneva (2010).
[54] SMITH, E., LEBRUN, A., LABELLA, R., "Unattended safeguards instrumentation at centrifuge enrichment plants", Proc. ESARDA Symp. Bruges, 2013, European Safeguards Research and Development Association, Ispra, Italy (2013).
[55] MARKIN, J., STEWART, J., GOLDMAN, A., "Data analysis for neutron monitoring in an enrichment facility", Proc. Specialist Mtg on Harmonization and Standardization in Nuclear Safeguards, 4th ESARDA Annual Symp. Petten, 1982, European Safeguards Research and Development Association, Ispra, Italy (1982).
[56] JOHNSON, S., Process Monitoring for International Safeguards, Rep. INL/MIS-14-31408, Idaho National Laboratory, Idaho Falls ID (2014).
[57] BOYER, B., DURST, P., KOVACIC, D., MORGAN, J., "Process monitoring approaches for gas centrifuge enrichment plants", Proc. ANS Annual Mtg Anaheim, CA, 2008, ANS, La Grange, IL (2008).
[58] JANSSENS-MAENHOUT, G., DECHAMP, L., Process monitoring appropriate for near real time accountancy, JNMM **32** 3 (2004) 100.
[59] BURR, T., HAMADA, M., SKURIKHIN, M., WEAVER, B., Pattern recognition options to combine process monitoring and material accounting data in nuclear safeguards, Stat. Res. Lett. **1** (2012) 6–31.
[60] HOWELL, J., BEVAN, G., BURR, T., Inspector interfaces to facilitate subjective reasoning about quantities in trends, CCENDW **48** (2013) 29.

[61] TILLWICK, D.L., et al., “Strengthening of safeguards — Remote monitoring in South Africa”, IAEA-SM-367/7/09/P, paper presented at the IAEA Safeguards Symposium, Vienna, 2006.
[62] SPRINKLE, J., Jr., “UNARM (Unattended and Remote Monitoring) overview”, IAEA-SM-367/A/7/07/P, poster presented at the IAEA Safeguards Symposium, Vienna, 2001.
[63] BUSBOOM, A., SEQUEIRA, V., LANGLANDS, D., WISHARD, B., POIRIER, S., “Laser item identification system development for a laser based identification of UF6 cylinders”, The 29th ESARDA Symp. Aix-en-Provence, European Safeguards Research and Development Association, Ispra, Italy (2007).
[64] YAO, J., TADDEI, P., RUGGERI, M., BOSTRÖM, G., SEQUEIRA, V., Automatic laser-based identification for UF_6 cylinders, Mach. Vis. & Appl. **24** (2013) 305.
[65] TOMIKAWA, H., WATAHIKI, M., KUNO, Y., “The evolution of safeguards technology for bulk handling facilities for nuclear fuel cycle in Japan — from Ningyo-toge & Tokai to Rokkasho”, Proc. 55th INMM Annual Mtg Atlanta, GA, 2014, INMM, Deerfield, IL (2014).
[66] TOLK, K., MERKLE, P., APARO, M., “The impact of safeguards authentication measures on the facility operator”, Proc. 8th Intl. Conf. on Facility Operations — Safeguards Interface, Portland, OR, 2008, ANS, LA Grange, IL (2008).
[67] COOPER, H., et al., Definition of Essential Equipment for Facility Operation — An Operator’s Perspective, Rep. SRDP-R260, Department of Trade and Industry, London (2002).

BIBLIOGRAPHY

Strengthening of Agency Safeguards, The Provision and Use of Design Information, GOV/2554/Att. 2/Rev. 2, IAEA, Vienna (1992).

Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC 540 (Corrected), IAEA, Vienna (1997).

ASTM INTERNATIONAL, West Conshohocken, PA

Standard Guide for Making Quality Nondestructive Assay Measurements, ASTM C 1592 (2009).

Standard Test Method for Nondestructive Assay of Special Nuclear Material in Waste by Passive and Active Neutron Counting Using a Differential Die-Away System, ASTM C 1493 (2009).

Standard Guide for Design of Equipment for Processing Nuclear and Radioactive Materials, ASTM C 1217 (2012).

Standard Guide for Establishing a Quality Assurance Program for Analytical Chemistry Laboratories within the Nuclear Industry, ASTM C 1009 (2013).

Standard Test Method for Determination of Uranium or Plutonium Isotopic Composition or Concentration by the Total Evaporation Method Using a Thermal Ionization Mass Spectrometer, ASTM C 1672 (2017).

Standard Test Method for Measurement of ^{235}U Fraction Using the Enrichment Meter Principle, ASTM C 1514 (2017).

Standard Test Method for Nondestructive Assay of Nuclear Material in Scrap and Waste by Passive-Active Neutron Counting Using a ^{252}Cf Shuffler, ASTM C 1316 (2017).

Standard Test Method for Nondestructive Assay of Special Nuclear Material in Low-Density Scrap and Waste by Segmented Passive Gamma-ray Scanning, ASTM C 1133 (2018).

BARI, R., et al., Facility Safeguardability Assessment Report, Rep. PNNL-20829, Pacific Northwest National Laboratory, Richland, WA (2011).

CARCHON, R., et al., Load cell monitoring in gas centrifuge enrichment plants: Potentialities for improved safeguard verifications, NEDEAU **24** 1 (2011) 349356.

COJAZZI, G.G.M., RENDA, G., SEVINI F., Proliferation resistance characteristics of advanced nuclear energy systems: A safeguardability point of view, ESARDA Bull. **39** (2008).

GENERATION IV INTERNATIONAL FORUM, Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems, Rev. 6, The Proliferation Resistance and Physical Protection Evaluation Methodology Working Group, GIF, Paris (2011).

INTERNATIONAL ATOMIC ENERGY AGENCY, Vienna

Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual — Proliferation Resistance, Volume 5 of the Final Report of Phase 1 of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1575 Rev. 1 (2007).

Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA Safeguards, IAEA Safeguards Technical Report No. IAEA-STR-360 (2009).

Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13 (2011).

Project Management in Nuclear Power Plant Construction: Guidelines and Experience, IAEA Nuclear Energy Series No. NP-T-2.7 (2012).

Milestones in the Development of a National Infrastructure for Nuclear Power, IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1) (2015).

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Geneva

Subsampling of Uranium Hexafluoride in the Liquid Phase, ISO 9894 (1996).

Nuclear Energy — Isotopic Analysis of Uranium Hexafluoride — Double Standard Gas-Source Mass Spectrometric Method, ISO 15647 (2004).

Nuclear Facilities — Criteria for the Design and Operation of Ventilation Systems for Nuclear Installations other than Nuclear Reactors, ISO 17873 (2004).

Sampling Airborne Radioactive Materials from the Stacks and Ducts of Nuclear Facilities, ISO 2889 (2010).

SCHWALBACH, P., SMEJKAL, A., ROESGEN, E., GIRARD, T., RADAR and CRISP — Standard tools of the European Commission for remote and unattended data acquisition and analysis for safeguards, IAEA-CN-148/195P, paper presented at the IAEA Safeguards Symposium: Addressing Verification Challenges Vienna, 2006.

SEVINI, F., RENDA, G., SIDLOVA, V., "A safeguardability check-list for safeguards by design", ESARDA 33rd Annual Meeting (Proc. Int. Symp. Budapest, 2011), Publications Office of the European Union, Luxembourg (2011).

SMITH, L.E., LEBRUN, A.R., LABELLA, R., Unattended safeguards instrumentation at centrifuge enrichment plants, ESARDA Bull. **51** (2014).

UNITED STATES DEPARTMENT OF ENERGY, Next Generation Safeguards Initiative (2017), https://www.energy.gov/sites/prod/files/2017/10/f37/Next%2520Generations%2520Safeguards%2520Initiative_0%5B1%5D.pdf

UNITED STATES DEPARTMENT OF ENERGY, OFFICE OF NONPROLIFERATION AND INTERNATIONAL SECURITY, Next Generation Safeguards — Safeguards by Design, (Proc. 3rd Int. NGSI Mtg, 14–15 December 2010), USDOE, Washington, DC (2011).

Annex I

TERMINOLOGY

Like any technical field, IAEA safeguards has its own lexicon and applies specialized meanings to many words in common everyday usage. This annex offers simple definitions for terminology used in the field; many, but not all of the terms, are used in this publication. More complete explanations as well as translations of these terms into eight languages can be found in the IAEA Safeguards Glossary[1].

NUCLEAR AND NON-NUCLEAR MATERIAL

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

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

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

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

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

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

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

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

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

NUCLEAR INSTALLATIONS AND EQUIPMENT

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

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

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

---

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

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

NUCLEAR MATERIAL ACCOUNTANCY

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

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

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

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

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

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

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

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

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

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

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

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

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.

---

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

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

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

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

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

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

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

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

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

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

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

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

CONTAINMENT AND SURVEILLANCE

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

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

---

3 An inspection for which less advance notice, e.g. 24 hours, is provided by the IAEA to the State than that provided for under para. 83 of The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-proliferation of Nuclear Weapons, INFCIRC/153/Corr., IAEA, Vienna (1972).

4 An inspection performed on a date chosen randomly.

5 This definition differs from that generally used in safety.

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

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

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

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

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

MISCELLANEOUS

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

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

Annex II

SAFEGUARDS CONSIDERATIONS IN FACILITY LIFE CYCLE STAGES

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

II–1. CONCEPTUAL DESIGN

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

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

II–2. BASIC DESIGN

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

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

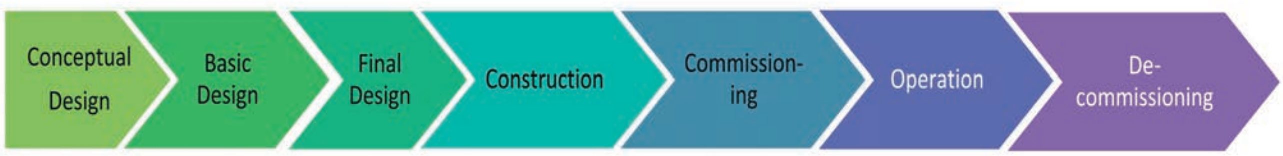

FIG. II–1. Facility life cycle stages.

II–3. FINAL DESIGN

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

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

II–4. CONSTRUCTION

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

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

II–5. COMMISSIONING

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

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

II–6. OPERATION

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

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

---

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

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

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

II–7. DECOMMISSIONING

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

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

Annex III

IDENTIFYING SAFEGUARDABILITY ISSUES

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

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

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

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

The screening questions in Table III–1 may be helpful in assessing safeguardability of a facility design, particularly as compared with a design of a similar facility which has an established safeguards approach.

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

TABLE III–1. FACILITY SAFEGUARDABILITY ASSESSMENT

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

Annex IV

DESIGN INFORMATION QUESTIONNAIRE INFORMATION FOR ENRICHMENT 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.

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

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

ABBREVIATIONS

C/S	containment and surveillance
CSA	comprehensive safeguards agreement
DA	destructive assay/analysis
DIQ	design information questionnaire
DIV	design information verification
F/W	feed and withdrawal
GCEP	gas centrifuge enrichment plant
HEU	high enriched uranium
LOF	location outside a facility [containing nuclear material]
MBA	material balance area
MUF	material unaccounted for
NDA	non-destructive assay
PIV	physical inventory verification
PM	process monitoring
RFID	radiofrequency identification
SBD	safeguards by design
SRA	State or regional authority responsible for safeguards implementation[1]
SRD	shipper–receiver difference

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

CONTRIBUTORS TO DRAFTING AND REVIEW

Amaraggi, D.	International Atomic Energy Agency
Ansaranta, T.	Radiation and Nuclear Safety Authority, Finland
Boyer, B.	Los Alamos National Laboratory, United States of America
Bruno, A.	International Atomic Energy Agency
Button, P.	Canadian Nuclear Safety Commission, Canada
Canadell-Bofarull, V.	European Commission
Catton, A.	International Atomic Energy Agency
Cazalet, J.	French Alternative Energies and Atomic Energy Commission, France
Chahid, A.	International Atomic Energy Agency
Chinondo, H.	International Atomic Energy Agency
Ciuculescu, C.	International Atomic Energy Agency
Coadou, J.	European Commission
Cohen-Unger, S.	Consultant, Australia
Cojazzi, G.	Joint Research Centre, European Commission
Cooley, J.	International Atomic Energy Agency
Dale, D.	Los Alamos National Laboratory, United States of America
Dams, C.	Federal Agency for Nuclear Control, Belgium
Defrancia, C.	International Atomic Energy Agency
Disser, J.	International Atomic Energy Agency
Dyck, G.	International Atomic Energy Agency
Fairbairn Tuley, N.	International Atomic Energy Agency
Fernandez Moreno, S.	Brazilian–Argentine Agency for Accounting and Control of Nuclear Materials, Argentina
Francis, S.	National Nuclear Laboratory, United Kingdom
Friend, P.	Consultant, United Kingdom
Furnish, K.	International Atomic Energy Agency
Gauthier, A.	Canadian Nuclear Safety Commission, Canada
Grigoriev, A.	International Atomic Energy Agency
Habjouqa, A.	International Atomic Energy Agency
Hanks, D.	Nuclear Regulatory Commission, United States of America
Homer, A.	Sellafield Ltd, United Kingdom

Honghe, Y.	China Institute of Atomic Energy, China
Honkamaa, T.	Radiation and Nuclear Safety Authority, Finland
Janin, V.	AREVA, France
Johnson, S.	Tucker Creek Consulting, United States of America
Johnson, S.	Springfields Fuel Fabrication, United Kingdom
Kavka, A.	European Commission
Kent, M.	Canadian Nuclear Safety Commission, Canada
Korbmacher, T.	Urenco, Germany
Koutsoyannopoulos, C.	European Commission
Kovacic, D.	Oak Ridge National Laboratory, United States of America
Kyffin, J.	Sellafield Ltd, United Kingdom
Lahti, M.	Posiva Oy, Finland
LeBrun, A.	International Atomic Energy Agency
Marie, Y.	European Commission
Martikka, E.	Radiation and Nuclear Safety Authority, Finland
Mathews, C.	International Atomic Energy Agency
McCarthy, W.	Department of Energy and Climate Change, United Kingdom
Miller, M.	Los Alamos National Laboratory, United States of America
Moldovan, B.	International Atomic Energy Agency
Moran, B.	Nuclear Regulatory Commission, United States of America
Niemeyer, I.	Forschungszentrum Jülich, Germany
Okko, O.	Radiation and Nuclear Safety Authority, Finland
Orton, C.	Pacific Northwest National Laboratory, United States of America
Ozols, A.	European Commission
Paterson, R.	Sellafield Ltd, United Kingdom
Pederson, A.	Oak Ridge National Laboratory, United States of America
Peixoto, O.	Brazilian–Argentine Agency for Accounting and Control of Nuclear Materials, Brazil
Phillips, J.	International Atomic Energy Agency
Pickett, S.	International Atomic Energy Agency
Ping, H.	Permanent Mission of the People’s Republic of China to the IAEA, China
Plumb, E.	International Atomic Energy Agency
Poirier, S.	International Atomic Energy Agency

Portaix, C.	International Atomic Energy Agency
Pshakin, G.	Institute of Physics and Power Engineering, Russian Federation
Qun, Y.	Consultant, China
Raymond, P.	French Alternative Energies and Atomic Energy Commission, France
Remagen, H.	Consultant, Germany
Renda, G.	Joint Research Centre, European Commission
Rezniczek, A.	UBA Unternehmensberatung, Germany
Rissanen, J.	International Atomic Energy Agency
Rockwood, L.	International Atomic Energy Agency
Schanfein, M.	Pacific Northwest National Laboratory, United States of America
Seppala, M.	Fennovoima Oy, Finland
Sidlova, V.	State Office for Nuclear Safety, Czech Republic
Smith, E.	Pacific Northwest National Laboratory, United States of America
Sprinkle, J.	Los Alamos National Laboratory, United States of America
Sprule, U.	European Commission
Stanley, W.	International Atomic Energy Agency
Starz, A.	International Atomic Energy Agency
Stein, G.	Consultant, Germany
Stein, M.	Canberra Industries (AREVA), United States of America
Swan, K.	International Atomic Energy Agency
Tushingham, J.	National Nuclear Laboratory, United Kingdom
Van der Meer, K.	Belgian Nuclear Research Centre (SCK•CEN), Belgium
Van Sickle, M.	International Atomic Energy Agency
Whichello, J.	Consultant, Australia
Wonder, E.	Consultant, United States of America

Consultants Meetings

Vienna, Austria: 28–31 October 2008, 11–14 September 2012, 25–28 March 2013, 23–27 September 2013

Structure of the IAEA Nuclear Energy Series

Nuclear Energy Basic Principles
NE-BP

Nuclear General Objectives
NG-O

- 1. Management Systems — NG-G-1.# — NG-T-1.#
- 2. Human Resources — NG-G-2.# — NG-T-2.#
- 3. Nuclear Infrastructure and Planning — NG-G-3.# — NG-T-3.#
- 4. Economics — NG-G-4.# — NG-T-4.#
- 5. Energy System Analysis — NG-G-5.# — NG-T-5.#
- 6. Knowledge Management — NG-G-6.# — NG-T-6.#

Nuclear Power Objectives
NP-O

- 1. Technology Development — NP-G-1.# — NP-T-1.#
- 2. Design and Construction of Nuclear Power Plants — NP-G-2.# — NP-T-2.#
- 3. Operation of Nuclear Power Plants — NP-G-3.# — NP-T-3.#
- 4. Non-Electrical Applications — NP-G-4.# — NP-T-4.#
- 5. Research Reactors — NP-G-5.# — NP-T-5.#

Nuclear Fuel Cycle Objectives
NF-O

- 1. Resources — NF-G-1.# — NF-T-1.#
- 2. Fuel Engineering and Performance — NF-G-2.# — NF-T-2.#
- 3. Spent Fuel Management and Reprocessing — NF-G-3.# — NF-T-3.#
- 4. Fuel Cycles — NF-G-4.# — NF-T-4.#
- 5. Research Reactors — Nuclear Fuel Cycle — NF-G-5.# — NF-T-5.#

Radioactive Waste Management and Decommissioning Objectives
NW-O

- 1. Radioactive Waste Management — NW-G-1.# — NW-T-1.#
- 2. Decommissioning of Nuclear Facilities — NW-G-2.# — NW-T-2.#
- 3. Site Remediation — NW-G-3.# — NW-T-3.#

Key

BP:	Basic Principles
O:	Objectives
G:	Guides
T:	Technical Reports
Nos 1-6:	Topic designations
#:	Guide or Report number (1, 2, 3, 4, etc.)

Examples

NG-G-3.1:	Nuclear General (**NG**), Guide, Nuclear Infrastructure and Planning (topic **3**), **#1**
NP-T-5.4:	Nuclear Power (**NP**), Report (**T**), Research Reactors (topic **5**), **#4**
NF-T-3.6:	Nuclear Fuel (**NF**), Report (**T**), Spent Fuel Management and Reprocessing (topic **3**), **#6**
NW-G-1.1:	Radioactive Waste Management and Decommissioning (**NW**), Guide, Radioactive Waste (topic **1**), **#1**

IAEA
International Atomic Energy Agency

No. 26

ORDERING LOCALLY

IAEA priced publications may be purchased from the sources listed below or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

NORTH AMERICA

Bernan / Rowman & Littlefield

15250 NBN Way, Blue Ridge Summit, PA 17214, USA
Telephone: +1 800 462 6420 • Fax: +1 800 338 4550
Email: orders@rowman.com • Web site: www.rowman.com/bernan

Renouf Publishing Co. Ltd

22-1010 Polytek Street, Ottawa, ON K1J 9J1, CANADA
Telephone: +1 613 745 2665 • Fax: +1 613 745 7660
Email: orders@renoufbooks.com • Web site: www.renoufbooks.com

REST OF WORLD

Please contact your preferred local supplier, or our lead distributor:

Eurospan Group

Gray’s Inn House
127 Clerkenwell Road
London EC1R 5DB
United Kingdom

Trade orders and enquiries:

Telephone: +44 (0)176 760 4972 • Fax: +44 (0)176 760 1640
Email: eurospan@turpin-distribution.com

Individual orders:

www.eurospanbookstore.com/iaea

For further information:

Telephone: +44 (0)207 240 0856 • Fax: +44 (0)207 379 0609
Email: info@eurospangroup.com • Web site: www.eurospangroup.com

Orders for both priced and unpriced publications may be addressed directly to:

Marketing and Sales Unit
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530 • Fax: +43 1 26007 22529
Email: sales.publications@iaea.org • Web site: www.iaea.org/publications

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA
ISBN 978–92–0–104419–8
ISSN 1995–7807