NIS Office of Nuclear
Safeguards and Security

NEXT GENERATION
SAFEGUARDS INITIATIVE
Safeguards-By-Design Facility Guidance Series (NGSI-SBD-006)

September 2012

Guidance for Gas Centrifuge Enrichment Plants

National Nuclear Security Administration

Office of Nonproliferation and International Security (NIS)

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2012/364

Implementing Safeguards-by-Design at Gas Centrifuge Enrichment Plants

September 2012

UT-BATTELLE

ORNL-27 (4-00)

DOCUMENT AVAILABILITY

Reports produced after January 1, 1996, are generally available free via the U.S. Department of Energy (DOE) Information Bridge.

Web site http://www.osti.gov/bridge

Reports produced before January 1, 1996, may be purchased by members of the public from the following source.

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone 703-605-6000 (1-800-553-6847)
TDD 703-487-4639
Fax 703-605-6900
E-mail info@ntis.gov
Web site http://www.ntis.gov/support/ordernowabout.htm

Reports are available to DOE employees, DOE contractors, Energy Technology Data Exchange (ETDE) representatives, and International Nuclear Information System (INIS) representatives from the following source.

Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
Telephone 865-576-8401
Fax 865-576-5728
E-mail reports@osti.gov
Web site http://www.osti.gov/contact.html

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/TM-2012/364

Implementing Safeguards-by-Design at Gas Centrifuge Enrichment Plants

Mark Laughter
Janie McCowan
Brent McGinnis
Jim Morgan*
Michael Whitaker
Ann Pederson

*Through subcontract with InSolves Associates

September 2012

Prepared by
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE 37831-6283
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

This page intentionally blank.

CONTENTS

Page

This page intentionally blank.

FIGURES

This page intentionally left blank.

ABBREVIATED ACRONYMS

CEMO	continuous enrichment monitor
CHEM	cascade header enrichment monitor
C/S	containment/surveillance
DA	destructive analysis
DIQ	design information questionnaire
DIV	design information verification
F/W	feed and withdrawal
GCEP	gas centrifuge enrichment plant
HEU	highly enriched uranium
HPGe	high-purity germanium
IAEA	International Atomic Energy Agency
ID	identification
KMP	key measurement point
LEU	low-enriched uranium
LFUA	Low-frequency, unannounced access
MBA	material balance area
MC&A	material control and accounting
NDA	nondestructive assay
NPT	*Treaty on the Non-Proliferation of Nuclear Weapons*
PIV	physical inventory verification
SBD	Safeguards-By-Design
SME	subject matter expert
SNRI	short notice random inspection
SRA	State Regulatory Authority
SWU	separative work unit
TID	tamper-indicating device
UF_6	uranium hexafluoride

This page intentionally left blank.

1. INTRODUCTION AND PURPOSE

This document is part of a series of guidance documents developed by the National Nuclear Security Administration's Next Generation Safeguards Initiative to assist facility designers and operators in implementing international Safeguards-by-Design (SBD). SBD has two main objectives: (1) to avoid costly and time-consuming redesign work or retrofits of new nuclear fuel cycle facilities and (2) to make the implementation of international safeguards more effective and efficient at such facilities. In the long term, the attainment of these goals would save both industry and the International Atomic Energy Agency (IAEA) time, money, and resources—a mutually beneficial win-win endeavor.

The purpose of the IAEA safeguards system is to provide credible assurance to the international community that nuclear material and other specified items are not diverted from peaceful nuclear uses.[1] The safeguards system consists of the IAEA's statutory authority to establish safeguards, the safeguards rights and obligations in safeguards agreements and additional protocols, and technical measures implemented pursuant to those agreements. Of foremost importance as a basis for IAEA safeguards is the international safeguards agreement between a country and the IAEA, concluded pursuant to the *Treaty on the Non-Proliferation of Nuclear Weapons* (NPT).

According to a 1992 IAEA Board of Governors decision[2], countries must notify the IAEA of a decision to construct a new nuclear facility as soon as such decision is taken, provide design information on such facilities as the designs develop, and provide detailed design information (called a "Design Information Questionnaire" in IAEA parlance) based on construction plans at least 180 days prior to the start of construction and on "as-built" designs at least 180 days before the first receipt of nuclear material. Since the main interlocutor with the IAEA in each country is a State Regulatory Authority (SRA) or Regional Regulatory Authority (e.g., EURATOM), the responsibility for transferring this design information falls to the SRA.

For the nuclear industry to reap the benefits of SBD (i.e., avoided costs and averted schedule slippages), designers/operators should work closely with the SRA as soon as a decision is taken to build a new nuclear facility. Ideally, this interaction should begin during the conceptual design phase and continue throughout construction and start-up of a nuclear facility. Such early coordination and planning could influence decisions on, for example, the chemical processing flowsheet and design, the material storage and handling arrangements, and the facility layout. Communication among the designer, operator, SRA, and IAEA should be frequent and iterative throughout the design/construction/start-up. This dialog will help to more effectively and efficiently incorporate IAEA safeguards into the design of nuclear facilities and to minimize misunderstandings that could arise from misinterpretation of the safeguards input and guidance.

1 *The Safeguards System of the International Atomic Energy Agency*, http://www.iaea.org/OurWork/SV/Safeguards/documents/safeg_system.pdf

2 IAEA Board of Governors Document GOV/2554/Attachment 2/Rev.2

2. KEY DEFINITIONS

CEMO	continuous enrichment monitor	An unattended monitor placed on piping to monitor material enrichment and send periodic messages to the IAEA.
CHEM	cascade header enrichment monitor	A portable monitor that is placed on header pipes by the IAEA to monitor material enrichment.
C/S*	containment/surveillance	The use of C/S measures is aimed at verifying information on movement of nuclear or other material, equipment, and samples or preservation of the integrity of safeguards-relevant data. C/S measures cover the periods when the inspector is absent, thus ensuring the continuity of knowledge for the IAEA and contributing to cost-effectiveness.
DA*	destructive analysis	A method used to determine nuclear material content and, if required, the isotopic composition of chemical elements present in a sample. The DA method normally involves destruction of the physical form of the sample.
DIQ	design information questionnaire	Means used by the State to submit design information to the IAEA.
DIV*	design information verification	An activity carried out by the IAEA at a facility to verify the correctness and completeness of the design information provided by the State. An initial DIV is performed on a newly built facility to confirm that the as-built facility is as declared. A DIV is performed periodically on existing facilities to confirm the continued validity of the design information and of the safeguards approach.
F/W	feed and withdrawal	Stations within a GCEP where uranium hexafluoride is transferred between cascades into cylinders.
GCEP	gas centrifuge enrichment plant	A facility that performs uranium isotope separation using gas centrifuges.
HEU*	highly enriched uranium	Uranium containing 20% or more of the isotope ^{235}U.
HPGe	high-purity germanium	A radiation detection technology that utilizes high-purity germanium and provides sufficient information to accurately and reliably identify radionuclides from their passive gamma ray emissions.
IAEA	International Atomic Energy Agency	An international organization created to promote the peaceful use of nuclear energy and inhibit its use for military purpose through systems of safeguards.
ID*	identification	Tag or other means to identify a specific item.
KMP*	key measurement point	Locations where nuclear material appears in such a form that it may be measured to determine material flow or inventory. KMPs thus include, but are not limited to, the inputs and outputs (including measured discards) and storages in material balance areas.

LEU*	low-enriched uranium	Enriched uranium containing less than 20% of the isotope ^{235}U.
LFUA*	Low-frequency, unannounced access	An inspection developed specifically for GCEPs; it is performed with low frequency and unannounced access to the cascade area of the plant concerned.
MBA*	material balance area	An area in or outside of a facility such that (a) the quantity of nuclear material in each transfer into or out of each MBA can be determined; and (b) the physical inventory of nuclear material in each MBA can be determined when necessary, in accordance with specified procedures, in order that the material balance for Agency safeguards purposes can be established.
MC&A	material control and accounting	The comprehensive, integrated technical and administrative programs for nuclear material control, inventories (including measurement and measurement control), accounting, and reporting activities.
NDA*	nondestructive assay	Method to determine the nuclear material content or the elemental or isotopic concentration of an item without producing significant physical or chemical changes in the item. It is generally carried out by observing the radiometric emission or response from the item and by comparing that emission or response with a calibration based on essentially similar items whose contents have been determined through destructive analysis.
PIV*	physical inventory verification	Is an inspection activity that follows closely, or coincides with, the physical inventory by the operator and closes the material balance period. The basis for a PIV is the list of inventory items prepared by the operator. The data are correlated with the physical inventory listing reports submitted by the State to the IAEA.
SBD	Safeguards-By-Design	A design approach whereby international and State safeguards are designed into the process of a nuclear facility, from initial planning through design, construction, and operation.
SME	subject matter expert	A person who is an expert in a particular area or topic.
SNRI*	short notice random inspection	An inspection performed both on short notice and randomly. SNRIs are part of a safeguards approach to provide improved coverage of domestic transfers of nuclear material.

SRA	Safeguards Regulatory Authority	A State or Regional agency responsible for exercising autonomous authority in a regulatory or supervisory capacity over the State's safeguards responsibilities. In most cases the State has a Safeguards Regulatory Authority except where a Regional Safeguards Regulatory Authority exists.
SWU	separative work unit	Unit of separation done by an enrichment process.
TID	tamper-indicating device	A device that makes unauthorized access to the protected object easily detected. Seals, markings or other techniques may be tamper indicating.
U	uranium	A naturally occurring radioactive element with atomic number 92 and symbol U. Natural uranium contains isotopes 234, 235, and 238; uranium isotopes 232, 233, and 236 are produced by transmutation.
UF_6	uranium hexafluoride	A volatile compound of uranium and fluorine that is a white crystalline solid at room temperature and atmospheric pressure but vaporizes upon heating, at 56.6°C. The gas is made and purified at a conversion plant and then shipped to an enrichment facility, where it is used as feedstock in the enrichment process.

* "IAEA Safeguards Glossary: 2001 Edition", International Atomic Energy Agency, 2001.

3. IAEA SAFEGUARDS

To understand and apply the design considerations and recommendations for a gas centrifuge enrichment plant (GCEP), a basic understanding of IAEA safeguards objectives and activities is needed. A main goal of the SBD initiative is to inform designers of IAEA safeguards objectives and the activities that inspectors currently perform to accomplish their jobs such that designers can make the design choices that will enable the application of safeguards in a more economical, effective, and efficient manner.

3.1 SAFEGUARDS OBJECTIVES

At the most fundamental level, the IAEA defines the objective of safeguards to be "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."[3] For GCEPs the overall objective of detecting and deterring diversion of nuclear material is broken down into three facility-level objectives:

- detecting diversion of declared material,
- detecting undeclared feed and resulting production of excess low-enriched uranium (LEU), and
- detecting undeclared production of highly enriched uranium (HEU).

3.2 TRADITIONAL AND INTEGRATED SAFEGUARDS

Traditionally, the plant operator makes an accountancy declaration of the material balance for the GCEP, and the IAEA verifies the declaration. The verification measures include the verification of plant design information, auditing of records and reports, and independent measurement of a portion of the nuclear materials that comprise the flows and inventories of the declared material balance.

Other safeguards measures are needed to detect undeclared processing. The IAEA uses short notice random inspections (SNRIs) during the year to gain more flexibility and unpredictability in conducting inspections. These inspections are performed as a means to detect and deter diversion and misuse of nuclear materials. Also, unattended monitoring methods which are capable of detecting the diversion of declared material, the excess production of LEU, and the undeclared production of HEU are utilized.

A summary of the general relationships between the safeguards objectives for a GCEP, current safeguard technologies being used, and possible new applicable safeguards technologies is presented in Appendix 1 of this report.

3.3 SAFEGUARDS RESPONSIBILITIES

3.3.1 State/Regional Regulatory Authority Responsibilities

The SRA is responsible for notifying the IAEA of the planned construction of a nuclear facility when the decision to build is approved by the State. The SRA provides progressively more detailed design information to the IAEA as the project moves through the design and construction phases. The responsibility for providing the information to the SRA to meet the requirements of the applicable international safeguards agreement and for facilitating IAEA inspector access to the facility falls upon

3 *The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons*, IAEA INFCIRC/153 (Corrected), Vienna, June 1972.

the facility owner/operator. The owner/operator interactions are with the SRA, who interacts with the IAEA and who obtains the design information from the owner/operator and its designer. At the time of the decision to construct, or to authorize the construction of any nuclear facility, the SRA should provide information to the IAEA that will

- facilitate incorporating features into the facility design—including the design of the nuclear materials accountancy system—which will make it easier to implement safeguards at the facility;
- allow time for safeguards research and development work that may be necessary;
- enable the IAEA to do the budgetary planning necessary to effectively and efficiently implement safeguards;
- permit identifying and scheduling of actions which need to be taken jointly by the State, the facility operator, and the IAEA, including the installation of safeguards equipment during construction of the facility; and
- verify design information of the facility.

In order to ensure that the early provision of design information on new or modified facilities is adequate and meets IAEA requirements, the SRA should do the following:

- Inform the IAEA of new nuclear facilities and activities and any modifications to existing facilities via the provision of preliminary design information as soon as the decision to construct, to authorize construction, or to modify has been taken.
- Provide the IAEA with further information on designs as they are developed. The information should be provided early in the project definition, preliminary design, construction, and commissioning phases.
- Provide the IAEA with completed Design Information Questionnaires (DIQ) for new facilities based on preliminary construction plans as early as possible, not later than 180 days prior to the start of construction. DIQs based on "as-built" designs should be provided as early as possible, but not later than 180 days before the first receipt of nuclear material at the facility.

The IAEA uses design information to (1) develop the safeguards approach, (2) establish the list of facility-specific equipment, systems and structures essential for the declared operation of a facility, and (3) prepare the Facility Attachment. The DIQ forms the basis for the practical implementation of IAEA safeguards at the facility. The DIQ contains safeguards-relevant information that includes, but is not limited to

- facility identification, location, layout, purpose (including material type), and status;
- site practices (including procedures for creating material accountancy source data);
- measurement locations, instrumentation, and accuracies; and
- material balance area (MBA) structure.

3.3.2 IAEA Responsibilities

The principal responsibility of the IAEA in safeguarding the facility is to verify that the GCEP operations are as declared by the operator, and that no diversion of nuclear material or production of undeclared material outside of safeguards has taken place at the facility. The IAEA will perform independent measurements, with separate instruments where possible. To facilitate accountability efforts, the plant is divided into MBAs over which the nuclear material inventory is determined and verified. While IAEA inspectors make use of samples for destructive assay (DA), the majority of their measurements will be nondestructive assay (NDA) of product and waste streams, with process monitoring (e.g., online enrichment meters) and containment/surveillance (C/S) (e.g., seals, tamper-indicating covers, cameras) to allow them to follow nuclear material movement and verify that it occurred as declared.

4. ELEMENTS OF FACILITY DESIGN THAT ARE RELEVANT FOR SAFEGUARDS

GCEPs are often very large facilities, typified by large lengths of process pipes carrying uranium hexafluoride (UF_6) between separation areas containing centrifuge machines and feed and withdrawal (F/W) stations. The complexity of the process and the sensitivity of the equipment make establishing independent material accountancy in GCEPs quite difficult. The general flow of nuclear material in a GCEP is described in Fig. 1.

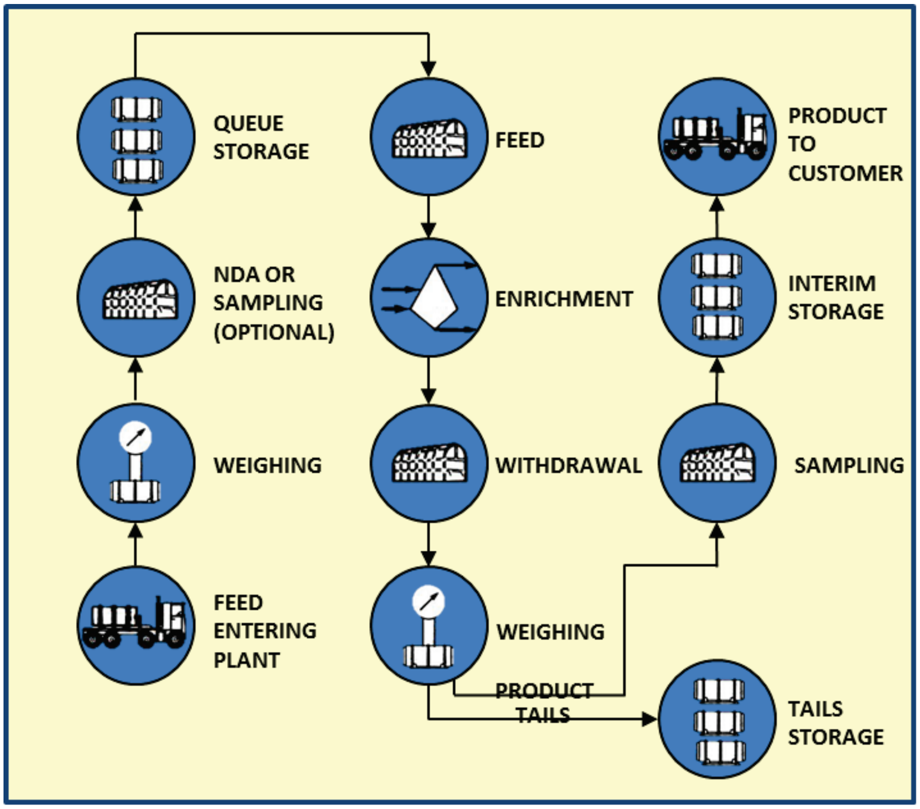

Fig. 1. Typical GCEP flowsheet.

4.1 DESIGN FEATURES THAT IMPACT SAFEGUARDS

Ideally, the engagement with IAEA regarding its safeguards approach to the facility and the specific IAEA safeguards tools and measures and inspection activities that the facility must accommodate should commence early in the design phase of a GCEP, giving the IAEA an opportunity to input its needs prior to design finalization. Once the project enters the construction and start-up phases, it is important for this dialogue to be an on-going iterative process.

The configuration of processing equipment, piping, and material storage areas can have a direct impact on the ability to perform safeguards verification activities at both storage and key measurement points (KMPs) in the process. The facility layout (e.g., physical structure and boundaries) can directly areas affect how MBAs are determined. MBAs and KMPs are key components that provide the ability to effectively measure the enrichment levels, material flow, and inventory of nuclear materials in the GCEP.

Several factors need to be considered when determining the number, locations, and structure of MBAs at the facility. Recommendations for the MBA and sub-MBA structure are as follows:

- Physical boundaries for MBAs should be considered within the conceptual design of the facility.
- Software/hardware to automate material transfers should be considered.
- Automated uploads to the IAEA "mailbox" declaration interface and the state accounting system should be included in the design.
- Key measurement points and systems should be identified.

4.1.1 Misuse and Diversion Scenarios

The capability of GCEPs to change the isotopic concentration of uranium makes enrichment a sensitive process and creates a proliferation concern. Thus nuclear materials accountancy is of fundamental importance to IAEA safeguards in a GCEP, and designers should take steps to understand all possible misuse and diversion scenarios. This includes not just the material itself but also the facility structure and how it relates to system processes and storage areas.

Particular attention should be paid to all possible F/W scenarios that permit misuse of the facility, even if the scenario appears impractical from an operator's perspective. Design features should be engineered into the cascades that either restrict or disable the use of auxiliary systems that could be used to divert material from the inventory. The design should incorporate the capability to detect misuse of any auxiliary system component for diverting cascade inventory.

5. KEY ELEMENTS OF SAFEGUARDS APPROACH TO GCEPS

Safeguards approaches at GCEPs include nuclear material accountancy, C/S measures, and inspections (physical inventory verifications [PIVs], interim inspections for inventory change verification, limited frequency unannounced access [LFUA] inspections, and design information verifications [DIVs]). IAEA activities at a GCEP are aimed at verifying that no diversion of material has occurred and that no undeclared production of LEU or HEU has occurred. Typical IAEA inspection activities at GCEPs include but are not limited to

- DIV—IAEA confirmation of facility layout, material flows, and other information provided in the DIQ;
- material accountancy through an annual PIV and a number of interim inventory verifications, including UF_6 cylinder identification and counting, NDA of cylinders, and DA on a sample collection of UF_6;
- application of C/S technologies utilizing seals and tamper-indicating devices (TIDs) on cylinders, containers, storage rooms, and IAEA instrumentation to provide continuity of knowledge between inspections; and
- verification of the absence of undeclared material and operations, especially HEU production, through SNRIs, LFUA of cascade halls, and environmental swipe sampling.

5.1 VERIFYING THAT DECLARED MATERIALS ARE NOT BEING DIVERTED

The IAEA activities to verify that there is no diversion of declared materials include reviewing operator inventory documentation, verifying the contents of UF_6 cylinders (Fig. 2), and conducting annual inventories. During the annual PIV, the IAEA needs to be able to independently verify the quantity of material on site. This requires a cylinder switchover.[4] The IAEA must be able to verify the full feed, product, and tail before switchover, and verify the partially filled cylinders attached to the process after switchover.

Fig. 2. NDA measurement of a 30B UF_6 cylinder.

4 A cylinder switchover is performed between material balances periods to distinguish the quantity of material in the feed, product, and tails cylinders from the material in the cascade. At the "switchover" time, the partially filled cylinders connected to the cascade are replaced (switched) with previously verified cylinders. If the plant is equipped with weighing devices on all the feed and withdrawal stations, the switchover is not necessary.

5.2 VERIFYING THAT HEU IS NOT BEING PRODUCED

To verify the absence of HEU production, the IAEA safeguards approach relies upon LFUA inspections of the cascade halls. It is the responsibility of the operator to protect all visual-sensitive, proprietary, and export-controlled operating data. During an LFUA inspection, the operator must provide the IAEA with access to the cascade within 2 hours of notification. Typical safeguards measures associated with LFUA inspections include visual access, environmental sampling, NDA measurements on header pipes, and direct sampling of the cascade header pipes.

5.2.1 Visual Inspection

Inspectors observe the cascade hall to confirm the absence of undeclared F/W operations and reconfiguration of declared process piping. Inspectors also strive to verify the absence of hidden F/W capabilities and extra pipes leaving the cascade area. To aid visual inspections, a site should have a well-defined inspection route to protect visal-sensitive enrichment technology yet provide visual access to the necessary piping for inspectors.

5.2.2 Environmental Sampling

IAEA inspectors collect swipe samples at enrichment plants using standardized sampling kits. These samples are "bagged" and taken off-site by the inspectors. The SRA can receive a duplicate sample. An extensive sampling campaign is conducted at the onset to establish a baseline for the facility, and then random samples are collected periodically (Fig. 3).

Fig. 3. Environmental swipe sampling.

5.2.3 NDA Measurements on Product Pipes

The IAEA conducts NDA measurements on product header pipes to independently confirm the absence of HEU in the piping—this is typically a go/no-go measurement to determine whether the enrichment is less than 20-percent ^{235}U. It is necessary for the IAEA to be able to trace the measured product pipe from the measurement location back to the cascade.

Two technologies have been deployed by the IAEA: (1) a portable Cascade Header Enrichment Monitor (CHEM) system (Fig. 4), and (2) an installed Continuous Enrichment Monitor (CEMO) (Fig. 5). The CEMO is an unattended, on-line system that transmits a periodic message directly to the IAEA's headquarters in Vienna, Austria. A number of factors make these measurements challenging,

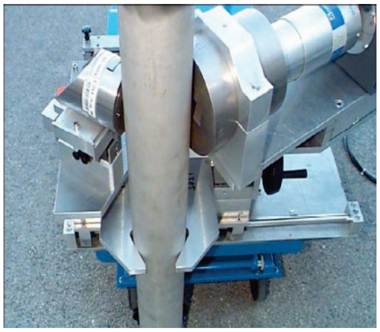

Fig. 4. IAEA CHEM system.

Fig. 5. IAEA CEMO system.

including extremely low gas pressures, the need to distinguish the signal of the gas from the signal of the pipe deposit, and the operator requirement to protect sensitive information.

The IAEA is moving toward the routine utilization of the collection of gas samples directly from the cascade. It is recommended that all sample-related piping be visually traceable and that the site provide a capability for the IAEA to receive duplicate samples from the operator's on-line mass spectrometers.

5.3 VERIFYING THAT EXCESS LEU IS NOT BEING PRODUCED

To verify the absence of excess LEU production, the IAEA strives to verify the total mass of UF_6 throughput and to verify the absence of undeclared feed cylinders and undeclared F/W capabilities. Inspection activities include SNRI inspections of F/W areas, site mailbox declarations, closing material balances, and conducting separative work unit (SWU) balances.

5.3.1 Verifying the Absence of Undeclared Material in the F/W Area

The type and quantity of UF_6 cylinders located in a F/W area for a facility that operates in a constant state is generally very predictable. The IAEA will review the information provided in the DIQ and determine whether the cylinder stay times and mass ratios are consistent with the design of the plant. In addition, inspectors use SNRIs to verify the absence of undeclared material in a F/W area; therefore, the facility should be designed to minimize delays to the F/W area for these inspections.

The facility designer could consider the use of modernized technologies for identifying and tracking UF_6 cylinders. The cylinder identification techniqes should be robust enough to withstand a range of environmental and facility operational conditions and provide an indicator if the identification technique of the cylinder has been altered.

5.3.2 Verifying that Undeclared Material Is Not Processed in the F/W Area Between Inspections

The operator may consider using real-time process monitoring and surveillance systems to detect any potential misuse of the F/W area. Incorporating such a system into the original design of the facility will minimize the impact on material flows. A cylinder portal monitor could be designed to provide verification of the cylinder identity, gross weight, uranium mass, and ^{235}U mass. It should also have the capability to report to the IAEA mailbox.

In addition, the designer should minimize the number of connection ports to the F/W system, and all process connections should be contained to prevent access and to provide for a means for applying

TIDs to detect unauthorized access to the process cascades and piping headers. If a centralized entry and exit portal is incorporated into the design of the facility, the operator may consider random imaging/photographing of all items processed through the controlled access points. The IAEA inspector could review the random images in the presence of site personnel to alleviate any concerns.

The facility operator should incorporate equipment into the design of the F/W area that is not export-controlled or sensitive for observation by the IAEA. No decontamination or dismantling of cascade components should occur in the area where material is fed into or removed from the cascade. Other ingress and egress points to the F/W area should be alarmed and sealed to detect unauthorized access to the area. In addition, the operator may consider localized surveillance at the primary entrance to the F/W area.

6. SAFEGUARDS-BY-DESIGN BEST PRACTICES

The goal for SBD in a GCEP is to have safeguards fully integrated into the design process of the facility from initial planning through design, construction, operation, and decommissioning. The following focuses specifically on what, in terms of safeguards, would likely be implemented at a GCEP along with design considerations for implementation of such features.

6.1 GENERAL REQUIREMENTS

The following is a list of the types of safeguards equipment that could be utilized by the IAEA at a GCEP:

- high-purity germanium (HPGe) detectors
- calibration weights
- sample equipment and containers
- ultrasonic thickness gauges
- seals/TIDs
- enrichment measurement equipment
- surveillance cameras
- information transfer (mailbox equipment)
- workstations
- certified weighing equipment (scales, load cells, and balances)

Designers should also incorporate technical specifications for a mailbox declaration interface into the hardware for the facility. The location of the mailbox and necessary cabling and communication infrastructure should be considered. The type and quantity of UF_6 cylinders located in the F/W area for a facility operating in constant state is generally very predictable. Small variations will occur if the production capacity changes, additional feed cylinders are placed in a prestaging area, or product and/or tails cylinders are not removed from the storage areas in these locations (e.g., maintenance activities occurring in the area or the lack of human resources due to plant emergencies, holidays, etc.). The IAEA should work closely with the state regulator and facility designers to ensure that shared use of the process monitoring equipment meets the IAEA's requirements for independent verification.

6.2 LAYOUT REQUIREMENTS AND GUIDELINES

The layout of a GCEP should take into account the need to perform material accountancy in a timely and effective manner. Proper establishment of MBAs is vital in the ability to effectively inventory nuclear materials in a GCEP. The facility should be designed to minimize delays, and the operator should consider the location of export-controlled items or classified items in the path between the plant entrance and the F/W area. The use of temporary curtains or covers should be considered, and the security plan/access procedures should be automated to the extent possible.

Also, consideration must be given to how inspectors, who will be foreign nationals, will access each MBA. For example, site-specific training requirements, access times, escorts, and protection of sensitive information must be considered. The IAEA will likely require access to all areas where declared nuclear materials are received, stored, and shipped. Access to other areas, such as site analytical laboratories and waste measurement areas with small quantities of nuclear materials, may also be included.

6.3 SPACE ALLOCATION REQUIREMENTS AND GUIDELINES

IAEA inspectors will periodically visit selected sites to independently verify the declarations made by the operator. This section describes the design considerations related to site access, office space, and instrument storage.

6.3.1 Safeguards Equipment

The IAEA may have a need to store heavier, less-portable inspection equipment and calibration standards at the site between inspections. Equipment may include detectors, seals and TIDs, calibration weights, and radioactive calibration sources. Facility design should factor in what types of storage environments, on-site calibration, site utilities, and power requirements are needed for these devices.

6.3.2 Inspector Office Space, Storage Space, and Equipment

IAEA requirements for office/work and storage space should be established early on in the design of the GCEP. The selection of specific offices and workspace locations for inspectors should take into account proximity to inspection areas; environmental, safety, and health requirements; ergonomics; evacuation routes; and proximity to restrooms. Computers, printers, and telecommunications requirements should be coordinated with the IAEA during design of a GCEP. Also, accommodations should be made for adequate secured storage space at or near their office/work area for items belonging to the inspectors (e.g., spare equipment, office supplies, documentation, personal protective equipment).

6.3.3 On-site Sample Analysis and Sample Storage

DA is a key tool for safeguards in addition to surveillance, seals, and NDA techniques. A facility should provide the IAEA with work space for storing the samples and for packaging, sealing, and shipping the samples to an off-site laboratory. Maintaining continuity of knowledge for samples in storage areas must also be considered.

6.4 DESIGN IMPACTS OF FACILITATING INSPECTION

6.4.1 Design Features to Facilitate Design Information Verification

To verify that the design has not changed and to complete a DIV, the IAEA inspector compares what is seen during the inspection to photos—kept on site—that were taken when the facility was originally built. The designers should consider designing and constructing a GCEP with safeguards in mind and with the intent of making the facility ready for such an inspection. In addition, by participating early in the design of a GCEP, IAEA inspectors can develop a good understanding of the facility, its layout, equipment, and processes and thus can help facilitate inspectors when they complete inspections and DIVs.

The current method used by the IAEA to verify that the cascade design has not changed is LFUA to the cascade hall. The inspector compares what is seen during the inspection to photos—kept on site—that were taken when the cascade was initially built. During DIVs the IAEA will need to verify that there are no flow slip stream/diversion paths. If, for example, nonvisible or inaccessible lengths of piping exist, the IAEA may be unable to verify that there are no undeclared F/W capabilities. Thus, some items to consider include

- avoiding non-accessible process equipment/piping,

- minimizing ingress and egress paths for processing areas,
- locating sample points in areas accessible to inspectors,
- avoiding portable equipment in processing areas, and
- keeping the facility uncluttered.

6.4.2 Design Features to Facilitate Inspections During Operations

It is very likely that operations will continue at a facility during IAEA inspections; thus designers should consider practices that both aid inspections and protect proprietary information while limiting effects on operations. Therefore, designers should consider the following design features to facilitate inspections at a GCEP.

6.4.2.1 Protection of proprietary information

The facility designer should consider using data displays that have the capability to deactivate the display capability at the unit if the information displayed is considered sensitive. This capability should be controlled at a central area. Deactivation of the display should not hinder the capability of the process monitor to accurately measure cascade parameters. Other options include covers or localized display switches. The facility designer should work closely with equipment manufacturers to incorporate these capabilities in a safe and effective manner.

6.4.2.2 Physical inventory

During inspections, IAEA inspectors may request current physical inventory lists and inventory change reports (e.g., a listing of receipts, shipments, and location of UF_6 cylinders). Inspectors should be able to quickly and accurately verify the cylinder indentification numbers (Fig. 6). Therefore, operators must provide a listing of exact locations of all cylinders on site, be able to physically and quickly locate any cylinder selected by the IAEA from the inventory list.

Fig. 6. UF_6 cylinder with multiple barcodes attached.

The IAEA verifies the safeguards-relevant information concerning the UF_6 cylinders (e.g., tare weight, gross weight, fill times, mass U, enrichment, purity). Thus, in addition to being able to locate a cylinder, operators should store cylinders so that they are accessible and can be moved to scales for weighing, any IAEA-applied seals are accessible and not damaged, and portable IAEA load cells can be safely attached to the site lifting devices (Fig. 7).

Fig. 7. Cylinder weighing operation.

6.4.2.3 Process piping

Every effort should be made by designers to minimize routing process headers through inaccessible spaces. If it cannot be avoided, the designer should use access panels that are easily removable and sealable to detect unauthorized access. The access panels should have TIDs (e.g., magnetic switches) that provide an alarm indication reported to the IAEA mailbox in the event an access panel is removed. The header piping through these areas should be continuous and should not incorporate valves or the capability to access process gas or introduce material to the cascade in that area. The designer should also provide receptacles and cable connections in the event the IAEA wants to install localized surveillance cameras within the confined space (Fig. 8).

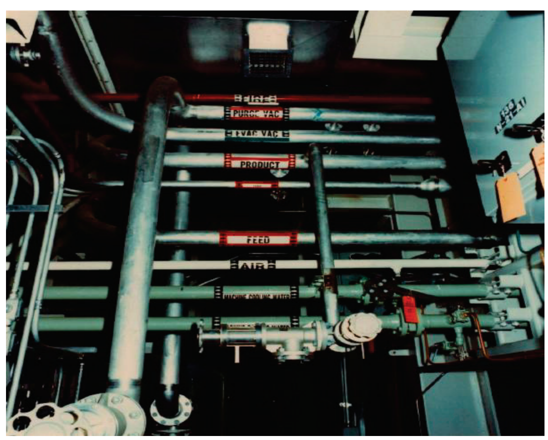

Fig. 8. Cascade header pipes.

6.4.2.4 Sampling points

While sampling points should be installed in areas accessible by inspectors, access to the sampling locations should be restricted, including internal sampling points if in-line monitoring systems such as flow monitors and gas mass spectrometers are utilized. Further, sampling ports should be designed to detect tampering or unauthorized access to the cascade.

The designer should consider the use of automated sampling devices that require special connections and the use of electrically operated sample valves that shut off after a period of time necessary to acquire enough sample material for the required analysis. If utilizing automated sampling techniques, operators should consider shared-use with the IAEA in such a manner that provides the operator with assurances that national security and commercially sensitive data are protected. The operator must coordinate use of such systems with the IAEA to ensure that they pass the IAEA's certification process.

6.5 DESIGN TEAM DISCIPLINE-SPECIFIC IMPACTS

SBD incorporation into GCEPs will require a multidiscipline design team, including all engineering disciplines, along with subject matter experts (SMEs) for safeguards, material control and accountability (MC&A), and security. The SMEs are essential to ensuring that safeguards requirements are met and integrated into the design of the systems, structures, and components. The extent to which SBD is implemented will have a direct impact on the work load of the design team and will vary depending on the scope of the implementation. The following provides potential design features that individual design team disciplines will have to address as a result of implementing safeguards in a GCEP:

Electrical Engineering/Instrumentation and Controls

- C/S systems, including lighting and power
- Uninterruptible power supply to safeguards equipment
- Data transmission (locally and remote)
- Electrical interface between plant instrumentation and IAEA instruments/data collection

Chemical Engineering

- Process equipment configuration (accessibility, minimize penetrations)
- MBAs
- Material hold-up
- KMPs (on-line monitoring/sampling stations/accessibility)
- Accountability of material throughput (process, recycle, waste, hold-up)
- Interface between process equipment and C/S systems
- Material storage (accessibility, ability to seal items)

Chemists

- DA techniques for determining uranium content (process, salvage, waste streams)
- KMPs (on-line monitoring/sampling)

Mechanical

- Equipment/piping configuration (accessibility, minimize penetrations)
- Implementation of IAEA seals on equipment and containers
- Accountability weigh systems (weigh scales, accountability tanks, calibration weights)

Civil/Architecture

- MBAs (Facility boundaries)
- Facility accessibility
- Office/work space for inspectors

Software/Computer Engineering

- Accountability systems
- Secure data transmission
- Mailbox systems interface
- Interface between process instrumentation/data collection and IAEA equipment (i.e., use of joint equipment)

This page intentionally blank.

APPENDIX 1

Safeguards Technologies—Current and under Investigation—Used by IAEA to Achieve Safeguards Objectives

Safeguards objectives	Typical inspection activities	Associated safeguards technology	New safeguards methods being investigated
Verifying that declared materials are not being diverted	Locating UF_6 cylinders to verify presence and identification	None	Standardized identification, On-site tracking system
	Weighing UF_6 cylinders to verify declared gross weights	Reweighing on operator's scales	Authenticated shared use of operator's accountability scales
		Portable IAEA load scales	
	Measuring enrichment of UF_6 in cylinders to verify declared enrichment level	Portable NDA, Off-site DA of samples	Integrated NDA with weighing station, Shared-use of in-line mass spectrometers, On-site DA capability
Verifying that HEU is not being produced	Visual inspection to verify cascade configurations and the absence of undeclared operations	Photographs	3D-laser systems, 3D-laser+gamma imaging systems
	Environmental sampling to verify absence of HEU	Off-site ultra-trace sample analysis	
	Enrichment of UF_6 gas within header piping to verify absence of HEU	Portable NDA; Continuous, unattended NDA	Improved continuous, unattended monitoring
		Off-site DA of sample	On-site DA capability
	Design verification to verify absence of F/W capabilities	Photographs	3D-laser systems
Verifying that excess LEU is not being produced	Visual inspection to verify absence of undeclared UF_6 cylinders	Daily mailbox declarations with short-notice access to F/W areas	Laser-based cylinder identification system, Cylinder tracking system, Cylinder portal
	Verify that undeclared material is not being processed at declared F/W stations	Daily mailbox declarations with short-notice access to F/W areas, SWU calculations	Continuous process scale monitoring, Continuous monitoring of cylinder handling systems, Continuous flow monitoring

This page intentionally blank.

Office of Nonproliferation and International Security (NIS)

National Nuclear Security Administration
Defense Nuclear Nonproliferation

www.nnsa.energy.gov/nonproliferation/nis

United States Department of Energy
National Nuclear Security Administration
Defense Nuclear Nonproliferation
Office of Nonproliferation and International Security
1000 Independence Avenue, S.W.
Washington, D.C. 20585