



NIS Office of Nuclear
Safeguards and Security



NEXT GENERATION SAFEGUARDS INITIATIVE

Safeguards-By-Design Facility Guidance Series (NGSI-SBD-002)

August 2012

Implementing Safeguards-by-design at Natural Uranium Conversion Plants



Office of
**Nonproliferation
and International
Security (NIS)**

IMPLEMENTING SAFEGUARDS-BY-DESIGN AT NATURAL URANIUM CONVERSION PLANTS

Lisa Loden
John Begovich

Date Published: July 2012

CONTENTS

	Page
CONTENTS	IV
1. INTRODUCTION AND PURPOSE	1
2. KEY DEFINITIONS	2
3. SAFEGUARDS AT NUCPS	7
3.1 SAFEGUARDS OBJECTIVES	7
3.2 TRADITIONAL AND INTEGRATED SAFEGUARDS	7
3.3 SAFEGUARDS RESPONSIBILITIES	8
3.3.1 STATE REGULATORY AUTHORITY RESPONSIBILITIES	8
3.3.2 IAEA RESPONSIBILITIES	9
4. ELEMENTS OF FACILITY DESIGN THAT ARE RELEVANT FOR SAFEGUARDS	10
4.1 DESIGN FEATURES THAT IMPACT SAFEGUARDS	11
4.2 MISUSE AND DIVERSION SCENARIOS	12
5. KEY ELEMENTS OF SAFEGUARDS APPROACH TO NUCP	13
5.1 VERIFYING THE DECLARED MATERIALS	13
5.2 WEIGHING CONTAINERS/CYLINDERS	14
5.3 NON-DESTRUCTIVE/DESTRUCTIVE ANALYSIS	14
5.4 CONDUCTING ANNUAL PHYSICAL INVENTORIES	15
6. SAFEGUARDS-BY-DESIGN BEST PRACTICES	16
6.1 GENERAL REQUIREMENTS (LIST OF SAFEGUARDS EQUIPMENT THAT MUST BE SUPPORTED)	16
6.2 LAYOUT REQUIREMENTS AND GUIDELINES	16
6.3 SPACE ALLOCATION REQUIREMENTS AND GUIDELINES	17
6.3.1 SAFEGUARDS EQUIPMENT	17
6.3.2 INSPECTOR OFFICE SPACE, ETC.	17
6.3.3 ON-SITE SAMPLE ANALYSIS AND SAMPLE STORAGE	17
6.4 DESIGN IMPACTS OF FACILITATING INSPECTION	18
6.4.1 DESIGN FEATURES TO FACILITATE DIE/DIV	18
6.4.2 DESIGN FEATURES TO FACILITATE INSPECTIONS DURING OPERATIONS ..	18
6.4.3 VERIFYING THAT UNDECLARED MATERIAL IS NOT PROCESSED IN THE NUCP BETWEEN INSPECTIONS	20
6.5 DESIGN TEAM DISCIPLINE-SPECIFIC IMPACTS	20
APPENDIX 1	22
APPENDIX 2	23

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, 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.² 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 flow sheet 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

AUC	ammonium uranyl carbonate	This compound is a component in the conversion process of uranium hexafluoride (UF ₆) to uranium dioxide (UO ₂). Conversion to UO ₂ is often performed as the first stage of nuclear fuel fabrication. It is also one of the many forms called yellowcake.
BNL	Brookhaven National Laboratory	This national laboratory located in Upton, New York, U.S.
C/S*	Containment/surveillance measures (C/S measures)	The application of containment and/or surveillance complements nuclear material accountancy. 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. In many instances 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	To determine nuclear material content and, if required, the isotopic composition of chemical elements present in the sample, this method normally involves destruction of the physical form of the sample.
DIE*	design information examination	These activities are carried out by the IAEA to determine that the State has provided all relevant descriptive and technical information needed, inter alia, to design a safeguards approach for a specific facility.
DIQ	design information questionnaire	This is the means used by the State to submit design information to the IAEA.
DIV*	design information verification	These activities are 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. The IAEA's authority for performing a DIV is a continuing right throughout all phases of a facility's life cycle until the facility has been decommissioned for safeguards purposes.
DOE	U.S. Department of Energy	
ES&H	Environmental, Safety, and Health	

* IAEA Safeguards Glossary, 2001

FA	facility attachment	This confidential document is used for all safeguards Agreements to describe in detail the arrangements for safeguarding each plant. It is prepared for each facility by the IAEA, SSAC, and facility operator.
HPGe	high purity germanium	This radiation detection technology provides sufficient information to accurately and reliably identify radionuclides from their passive gamma ray emissions.
IAEA	International Atomic Energy Agency	
ID*	identification	Tag or other means to identify a specific item.
KMP*	key measurement points	KMPs are a location 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.
LANL	Los Alamos National Laboratory	This U.S. DOE national laboratory is located in Los Alamos, New Mexico, US.
LLNL	Lawrence Livermore National Laboratory	This US national laboratory was founded by the University of California in 1952. It is primarily funded by the U.S. DOE.
MBA*	material balance area	Is an area in or outside of a facility such that: <ul style="list-style-type: none"> (a) The quantity of nuclear material in each transfer into or out of each ‘material balance area’ can be determined; and (b) The physical inventory of nuclear material in each ‘material balance area’ can be determined when necessary, in accordance with specified procedures, in order that the material balance for Agency safeguards purposes can be established.
MC&A	material control & accountability	The comprehensive, integrated technical and administrative programs for nuclear material control, inventories (including measurement and measurement control), accounting, and reporting activities.
MTU	metric ton uranium	One thousand kilograms of uranium.
MUF*	material unaccounted for	Is calculated for a material balance area (MBA) over a material balance period using the material balance equation, commonly written as: $MUF = (PB + X - Y) - PE$ where <ul style="list-style-type: none"> PB is the beginning physical inventory, X is the sum of increases to inventory, Y is the sum of decreases from inventory, PE is the ending physical inventory.

* IAEA Safeguards Glossary, 2001

		<p>Because book inventory is the algebraic sum of PB, X and Y, MUF can be described as the difference between the book inventory and the physical inventory. For item MBAs, MUF should be zero, and a non-zero MUF is an indication of a problem (e.g. accounting mistakes) which should be investigated. For bulk handling MBAs, a non-zero MUF is expected because of measurement uncertainty and the nature of processing. The operator's measurement uncertainties associated with each of the four material balance components are combined with the material quantities to determine the uncertainty of the material balance.</p>
NaI	sodium iodide	A scintillator type of gamma-ray detector.
NDA*	non-destructive assay	A measurement of the nuclear material content or of the element 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.
NUCP	natural uranium conversion plant	A facility where the process in which concentrated uranium is converted to a highly purified gas, uranium hexafluoride, for subsequent enrichment, is performed.
ORNL	Oak Ridge National Laboratory	A national laboratory managed for Department of Energy (DOE) and located in Oak Ridge, Tennessee, US.
PIV*	physical inventory verification	Is an inspection activity that follows closely, or coincides with, the physical inventory taking 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.
RFID	radio frequency identification device	Is a wireless non-contact device/system that uses radio-frequency electromagnetic fields to transfer data from a tag attached to an object, for the purposes of automatic identification and tracking.
SBD SME	Safeguards-By-Design 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.
SQ*	significant quantity	The approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. Significant quantities take into account unavoidable losses due to conversion and manufacturing processes and should not be confused with critical masses. Significant quantities are used in establishing the quantity component of the IAEA inspection goal.
SRA	State Regulatory Agency	A state authority or government agency responsible for exercising autonomous authority over a regulatory or supervisory capacity.
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 ₄	uranium tetra fluoride	A green crystalline solid compound of uranium with an insignificant vapor pressure and very slight solubility in water. UF ₄ is generally an intermediate in the conversion of uranium hexafluoride (UF ₆) to either uranium oxides (U ₃ O ₈ or UO ₂) or uranium metal.
UF ₆	uranium hexafluoride	A volatile compound of uranium and fluoride 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.
UO ₂	uranium dioxide	The chemical form of uranium that is most commonly used in power reactors. Also known as “brown oxide,” even though it is nearly black when pressed into pellets.
UO ₃	uranium trioxide	The hexavalent oxide of uranium. The solid may be obtained by heating uranyl nitrate to 400°C. Its most commonly encountered polymorph, γ-UO ₃ , is a yellow-orange powder.

* IAEA Safeguards Glossary, 2001

* IAEA Safeguards Glossary, 2001

UOC uranium ore concentrate

Also called "Yellowcake", produced in the milling process contains a mixed oxide usually referred to as " U_3O_8 " ($\text{UO}_2 \cdot 2 \text{UO}_3$). Due to a number of impurities contained, it needs further refining before it can be used for nuclear fuel production. 1 t U_3O_8 is equivalent to 0.848 t U.

U.S. United States
YC Yellowcake

A kind of uranium concentrate powder obtained from leach solutions, in an intermediate step in the processing of uranium ores. Yellowcake concentrates are prepared by various extraction and refining methods, depending on the types of ores. Typically, yellowcakes are obtained through the milling and chemical processing of uranium ore forming a coarse powder which has a pungent odor, is insoluble in water and contains about 80% uranium oxide, which melts at approximately 2878 °C.

3. SAFEGUARDS AT NUCPS

To understand and apply the design considerations and recommendations in this report, 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

The IAEA inspection goal for a Natural Uranium Conversion Plant (NUCP) consists of both a quantity and a timeliness component. These components are regarded as fully attained if all the safeguards criteria relevant to the material types and material categories present at the NUCP have been satisfied and all anomalies involving one significant quantity (SQ) or more of nuclear material have been resolved in a timely manner.³ The two principal safeguards concerns at a NUCP are:

- Diversion of pure materials (intermediate and final products) for further processing or use elsewhere.
- Processing of undeclared feed to produce in a safeguarded facility undeclared pure products (e.g., uranium metal, UO₂, UF₆) outside of safeguards

The goal of IAEA safeguards is the timely detection of a diversion of a SQ of nuclear material. By IAEA definition, an SQ of natural uranium is 10 MTU with the timeliness being one year using a detection probability of 50%.

3.2 TRADITIONAL AND INTEGRATED SAFEGUARDS

Traditionally, the plant operator makes an accountancy declaration of the material balance for the NUCP, 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.

Safeguards at nuclear facilities are transitioning from a traditional to more of an integrated role. Integrated safeguards refers to an optimized combination of all safeguards measures available to the IAEA under comprehensive safeguards agreements and additional protocols to achieve maximum effectiveness and efficiency in meeting the IAEA's safeguards obligations within available resources. One way to achieve this optimization of resources is to provide continuous unattended radiation and surveillance monitoring systems that are remotely accessed by the IAEA inspectors. By doing this inspector time can be reduced on-site without compromising safeguards. In a NUCP, monitoring stations established at key parts of the facility with data transmission and remote accessibility by the IAEA would be a key component of integrated safeguards. This unattended monitoring may be both intrusive and non-intrusive (e.g., measuring flow rates of uranium solutions vs. camera surveillance). Integration of this type of monitoring into the NUCP would require close coordination between the IAEA and the NUCP design team.

³ Safeguards Technical Report 342 (STR 342), *Safeguards Approaches for Natural Uranium Conversion Plants*, IAEA, February 2004.

A summary of the general relationships between the safeguards objectives for a NUCP, current safeguards technologies being used, and possible new applicable safeguards technologies that demonstrate a more integrated approach are presented in Appendix 1 of this report.

3.3 SAFEGUARDS RESPONSIBILITIES

3.3.1 State Regulatory Authority responsibilities

The State Regulatory Authority⁴ (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 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 the incorporation into the facility design - including the design of the nuclear materials accountancy system - features 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 Agency to do the budgetary planning necessary for the effective and efficient implementation of safeguards,
- Permit the identification and scheduling of actions which need to be taken jointly by the State, the facility operator and the Agency, including
 - installation of safeguards equipment during construction of the facility; and
 - verification of information on the design 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:

- 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 Agency with completed Design Information Questionnaires (DIQ) for new facilities based on preliminary construction plans as early as possible, in any event not later than 180 days prior to the start of construction. Design Information Questionnaires based on "as-built" designs should be provided as early as possible, and in any event not later than 180 days before the first receipt of nuclear material at the facility.

⁴ The State Regulatory Authority is the governmental entity responsible for overseeing State implementation of IAEA safeguards, and often is part of the State nuclear regulatory agency.

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.⁵ 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 measurement 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 NUCP 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. The IAEA also needs the instruments to be largely unattended. To facilitate accountability efforts, the plant is divided into MBAs over which the nuclear material inventory is determined and verified. While the IAEA inspectors make use of samples, the majority of their measurements will be non-destructive assay (NDA) of product and waste streams, with process monitoring (tank level, flow meters, etc.) and containment/surveillance (C/S) (seals, tamper indicating covers, cameras, etc.) to allow them to follow nuclear material movement and verify that it occurred as declared.

⁵ International Safeguards, NRC website, July 2008, www.nrc.gov/about-nrc/ip/intl-safeguards.html.

4. ELEMENTS OF FACILITY DESIGN THAT ARE RELEVANT FOR SAFEGUARDS

Uranium conversion plants are chemical facilities, typified by large numbers of process vessels, with lots of process pipe work carrying not only uranium materials but also supporting process chemicals, water and gases. Establishing material accountancy in such facilities can be quite difficult given their complexity.

The feed to a NUCP is normally uranium ore concentrate (UOC), which is also referred to as “yellowcake” (YC). A common process method (see Figure 1) involves dissolution, purification, and evaporation followed by several chemical conversion steps to produce the desired final product, such as UO_2 or UF_6 .

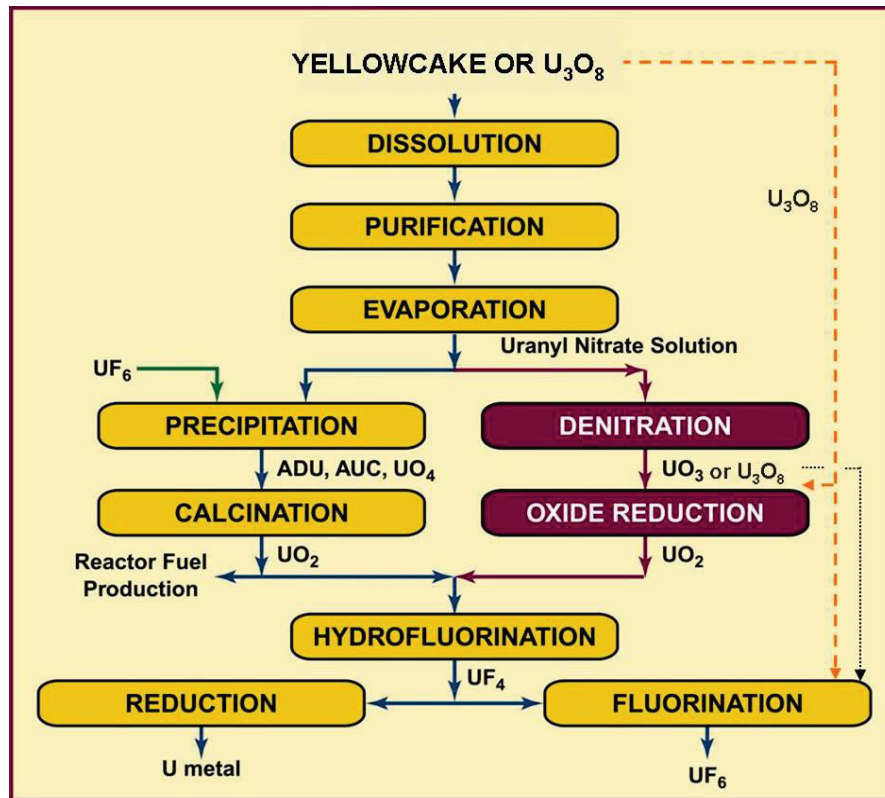


Fig. 1. Typical NUCP Flowsheet

4.1 DESIGN FEATURES THAT IMPACT SAFEGUARDS

Guidance on determining the point in a NUCP at which nuclear material reaches a purity and composition suitable for fuel fabrication or isotopic enrichment (as referred to in Para. 34(c) of INFCIRC/153) is provided by Safeguards Policy Series 18.^{6,7} In general, purified oxides of uranium and purified aqueous solutions of uranium are considered to be materials subject to the full safeguards requirements of INFCIRC/153, while YC or UOC material is not. It may not be practical to make the necessary accountancy measurements at the point where uranium oxide or aqueous uranium solution reaches the purity specified in Policy Series 18 which leaves the process stage where it is produced. In such situations, the application of full safeguards measures begins earlier in the process, at the nearest point where it is practical to make the necessary measurements. A typical point for starting full safeguards procedures can be the introduction of impure UOC into a dissolution system.⁸

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 (KMP) in the process. The facility layout (e.g., physical structure and boundaries) can directly impact how material balance areas are determined.

In order to meet concerns for diversion of material and the processing of undeclared feed, safeguards objectives for a NUCP should be based on:

- Independent verification of the flow of declared materials into and out of the plant.
- Independent verification of the inventories of materials in the plant.

This is done by establishing an effective nuclear materials accountancy program and providing for the ability to independently perform activities to determine process inventory and processing throughputs at any given time.

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 NUCP, 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. Design information verification (DIV) is carried out by IAEA on a continuing basis. The initial DIV covers the whole plant and includes the determination of MBAs, strategic points, and KMPs to permit the application of safeguards procedures to nuclear material in the plant. Continuing DIV visits include the verification of any modifications to the facility. The DIV is based on a visual comparison of the installed equipment with the submitted DIQ, supported by other techniques as appropriate.

⁶ INFCIRC/153, *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.

⁷ Safeguards Policy Series, Number 18. *Safeguards Measures Applicable in Conversion Plants Processing Natural Uranium*, IAEA, June 2003.

⁸ Safeguards Technical Report 342 (STR 342), *Safeguards Approaches for Natural Uranium Conversion Plants*, IAEA, February 2004.

4.2 MISUSE AND DIVERSION SCENARIOS

In bulk handling facilities, such as a NUCP, the material is processed in loose forms (powder, liquid and gas) where the physical integrity of items as received is not maintained. The amount of nuclear material present at different stages of the process is estimated by weight and volume determination, combined with measurements of concentration and isotopic composition based on the nuclear properties of the material. One of the biggest challenges for safeguarding a NUCP is the verification of the nuclear material flow through the facility. The material flow includes not only the feed in and product out of the facility, but also the large quantities of non-product (scrap and waste) and in-process (also referred to as “hold-up”) materials. These multiple material streams present opportunities for misuse and diversion thus making the ability to verify nuclear material flow in a NUCP a key component of safeguards activities.

Nuclear materials accountancy is of fundamental importance to IAEA safeguards at a NUCF. This includes not just the system itself and how information on material movements is collected and processed but also the underlying MBA structure and how this relates to facility processes and storage areas. MBAs and KMPs are key components that provide the ability to effectively measure the flow and inventory of nuclear materials in the NUCP. Placement of KMPs in the NUCP should take into account the following considerations:

- Measurement/estimation of in-process material at PIV
- Complexity of process piping
- Fluctuating storage within the facility
- Access to sample/measurement points
- Internal recycle of material
- Potential diversion routes
- Processing of undeclared feed.

Designers should keep these requirements in mind when laying out the plant, factoring in the need of the IAEA to independently determine the inventory of nuclear materials and to ensure that diversion or undeclared processing is not occurring. Designers should size facility material storage for ease of access to material. The facility also needs to provide an adequate verification space for inspections and reserve spaces for installation of IAEA safeguards C/S equipment. Suggested KMPs in a generic NUCP is presented in Appendix 2.

5. KEY ELEMENTS OF SAFEGUARDS APPROACH TO NUCP

Safeguards approaches at NUCPs include nuclear material accountancy, containment and surveillance measures, inspections (physical inventory verification, interim inspections for inventory change verification, and design information verification).⁹ IAEA activities at a NUCP are aimed at verifying that no diversion of declared materials or processing of undeclared materials at the facility has occurred. Typical IAEA inspection activities at NUCPs include, but are not limited to:

- Examination of records, including confirmation of facility layout, material flows, and other information provided in the DIQ;
- Inventory and material transaction;
- Verification of the performance and calibration of operator instruments and equipment;
- Application and servicing of IAEA safeguards equipment installed at the facility.

During inspections, IAEA inspectors perform the following type of activities in a NUCP:

- Locate and verify material identity;
- Determine material flow and processing;
- Perform weight measurements of material;
- Perform non-destructive measurements and collect samples for destructive (DA) measurements;
- Perform design information and facility change reviews.

To supplement the monitoring described above, the safeguards approach at a NUCP considers that some uranium material, e.g., recycle material or waste materials, might be accumulated and verified by the IAEA either at the time of the annual PIV, during an interim inventory verification or SNRI, or during special inspections performed to accommodate both process operations and safeguards needs. In order to track uranium material, the plant submits information on at least the principal feed and product flows on a daily basis or at regular intervals to the IAEA along with information on any other uranium-containing materials to be shipped from the plant. To ensure accurate and timely data transfer, consideration should be given to the design and interface of a “mailbox”^{10,11} system with NUCP accountability and operation data collection systems.

5.1 VERIFYING THE DECLARED MATERIALS

During inspections, the location and identification of all declared materials are provided to the IAEA, and the IAEA verifies the safeguards-relevant information (e.g., tare weight, gross weight, uranium mass, uranium concentration). Discrete items of material include drums of yellowcake, containers of in-process material, containers of product, and containers of waste material. All nuclear material items should be unambiguously identified. Designers should give consideration as to how material usage and movement history can be fully traced. The material subject to accountancy needs to be clearly defined and identified.

⁹ Safeguards Technical Report 342 (STR 342), *Safeguards Approaches for Natural Uranium Conversion Plants*, IAEA, February 2004.

¹⁰ “The Applications of Mailboxes in Safeguards”, ESARDA Bulletin, No. 40, December 2008.

¹¹ Safeguards Technical Report 302 (STR 302), *Field Test of Short Notice Random Inspections for Inventory Change Verifications at a Low Enriched Uranium Fuel Fabrication Plant*, IAEA, April, 1995.

The inspectors require the ability to locate in a timely manner the items provided on the site's inventory list. Access to the items and the ability to move selected items to/from a storage area to perform further activities on the items (weighing, NDA, DA, application of seals, etc.) is necessary.

These requirements for item identification, storage, and movement should be considered during design of a NUCP. The following capabilities should be included at a NUCP:

- Capability to provide the IAEA with a listing of exact locations of all discrete items on site
- Capability to physically and quickly locate any item selected by the IAEA from the inventory list
- Capability for the IAEA to access all areas on site where items might be located
- Assurance that items are stored in a configuration that would allow for the IAEA to read labeling/identifications.

5.2 WEIGHING CONTAINERS/CYLINDERS

The inspectors will select containers/cylinders for independent weighing either by using the operator's scales or IAEA scales. To verify the accuracy of the operator's scales, the inspectors may present weight standards for the operator to weigh. After weighing cylinders/containers, the IAEA may apply seals to provide continuity-of-knowledge between inspections; thus, validating contents have not changed. For sealed containers, the IAEA may only have to verify that the seal has not been compromised. To perform these activities, the following would be expected at the NUCP:

- Ensure that stored containers /cylinders are accessible and that discrete items can be moved to scales for weighing
- Ensure that containers/cylinders are designed such that IAEA seals can be applied
- Ensure that any IAEA-applied seals are accessible and not damaged
- Certified scales with the appropriate accuracies are available for weighing of items
- Certified check weights are available for use during IAEA inspections.

5.3 NON-DESTRUCTIVE/DESTRUCTIVE ANALYSIS

The inspectors use both NDA and DA techniques to validate processing activities and material integrity. Non-destructive techniques include visual inspections (appearance, counting items, facility layouts, and surveillance cameras), physical inspections (processing parameters such as flow rates, density, and mass) and nuclear verification using instruments [such as sodium iodide (NaI) or high purity germanium (HPGe) detectors]. For DA, the IAEA will select items and in-process material to be sampled for analysis.

For non-destructive measurement of materials at the NUCP, the IAEA typically stores instrumentation on site between inspections. Some systems (e.g., HPGe) require liquid nitrogen or other site utilities. Some of the NDA techniques are intrusive to the processing equipment (i.e., flow rates, temperature, and density measurements), thus requiring close coordination with the designers of the equipment for installation. Also, for NDA applications, designers should consider sufficient spacing between equipment where large sources of radiological material are contained (such as tanks) in an attempt to minimize background levels.

For DA, the items will need to be homogenized to assure that the sample is representative of the entire contents. In some instances, on-line sampling stations may be utilized at KMPs in a NUCP. In order to perform these DA activities, the following would be expected at the NUCP:

- Ensure the IAEA can have access to sampling areas and can observe sampling process
- Ensure the IAEA can trace sample withdrawal from items to sample container
- Ensure that material can be collected in, or transferred to, an IAEA sample container
- Ensure that the IAEA sample containers can be stored on site until shipped to Vienna.

5.4 CONDUCTING ANNUAL PHYSICAL INVENTORIES

During the annual PIV, the IAEA needs to be able to independently verify the quantity of uranium bearing material in plant, including material in process, storage, recycle, and waste. To perform these inventory verifications, the following would be expected at the NUCP:

- Ensure the IAEA can verify in-process materials during inventory
- Ensure the IAEA can verify uranium content in waste and recycle material.

6. SAFEGUARDS-BY-DESIGN BEST PRACTICES

The goal for safeguards-by-design in a NUCP 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 NUCP along with design considerations for implementation of such features.

6.1 GENERAL REQUIREMENTS (LIST OF SAFEGUARDS EQUIPMENT THAT MUST BE SUPPORTED)

The following is a list of the types of safeguards equipment that would be utilized at a NUCP:¹²

- Certified weighing equipment (scales, load cells, and balances)
- Calibration standards
- Surveillance cameras
- Information transfer (“Mailbox” equipment)
- NDA equipment
- Material sampling stations
- Sampling equipment and containers
- Tamper indicating seals (TIDs)
- Workstations (computers/document storage/electronic data transmittal, etc.)

6.2 LAYOUT REQUIREMENTS AND GUIDELINES

When laying out a NUCP, the designers should take into account the need to perform material accountability in a timely and effective manner. Proper establishment of MBAs and KMPs are vital in the ability to effectively measure the flow and inventory of nuclear materials at a NUCP.

The IAEA uses several criteria to establish MBAs, including accuracy considerations, the ability to apply C/S measures to ensure the completeness of flow measurements, and the nature of the activities and form of the nuclear materials within the MBA. The IAEA will conduct a material balance for each MBA and make a determination if the material unaccounted for (MUF) exceeds a SQ. For larger plants, the in-process inventory could exceed a SQ, with a correspondingly larger MUF that could limit the IAEA’s capability to independently verify there was no diversion. Therefore, the appropriate number of MBAs should be optimized for process operations, and the need for international inspections should be considered.

A NUCP typically is comprised of one MBA. However, in cases where in-process materials can be accounted for as separate batches in the storage area, it is recommended to have more than one MBA in the NUCPs. Although the main UOC storage area is not included in a MBA, UOCs designated for near-term feeding to the process may be included within the process MBA and be assigned flow and inventory KMPs.¹³ In order to determine a material balance in a MBA, all transfers in and out of an MBA, along with MUF, must be included in the calculation. MBAs should be chosen so that inputs and outputs are not in a form that is difficult to measure. An MBA should not cut across a process if the materials within that process are changing form, inaccessible for measurement, or not amenable to

¹² International Nuclear Verification Series No. 1 (Rev.2), *Safeguards Techniques and Equipment: 2011 Edition*, IAEA, 2011.

¹³ Safeguards Technical Report 342 (STR 342), *Safeguards Approaches for Natural Uranium Conversion Plants*, IAEA, February 2004.

accurate measurement. Material storage areas in a NUCP should be designed for ease of access and inspection activities and movement of material to/from storage. Also, designers should provide for application of C/S devices for material storage areas. Recycle and waste storage areas should be sized for adequate retention time, such that waste and recycle material can be held in storage, where possible, between inspections.

Design and layout of processing equipment should try to minimize the holdup of material, thus keeping MUF values low in an MBA. Also, entry/exit points for material into the process should be kept to a minimum in an attempt to minimize the number of pathways in the NUCP along which diversion of material or introduction of undeclared feed could occur.

6.3 SPACE ALLOCATION REQUIREMENTS AND GUIDELINES

6.3.1 Safeguards equipment

The IAEA will likely carry portable equipment to support inspections but may need to store heavier, less portable inspection equipment and calibration standards at the site between inspections. Facility design should factor in what type of storage environments, on-site calibration, site utilities (e.g., liquid nitrogen), and power requirements are needed for these devices. Some of these instruments may use or contain active radioactive sources; if so, storing such items will need to be taken into account in design.

The IAEA may require a separate storage safe or cabinet for its seals. This storage device shall be designed to provide tamper indication. The IAEA can provide specifications for this unit.

Reference and calibration weights will also be used by the inspectors. Thus, design considerations should be given as to how to store and move these items on-site.

6.3.2 Inspector office space, etc.

The IAEA inspectors need an office/work area to review and analyze data and complete their inspection paperwork. The selection of specific offices and work space locations should take into account proximity to inspection areas; environmental, safety and health (ES&H) requirements; ergonomics; evacuation routes; proximity to restrooms; etc. Computers, printers, and telecommunications requirements should be coordinated with IAEA during design of a NUCP. Also, accommodations should be made for adequate secured storage space for inspectors' spare equipment, office supplies, documentation, personal protective equipment, etc., that is at or near their office/work area. IAEA requirements for office/work and storage space should be established early on in the design of the NUCP.

6.3.3 On-site sample analysis and sample storage

DA is a key tool for safeguards in addition to surveillance, seals and NDA. Safeguards laboratories may be located and operated on-site or samples can be sent for analysis to qualified off-site laboratories. The main techniques used by the IAEA for measurement of nuclear material samples include titration, gravimetric analysis, mass spectrometry, and densitometry. At a minimum, work space should be provided for conditioning the samples on-site to ensure that they are in a chemical form adequate for maintaining their integrity during transport, for storing the samples, and for packaging, sealing and shipment of the samples to an off-site laboratory. Storage areas for samples

must be designed such that continuity of knowledge of the samples, for IAEA safeguards purposes, is maintained. This normally means that the samples would be stored under IAEA seal that is affixed and removed by an IAEA inspector.

6.4 DESIGN IMPACTS OF FACILITATING INSPECTION

6.4.1 Design features to facilitate DIE/DIV

By participating early in the design of a NUCP, IAEA inspectors can develop a good understanding of the facility, its layout, equipment, processes, etc. and convey their requirements to the designer for inclusion in the design.

Designing and constructing a NUCP with safeguards in mind and with the intent of making the facility “inspection” ready should be considered by the designers. Some items to consider include minimizing ingress and egress paths for the processing areas, avoiding “hidden” process equipment/piping, making equipment accessible, avoiding the use of temporary connections, color-coding lines for various process and support streams, avoiding portable equipment in processing areas, and keeping the facility “uncluttered.” Doing so can all support facility design validation efforts.

Providing safeguards-relevant information with the IAEA starting early in the design process can potentially reduce the inspection activities after operations begin. For example, being able to verify there are no “hidden” areas where nuclear materials could be introduced or removed from the process could reduce or eliminate the inspection efforts to verify the absence of clandestine capabilities. Should there be specific areas where the IAEA would not be granted access, the applicability of C/S measures should be considered. Every effort should be made to minimize routing process piping and equipment through inaccessible spaces. If routing process piping through inaccessible spaces cannot be avoided, the designer should use easily removable and sealable access panels to detect unauthorized access with tamper-indicating devices (TIDs) that provide an alarm indication report to the IAEA “mailbox” in the event an access panel is removed. The piping through these areas should be continuous. The designer should not incorporate valves or the capability to access or introduce material to the process in this area. The designer should also provide receptacles and cable connections in the event the IAEA wants to install localized surveillance cameras within confined or hidden spaces.

It is important that during DIVs, the IAEA inspectors verify that no changes have been made to the NUCP that could result in diversion paths. One way the IAEA verifies that the NUCP design has not changed is by comparing what is seen during the inspection to photos taken when the NUCP was initially built. Also in areas of the NUCP where minimal changes have occurred, the inspectors may choose to use a laser-based system (3D-DIV) to detect changes.

6.4.2 Design features to facilitate inspections during operations

NUCPs are typical chemical plants with huge pipes, large equipment, and tanks with a higher flexibility flow required by the process quality control and safety. On-site inspections are performed by the IAEA in order to verify that the NUCP operations are as declared by the operator. During inspections IAEA inspectors will make use of NDA, samples, process monitoring (tank level, flow meters, etc.), and C/S (seals, TIDs, cameras, etc.) to allow them to follow nuclear material movement

and verify operator declarations. During these inspections, observations of the process areas are made to confirm the absence of undeclared conversion operations and reconfiguration of process piping. The designer should evaluate all possible scenarios that permit misuse of the NUCP, even if the scenario appears impractical from an operator's perspective. Design features should be engineered into the piping system that either restrict or disable the use of auxiliary systems. The design should incorporate the capability to detect misuse of any auxiliary system component for diverting inventory. The facility operator should allow the IAEA access to all auxiliary systems during inspections. IAEA access to all sampling and feed and removal points should be considered during the conceptual design of the NUCP.

Designers should consider, as good practices, the following design features that could facilitate inspections in a NUCP:

- All NUCP process equipment is visible.
- Material access points to the process are visible and accessible.
- Automated software is created to enable inspector to reconcile inventory lists with inspector observations.
- A system is designed that continuously shares operator data on mass throughput.
- The capability to automatically locate and/or track items on site (wireless system or with handheld readers) is designed.
- On-line monitoring is provided at KMPs in the NUCP (e.g., U content /concentration, density and pH monitors, mass and flow rate meters, weigh scales, and accountability tanks) with output to an IAEA "mailbox" system;
- IDs are attached to items that can be remotely and independently read by the IAEA [e.g., barcodes/radio frequency identification devices (RFIDs)]. The identification techniques should provide an indicator if the identification technique of the item has been altered;
- Include safeguards on-line process sampling and monitoring capabilities with the ability to readily remove samples from process/storage containers in the overall design. On-line sampling connections and instrumentation should provide for a means for applying TIDs to detect unauthorized access;
- Include an IAEA "mailbox" declaration interface in the design.

Prior to or at the beginning of an inspection, "mailbox" declarations of specified nuclear material quantities and operating parameters are provided to the IAEA for evaluation. Designers need to incorporate the necessary cabling and communication infrastructure needed to support "mailbox" declarations. IAEA mailbox systems should be placed in an area that permits easy access by foreign nationals. The IAEA may request that the mailbox be placed under localized surveillance. The operator and the IAEA should work closely together with the facility designer to ensure the mailbox is located in an area that is convenient to both. The IAEA will provide the equipment and work with the site to install it. The facility designer should consider incorporating a mechanism that provides automated notification to the IAEA if a mailbox declaration needs to be changed. The IAEA recognizes that such changes may occur. The designer should work with software engineers to develop the proper hardware and software interfaces that provide a means for identifying such occurrences to the IAEA.

6.4.3 Verifying that undeclared material is not processed in the NUCP between inspections

The designer should consider and understand all credible scenarios for potential misuse at a NUCP for receiving, storing, and processing undeclared material and design detection capabilities into the facility that alleviates these concerns.

As an enhancement to safeguards implementation the design may incorporate the use of real-time process monitoring and surveillance systems that provide assurances to the IAEA that only declared inventory is processed in the area. This could include the use of a combination of administrative and engineering controls that routinely monitor the introduction or removal of all items to and from the NUCP. C/S techniques are complementary to nuclear material accounting techniques and are aimed at verifying information on movements of nuclear material or preservation of the integrity of previously verified material. C/S techniques assure that the transport of nuclear material follows predetermined routes, containers' integrity remains unimpaired, and the material is accounted for at the correct measurement points. Typical activities of C/S techniques include; (1) optical surveillance and sealing, and (2) unattended and remote monitoring. Although, the potential for applying C/S measures may be limited at NUCPs due to frequent material movement and the complexity of the process equipment, it may be useful to apply seals to feed (including scrap) or product containers, or unused equipment. There may be some applications for surveillance in process at drumming stations and UF₆ cylinder filling stations.

Providing a real-time process monitoring system designed for material flow and accountability can be a complex endeavor in a NUCP. An accountability system could involve incorporation of on-line weighing, flow measurements, volumetric measurements, and sampling in the NUCP. This system should provide for independent validation by IAEA inspectors.

Data security is crucial for unattended and remote monitoring systems. The unattended equipment in remote monitoring transmits data off-site and requires high reliability and authentication of the data sources. These data need to be verified to guarantee their authenticity and may need to be encrypted.

6.5 DESIGN TEAM DISCIPLINE-SPECIFIC IMPACTS

SBD incorporation into NUCPs will require a multi-discipline 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 ensure safeguards requirements are met and integrated into the design of the systems, structures, and components. The extent to which safeguards 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 NUCP:

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)
- Material Balance Areas
- Material hold-up
- Key measurement points (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

- Destructive Analysis techniques for determining uranium content (process, salvage, waste streams)
- Key measurement points (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

- Material Balance Areas (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)

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 precipitate, oxide and UF ₄ containers or UF ₆ cylinders to verify presence and identification	<ul style="list-style-type: none"> • None 	<ul style="list-style-type: none"> • Standardized container identification • On-site container tracking system
	Weighing drums/containers/cylinders to verify declared gross weights	<ul style="list-style-type: none"> • Reweighing on operator's scales 	<ul style="list-style-type: none"> • Authenticated, shared-use of operator's accountability scales
		<ul style="list-style-type: none"> • Portable IAEA load scales 	
	Measuring uranium content	<ul style="list-style-type: none"> • Portable nondestructive assay (NDA) • Off-site destructive analysis (DA) of samples 	<ul style="list-style-type: none"> • Integrated NDA with mass/volume flow meters • On-site DA capability
Detect processing of undeclared feed to produce undeclared pure products	Visual inspection to verify process configuration and the absence of undeclared operations	<ul style="list-style-type: none"> • Photographs 	<ul style="list-style-type: none"> • Three-dimensional (3D) laser systems
	Environmental sampling	<ul style="list-style-type: none"> • Off-site ultra-trace sample analysis 	
	Measuring uranium flow and concentration at various key points in process	<ul style="list-style-type: none"> • Portable NDA • Continuous, unattended NDA 	<ul style="list-style-type: none"> • Improved continuous, unattended monitoring
		<ul style="list-style-type: none"> • Off-site DA of sample 	<ul style="list-style-type: none"> • On-site DA capability

APPENDIX 2

Suggested NUCP Safeguards Monitoring Points

ORNL working with personnel from Brookhaven National Laboratory (BNL), Lawrence Livermore National Laboratory (LLNL), and Los Alamos National Laboratory (LANL) evaluated natural uranium conversion processes and developed a list of suggested KMPs in a NUCP.^{14,15} These monitoring points were determined by using process modeling and analysis of potential diversion pathways at a NUCP. The following discussion provides possible locations for KMPs in the NUCP and is for information only. The actual locations of KMPs at a NUCP will be established between the facility owner and the IAEA.

Analysis of NUCP flowsheets for production capacity ranging from 100 to 10,000 MTU/year identified several possible pathways to either divert uranium or to use the equipment to process undeclared uranium. There are several potential exit points besides the main process flow for small amounts of uranium throughout the NUCP (undissolved yellowcake solids, dust, waste and/or recycled organic, ash, or slag). The uranium mass rate in these side streams increases as the plant capacity and main process mass rate increase. Much of this uranium can be recovered and recycled to improve efficiency. Thus, these plant waste and recycle streams must be taken into account, especially for larger plants, either as part of an unattended monitoring system or as part of the regular inspection schedule. Scrap material which has passed the 34(c) starting point remains under full safeguards procedures. When such material is processed with other nuclear materials not subject to full safeguards procedures at NUCPs, the mixed material becomes subject to full safeguards. Nuclear material which has become subject to full safeguards procedures prior to passing the 34(c) starting point and is removed from the process prior to the 34(c) starting point need not remain under safeguards procedures as long as any removal of such material is reported, the removed material is made available for verification and is not mixed with other materials subject to full safeguards.¹⁶

Uranium material — including all the solid intermediate products and the UF₆ product—becomes significantly more attractive for diversion after purification. Five monitoring locations after purification, including the final UF₆ product are recommended to be monitored. In addition, monitoring the yellowcake or UOC feed coming into the plant is required to provide a basis for establishing the process mass balance. The overall mass balance is obtained from the uranium coming in with the feed and leaving with the product (taking into account plant efficiency) and waste streams. Undeclared feed could be introduced at any point along the flow path. Internal unattended monitoring points provide a means of detecting this activity in addition to providing a check on the overall mass balance. At a NUCP, eight KMPs have been identified (see Figure 2) including:

- At the solid feed entering the plant.
- The solid feed being fed to the dissolver.
- The uranyl nitrate solution before purification.
- The uranyl nitrate strip solution just after purification.
- The stripped organic solvent just after purification. (6) the purified uranyl nitrate solution after being concentrated in the evaporator, (7) the first solid uranium after purification (after precipitation or thermal denitration), and (8) the final product are recommended. With all

¹⁴ R. Faulkner et al., *Oak Ridge Efforts to Enhance Conversion Plant Safeguards*, presented at the INMM 45th Annual Meeting, Orlando, Florida, 2004.

¹⁵ B. Boyer et al., *Systems Modeling Framework for Assessing Safeguards Approaches for a Generic Natural Uranium Conversion Plant (NUCP)*, BNL 077317-2006, August 15, 2006

¹⁶ Safeguards Technical Report 342 (STR 342), *Safeguards Approaches for Natural Uranium Conversion Plants*, IAEA, February 2004.

eight monitoring points, the probability of detecting a diversion of a SQ of uranium becomes high for small- and medium-size plants. The large plants may have a high detection capability if special attention is placed on waste stream disposition.

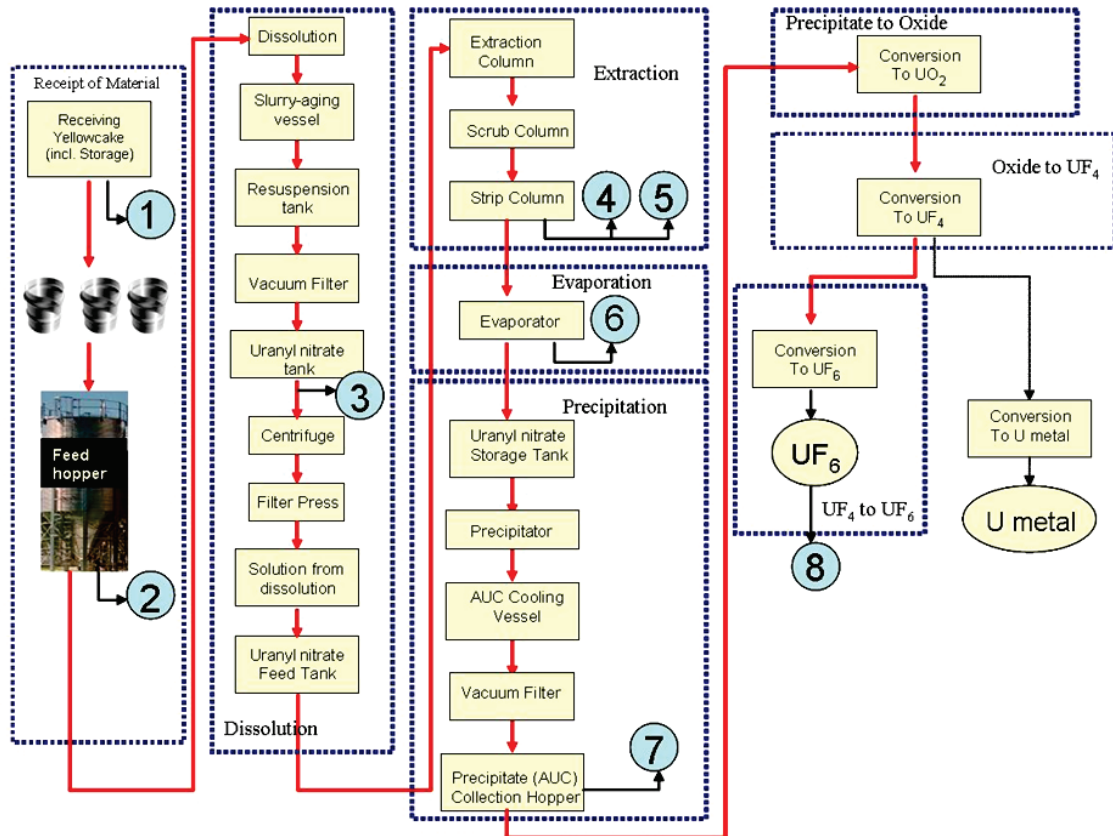


Fig. 2. Recommended Key Measurement Points

Table 1 summarizes safeguards approaches that can be used at the suggested KMPs in the NUCP. These approaches include material balance verification using DA and NDA as well as real-time process monitoring and surveillance systems. The combination of these applications is aimed at providing assurance to the IAEA that no undeclared inventory is being processed or that no material is being diverted from the NUCP.

Table 1. Safeguards for the suggested monitoring points at NUCP

Monitoring point number	Process parameters	Safeguards system
1	Solid yellowcake is received in drums, stored, and dumped into feed hopper for dissolver	<ul style="list-style-type: none"> Accounting with grab samples taken for DA NDA measurement of U in drum
2	Solid yellowcake fed from bottom of feed hopper to the dissolver	Mass rate of solid feed using process gravimetric techniques combined with analysis of U content from monitoring point 1 or destructive analysis of grab samples from monitoring point 2
3	Unpurified uranyl nitrate solution	In-line monitoring of U concentration, pH, density, conductivity, temperature, and flow rate
4	Purified uranyl nitrate solution	In-line monitoring of U concentration, pH, density, conductivity, temperature, and flow rate
5	Stripped organic liquid	In-line monitoring of U concentration, density, temperature, and flow rate
6	Concentrated purified uranyl nitrate solution	In-line monitoring of U concentration, pH, density, conductivity, temperature, and flow rate
7	Purified solid dry uranium (AUC or UO_3)	Accounting with grab samples taken for destructive analysis and mass rate
8	UF_6 collected and stored in cylinders	Accounting with grab samples taken for destructive analysis and mass rate on total produced



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