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The Concept of Goals-Driven Safeguards

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EXECUTIVE SUMMARY

The IAEA, NRC, and DOE regulations and requirements for safeguarding nuclear material and facilities have been reviewed and each organization’s purpose, objectives, and scope are discussed in this report. Current safeguards approaches are re-examined considering technological advancements and how these developments are changing safeguards approaches used by these organizations.

Additionally, the physical protection approaches required by the IAEA, NRC, and DOE were reviewed and the respective goals, objectives, and requirements are identified and summarized in this report. From these, a brief comparison is presented showing the high-level similarities among these regulatory organizations’ approaches to physical protection.

The regulatory documents used in this paper have been assembled into a convenient reference library called the Nuclear Safeguards and Security Reference Library. The index of that library is included in this report, and DVDs containing the full library are available.

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ACRONYMS

AFCI	Advanced Fuel Cycle Initiative
CFR	Code of Federal Regulations
COK	continuity of knowledge
CPPNM	Convention on Physical Protection of Nuclear Material
C/S	containment and surveillance
CSA	comprehensive safeguards agreement
DA	destructive analysis
DBT	design basis threat
DIV	Design Information Verification
EBR-II	Experimental Breeder Reactor-II
ER	electrorefiner
FCF	Fuel Conditioning Facility
GSP	Graded Security Protection (Policy)
IAEA	International Atomic Energy Agency (Austria)
INL	Idaho National Laboratory
ISSM	Integrated Safeguards and Security Management
ITV	international target values
KMP	key measurement point
LOF	location outside facilities
LWR	light-water reactor
MC&A	material control and accountability
MT	
MTIHM	metric tons of initial heavy metal
NDA	non-destructive assay
NMMS	Nuclear Materials Management Safeguards System
NNSA	National Nuclear Security Administration
NPT	non-proliferation treaty
MBA	material balance area
MUF	material unaccounted for
NPT	non-proliferation treaty
NRC	Nuclear Regulatory Commission
PC	process cell
PUREX	plutonium-uranium extraction

SAGSI	Standing Advisory Group on Safeguards Implementation
SSAC	State system of accounting for and control of nuclear material
SQ	significant quantity
SRD	shipper/receiver difference
U.S. DOE	United States Department of Energy

The Concept of Goals-Driven Safeguards

This report explores the concept of achieving safeguards goals by taking advantage of the inherent characteristics of advanced processing and reactor systems rather than by attempting to apply the detailed requirements that have been developed for conventional processing systems and existing reactors. A brief review of current safeguards goals, as expressed by the International Atomic Energy Agency (IAEA), Nuclear Regulatory Commission (NRC), and United States Department of Energy (U.S. DOE) is included. An example is then presented of an advanced processing system in which safeguards are achieved in an augmented manner. This is different than what is done in today's processing plants, potentially achieving a higher level of safeguards effectiveness.

Also, the most pertinent physical security regulations and requirements for securing nuclear materials and facilities, established by the IAEA, NRC, and U.S. DOE, are outlined and discussed in Appendix A. In Appendix B, the most relevant safeguards and security documents used in this report have been assembled into a quick- and targeted-reference library called the Nuclear Safeguards and Security Reference Library.

1. SAFEGUARDS – BACKGROUND AND BASIS

Safeguards have been developed and implemented by a number of domestic and international organizations to ensure that any potential weapons-usable fissionable civilian nuclear materials are not used for military purposes. To accomplish this goal, more specific requirements for the safeguards systems have been developed by various organizations, including the IAEA, the NRC, and the U.S. DOE. These requirements reflected the concerns that arose regarding the technologies for reactors, processing, and other systems that were in use, or perhaps planned for use, at the time the safeguards approaches were created. As such, the safeguards approaches have technology-specific features based on applications to such systems. The safeguards approaches also reflected the state of the technologies that could be used to monitor, track, and protect potential weapons-usable materials. As these technologies evolved, including those for monitoring and protection, safeguards approaches have also evolved.

The development of processing technologies in the Advanced Fuel Cycle Initiative (AFCI) project are radically different from technologies applied in existing commercial facilities, and proposals to link these technologies with reactor types are not in widespread use. For this reason, it is prudent to re-examine the bases for existing safeguards approaches and evaluate the appropriateness of extending these systems to the new technologies. It is also reasonable to examine the creation of new safeguards approaches specifically designed to take advantage of the characteristics of each processing technology and reactor system. To facilitate such an evaluation, it is necessary to review the existing safeguards goals, both domestic and international. In this report, the IAEA international safeguards are reviewed first, and then domestic safeguards are discussed based on NRC and DOE requirements.

1.1 International Safeguards: The IAEA

Internationally, the IAEA has been charged with the task of developing and implementing a safeguards system, according to the following statements from the IAEA Safeguards Glossary,[1] Chapter 1. The IAEA first wrote it "with the aim of facilitating understanding of the specialized safeguards terminology within the international community." Since then, the glossary has been revised several times to reflect the evolution of the safeguards agreements and measures, including the development of integrated safeguards starting in 1999.

> *IAEA Safeguards Glossary, Chapter 1. LEGAL INSTRUMENTS AND OTHER DOCUMENTS RELATED TO IAEA SAFEGUARDS*

Safeguards applied by the International Atomic Energy Agency (IAEA) are an important element of the global nuclear non-proliferation regime. This section provides information on legal instruments and other documents in the area of nuclear non-proliferation that establish the bases of the IAEA safeguards system or are otherwise closely linked to the application of IAEA safeguards. These include the Statute of the IAEA, treaties and supply agreements calling for the verification of nonproliferation undertakings, the basic safeguards documents, safeguards agreements and their relevant protocols, and guidelines related to the implementation of IAEA safeguards.

1.1 Statute of the International Atomic Energy Agency — the Statute of the IAEA [ST] was approved in October 1956 by the United Nations Conference on the Statute of the IAEA and entered into force in July 1957, as amended. According to Article II, the IAEA shall "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose." By Article III.A.5, the IAEA is authorized to "establish and administer safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities, and information made available by the Agency or at its request or under its supervision or control are not used in such a way as to further any military purpose; and to apply safeguards, at the request of the parties, to any bilateral or multilateral arrangement, or at the request of a State, to any of that State's activities in the field of atomic energy." Under this Article, the IAEA concludes agreements with the State or States concerned which refer to the application of safeguards. Articles XII.A and XII.B deal with the rights and responsibilities of the IAEA with respect to the application of safeguards and provide, inter alia, for IAEA inspection in the State or States concerned. Article XII.C refers to actions which may be taken by the IAEA in possible cases of non-compliance with safeguards agreements.

The underlined phrase defines the goals of IAEA safeguards. Since the special fissionable and other materials include all uranium (from depleted through enriched), thorium, and the plutonium isotope Pu-239, the processing and recycling in the advanced nuclear fuel cycles studied in the AFCI program will always use these materials. Any fuel processing and recycling approach must account for the need to ensure that the technologies would enable satisfying the requirement of non-military use of these materials.

This charter by the United Nations is supplemented by the Nuclear Non-Proliferation Treaty, which explains the need for safeguards and the activities and materials to which they apply, as described in the following section:[1]

IAEA Safeguards Glossary, Chapter 1.2. Treaty on the Non-Proliferation of Nuclear Weapons (Non-Proliferation Treaty, NPT) — the cornerstone of the nuclear non-proliferation regime. The Treaty was opened for signature in 1968, and entered into force in 1970; as of 31 December 2001, it is in force in 187 States. In 1995, the Treaty was extended indefinitely. Pursuant to Article I, each nuclear weapon State party to the NPT undertakes not to transfer, to any recipient whatsoever, nuclear *weapons or other nuclear explosive devices or control over such weapons or devices directly or indirectly; and not in any way to assist, encourage or induce any non-nuclear-weapon State to manufacture or otherwise acquire such weapons or devices or control over such weapons or devices.*

Pursuant to Article II, each non-nuclear-weapon State party to the NPT undertakes not to receive the transfer, from any transferor whatsoever, of nuclear weapons or other nuclear explosive devices or control over such weapons or devices directly or indirectly; not to manufacture or otherwise acquire such weapons or devices; and not to seek or receive any assistance in the manufacture of such weapons or devices. Pursuant to Article III.1, each non-nuclear-weapon State party to the NPT undertakes to accept IAEA safeguards on all source or special fissionable material in all peaceful nuclear activities within the territory of such State, under its jurisdiction, or carried out under its control anywhere. Pursuant to Article III.2, each State party to the NPT undertakes not to provide source or special fissionable material, or equipment or material especially designed or prepared for the processing, use or production of special fissionable material, to any non-nuclear-weapon State for peaceful purposes, unless the source or special fissionable material is subject to the safeguards required by Article III.1. Article III.4 requires each non-nuclear-weapon State party to the NPT to conclude a safeguards agreement with the IAEA, either individually or together with other States, within 18 months of the date on which the State deposits its instruments of ratification of or accession to the Treaty. Article IV affirms the right of all parties to the NPT to develop research, production and use of nuclear energy for peaceful purposes and to facilitate and participate in the fullest possible exchange of equipment, materials and information for the peaceful uses of nuclear energy.

The underlined sections identify the requirements on special nuclear material and technologies that can be used to produce special nuclear material. Again, the purpose is to ensure that such materials are not used for military purposes. There is additional detail in Chapter 1 of Reference 1 on implementing treaties and supply agreements, their basic safeguards documents including the Inspectorate, the Safeguards System, and other aspects such as the voluntary offer agreement, the additional protocol, and some guidelines and recommendations.

It is also important to note that safeguards implementation is governed by safeguards agreements. The activities that the secretariat considers necessary for fulfilling the agency's responsibilities under these agreements are incorporated in the safeguards criteria. These criteria are used for planning safeguards implementation activities in the field and at headquarters for all facilities and locations outside facilities as well as for the evaluation of inspection goal attainment at facilities and safeguards evaluation at the level of Entire States.

1.1.1 IAEA Safeguards Purpose, Objectives and Scope

In order to set up the IAEA safeguards, the IAEA further defines its intentions and adds specific details on the safeguards objectives in Chapter 2 of the Safeguards Glossary,[1] as follows.

IAEA Safeguards Glossary, Chapter 2. *IAEA SAFEGUARDS: PURPOSE, OBJECTIVES AND SCOPE*

Safeguards are applied by the IAEA to verify that commitments made by States under safeguards agreements with the IAEA are fulfilled. It is therefore necessary to define the objectives of safeguards in technical terms relevant to each type of safeguards agreement so that safeguards can be applied in an effective manner. What follows is an explanation of terms used in connection with safeguards objectives and with the scope of application of safeguards relevant to the safeguards agreement and additional protocols.

2.1. Objectives of IAEA safeguards — under a comprehensive safeguards agreement (CSA), safeguards are applied to verify a State's compliance with its undertaking to accept safeguards on all nuclear material in all its peaceful nuclear activities and to verify that such material is not diverted to nuclear weapons or other nuclear explosive devices. In this regard, the technical objective is specified: "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" [153, para. 28]. To address fully the verification of a State's compliance with its undertaking under a CSA, a second technical objective is pursued, viz. the detection of undeclared nuclear material and activities in a State (see No. 2.5). The implementation of measures under additional protocols based on [540] significantly strengthens the IAEA's capability to achieve this objective (see No. 3.6).

For an INFCIRC/66-type safeguards agreement, the objective is to ensure that the nuclear material, non-nuclear material, services, equipment, facilities and information specified and placed under safeguards are not used for the manufacture of nuclear weapons or any other nuclear explosive devices or to further any military purpose. To achieve this, the IAEA applies essentially the same technical objective in regard to detection of diversion of the nuclear material specified and placed under safeguards, as well as the detection of any misuse of the non-nuclear material, services, equipment, facilities or information specified and placed under safeguards. This is also the case for the nuclear material and/or facilities to which safeguards are applied under a voluntary offer safeguards agreement concluded between a nuclear weapon State and the IAEA.

As stated in the underlined phrases, the objectives of IAEA safeguards are the timely detection and diversion of significant quantities of nuclear materials and the detection of any undeclared nuclear materials or activities. The first objective is a function of the facilities and technologies being used at declared facilities. The second objective is detection of both undeclared activities at declared facilities, which is also technology dependent, and detection of undeclared activities outside of declared facilities, which is more of an intelligence-gathering issue and is largely technology independent. The goal is still to facilitate the timely detection of the production or use of nuclear materials by a state for other than peaceful purposes, whether through misuse of or diversion from a safeguarded facility, or by the use of undeclared materials, activities, or facilities which the state was required to declare. Part of the safeguards activity is to provide assurance of non-diversion and the absence of undeclared materials, activities, and facilities.

The extent to which safeguards are applied by the IAEA needs be to discussed, since that represents the extent of the monitoring and tracking needs, as summarized in the following.[1]

> *IAEA Safeguards Glossary, Chapter 2.10. Coverage of IAEA safeguards — the scope of application defined by the relevant safeguards agreement. Under a comprehensive safeguards agreement (CSA), safeguards are applied on "all source or special fissionable material in all peaceful nuclear activities within the territory of the State, under its jurisdiction or carried out under its control anywhere…" [153, para. 2]. Thus such agreements are considered comprehensive (or 'full scope'). The scope of a CSA is not limited to the nuclear material declared by a State, but includes all nuclear material subject to IAEA safeguards. Under an INFCIRC/66-type agreement, safeguards are applied only to the items specified in the agreement, which may include nuclear material, non-nuclear material, services, equipment, facilities and information. Under a voluntary offer agreement with a nuclear weapon State, safeguards are applied to the nuclear material and/or facilities specified in the agreement.*
>
> *2.11. Starting point of IAEA safeguards — the expression often used to refer to the point in a nuclear fuel cycle from which full safeguards requirements specified in comprehensive safeguards agreements start to apply to nuclear material. Under para. 34(c) of [153], the application of full safeguards requirements specified in the agreement begins when any nuclear material of a composition and purity suitable for fuel fabrication or for being isotopically enriched leaves the plant or the process stage in which it has been produced, or when such nuclear material, or any other nuclear material produced at a later stage in the nuclear fuel cycle, is imported into a State. However, under paras 34(a) and 34(b) of [153], when the State exports to a nonnuclear-weapon State, or imports, any material containing uranium or thorium which has not reached the stage of the nuclear fuel cycle described in para. 34(c) of [153], the State is required to report such exports and imports to the IAEA, unless the material is transferred for specifically non-nuclear purposes. Furthermore, under Article 2.a.(vi) of [540], the State is required to provide the IAEA with information on source material which has not reached the composition and purity described in [153, para. 34(c)]. That information is to be provided both on such material present in the State, whether in nuclear or non-nuclear use, and on exports and imports of such material for specifically non-nuclear purposes.*
>
> *2.12. Termination of IAEA safeguards — safeguards in a given State normally continue on nuclear material (and subsequent generations of nuclear material produced therefrom) until the material is transferred to another State which has assumed the responsibility therefor, or until the material has been consumed or has been diluted in such a way that it is no longer usable for any nuclear activity relevant from the point of view of safeguards, or has become practicably irrecoverable. Under paras 13 and 35 of [153] and para. 27 of [66], safeguards may be terminated for material transferred to non-nuclear use, such as the production of alloys*

or ceramics. Paragraph 26 of [66] provides that termination is also possible in the case of the substitution of material not under safeguards for safeguarded material. Under Article 2.a.(viii) of [540], the State is to provide the IAEA with information regarding the location or further processing of intermediate or high level waste containing plutonium, high enriched uranium or ^{233}U on which safeguards have been terminated. (See also No. 6.25.)

1.1.2 IAEA Safeguards Approach

Having defined the intent of safeguards and the extent to which safeguards would be applied in a state covered by a safeguards agreement, the IAEA then describes the approaches that are used in achieving the safeguards' goals.[1]

> *IAEA Safeguards Glossary, Chapter 3. SAFEGUARDS APPROACHES, CONCEPTS AND MEASURES*
>
> *Approaches to safeguards implementation are designed to allow the IAEA to meet the applicable safeguards objectives. What follows is an explanation of the basic concepts underlying the development and application of safeguards approaches at the level of the facility and the State, and the measures available to the IAEA under safeguards agreements and under additional protocols.*
>
> *3.1. Safeguards approach — a set of safeguards measures (see No. 3.6) chosen for the implementation of safeguards in a given situation in order to meet the applicable safeguards objectives (see No. 2.1). The safeguards approach takes into account the specific features of the safeguards agreement (or agreements) and, where applicable, whether the IAEA has drawn a conclusion of the absence of undeclared nuclear material and activities in the State (see No. 12.25). Safeguards approaches are developed for each facility under safeguards (see No. 3.3). In addition, safeguards approaches may be developed for generic facility types (see No. 3.2) and, mainly under integrated safeguards (see No. 3.5), for the State as a whole (see No. 3.4).*
>
> *3.2. Model (generic) facility safeguards approach — the recommended approach for a particular facility type developed for a postulated reference plant. The approach specifies the IAEA inspection goals (see No. 3.22) and safeguards activities for that reference plant, taking into account relevant diversion assumptions; available safeguards measures (see No. 3.6), including the technical capabilities of those measures; facility design information (see No. 3.28) and facility practices (see No. 3.27); the capabilities of the State system of accounting for and control of nuclear material (SSAC) (see No. 3.33); and the IAEA's experience in safeguards implementation. Model safeguards approaches are developed for most of the common facility types.*

At this point, the IAEA expects to develop safeguards approaches for each facility based on the safeguards approach for reference plants, which it recognizes have been developed for most common facility types. The expectation is that as new facility types are developed, new model safeguards approaches will be developed that enable the safeguards goals to be met in those facilities:

IAEA Safeguards Glossary, Chapter 3.3. Facility safeguards approach — the approach selected for safeguards implementation at a specific facility, developed by adapting the model approach (where such exists) to account for actual conditions at the facility as compared with the reference plant. The provisions for implementing the facility safeguards approach are incorporated in the Subsidiary Arrangements (see No. 1.26).

Subsequently, the safeguards measures used in the safeguards approach are defined:

IAEA Safeguards Glossary, Chapter 3.6. Safeguards measures — methods available to the IAEA under safeguards agreements and additional protocols based on [540] to achieve the applicable safeguards objectives (see No. 2.1). Paragraph 29 of [153] provides for the use of nuclear material accountancy as the safeguards measure of fundamental importance (see No. 6.1), with containment and surveillance as important complementary measures (see No. 8.6). These measures are applied for verifying that nuclear material inventories and flows are as declared by the State (and, under INFCIRC/66-type safeguards agreements, that non-nuclear material, services, equipment, facilities and information specified and placed under safeguards are not being used to further any proscribed purpose). Additional measures aimed at strengthening the effectiveness and improving the efficiency of safeguards were approved by the IAEA Board of Governors during 1992–1997. From a legal perspective, these measures may be categorized as follows: (a) measures that can be implemented under the existing legal authority of safeguards agreements (e.g. environmental sampling at locations to which IAEA inspectors have access during inspections and visits (see Nos 9.1 and 11.14)); and (b) measures that can only be implemented under the legal authority of additional protocols (e.g. complementary access (see No. 11.25)).

As stated, the main purpose of the safeguards measures is to verify that the nuclear material inventories and flows (movement of materials) are as declared by the State. At this point, it is important to review why the material inventories and flows are the target of the safeguards measures.

1.1.3 IAEA Diversion Detection and Timeliness

The "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities" requires definition of the amounts and times of interest. In determining time and quantity, other factors should be considered, as listed in the following from Ref. 1:

IAEA Safeguards Glossary, Chapter 3.10. Diversion rate — the amount of nuclear material which could be diverted in a given unit of time. If the amount diverted is 1 SQ or more (see No. 3.14) of nuclear material in a short time (i.e. within a period that is less than the material balance period (see No. 6.47)), it is referred to as an 'abrupt' diversion. If the diversion of 1 SQ or more occurs gradually over a material balance period, with only small amounts removed at any one time, it is referred to as a 'protracted' diversion.

3.13. Conversion time — the time required to convert different forms of nuclear material to the metallic components of a nuclear explosive *device.* *Conversion time does not include the time required to transport diverted material to the conversion facility or to assemble the device, or any subsequent period. The diversion activity is assumed to be part of a planned sequence of actions chosen to give a high probability of success in manufacturing one or more nuclear explosive devices with minimal risk of discovery until at least one such device is manufactured. The conversion time estimates applicable at present under these assumptions are provided in Table I.*

TABLE I. ESTIMATED MATERIAL CONVERSION TIMES FOR FINISHED Pu OR U METAL COMPONENTS

Beginning material form	Conversion time
Pu, HEU or ^{233}U metal	Order of days (7–10)
PuO_2, $Pu(NO_3)^4$ or other pure Pu compounds; HEU or ^{233}U oxide or other pure U compounds; MOX or other non-irradiated pure mixtures containing Pu, U ($^{233}U + ^{235}U \geq 20\%$); Pu, HEU and/or ^{233}U in scrap or other miscellaneous impure compounds	Order of weeks (1–3)[a]
Pu, HEU or ^{233}U in irradiated fuel	Order of months (1–3)
U containing <20% ^{235}U and ^{233}U; Th	Order of months (3–12)

[a] This range is not determined by any single factor but the pure Pu and U compounds will tend to be at the lower end of the range and the mixtures and scrap at the higher end.

3.14. Significant quantity (SQ) — 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 (see No. 3.23). Significant quantity values currently in use are given in Table II.

TABLE II. SIGNIFICANT QUANTITIES

Material	SQ
Direct use nuclear material	
Pu[a]	8 kg Pu
^{233}U	8 kg ^{233}U
HEU ($^{233}U \geq 20\%$)	*25 kg ^{235}U*
Indirect use nuclear material	
U (235U < 20%)b	75 kg 235U (or 10 t natural U or 20 t depleted U)
Th	20 t Th

a For Pu containing less than 80% 238Pu.

b Including low enriched, natural and depleted uranium.

3.15. Detection time — <u>the maximum time that may elapse between diversion of a given amount of nuclear material and detection of that diversion by IAEA safeguards activities.</u> Where there is no additional protocol in force or where the IAEA has not drawn a conclusion of the absence of undeclared nuclear material and activities in a State (see No. 12.25), it is assumed: (a) that all facilities needed to clandestinely convert the diverted material into components of a nuclear explosive device exist in a State; (b) that processes have been tested (e.g. by manufacturing dummy components using appropriate surrogate materials); and (c) that nonnuclear components of the device have been manufactured, assembled and tested. Under these circumstances, detection time should correspond approximately to estimated conversion times (see No. 3.13). Longer detection times may be acceptable in a State where the IAEA has drawn and maintained a conclusion of the absence of undeclared nuclear material and activities. Detection time is one factor used to establish the timeliness component of the IAEA inspection goal (see No. 3.24).

3.16. Detection probability — the probability, if diversion of a given amount of nuclear material has occurred, that IAEA safeguards activities will lead to detection. The detection probability is usually denoted as $1 - \beta$, with β being the non-detection probability (see No. 10.28). The detection probability for safeguards activities involving nuclear material accountancy can be quantified, and the accountancy detection probability $1 - \beta_a$ is preselected as an input parameter for establishing sampling plans. The values of $1 - \beta_a$ currently in use are 90% for 'high' and 20% for 'low' probability levels.

3.17. False alarm probability — the probability, α , that statistical analysis of accountancy verification data would indicate that an amount of nuclear material is missing when, in fact, no diversion has occurred (see No. 10.27). For nuclear material accountancy purposes, α (or the associated critical region (see No. 10.32)) is preselected as one of the input parameters for designing sampling plans and performing statistical tests. It is usually set at 0.05 or less, in order to minimize the number of discrepancies (see No. 3.25) or false anomalies (see No. 3.26) that must be investigated.

3.18. Inventory — the amount of nuclear material present at a facility or a location outside facilities (LOF). In the context of IAEA safeguards, the term 'inventory' is defined as the larger of: the maximum (running) inventory calculated from State reports (see Nos 12.5–12.8); or throughput, which is the estimated amount of material processed during the material balance period. This inventory is used for establishing the frequency and intensity of routine inspections for a facility or an LOF (see No. 11.16), as provided for in paras 79 and 80 of [153].

3.19. Annual throughput — <u>"the amount of nuclear material transferred annually out of a facility working at nominal capacity" [153, para. 99].</u> Paragraph 84 of [66] defines throughput as "the rate at which nuclear material is introduced into a facility operating at full capacity."

3.20. IAEA timeliness detection goal — the target detection times applicable to specific nuclear material categories (see No. 4.24). These goals are used for establishing the frequency of inspections (see No. 11.16) and safeguards activities at a facility or a location outside facilities during a calendar year, in order to verify that no abrupt diversion (see No. 3.10) has occurred. Where there is no additional protocol in force or where the IAEA has not drawn and maintained a conclusion of the absence of undeclared nuclear material and activities in a State (see No. 12.25), the detection goals are as follows:

—One month for unirradiated direct use material,
—Three months for irradiated direct use material,
—One year for indirect use material.

Longer timeliness detection goals may be applied in a State where the IAEA has drawn and maintained a conclusion of the absence of undeclared nuclear material and activities in that State.

Note that the IAEA defines "direct use material" as "nuclear material that can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment." It does not mean that the material can be directly used in its current form in a nuclear explosive device, but that chemical or other forms of processing may be required, such as separation from other elements and reduction of the oxide to metal. With this definition, any spent fuel would be characterized as direct-use material due to the presence of Pu-239, and the presence of the radiation field due to fission products and other elements only alters the goal detection time, increasing it from one month to three months.

IAEA Safeguards Glossary, Chapter 3.22. IAEA inspection goal — performance targets specified for IAEA verification activities at a given facility as required to implement the facility safeguards approach (see No. 3.3). The inspection goal for a facility consists of a quantity component (see No. 3.23) and a timeliness component (see No. 3.24). These components are regarded as fully attained if all the Safeguards Criteria (see No. 3.21) relevant to the material types (see No. 4.23) and material categories (see No. 4.24) present at the facility have been satisfied and all anomalies involving 1 SQ or more of nuclear material have been resolved in a timely manner (see No. 3.26). (See also Nos 12.23 and 12.25.)

3.23. Quantity component of the IAEA inspection goal — relates to the scope of the inspection activities at a facility that are necessary for the IAEA to be able to draw the conclusion that there has been no diversion of 1 SQ or more of nuclear material over a material balance period and that there has been no undeclared production or separation of direct use material at the facility over that period.

3.24. Timeliness component of the IAEA inspection goal — relates to the periodic activities that are necessary for the IAEA to be able to draw the conclusion that there has been no abrupt diversion (see No. 3.10) of 1 SQ or more at a facility during a calendar year.

3.26. Anomaly — an unusual observable condition which might result from diversion of nuclear material (see No. 2.3) or misuse of safeguarded items (see No. 2.4), or which frustrates or restricts the *ability of the IAEA to draw the conclusion that diversion or misuse has not occurred (see No. 12.25). Examples of possible anomalies would be:*

—Denial or restriction of IAEA inspector access for inspection (see No. 11.14);
—Unreported safeguards significant changes to facility design or operating conditions (see No. 3.28);
—A discrepancy involving 1 SQ or more of nuclear material (see No. 3.25);
—A significant departure from the agreed recording and reporting system (see No. 6.1);
—Failure of the facility operator to comply with agreed measurement standards or sampling methods (see No. 6.1);
—(For bulk handling facilities) a negative conclusion resulting from the evaluation of MUF (material unaccounted for), SRD (shipper/receiver difference) or other statistics (see No. 10.1);
—IAEA seals on equipment detached by non-IAEA staff, lost or showing signs of tampering (see Nos 8.5 and 8.12);
—Evidence of tampering with IAEA equipment (see No. 8.12).

3.33. State system of accounting for and control of nuclear material (SSAC) — organizational arrangements at the national level which may have both a national objective to account for and control nuclear material in the State and an international objective to provide the basis for the application of IAEA safeguards under an agreement between the State and the IAEA (see No. 6.1). Under a comprehensive safeguards agreement, the State is required to establish and maintain a system of accounting for and control of nuclear material subject to safeguards under the agreement. The system "shall be based on a structure of material balance areas, and shall make provision...for the establishment of such measures as:

(a) A measurement system for the determination of the quantities of nuclear material received, produced, shipped, lost or otherwise removed from inventory, and the quantities on inventory;
(b) The evaluation of precision and accuracy of measurements and the estimation of measurement uncertainty;
(c) Procedures for identifying, reviewing and evaluating differences in shipper/receiver measurements;
(d) Procedures for taking a physical inventory;
(e) Procedures for the evaluation of accumulations of unmeasured inventory and unmeasured losses;
(f) A system of records and reports showing, for each material balance area, the inventory of nuclear material and the changes in that inventory including receipts into and transfers out of the material balance area;
(g) Provisions to ensure that the accounting procedures and arrangements are being operated correctly; and
(h) Procedures for the provisions of reports to the Agency" [153, para. 32].

> *INFCIRC/66-type safeguards agreements do not explicitly call for States to establish and maintain a system of accounting for and control of nuclear material, but the fact that [66] calls for agreement between the IAEA and the State on a "system of records" and a "system of reports" implies the need for an appropriate organizational arrangement at the State level.*

Before reviewing further details on nuclear material accountancy, it is important to note key features of the issues discussed in these sections from the IAEA:

1. The system of accounting for and control of nuclear materials is based on the use of material balance areas, inventories, and material transfers, but the details appear to be the subject of an agreement rather than a specified technical basis that a state must follow. This is the point where the safeguards requirements are no longer generic, but are being postulated to suit the types of facilities currently existing, especially those used for processing.
2. However, it is also stated that the intent of safeguards is always directed to allow the IAEA to draw the conclusion that diversion or misuse has not occurred. The basis for this conclusion is to require that one accurately find all of the materials to ensure that none are missing. Such an approach can be problematic in a large commercial facility. Note that this may not be the only way that one can justify a conclusion that no diversion or misuse had occurred, as will be discussed later in this report.
3. Timeliness is based on several factors, including the type of material that could be diverted, the time required for the diversion, and the time required for conversion after the diversion.
4. The quantity of concern also depends on the material being diverted and its form.

1.1.4 IAEA Material Control and Accountancy

One of the key distinctions for IAEA safeguards is between "item facilities" and "bulk handling facilities," as follows:[1]

> *IAEA Safeguards Glossary, Chapter 5.27. Item facility — a facility where <u>all nuclear material is kept in item form and the integrity of the item remains unaltered during its residence at the facility.</u> In such cases, IAEA safeguards are based on item accountancy procedures (e.g. item counting and identification, non-destructive measurements of nuclear material and the verification of the continued integrity of the items). Examples of item facilities are most reactors and critical assemblies (critical facilities), and storage installations for reactor fuel.*
>
> *5.28. Bulk handling facility — a facility where <u>nuclear material is held, processed or used in bulk form.</u> Where appropriate, bulk handling facilities may be organized for safeguards purposes into multiple material balance areas (MBAs), for instance by separating activities relating only to the storage and assembly of discrete fuel items from those involving storage or processing of bulk material. In a bulk MBA, flow and inventory values declared by the facility operator are verified by the IAEA through independent measurements and observation. Examples of bulk handling facilities are plants for conversion, enrichment (or isotope separation), fuel fabrication and spent fuel reprocessing, and storage facilities for bulk material.*

As stated, spent fuel processing facilities are considered bulk handling facilities and reactors are item facilities.

IAEA Safeguards Glossary, Chapter 6.1. Nuclear material accountancy — the practice of nuclear material accounting as implemented by the facility operator and the State system of accounting for and control of nuclear material (SSAC) (see No. 3.33), inter alia, to satisfy the requirements in the safeguards agreement between the IAEA and the State (or group of States); and as implemented by the IAEA, inter alia, to independently verify the correctness of the nuclear material accounting information in the facility records and the reports provided by the SSAC to the IAEA. Nuclear material accountancy may include the following:

Facility level

(a) Dividing operations involving nuclear material into material balance areas (MBAs) (see No. 6.4);
(b) Maintaining records on the quantities of nuclear material held within each MBA;
(c) Measuring and recording all transfers of nuclear material from one MBA to another or changes in the amount of nuclear material within MBAs due to, for example, nuclear production (see No. 6.17) or nuclear loss (see No. 6.22);
(d) Determining periodically the quantities of nuclear material present within each MBA through the taking of the physical inventory (see No. 6.41);
(e) Closing the material balance over the period between two successive physical inventory takings and computing the material unaccounted for (MUF) (see No. 6.43) for that period;
(f) Providing for a measurement control programme to determine the accuracy of calibrations and measurements (see No. 6.33) and the correctness of recorded source data (see No. 6.9) and batch data (see No. 6.8);
(g) Testing the computed MUF against its limits of error for indications of any unrecorded nuclear loss or accidental gain (see Nos 6.22 and 6.18);
(h) Analysing the accounting information to determine the cause and magnitude of mistakes in recording unmeasured losses, accidental losses and unmeasured inventory (hold-up) (see No. 4.36).

State Authority level

(a) Preparing and submitting nuclear material accounting reports to the IAEA, as appropriate (see, for example, Nos 12.4–12.8);
(b) Ensuring that nuclear material accounting procedures and arrangements are adhered to;
(c) Providing for IAEA inspector access and co-ordination arrangements, as necessary, to enable the IAEA to carry out its verification activities;
(d) Verifying facility operators' nuclear material accountancy performance, as provided for in the SSAC regulations.

IAEA level

(a) Independently verifying nuclear material accounting information in facility records and State reports, and conducting activities as provided for in the safeguards agreement (see, for example, Nos 6.48–6.55);

(b) Determining the effectiveness of the SSAC (see No. 3.33);
(c) Providing statements to the State on the IAEA's verification activities (see, for example, Nos 13.2–13.8).

A key concept in this approach is the use of the material balance area (MBA):

> *IAEA Safeguards Glossary, Chapter 6.4. Material balance area (MBA) — as defined in para. 110 of [153], "an area in or outside of a facility such that:*
>
> *(a) The quantity of nuclear material in each transfer into or out of each 'material balance area' can be determined; and*
>
> *(b) The physical inventory of nuclear material in each 'material balance area' can be determined when necessary, in accordance with specified procedures, in order that the material balance for Agency safeguards purposes can be established."*
>
> *Paragraph 46(b) of [153] provides that design information made available to the IAEA shall be used: "To determine material balance areas to be used for Agency accounting purposes and to select those strategic points which are key measurement points and which will be used to determine the nuclear material flows and inventories; in determining such material balance areas the Agency shall, inter alia, use the following criteria:*
>
> *(i) The size of the material balance area should be related to the accuracy with which the material balance can be established;*
> *(ii) In determining the material balance area advantage should be taken of any opportunity to use containment and surveillance to help ensure the completeness of flow measurements and thereby simplify the application of safeguards and concentrate measurement efforts at key measurement points;*
> *(iii) A number of material balance areas in use at a facility or at distinct sites may be combined into one material balance area to be used for Agency accounting purposes when the Agency determines that this is consistent with its verification requirements; and*
> *(iv) If the State so requests, a special material balance area around a process step involving commercially sensitive information may be established."*

Containment and surveillance are introduced to augment the information collected about flow measurements and inventories to "simplify the application of safeguards and concentrate measurement efforts at key measurement points." The extended use of containment and surveillance will be discussed later in this report as a means of meeting safeguards goals. This is connected to the establishment of strategic points and key measurement points to verify the safeguards measures.

> *IAEA Safeguards Glossary, Chapter 6.5. Strategic point — "a location selected during examination of design information where, under normal conditions and when combined with the information from all 'strategic points' taken together, the information necessary and sufficient for the implementation of safeguards measures is obtained and verified; a 'strategic point' may include any location where key measurements related to material balance accountancy are made and where containment and surveillance measures are executed" [153, para. 116].*

IAEA Safeguards Glossary, Chapter 6.6. Key measurement point (KMP) — "a location where nuclear material appears in such a form that it may be measured to determine material flow or inventory. 'Key measurement points' thus include, but are not limited to, the inputs and outputs (including measured discards) and storages in material balance areas" [153, para. 108].

The expectations of what can be achieved for the measurements are provided, based on previous industrial experience with existing facilities.

IAEA Safeguards Glossary, Chapter 6.35. International standards of accountancy — values of the measurement uncertainty δ_E expected for closing a material balance. These values, which are based on operating experience at the various types of bulk handing facility, are considered achievable under the condition of normal operation. For calculating the international standard for the uncertainty of a material balance, the standard from Table III (expressed as a relative standard deviation) is multiplied by the throughput. The δ_E values can be used along with the International Target Values (see No. 6.36) to determine whether a facility's measurement system meets international standards.

TABLE III. EXPECTED MEASUREMENT UNCERTAINTY δ_E (RELATIVE STANDARD DEVIATION) ASSOCIATED WITH CLOSING A MATERIAL BALANCE

Bulk handling facility type	δ_E
Uranium enrichment	0.002
Uranium fabrication	0.003
Plutonium fabrication	0.005
Uranium reprocessing	0.008
Plutonium reprocessing	0.010
Separate scrap storage	0.04
Separate waste storage	0.25

IAEA Safeguards Glossary, Chapter 6.36. International Target Values (ITV) — target values for random and systematic measurement uncertainty components for destructive analysis (DA) (see No. 7.13) and non-destructive assay (NDA) (see No. 7.24) measurements performed on nuclear material. The values are expressed as per cent relative standard deviations, and are values for uncertainties associated with a single determination result; for example, this may be the result reported by one laboratory on one sample (independent of the analytical scheme applied internally in the laboratory), or the result of an NDA measurement performed on a single item. The values are based on actual practical measurement experiences and are intended to be used as a reference for routinely achievable measurement quality by facility operators, SSACs and the IAEA. The values are periodically updated to reflect currently achievable measurement capabilities and to incorporate newly developed measurement techniques and instruments. The currently used set of values (ITV 2000) was published as [STR-327].

At this point, it is possible to illustrate one of the potential difficulties with this approach to safeguards. If one is examining a commercial-scale facility for the processing of spent light-water reactor (LWR) fuel, with an assumed annual throughput of 800 MTIHM/year, the facility would be handling approximately 8–10 MT of plutonium annually, depending on the discharge burnup of the fuel. If one assumes 200 days of operation per year, this translates to about 40–50 kg of plutonium per day. At a standard deviation of 1% for closing the material balance, the error would be equivalent to 400–500 grams of plutonium per day, or it would only take about 16–20 days for the allowable error to equal 1 SQ. While the actual situation is more complicated than this example implies, the relative magnitude of the problem highlights the difficulties of trying to detect diversion of 1 SQ in large-capacity facilities. The IAEA recognizes this issue and accepts that the detection quantity goal may be several SQs, so that detection of diversion of 1 SQ would be done with lower probability.[2]

> *In bulk handling plants, verification requires measurement of large quantities of nuclear materials of different physical forms and chemical composition including materials of low quality such as scrap or waste. No instrument or measurement procedure ever ensures complete accuracy, and there are inevitably measurement uncertainties. Today these uncertainties are generally of the order of 1% of the total amount of nuclear material measured or sampled. <u>It should be emphasized that this measurement uncertainty does not reflect an actual physical loss or gain of material. One per cent of the inventory or throughput of a large bulk handling facility may be larger than 1 SQ — in some cases considerably larger. It would, however, be unreasonable to set a target that cannot be technically achieved today, and this uncertainty must be taken into account in setting the final inspection goals.</u>*
>
> *Finally, it should be borne in mind that the <u>adoption of a detection goal of several SQ does not mean that the diversion of a single SQ or even smaller quantities could not be detected at all.</u> Detection is possible also in this case, but with a smaller probability.*
>
> *The situation is obviously not entirely satisfactory and the <u>limitations of nuclear materials accounting must be offset by the development of effective containment and surveillance measures and by improving the techniques for measuring and accounting for nuclear materials.</u>*

The IAEA also acknowledges that large facilities may require full-time inspectors during operation to provide continuity of knowledge as a partial substitute for the potentially large amounts of material that could be contained in the balance errors.[2]

> *In the case of plutonium and highly enriched uranium, the inspection goals are set at two to three weeks, i.e. at the upper end of the range recommended by [Standing Advisory Group on Safeguards Implementation] SAGSI. If the material is moving through the plant (e.g. in a reprocessing or fabrication plant) these goals are met as far as possible by frequent partial inventory-taking carried out in such a way as to minimize disturbance of plant operation. <u>At some larger plants the IAEA also requires the continuous presence of inspectors to verify the internal flow of nuclear material, and thus to achieve the timeliness goal.</u>*

Thus it can be seen that even the current approaches may be viewed as less than desirable, but given that this is the best that can be achieved within the limitations of the technology and measurements, it is sufficient given that the goal of safeguards is to provide assurance that no diversion or misuse has taken place.

There are more details related to specific features of the IAEA safeguards approach, but this brief review is sufficient to provide the background for discussions on alternative methods of performing safeguards using the inherent characteristics of advanced technologies.

1.2 Domestic Safeguards: The NRC

The requirements for safeguards for domestic facilities are listed in Title 10 of the Code of Federal Regulations (10 CFR), mainly in Part 75, "Safeguards on Nuclear Material Implementation of US/IAEA Agreement." This part shows that the NRC will establish safeguards requirements, including material control and accountability, for domestic commercial facilities as expressed in the agreement with the IAEA (material control and accountability for facilities that are not covered by a US/IAEA agreement is discussed in Part 74). Part 75 starts with a discussion of the state system of accounting and control, as referred to in the previous section on IAEA requirements:[3]

> *§ 75.1 Purpose.*
>
> *This part establishes a system of nuclear material accounting and nuclear material control to implement, with respect NRC and Agreement State licensees, the Agreement between the United States and the International Atomic Energy Agency (IAEA) for the Application of Safeguards in the United States.*
>
> *§ 75.2 Scope.*
>
> *(a) Except as provided in § 75.3, the requirements in this part apply to all persons licensed by the Commission or Agreement States to possess source or special nuclear material at an installation, as defined in § 75.4(k), on the United States eligible list. They also apply, to the extent specified in §§ 50.78, 40.31(g), 70.21(g), and 150.17a of this chapter, to holders of construction permits and to persons who intend to receive source material or special nuclear material.*
> *(b) The United States eligible list is a list of installations eligible for IAEA safeguards under the US/IAEA Safeguards Agreement which the Secretary of State or his designee files with the Commission. A copy of this list is available for inspection at the NRC Web site, http://www.nrc.gov, and/or at the NRC Public Document Room. In accordance with the provisions of the Agreement, the following activities are excluded from the United States eligible list:*
> *(1) Activities having direct national security significance.*
> *(2) Activities involving mining and ore processing.*

Given the scope of the IAEA agreement, it is likely that any commercial facility, whether a nuclear reactor or an advanced spent fuel processing plant, would be on the eligible list for IAEA safeguards. In this respect, the NRC does not appear to have goals for safeguards in addition to those expressed by the IAEA.

Part 75.11 contains all of the information collection requirements that the NRC imposes on the licensees that are needed to satisfy the IAEA Safeguards Agreement, including identifying the features for material control and accountability, containment, and surveillance, as shown in the underlined sections. The loss limits and changes to containment are included in facility attachments as described in Part 75.8, with the section underlined.[3]

§ 75.11 Installation information.

(a) Each licensee subject to the provisions of this part shall submit installation information, in response to a written request from the Commission, with respect to any installation which the Commission indicates has been identified under the Agreement and in which the licensee carries out licensed activities. (The Commission request shall state whether the installation has been identified under Article 39(b) of the principal text of the Agreement or Article 2(a) of the Protocol.) The licensee shall submit such information to the Commission within the period, which shall be at least 45 days, specified in the Commission's request.

(b) Installation information includes:

(1) The identification of the installation, stating its general character, purpose, nominal capacity (thermal power level, in the case of power reactors), and geographic location, and the name and address to be used for routine purposes;

(2) A description of the general arrangement of the installation with reference, to the extent feasible, to the form, location and flow of nuclear material, and to the general layout of important items of equipment which use, produce, or process nuclear material;

(3) <u>A description of features of the installation relating to material accounting, containment, and surveillance</u>; and

(4) <u>A description of the existing and proposed procedures at the installation for nuclear material accounting and control, with special reference to material balance areas established by the licensee, measurement of flow, and procedures for physical inventory taking.</u> (As part of this description, the licensee may identify a process step involving information which it deems to be commercially sensitive and for which it proposes that a special material balance area be established so as to restrict IAEA access to such information.)

(c) Each licensee shall thereafter submit to the Commission information with respect to any modification at the installation affecting the information referred to in paragraph (a) of this section. Such information shall be submitted:

(1) With respect to a modification of a type described in the license conditions: At least 70 days before the modification is scheduled to be completed, except that in an emergency or other unforeseen situation a shorter period may be approved by the Commission.

(2) With respect to any other modification relevant to the application of the provisions of the Agreement: At the time the first inventory change report is submitted after the modification is completed.

(d) The information specified in paragraphs (a) and (c) of this section shall be prepared on Form N-71 or other forms supplied by the Commission (including appropriate IAEA Design Information Questionnaire forms). <u>The information shall be sufficiently detailed to enable knowledgeable determinations to be made in the development of Facility Attachments or amendments thereto, including</u>:

(1) Identification of the features of installations and nuclear material relevant to the application of safeguards to nuclear material in sufficient detail to facilitate verification;

(2) Determination of IAEA material balance areas to be used for IAEA accounting purposes and selection of those strategic points which are key measurement points and which will be used to determine flow and inventory of nuclear material;

(3) Establishment of the nominal timing and procedures for taking of physical inventory of nuclear material for IAEA accounting purposes;

(4) Establishment of the records and reports requirements and records evaluation procedures;

(5) Establishment of requirements and procedures for verification of the quantity and location of nuclear material; and

(6) Selection of appropriate combinations of containment and surveillance methods and techniques at the strategic points at which they are to be applied.

(e) The licensee's detailed security measures for the physical protection of an installation shall be included in the installation information only when and to the extent specifically requested by the Commission.

§ 75.4 Definitions. (edited)

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

(e) Containment (the term refers to nuclear material safeguards rather than radiological protection) means:

(1) The application of any devices designed to limit the mobility of nuclear material, the access of personnel, or the unauthorized operation of equipment such as transfer valves and sampler lines; and

(2) Structural elements, including the design of buildings and layout of equipment, which minimize and control access to nuclear material.

(f) Effective kilogram means a unit used in safeguarding nuclear material. The quantity is:

(1) For special nuclear material: The amount specified in § 70.4 of this chapter.

(2) For source material: The amount specified in § 40.4(q) of this chapter.

(g) Facility Attachment means that portion of the Subsidiary Arrangements to the principal text of the Agreement that pertains to a particular installation that has been identified pursuant to Article 39(b) thereof.

(h) IAEA means the International Atomic Energy Agency or its duly authorized representatives.

(i) IAEA material balance area means an area established for IAEA accounting purposes, such that:

(1) The quantity of nuclear material in each transfer into or out of each material balance area can be determined; and

(2) The physical inventory of nuclear material in each material balance area can be determined when necessary in accordance with specified procedures.

(l) Inventory change means an increase or decrease, established in accordance with the procedures required by this part, in terms of batches of nuclear material in an IAEA material balance area.

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

(n) Nuclear material means any source material or any special nuclear material.

(p) Surveillance means instrumental or human observation to indicate or detect the movement of nuclear material.

§ 75.8 Facility attachments.

(a) The Facility Attachment or Transitional Facility Attachment will document the determinations referred to in § 75.11 and will contain such other provisions as may be appropriate.

(b) The Commission will issue license amendments, as necessary, for implementation of the principal text of the Agreement and the Facility Attachment (as amended from time to time). <u>The license amendments through reference to the Facility Attachment or Transitional Facility Attachment, or otherwise, will specify:</u>

(1) IAEA material balance areas;

(2) Types of modifications with respect to which information is required, under § 75.11, to be submitted in advance;

(3) Procedures, as referred to in § 75.21;

(4) The extent to which isotopic composition must be included in batch data (under § 75.22) and advance notification (§ 75.45);

(5) Items to be reported in the concise notes accompanying inventory change reports, as referred to in § 75.34;

(6) <u>Loss limits and changes in containment</u>, as referred to in § 75.36 (pertaining to special reports);

(7) Actions required to be taken, in accordance with § 75.42(e)(2), at the request of an IAEA inspector;

(8) Procedures to be used for documentation of requests under § 75.46 (pertaining to expenses); and

(9) Such other matters as may be appropriate.

(c) The Commission will also issue license amendments, as necessary, for implementation of the Protocol to the Agreement and the Transitional Facility Attachment (as amended from time to time).

(d) License amendments will be made in accordance with the Commission's rules of practice (part 2 of this chapter). Specifically, if the licensee does not agree to an amendment, an order modifying the license would be issued under § 2.204.

(e) Subject to constraints imposed by the Agreement, <u>the Commission will afford the licensee a reasonable opportunity to participate in the development of the Facility Attachment or Transitional Facility Attachments applicable to the licensee's installation, and any</u>

amendments thereto, and to review and comment upon any such instrument before it has been agreed to by the United States. The Commission will provide to the licensee a copy of any such instrument that has been completed in accordance with the Agreement.

An interesting component of the process is that the licensee will have input to the development of the facility attachments, which presumably would include specifications for items like loss limits and reporting, prior to formal agreement with the IAEA.

It is useful to note the similarities between the NRC requirements and the IAEA requirements as listed in Chapter I-C of this report, identified as section 3.33. The remainder of Part 75 is devoted to descriptions of the other details related to the IAEA safeguards agreement. For material control and accounting, the general requirements are listed in 75.21:

§ 75.21 General requirements.

(a) Each licensee who has been given notice by the Commission in writing that its installation has been identified under the Agreement shall establish, maintain, and follow written material accounting and control procedures. The licensee shall retain as a record current material accounting and control procedures until the Commission terminates the license for the installation involved with the request or until the Commission notifies the licensee that the licensee is no longer under the agreement. Superseded material must be retained for three years after each change is made.
(b) The material accounting and control procedures required by paragraph (a) of this section shall include, as appropriate:
(1) A measurement system for the determination of the quantities of nuclear material received, produced, shipped, lost or otherwise removed from inventory, and the quantities on inventory;
(2) The evaluation of precision and accuracy of measurements and the estimation of measurement uncertainty;
(3) Procedures for identifying, reviewing and evaluating differences in shipper/receiver measurements;
(4) Procedures, including frequency, for taking a physical inventory;
(5) Procedures for the evaluation of accumulations of unmeasured inventory and unmeasured losses; and
(6) A system of accounting and operating records.
(c)
(1) The procedures shall, unless otherwise specified in license conditions, conform to the installation information submitted by the licensee under § 75.11.
(2) Until installation information has been submitted by the licensee, the procedures shall be sufficient to document changes in the quantity of nuclear material in or at its installation. Observance of the procedures described in §§ 40.61 or 74.15 of this chapter (or the corresponding provisions of the regulations of an Agreement State) by any licensee subject thereto shall constitute compliance with this paragraph.
(d) The requirements of this section are in addition to any other requirements of this chapter, relating to material accounting and control, that may apply to the licensee.

[45 FR 50711, July 31, 1980, as amended at 53 FR 19263, May 27, 1988; 67 FR 78149, Dec. 23, 2002]

The definition of special nuclear material for the NRC is contained in Part 70.4:

Special nuclear material *means (1) plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the act, determines to be special nuclear material, but does not include source material; or (2) any material artificially enriched by any of the foregoing but does not include source material;*

Special nuclear material of low strategic significance *means:*

(1) Less than an amount of special nuclear material of moderate strategic significance as defined in paragraph (1) of the definition of strategic nuclear material of moderate strategic significance in this section, but more than 15 grams of uranium-235 (contained in uranium enriched to 20 percent or more in U-235 isotope) or 15 grams of uranium-233 or 15 grams of plutonium or the combination of 15 grams when computed by the equation, grams = (grams contained U-235) + (grams plutonium) + (grams U-233); or

(2) Less than 10,000 grams but more than 1,000 grams of uranium-235 (contained in uranium enriched to 10 percent or more but less than 20 percent in the U-235 isotope); or

(3) 10,000 grams or more of uranium-235 (contained in uranium enriched above natural but less than 10 percent in the U-235 isotope). <u>This class of material is sometimes referred to as a Category III quantity of material.</u>

Special nuclear material of moderate strategic significance *means:*

(1) Less than a formula quantity of strategic special nuclear material but more than 1,000 grams of uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope) or more than 500 grams of uranium-233 or plutonium, or in a combined quantity of more than 1,000 grams when computed by the equation, grams = (grams contained U-235) + 2 (grams U-233 + grams plutonium); or

(2) 10,000 grams or more of uranium-235 (contained in uranium enriched to 10 percent or more but less than 20 percent in the U-235 isotope). <u>This class of material is sometimes referred to as a Category II quantity of material.</u>

Special nuclear material scrap *means the various forms of special nuclear material generated during chemical and mechanical processing, other than recycle material and normal process intermediates, which are unsuitable for use in their present form, but all or part of which will be used after further processing.*

Strategic special nuclear material *means uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope), uranium-233, or plutonium.*

> ***Formula quantity*** *means strategic special nuclear material in any combination in a quantity of 5000 grams or more computed by the formula, grams = (grams contained U-235) + 2.5 (grams U-233 + grams plutonium). <u>This class of material is sometimes referred to as a Category I quantity of material.</u>*
>
> ***Effective kilograms of special nuclear material*** *means: (1) For plutonium and uranium-233 their weight in kilograms; (2) For uranium with an enrichment in the isotope U-235 of 0.01 (1%) and above, its element weight in kilograms multiplied by the square of its enrichment expressed as a decimal weight fraction; and (3) For uranium with an enrichment in the isotope U-235 below 0.01 (1%), by its element weight in kilograms multiplied by 0.0001.*

In summary, while there are differences in some of the details, especially in identifying the materials of concern and the manner in which the amounts are calculated, the NRC appears to have basically the same general safeguards requirements as the IAEA.

1.3 Domestic Safeguards: U.S. DOE

Safeguards within the DOE are part of Integrated Safeguards and Security Management, as described by DOE Orders in the 470 group. Safeguards includes the same concepts of physical protection, material control, and accountability. The material control and accountability requirements and procedures are discussed in DOE M 470.4-6, "to establish a program for the control and accountability of nuclear materials within the U.S. Department of Energy (DOE), including the National Nuclear Security Administration (NNSA)." The general guidelines are similar to those discussed above for the IAEA and the NRC, as stated in Section A of DOE M 470.4-6 (Ref 4):

> *<u>GENERAL</u>. This Chapter provides minimum requirements for implementing a nuclear material control and accountability (MC&A) program at Department of Energy (DOE) facilities and for DOE- owned materials at other facilities that are exempt from licensing by the Nuclear Regulatory Commission (NRC). DOE line management and site/facility operators must consider MC&A requirements, systems, technologies, and activities when planning, designing, constructing, and operating new or renovated DOE facilities. The site/facility operator must use techniques and equipment that <u>maximize material loss detection sensitivity</u>, increase the quality of accountability measurements, minimize material holdup, and <u>reduce the magnitude of inventory differences and associated control limits consistent with the consequences of the loss of the material.</u>*
>
> *a. An MC&A program must be established and maintained for all materials identified in Table I-1, Nuclear Materials. The level of control and accountability must be graded based on the consequence of their loss.*
> *b. Special nuclear material (SNM) must not be received, processed, or stored at a facility until a facility approval has been granted.*
> *c. MC&A programs must be designed to deter and detect theft and diversion of nuclear material by both outside and inside adversaries.*
> *d. A performance testing program to verify MC&A procedures and practices and to demonstrate that material controls are effective must be established.*

e. MC&A programs must address both the theft and diversion of SNM and the unauthorized control of a weapon, test device, or materials that can be used to make an improvised nuclear device.

DOE uses a “graded” safeguards approach for characterizing the quantities of material, which means that the safeguards requirements are different depending on the type and amount of material and different requirements are assigned to each category, as defined in Table I-4 from DOE M 470.4-6. This is reflected in varying limits for inventory balances, depending on the category of material:[4]

(7) Inventory Difference Control Limits.
(a) For Category I and II MBAs, limits-of-error must not exceed 2 percent of the active inventory during the inventory period or a Category II quantity of material.
(b) For Category III and IV MBAs, limits-of-error of inventory differences must not exceed a specified percentage of the active inventory during the inventory period to a maximum of a specified quantity; the specified percentage and maximum quantity must be approved by the DOE cognizant security authority.
(c) For purposes of the performances requirements (a) and (b), the term “active inventory” means the sum of additions to inventory, beginning inventory, ending inventory, inventory adjustments, and removals from inventory after all “common terms” have been excluded (in this context, “common terms” are material values that appear in the active inventory calculation more than once and come from the same measurement).

For Category I and II materials, the limit for the inventory difference on the mass balance in the MBA is 2% of the active inventory or a Category II quantity. This is essentially the same approach taken by the IAEA, where the goal is to detect 1 SQ, with an allowable standard deviation on the measurements of 1% of inventory; however, there is a finer distinction between the types of materials and the amounts of concern for each type of material.

Table 1. Nuclear Materials.

Material Type	SNM, Source, or Other	Reportable Quantity*	Weight Field Used for Element	Weight Field Used for Isotope	Material Type Code
Depleted Uranium (U)	source	kilogram	total U	U-235	10
Enriched Uranium	SNM	gram	total U	U-235	20
Normal Uranium	source	kilogram	total U	—	81
Uranium-233	SNM	gram	total U	U-233	70
Plutonium-2421 (Pu)	SNM	gram	total Pu	Pu-242	40
Plutonium-239-241	SNM	gram	total Pu	Pu-239 + Pu-241	50
Plutonium-2382	SNM	tenth of a gram	total Pu	Pu-238	83
Americium2413 (Am)	other	gram	total Am	Am-241	44
Americium-2433	other	gram	total Am	Am-243	45
Berkelium6 (Bk)	other	microgram	—	Bk-249	47
Californium-252 (Cf)	other	microgram	—	Cf-252	48
Curium (Cm)	other	gram	total Cm	Cm-246	46
Deuterium4 (D)	other	tenth of a kilogram	D2O	D2	86
Enriched Lithium (Li)	other	kilogram	total Li	Li-6	60
Neptunium-237 (Np)3	other	gram	total Np	—	82
Thorium (Th)	source	kilogram	total Th	—	88
Tritium5 (H-3)	other	gram	total H-3	—	87
Uranium in Cascades	SNM	gram	total U	U-235	89

* Reportable quantity is the minimum amount of material subject to the requirements of this Manual. Facilities with less than a reportable quantity of a material are exempt from the requirements of the manual for that material. Facilities with more than reportable quantities are to report transactions that exceed a reporting unit or more of material. Reporting unit is the mass unit that facility/site nuclear materials accounting systems must use for recording and reporting inventories and transactions.

1. Report as Pu-242 if the contained Pu-242 is 20 percent or greater of total plutonium by weight; otherwise, report as Pu-239-241.
2. Report as Pu-238 if the contained Pu-238 is 10 percent or greater of total plutonium by weight; otherwise, report as Pu-239-241.
3. Americium and Neptunium-237 contained in plutonium as part of the natural in-growth process are not required to be accounted for or reported until separated from the plutonium.
4. For deuterium in the form of heavy water, both the element and isotope weight fields will be used; otherwise, report isotope weight only.
5. Tritium contained in water (H_2O or D_2O) used as a moderator in a nuclear reactor is not an accountable material.
6. Berkelium must be accounted for at the site level. It is not required that it be reported to Nuclear Materials Management Safeguards System (NMMSS).

Table 2. Graded Safeguards.

	Attractiveness Level	Pu/U-233 Category (kg)				Contained U-235/Separated Np237/Separated Am-241 and -243 Category (kg)				All E Materials Category IV
		I	II	III	IV	I	II	III	IV	
WEAPONS Assembled weapons and test devices	A	All	N/A	N/A	N/A	All	N/A	N/A	N/A	N/A
PURE PRODUCTS Pits, major components, button ingots, recastable metal, directly convertible materials	B	≥2	≥0.4 < 2	≥0.2 < 0.4	<0.2	≥5	≥1 < 5	≥0.4 < 1	<0.4	N/A
HIGH-GRADE MATERIALS Carbides, oxides, nitrates, solutions (>25 g/L) etc.; fuel elements and assemblies; alloys and mixtures; UF4 or UF6 (> 50% enriched)	C	≥6	≥2 < 6	≥0.4 < 2	<0.4	≥20	≥6 < 20	≥2 < 6	<2	N/A
LOW-GRADE MATERIALS Solutions (1 to 25 g/L), process residues requiring extensive reprocessing; moderately irradiated material; Pu-238 (except waste); UF4 or UF6 (> 20% < 50% enriched)	D	N/A	≥16	≥3 < 16	<3	N/A	≥50	≥8 < 50	<8	N/A
ALL OTHER MATERIALS Highly irradiated forms, solutions (<1 g/L), uranium containing <20% U-235 or <10% U-233 (any form, any quantity)	E	N/A	N/A	N/A	Reportable Quantities	N/A	N/A	N/A	Reportable Quantities	Reportable Quantities

1. The lower limit for Category IV is equal to reportable quantities in this Manual.

2. The total quantity of U-233 = [Contained U-233 + Contained U-235]. The category is determined by using the Pu/U-233 side of this table.

The concern then becomes determining how often the material balances should be taken to ensure that the expected loss of material, given the accuracy of measurements within the system, does not exceed either 2% of active inventory or a Category II quantity. For example, one SQ for the IAEA is 8 kg of plutonium, while the Category II quantity of plutonium oxide for the DOE would be 6 kg. As described above, the IAEA requirements would necessitate balance periods of less than 16–20 days for the example of a processing plant of 800 MT/yr capacity operating 200 days/year. For the same example, if the requirement is to detect the Category II quantity, 6 kg, with an allowable 2% limit of error on the inventory difference, this would require a balance period of 6–8 days. In this sense, the DOE approach would require more frequent balances due to the smaller allowable loss amount and the larger allowable error in the inventory difference, but the principle is basically the same.

1.4 Summary of Safeguard Goals

The safeguards goals for the IAEA, NRC, and the U.S. DOE can be summarized as follows:

IAEA — The fundamental objective is "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." This goal is achieved by detecting the loss of 1 SQ, with timeliness determined by the type of material, either 1 month for unirradiated direct-use material or 3 months for irradiated direct-use material, where direct-use material is defined as material which can be used without further enrichment or irradiation. The goal is to be able to conclude that no diversion has occurred.

NRC — Basically the same as the IAEA requirements, since the NRC-licensed commercial facilities would be placed under IAEA safeguards.

DOE — Essentially the same concept as for the IAEA although the objectives are stated as maximizing the material loss sensitivity, but with different detection quantities and larger allowable limit of error on the inventory difference: 2% for DOE vs. 1% for IAEA (and NRC). However, the DOE requires any operator to reduce the magnitude of inventory differences and associated control limits consistent with the consequences of the loss of the material, which could imply that while the allowable limits of error on the inventory difference are given, the operator must also be able to show that he is using the best practices available to lower these below the limits.

As with the approach taken by the IAEA and NRC, in order to achieve the goal of being able to conclude that no loss or diversion has occurred, the basic principle is that one must be able to verify the presence of all of the nuclear materials of interest to within the acceptable limits of uncertainty. However, there may be other approaches for concluding that no loss or diversion has occurred, depending on the characteristics of the systems being safeguarded. That is the subject of the next section of this report.

2. AN ADVANCED SPENT FUEL PROCESSING TECHNOLOGY EXAMPLE

As part of the DOE AFCI program and earlier programs, advanced spent fuel processing technologies are being developed that provide additional separations and waste-stream differentiation as compared to typical plutonium-uranium extraction (PUREX) processing in order to achieve recycling and waste disposal goals. One of these advanced technologies is pyroprocessing, also referred to as electrochemical processing. The basic features of this processing technology are summarized in the following sections.

2.1 Description of Pyroprocessing

Pyroprocessing is fundamentally different from aqueous processing in that only non-aqueous steps are used, with molten salts being the medium of choice in the AFCI program, operating at elevated temperatures due to the relatively high melting points of the process salts. In addition, all of the operations can be performed using discrete operations in separate pieces of equipment. This is in contrast to the flowing system typically used with PUREX separations technology and offers the opportunity to use a different approach for safeguards.

A concept for pyroprocessing spent LWR fuel is shown in Figure 1, followed by a list of the processing operations and material flows.

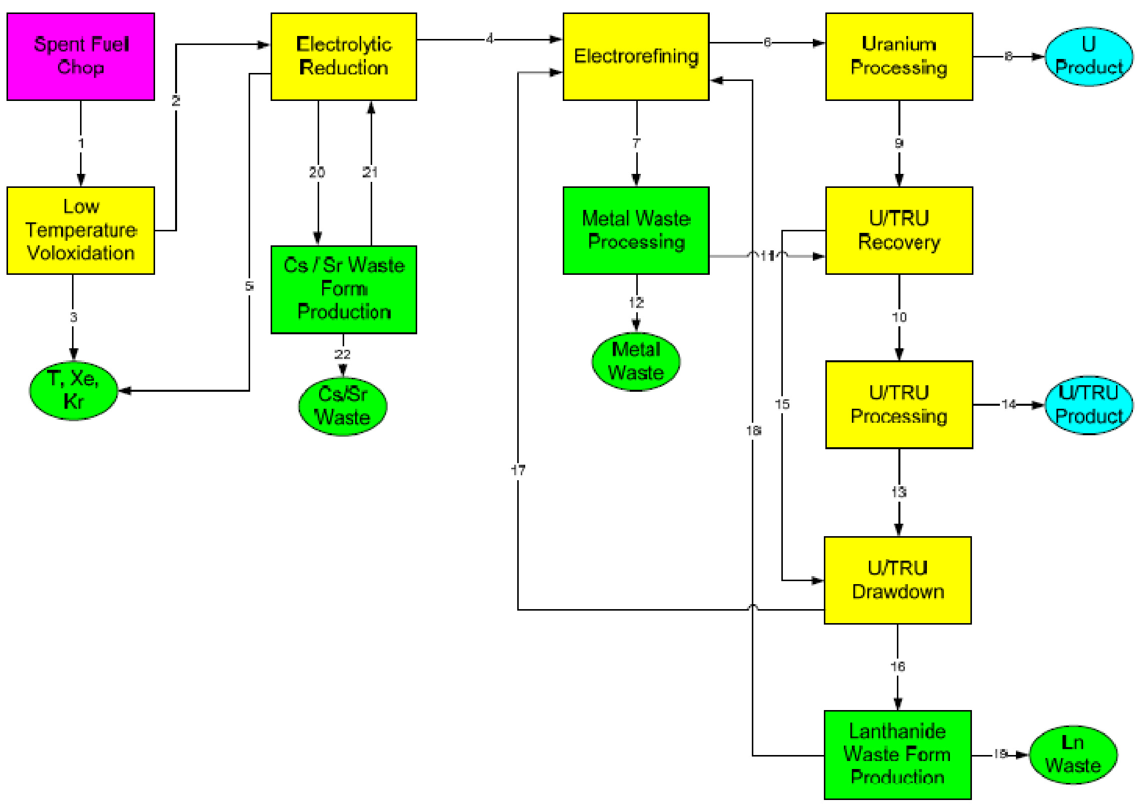

Figure 1. An example of the operations and material flow for pyroprocessing of spent LWR fuel.

Path Contents:

1. Segments of spent LWR fuel, as chopped (spent oxide fuel, fission products, cladding hulls, and assembly hardware)

2. Segments of spent LWR fuel, with tritium and some fission product gases removed
3. Volatile fission products such as tritium, xenon, and krypton
4. Segments of spent LWR fuel, with all elements reduced from the oxide (elements from spent oxide fuel, fission products, cladding hulls, assembly hardware, and adhering LiCl salt from the electrolytic reduction vessel)
5. Additional volatile fission product amounts released during reduction step
6. Uranium metal product recovered at the cathode with adhering electrorefiner (ER) salt, which contains U/TRU and more chemically active fission products
7. Remaining anode basket contents (cladding hulls and assembly hardware, less chemically active fission product elements) with adhering electrorefiner salt (contains U/TRU and more chemically active fission products)
8. Uranium metal ingot
9. Recovered electrorefiner salt that adhered to the uranium product
10. Uranium/TRU metal product with adhering salt
11. Recovered electrorefiner salt that adhered to anode basket contents
12. Metal ingot containing cladding materials, assembly hardware, and less chemically active fission products
13. Recovered U/TRU recovery vessel salt from the U/TRU metal product
14. Metal ingot containing uranium and transuranic elements (about 50/50)
15. Remaining U/TRU recovery vessel salt
16. U/TRU recovery vessel salt after U/TRU drawdown
17. Residual U/TRU metal contaminated with lanthanide metal after U/TRU drawdown
18. Salt from the lanthanide metal recovery process returned to the electrorefiner
19. Consolidated lanthanide elements waste form
20. Salt sent through an ion exchange to remove the Cs and Sr
21. Salt returned to the electrolytic reduction vessel after removal of Cs and Sr
22. Consolidated Cs/Sr waste form.

The first step of the process is to mechanically chop the spent LWR fuel pins and collect the segments in baskets, which are then physically transferred (path 1) to a furnace where they can be heated to about 480°C in air. This is done to drive off the tritium (path 3), which should be collected in an offgas system similar to that used for aqueous processing. The spent fuel segments are then transferred (path 2) to the next vessel for electrolytic reduction of the oxide fuel to metal. This is accomplished using an electrochemical process conducted in a LiCl salt at a temperature of about 650°C. Additional fission product gases such as xenon and krypton are released during this step and are collected. During this step, the Cs and Sr partition to the salt phase and are recovered in a separate operation when the LiCl salt is cleaned, possibly through the use of ion exchange (least mature of all of the pyroprocessing steps), (path 20) for consolidation into a separate waste form (path 22). After cleaning, the salt with Cs and Sr removed is then returned to the electrolytic reduction vessel (path 21).

Once the elements in the chopped fuel pin segments have been reduced from oxide to metal, the spent fuel segments, with some adhering LiCl salt, are then removed from the oxide reduction vessel and transferred to the electrorefiner vessel (path 4) using the same baskets so that there is no transfer of spent fuel segments from one basket to another. The baskets containing the segments are used as the anode in the electrorefining process. The electrorefining process uses a LiCl/KCl salt mixture, which during operation also contains chloride compounds of all of the actinide elements and some of the fission products. Once loaded into the electrorefiner vessel, the anode basket contents can be ionized into the salt using an electric current, effectively forming chloride compounds of the U/TRU elements and some of the fission products. Some of the elements can also react spontaneously with the compounds in the electrorefiner salt, forming chloride compounds.

The electrorefining process operates at 500°C and will separate and recover the uranium from the spent fuel as a solid uranium product at the cathode, typically as a finely divided uranium solid in a basket, with some electrorefiner salt adhering to the product (path 6). Since the electrorefiner salt contains the transuranic elements as chlorides, along with other elements such as lanthanide fission products, the salt adhering to the uranium product will also have these elements. The uranium processing step (cathode processor) melts the uranium product and salt collected at the cathode and distills the salt under vacuum (up to 1200°C) to separate it from the uranium metal, which is consolidated into a uranium metal ingot (with about 0.02–0.025% TRU contamination at most) in the cathode processor at the same time as the distillation is occurring. The cathode processor contains a reusable coated metallic crucible to avoid chemical interaction with the salt and liquid uranium and prevent losses during this operation, ensuring complete recovery of the salt. The uranium metal ingot is sent to storage (path 8) and is one of the products of the pyroprocessing operation (although it is also possible to send some of the uranium product to an oxidant production step to supply new process chemicals for the electrorefiner; that variation is not shown here as it would not alter the basic safeguards approach). The distilled salt is condensed in a separate container. The recovered salt is transferred to the U/TRU recovery vessel for processing to recover the U/TRU (path 9).

The materials remaining in the anode basket, after the electrotransport of uranium to the cathode and the electrodissolution of the other actinides and the more active fission products, are the cladding hulls and the less active fission products. The anode basket contents will also have electrorefiner salt adhering to them. The contents of the anode baskets are transferred (path 7) to the metal waste furnace, which is similar to the cathode processor in that the adhering salt is distilled under vacuum at high temperature (up to 1600°C), leaving the metals to be consolidated into an ingot. The ingot is transferred to storage (path 12). The distilled salt is condensed and the recovered salt is also transferred (path 11) to the U/TRU recovery vessel, where it is combined with the salt recovered from the cathode processor operations.

The U/TRU recovery step can be one of several options. At this time, partial electrolysis of the salt is proposed in the first step to recover the majority of the uranium and transuranic materials as metals, as this has proven to be a viable approach. This process will probably operate at 500°C and will produce chlorine gas as the U/TRU chloride compounds are reduced to metals. As it is removed from the U/TRU recovery vessel, the resulting metallic U/TRU product will have adhering salt, and the product needs to be processed to distill the salt from the metal product in the U/TRU processing step. The resulting metal U/TRU ingot (path 14) is another major product of the pyroprocessing operation. The U/TRU composition in the metallic ingot is typically about 50% U/50% TRU, but the process can be adjusted if desired to achieve as high as 75–85% TRU. The recovered salt is combined with the salt remaining in the U/TRU recovery vessel for the drawdown operation (paths 13 and 15), potentially using the same vessel.

The U/TRU drawdown step is a further electrolysis of the salt to complete the electrolysis of the U/TRU for recovery of the remaining U/TRU in the salt. The metallic U/TRU product recovered in this step is contaminated with lanthanide metals. The metallic product mixture of U/TRU and lanthanide metal is recycled back to the electrorefiner for further processing with additional chopped fuel pin segments (path 17). Additional chlorine gas is produced during this process. After the drawdown step to recover the remaining U/TRU, most of the remaining lanthanide fission products are recovered with additional electrolysis, with some salt still remaining in the U/TRU drawdown vessel. The lanthanide metal product is removed and sent for processing into a waste form, another major product of the process (path 16). The waste processing recovers any salt adhering to the lanthanide metal product, which is combined with the rest of the salt from the lanthanide recovery step and returned to the electrorefiner (path 18), while the lanthanide ingot is transferred to storage (path 19).

As this brief discussion of pyroprocessing operations illustrates, pyroprocessing operates with a small number of independent and discrete vessels, with a limited number of material transfers between vessels. In addition, during normal operations, the material transfers are unique, in that material originating in one vessel only has one destination, either another vessel or product storage. It is this discrete handling and the uniqueness of the material motions that make an alternative safeguards strategy possible with pyroprocessing. Depending on the inherent characteristics of other advanced processing options, it is possible that similar features can be exploited in developing the appropriate safeguards approach for that technology.

2.2 Pyroprocessing Equipment and Potential Facility Description

Based on the discussion of processing spent LWR fuel with pyroprocessing, the following is a list of the equipment that can contain the actinide elements during the process:

- Chopper for spent LWR fuel
- Low temperature voloxidation furnace
- Electrolytic reduction vessel
- Electrorefiner vessel
- Uranium cathode processor
- Metal waste furnace
- U/TRU recovery vessel (salt processing)
- U/TRU cathode processor (may be the same as the uranium cathode processor)
- U/TRU salt drawdown vessel (may be the same as the U/TRU recovery vessel)
- Lanthanide waste processor
- Ceramic waste furnace

It is important to recognize that each of these pieces of equipment is of relatively small size due to criticality constraints. Typical volumes are on the order of several cubic meters or less, depending on the limits needed to prevent criticality by using criticality-safe geometry, especially for the U/TRU products. These product ingots are expected to be typically on the order of 5–10 kg, with the equipment sized appropriately. It is also important to note that all materials, although not items in the traditional sense, are moved and can be tracked as items between each piece of equipment, as will be discussed below.

There are several advantages to small size for processing equipment:

- All of the processing equipment can be placed in one compact, inerted (i.e., argon atmosphere), hot-cell environment with a substantial background radiation field
- Each piece of equipment is small, facilitating maintenance and repair
- Processing monitoring functions only need to be focused on one compact area
- A very limited number of penetrations for material movement, typically on the order of 4–5

- Introducing spent fuel assemblies
- Introducing product chemicals (as needed, such as chlorine and LiCl/KCl salt, with the option of adding zeolite and glass frit if waste processing occurs in this hot cell) or new small equipment (could be the same portal used for the spent fuel assemblies)
- Product shipment
- Waste shipment
- Samples to the analytical laboratory

The limited number of penetrations facilitates monitoring of the hot-cell portals and is another inherent characteristic of a pyroprocessing facility that can be advantageous in designing the safeguards system.

2.3 An Example of Traditional Safeguards Approach for Pyroprocessing

Pyroprocessing has typically been considered for the processing of spent fast reactor fuel and has been applied in experimental testing at the Fuel Conditioning Facility (FCF) at Idaho National Laboratory (INL) for the treatment of spent Experimental Breeder Reactor-II (EBR-II) fuel. Based on this experience, conceptual designs for larger facilities have been developed and have been the subject of an initial safeguards study for application to processing fast reactor fuel.[5] There are features in these analyses that are not being considered in this example, such as the fabrication of fast reactor fuel from the recovered materials, and there are processing steps and pathways that are not applicable to the processing of spent LWR fuel being discussed here. Nevertheless, this initial study can provide useful examples for the application of traditional safeguards approaches to such a facility.

Of interest in this report are the details of the approach and the conclusions on limitations pertaining to such a facility that were described in the progress report for the study. The goals and proposed approach can be summarized as follows, both for the processing itself and the safeguards measures that would be used:[5]

> *Equipment and Material Transfer Batch Sizes*
>
> *Given the required daily material flows, both equipment and material transfer batch sizes are estimated. The design criteria for these batch sizes aim to balance multiple operations and safeguards-related objectives, including, most importantly, the following:*
>
> *i) Minimize material transfers*
> *ii) Optimize interfaces between consecutive process steps*
> *iii) Minimize in-transit material inventory (especially to facilitate safeguards inspection efforts)*
> *iv) Facilitate the implementation of safeguards monitoring techniques by suggesting material transfer batch sizes that can be assayed, for example, using feasible NDA instrumentation*
> *v) Minimize number of multiple process lines*
> *vi) Satisfy criticality constraints*
> *vii) Select equipment cycle times that would not demand significant R&D development but are based on currently achievable operational values.*
>
> *With respect to safeguards requirements, all items entering or exiting the process cell should be monitored using a combination of containment and surveillance (C/S), destructive assay (DA), and non-destructive assay (NDA) methods.*

Material Balance Areas

One MBA is proposed for the pyroprocessing operations that occur in the process cell, including chopping the fuel pins, uranium electrorefining, uranium product processing, TRU recovery, and TRU product processing.

Safeguards Approach Overview

The proposed safeguards approach for the spent fast reactor fuel pyroprocessing that occurs in the process cell consists of the following main features:

- *Mass tracking, particularly of the inputs to and outputs from the shipping/receiving and process cells. Specifically, the mass of the spent fuel is balanced against the mass of the assembly hardware waste and the fuel pins from the receiving portion of the shipping/receiving cell. The mass of the pins, pin hardware, and assembly hardware is balanced against the mass of the fresh fuel pins in the assembly portion of the shipping/receiving cell. The mass of the fuel pins, external TRU, and external U input to the process cell is balanced against the salt and clad sent to metal waste, the salt sent to ceramic waste, and the products sent to storage.*
- *Total neutron measurement on each element as it transfers from the shipping/receiving cell to the PC for chopping.*
- *Total neutron measurement on the chopped pin segments as they transfer to the electro-refiner.*
- *Total neutron measurement of the waste streams (salt and metal) leaving the process cell.*
- *Validation of the modeled (burnup calculation) Cm/Pu ratio in the chopped pins via DA (Sample A).*
- *Destructive analyses (DA) of the electrorefiner contents (sample) to validate burnup calculations, the Pu content of the salt/clad sent to waste, and the homogeneity of the salt.*
- *Destructive analyses (DA) of the spent salt from TRU recovery (sample) to validate the Pu content of the salt sent to ceramic waste processing, and the homogeneity of the salt.*
- *Process monitoring on the electro-refiner and TRU recovery.*
- *Integrated optical surveillance and neutron monitoring of all MBA transfer paths and the transfer of chopped pins from the chopper to the ER within MBA-2.*

The inspection regime will be complemented by optical surveillance and neutron monitoring (total neutrons) applied to all ports that provide access to the shipping/receiving cell. This includes the loading port(s), the transfer port(s) to the process cell, and the equipment hatch to the shielded repair area. The neutron monitor on the transfer port to the process cell may be the same instrument used to measure the total neutron rate from each element. The neutron monitor on the shipping/receiving loading port is qualitative, being used to detect the transfer of nuclear material but not provide a non-destructive assay.

The safeguards approach for the process cell is based on extensive process monitoring and C/S measures to complement the accounting verification. The uncertainty in measurement of the Pu in the process is expected to be high from a safeguards perspective for several reasons. First, the bulk material is not expected to be verifiably homogeneous. Second, NDA methods (e.g. neutron counting) have an uncertainty of several percent, which would result in a large uncertainty in terms of kg of Pu. That would be compounded because existing methods based on curium counting require determining the ratio of Cm to Pu from a DA (which is complicated because the materials are not assured of being homogeneous). Other forms of NDA (e.g. gamma spec) would not have significantly better uncertainty, and there do not appear to be any new methods or technologies on the foreseeable horizon that would facilitate sufficient accuracy to meet IAEA needs without C/S and process monitoring. Finally, the holdup within the equipment in this MBA is expected to be large, and means to verify holdup are expected to be limited. Hence, while the safeguards approach would undoubtedly include review/audit of the accounting records and some degree of verification of the quantities reported in the accounting records, the main focus would be on ensuring that the process is operating as declared and using C/S to provide confidence that no material is diverted from the process.

The safeguards approach consists of:

1. *Audit of the accounting records for self-consistency and consistency with accounting records from external sources that involve inputs/outputs to the system.*
2. *Surveillance cameras integrated with monitoring of neutron signals at all inputs to and outputs from the process cell (PC). These would be used, in part, to detect undeclared process modifications and to ensure that material movements are along declared paths, etc. Surveillance cameras monitor transfers within the process cell.*
3. *Measurement of total neutrons from each fuel pin as it transfers into the process cell.*
4. *A DA sample of the chopped pins to validate the burnup calculations, which provide the Cm/Pu ratio and absolute Pu content. Initially, several samples per assembly at various pin and axial positions will be taken to confirm the validity of the burnup calculation method for the axial and radial isotopic variation in that reactor. Once the burnup calculations have been validated, it should be possible to reduce sampling to one sample per assembly.*
5. *Measurement of total neutrons from the chopped fuel pins as they are transferred into the electrorefiner (ER) in the anode basket.*
6. *The metal waste (cladding) stream from the electrorefiner will be monitored with a neutron counter supported by DA sample to measure the TRU content. Optical surveillance will support continuity of knowledge (COK) for the stream, verifying that the metal moves from the ER through the detector and on to the next stage of waste processing outside of the PC.*
7. *Uranium metal removed from the ER is transferred to U Product Processing. As with the metal waste stream, this stream is expected to contain little TRU, although the electrodes will be coated in salt from the ER. Optical*

surveillance will provide COK for the stream, verifying that the electrodes move from the ER to the UP.

8. *The salt transferred to ceramic waste is expected to contain very small (loss) amounts of TRU. Neutron counting in combination with the Cm/Pu ratio measured in a sample is used to verify the TRU content of the salt transferred to ceramic waste.*
9. *Neutron measurement and optical surveillance are used to verify that TRU is not transferred out of the process cell through a non-standard route.*
10. *The ingots produced by the TRU Product Processing process and the U Product Processing process are transferred to the Product Prep stage. For both of these in-cell transfers, surveillance cameras are used to verify that ingots are not diverted during the short transfer. It is assumed that a 1-month processing inventory can be contained in the Product Prep stage area. (Product Prep was needed in the study to prepare materials for fuel fabrication, a part of the process not considered in the example in this report).*
11. *Additional radiation monitors, surveillance cameras, and seals will be applied to other cell penetrations that provide potential diversion paths. At this stage, it is assumed that infrequently used hatches will be sealed, but that in addition neutron monitors and cameras will be installed to monitor activity when the hatches are unsealed. Penetrations that are never intended to see the transfer of radioactive material may be monitored with radiation detectors configured to prevent shielding. Penetrations intended for only 1-way flow have pairs of radiation detectors to verify reverse flow including insertion of neutron emitters that could be used to provide false signals to neutron detectors. All of these monitors tie into a central data collection point for remote monitoring by the IAEA.*
12. *In addition, extensive process monitoring is used to verify that the facility is operated as declared. Where possible, authenticated signals from the operator's process monitoring equipment are used, but where required, independent IAEA monitoring equipment may be installed. The process monitoring in the electrorefiner is outlined as follows:*

    a. *Cell voltage*

       The cell voltage in the electrorefiner provides an indication of the quality of the product being collected at the cathode. Under normal operation, the cell voltage should remain within a specified range, below an upper limit. Exceeding this limit can signal the production of a cathode deposit with a TRU/U ratio higher than design specifications.

    b. *Cell current*

       The cell current in the electrorefiner provides an indication of the rate that material is being electrotransported to the cathode. Cell current is controlled as part of the electrorefining process, provided cell voltage does not exceed the limit as described in the previous paragraph. Observing a nonzero value for the current between the anode and the cathode, along with an adequate value for cell voltage, will signal that the electrorefiner is being operated and that a cathode *deposit is being produced. Cell current is integrated with respect to time to compute the ampere hours passed during each electrorefiner run. This ampere-hours value is related to the amount of material (primarily uranium) electrotransported and deposited at the respective cathode during the given electrorefiner run. In steady state operation, the ampere-hours value of any electrorefiner run should be within an expected range, depending on the mass in the anode basket. The case of a low ampere-hour value associated with an electrorefiner run may signal incomplete processing of a given spent fuel batch, which could imply subsequent unauthorized material diversion or processing scenarios. These integrated cell currents can also be used as a consistency check against material inventories that may be computed from measurements taken at subsequent process steps.*

c. Species concentration

The concentrations of important species (particularly U and Pu) in the electrolytic salt are monitored for process control and also provide an indication on the quality of the cathode material that may be produced not only by electrorefining but also by electrolysis (when the salt is transferred out for further processing). The concentrations are periodically measured by sampling the electrorefiner salt. In general, these concentration measurements provide salt chemistry information of potential utility for safeguards. Under normal operation, the Pu/U ratio should remain within a specified range, below an upper limit. Production of unauthorized material with a high TRU/U ratio can be facilitated if a salt material with high TRU/U ratio is used, although criticality may limit the extent to which this can be done. It may also be possible to monitor concentrations of these ionic species online (i.e., U and Pu) in the eutectic salt using a technique based on voltammetry.

d. Salt level and density

Two additional process variables in the electrorefiner are periodically monitored for safeguards purposes, i.e., salt level and density. Given these two measurements and information on salt chemistry (from DA analysis or using the above online method for detecting and quantifying U and Pu concentrations), a total inventory of these species can be estimated for the electrorefiner. These values can then be used to compute, confirm, or calibrate U and Pu inventories derived from other methods.

In addition to the measures described above, the facility will provide the IAEA with remote access to near real-time accounting information, allowing the IAEA to monitor for declared deviations from routine process flow patterns and consistency with monitoring and surveillance data. It is likely that the IAEA will maintain a resident inspector at or near the site or facility. Because of the relatively clean TRU emerging from the TRU extraction, this facility will require monthly interim inspection in addition to an annual Physical Inventory Verification.

The IAEA would be expected to perform Design Information Verification (DIV) regularly on the process to monitor for process changes. In addition to process *monitoring, this would include visual inspection (to the extent possible) to look for modifications to the facility.*

Assumptions

1. *Process and support equipment modules will be computer controlled for automated operation and production with very limited operator involvement. Actuators, motors, cranes, and electromechanical manipulators will be used to perform the necessary operations. Small parts of the process may require the use of operators using master-slave manipulators to perform delicate tasks or tasks that cannot be easily automated. Cameras will be used to observe and operate equipment in the cell wherever possible. These cameras also can be part of a safeguards containment and surveillance (C/S) system to monitor material and equipment movements and to analyze operational events in near real-time viewing for safeguards purposes.*
2. *The facility is designed to minimize, locate, and monitor penetrations in an optimal manner consistent with safeguards and inspection requirements. These penetrations can be classified according to their functions. For example, in-cell equipment requires feed-throughs with electrical power, video, instrumentation and control wiring, and gas supplies. There are also penetrations, such as hatches (e.g., the fuel assembly transfer hatch) and locks (e.g., the waste transfer lock), used to move material and equipment between cells. Pneumatic transfer systems are also present for transporting small amounts of material out-of-cell for testing and evaluation. There are also penetrations to accommodate thru-wall and thru-roof endoscope cameras, for example.*
3. *Samples will leave the process cell in uniquely numbered tamper-resistant containers that are weighed and tracked. Assume a 1-week turnaround for sample results from the analytical laboratory. (No sample material is returned from the analytical laboratory. Assume all samples are consumed and destroyed.) Assume that samples are ~1 gram.*

As can be seen from the list of planned activities and assumptions, there is a significant emphasis on NDA and sampling, although some of the proposed NDA would likely be difficult in the high radiation environment expected in the process cell. Portal monitoring is also used, consisting of optical surveillance and neutron monitoring. It is clear that the underlying basis of the approach is mass balances, while recognizing that equipment holdup is expected to be large with limited means of verification. While no evaluation of the effectiveness of this safeguards approach was made in the study, it is noted that "the safeguards approach for the process cell is based on extensive process monitoring and C/S measures to complement the accounting verification. The uncertainty in measurement of the Pu in the process is expected to be high from a safeguards perspective. It is not clear that this safeguards approach would be judged as adequate to meet safeguards goals or not, but there is significant room for improvement by considering the characteristics of the process and the processing operations.

2.4 An Alternative Approach to Meeting Safeguards Goals

The previous section has described an approach to safeguards that essentially follows current practice for processing plants using PUREX, with emphasis on material accounting and NDA. It is likely that this approach would face the same limitations that occur with a large PUREX processing plant in that the throughput is so large that detecting the quantity of interest, 1 SQ, within technically achievable measurement error limits is extremely difficult. However, with this pyroprocessing example, it is possible to take advantage of the nature of the pyroprocess, and the discrete batch nature of the process operations to provide a different path towards verifying that there has not been any production or diversion of material.

2.4.1 The Process Cell

In developing an alternate safeguards approach, the first area to consider is the process cell itself, which is a heavily shielded hot cell that contains all of the equipment used for the pyroprocessing operations in an inert gas atmosphere, starting with chopping of the fuel. The process cell has a limited number of penetrations, designed for the following:

1. Insertion of the spent-fuel assemblies, occurring at a rate consistent with processing needs
2. Insertion of process chemicals sufficient to support processing needs (although this can be very limited depending on the amount of process chemical regeneration that is planned within the process cell)
3. Replacement equipment as needed
4. Withdrawal of products, including uranium and U/TRU
5. Withdrawal of waste materials for both the ceramic and metallic waste forms.

To verify that these are the only materials that enter the process cell, monitoring the process cell portals would be sufficient. It is not unreasonable to expect that this could be achieved with 100% certainty (i.e., there should be no reason that materials and equipment not needed for normal operation would not be detected) given the limited types of materials that enter and their characteristics, and that the monitoring could also be verified remotely if desired. Both visual observation and NDA are sufficient to verify that either spent fuel or the appropriate process chemicals are being introduced to the cell. Replacement equipment would also be readily verified, as would the removal of equipment for repair or replacement.

For materials leaving the cell, the uranium and U/TRU product ingots would be verifiable by NDA, and samples taken within the process cell and analyzed in the analytical laboratory would verify the composition. Waste stream materials can also be verified for the lack of TRU by NDA, given the relatively small masses that would exit at each time. However, the ability to make fine distinctions in the amount of TRU on the U/TRU ingots and in the waste streams to the desired accuracy is probably not achievable with NDA. This difficulty can be addressed with the conduct of operations within the process cell and additional instrumentation. Note that development of new NDA or other technologies for portal monitoring would likely not be required with this approach in order to meet safeguards goals.

2.4.2 Item, Motion, and Position Accounting in the Process Cell

Following the example used in the FCF for processing EBR-II spent fuel, all movements of materials within the process cell would be monitored. The discrete nature of the pyroprocessing operations allows creation of “items,” even though the materials are being handled are “bulk” in nature. Starting with the incoming fuel assembly, the first operation is to chop the assembly. Note that the spent fuel assembly would only have one introduction point through the appropriate portal, and it would have only one destination, the fuel assembly chopping machine, although it is likely that the first operation performed in the cell would be to weigh the assembly. In this proposal, the equipment that moves the spent fuel assembly from the portal to the weighing station and then to the chopping machine would be instrumented for location within the cell so that the data coming from the equipment would allow one to verify that the fuel assembly had moved from the portal to the weighing station and then to the fuel assembly chopping machine, and nowhere else. If desired, one could also attach a time “stamp” to the movements, similar to that used in FCF. Any movement of the fuel assembly outside of the normal path would be detected as an anomaly and could be used to send an alarm.

At the chopping machine, the spent fuel assembly would be chopped into pieces suitable for the next stage of the process. All of the pieces would be directed into containers, each of which is numbered and tracked within the process cell as an item. The procedure would be to chop the assembly (the chopping action is also monitored by assembly position, and is needed for assuring that the chopped pin pieces are of the appropriate size), collect the pieces in a number of containers, and move the containers to a weighing station where the mass in each container would be measured. The container number, its weight, and the time when the container was weighed define the creation of an "item" for tracking purposes. Again, there is only one path from the chopper to the weighing station. Once weighed, it is likely that the containers would be temporarily stored prior to the next step of the process and that this storage location would be between the fuel assembly chopping machine and the low-temperature voloxidizer in this case, referring to Figure 1. The specific storage location would also correspond to specific movements by the equipment moving the containers, and the movements would be recorded to verify that a given container has gone to a specific storage location at a specific time. In this manner, it is possible to accurately and positively track the motion and location of all materials within the process cell even if there is uncertainty about the composition of the materials in the container. It is also possible to positively detect any non-standard movement of material within the process cell, greatly limiting the ability of the operator to perform non-standard operation. (The method of tracking the creation of items and the time stamp for weighing has already been demonstrated in FCF, and has been successful in detecting improper procedures from a remote location.)

When the container is retrieved from storage at the time of processing in the voloxidizer, the desired container number is identified, as is its current location in the temporary storage area. Upon retrieval, the container number is verified, and the container is reweighed to check that there has been no change (within weighing error, typically on the order of grams) in the contents of the container. If the new measured weight does not agree with the weight when the "item" was created, within weighing error limit, an alarm is sent. Note that even if one had wanted to substitute material in the container, with all equipment in the process cell monitored for movement (as are uses of the scales for weighing), it would not be possible to substitute material without being detected, as such movements would also be non-standard. There is also the question of what material would be used, since all materials entering and leaving the cell are verified, so that no non-standard material would be available for the substitution.

If the same container is used in the next operation, as could occur with the voloxidizer (where volatile fission products are removed), electrolytic reduction (where the container could be used as the anode basket and the oxides are reduced to elements), and the electrorefiner (where the container could be used as the anode basket and the actinides and some fission products are electrotransported), the container would be weighed before and after each operation, and every movement of the container is monitored and recorded as well. Any non-standard movement would be detected. After the electrorefiner run was finished, the container would now only contain cladding hulls and fission products that are less reactive than uranium in the electrorefiner salt. After removal from the electrorefiner and weighing, the container would be emptied and the existence of the "item" would be terminated. Note that the "item"—the container and its contents—changes weight as a result of processing, and all weights and times of weighing are recorded. Once empty, the container is weighed to verify or adjust the tare weight for the container for its next use.

The same approach is used throughout the process cell. In this manner, it is possible to detect any non-standard movement of material. With monitoring of the operating conditions on the processing equipment, it is also possible to detect non-standard equipment operation, making undetected misuse or production in the facility impossible. It is interesting to note that with this approach, it is possible for one to conclude with certainty that no diversion or misuse has occurred within the process cell even if one has no knowledge of the compositions of materials within the process cell, and the goal of safeguards can been achieved in a completely different manner than is done in a PUREX plant.

2.4.3 Material Compositions

As a practical matter, it is important to have some knowledge of the compositions of materials within the cell for process control and criticality concerns. The approach discussed above has been used in FCF and would likely be continued in a future pyroprocessing facility. The compositions are based on calculations of the spent fuel contents that are verified by taking one or more samples when the spent fuel is chopped. Any axial distribution of fuel composition is adjusted so that the calculated composition matches the measured composition at the sample(s) location. As the fuel is chopped, the adjusted calculated compositions are used to specify the composition of the contents of the container, and become another part of the item description, and follow the item as it moves through the facility. When processing occurs on an item, as would happen in the electrorefiner for example, the composition of the container would be modified either based on samples taken, or on models of the process operation. In this manner, an estimate of composition is available for all locations in the process cell, even for those where sampling is not possible.

In some cases, the generation of an estimated composition for an item at a given location requires data from both pre- and post-processing samples. For example, to fully provide all of the information required by the electrorefiner model in FCF, it was necessary to use the incoming spent fuel compositions and the product compositions at the end of processing. As part of the calculation process, it is also necessary to propagate the compositions through other equipment, such as the cathode processor, using additional models as needed. The end result is that the compositions can always be estimated, although for some items, the compositions are only known after processing has been completed and the item no longer exists. As has been mentioned, this information is only used for process control and is not part of the information needed for safeguards.

2.4.4 Mass Tracking

As part of process control, the sampled and calculated/propagated material compositions are used to perform mass balances on the process cell. This was done for the FCF EBR-II spent fuel processing and was successful in demonstrating that this approach could be used to verify the inventory and flow of uranium and plutonium in the facility. The same approach would be used in the large-scale pyroprocessing facility, but one would again have to address the issue of having 1 SQ of material being well within the ability to resolve, given the anticipated measurement accuracies. However, as described above, the ability to provide the mass balance to a certain degree of accuracy is not necessary for achieving safeguards goals in this facility.

3. SUMMARY

As stated earlier in this report, the fundamental objective of safeguards is "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." This goal is achieved by the detection of the loss of 1 SQ, with timeliness determined by the type of material, either 1 month for unirradiated direct-use material or 3 months for irradiated direct-use material, where direct-use material is defined as material which can be used without further enrichment or irradiation. The goal is to be able to conclude that no diversion has occurred. The example of a pyroprocessing facility has been used in this study to illustrate how one could meet the safeguards goals in a non-traditional manner, possibly achieving an even greater measure of assurance than is possible today with conventional spent fuel processing and the existing safeguards approaches, and removing the burden of developing and implementing new NDA and other technologies as they are not essential to achieving safeguards goals.

An additional advantage of the type of monitoring described in this study is that the oversight required for safeguards can be performed remotely to a significant level of detail, even to the point of observing operations and all material movements in a virtual 3-D environment as they occur, if desired. A simplified version of this approach has already been demonstrated to be effective in this manner through the detection at a remote location of improper operations at FCF. All of the material movements associated with standard processing procedures will follow unique pathways through the facility; when used with item accounting as described in this study, this type of process monitoring will ensure that only standard processing is occurring, and that no non-standard processing is being done, reinforcing the conclusion that no diversion or misuse has occurred.

4. REFERENCES

1. "IAEA Safeguards Glossary – 2001 Edition," International Atomic Energy Agency, International Nuclear Verification Series No. 3, Vienna, Austria, June 2002.
2. "IAEA Safeguards: Aims, Limitations, Achievements," International Atomic Energy Agency, Vienna, Austria, 1983.
3. "Safeguards On Nuclear Material—Implementation of US/IAEA Agreement," 10 CFR 75, Code of Federal Regulations, Office of Federal Register, January 1, 2002
4. "Safeguards and Security Program References," DOE M 470.4-7, U.S. Department of Energy, August 26, 2005.
5. "ESFR Pyroprocessing Facility Description and Preliminary Safeguards Approach for PR&PP Demonstration Study," I. Therios, Argonne National Laboratory, September 30, 2006.

Appendix A

IAEA, DOE, and NRC Approaches to Physical Protection of Nuclear Facilities

Appendix A

IAEA, DOE, and NRC Approaches to Physical Protection of Nuclear Facilities

The most relevant regulation and requirement documents used to safeguard and secure nuclear material and nuclear facilities, produced by the Department of Energy (DOE), International Atomic Energy Agency (IAEA), and Nuclear Regulatory Commission (NRC), have been assembled into a user-friendly targeted reference library called the Nuclear Security Reference Library. This quick-reference library provides easy access to the most pertinent regulatory documents related to safeguards and security used to determine the highest level goals, objectives, and strategies that each regulatory body uses to protect nuclear materials, equipment, and facilities. A high-level review of each organization's physical protection regulations and requirements will be given, followed by a comparison of the common goals, objectives, and strategies of each organization.

Department of Energy

The DOE is principally a national security agency that supports national security interest through ensuring the United States' energy security, nuclear security, advancements in technology, and providing a responsible resolution to the nuclear weapons legacy. Focusing on DOE's nuclear security responsibilities, their goal is to prevent security events that could potentially lead to interruption, disruption, or compromise of DOE operations or facilities. The DOE has identified unauthorized access, theft, and sabotage involving nuclear material as unacceptable security events, stated in the Objectives section of DOE M 470.4-2 Chg 1. The DOE has determined that risks associated with security events can be greatly mitigated by implementing a physical protection system whose objectives are to prevent, detect, assess, delay, and deter unauthorized individuals and materials from passing through controlled boundaries. Section A of Part 1 of DOE M 470.4-1 states this as follows: "to prevent, detect, or deter unauthorized access to or loss of controlled matter." These system requirements are mandated in Chapter 4 of DOE M 470.4-2 Chg 1. The overarching goal and high-level objectives are the products of four governing principle strategies that embody the DOE's physical protection philosophy.

The governing principle strategies that guide the DOE's physical protection system are: incorporation of the design basis threat (DBT), graded protection of nuclear material, defense-in-depth strategy, and the Integrated Safeguards and Security Management program. In August 2008, the DBT was replaced by a new strategy called the Graded Security Protection (GSP) Policy, instituted by DOE O 470.3B, which replaced DOE O 470.3A. The GSP is steadily being worked into the current physical protection system. Due to the newness of the GSP and the long-standing history of applying the DBT, the DBT will be used here to establish the principle rationale that the DOE has used to successfully implement their physical protection system. The aforementioned four principle strategies are established and discussed in detail in the following documents: DOE O 470.3B, DOE M 470.4-3 Chg 1, DOE M 470.4-1 Chg 1, DOE M 470.4-2 Chg 1, and DOE P 470.1. The DBT identifies potential adversaries and assesses their capabilities and tactics. The DBT is changed when perceived threats change. The DBT is used in the design of DOE physical protection systems and is used to protect nuclear material and nuclear facilities. Nuclear facilities are protected by tailoring physical protection systems to be able to counter all perceived threats from all potential adversaries. It is stated in the Requirements section of Section A of DOE M 470.4-1 Chg 1 that the "DBT policy must be used with local threat guidance during the conduct of the vulnerability assessments" of nuclear facilities. The physical protection system is designed to address sub-national threats, which consider two possible scenarios: theft of controlled material by an invading force, with or without insider assistance, and sabotage by an invading force, with or without insider assistance.

Procedures and requirements are in place to ensure that planning is continually occurring to counter current and developing threats, which is mandated in DOE O 470.4A and DOE P 470.1.

The second principle strategy is the mandatory implementation of the graded approach to physical protection, which is established in Chapter 1 of DOE M 470.4-2 Chg 1 and DOE M 470.4-1 Chg 1. This principle requires that material categorization is a key consideration in the establishment of physical protection requirements. The DOE classifies nuclear material by considering material quantity, chemical forms, isotopic composition purities, ease of separation, accessibility, concealment, portability, radioactivity, and self-protecting features. Nuclear material categorization requirements are provided in Chapter 1 of DOE M 470.4-6 Chg 1. Nuclear material that is categorized as having a greater potential for adverse consequences associated with material is more stringently protected. Similarly, nuclear material classified as having less pejorative consequences would be less stringently protected. The requirements associated with the establishment of security areas based on material categorization is discussed in Chapter 4 of DOE M 470.4-2c1.

The third principle strategy of the DOE's physical protection system is the implementation of the defense-in-depth strategy. The requirements for this strategy are discussed in DOE P 454.1 and Chapter 2 of DOE G 454.1-1. The defense-in-depth strategy requires the use of multiple layers of active and passive obstacles to force an adversary to defeat or circumvent obstacles. The layered protection strategy reduces the importance of a single obstacle and allows for the implementation of different types of defenses, which increases the complexity of an intruder's task. This strategy makes use of physical barriers, intrusion detection and assessment systems, contraband detection systems, and protective force.

The three previously discussed principle strategies form a strongly coupled system that is specifically designed to counter sub-national threats. The fourth and final principle strategy further strengthens these tightly coupled systems by incorporating formal practices that establish requirements for physical protection planning, performance assessments, and process improvements. The fourth principle is the Integrated Safeguards and Security Management program and the established requirements are available in DOE P 470.1. The focus of this program is to integrate safeguards and security into management and work practices to incorporate risk management-based decision making into the physical protection system, further minimizing the possibilities of security events. This program is designed to increase the efficiency and effectiveness of the DOE physical protection system.

The requirements and objectives mentioned above are applicable to the protection of nuclear materials at fixed facilities and in transit. The mechanisms used to prevent unauthorized access to nuclear material may be different for transporting nuclear material than that for fixed facilities, but the levels of protection should be comparable. Additionally, the same strategies that are used to protect nuclear material in fixed facilities are also used to protect nuclear material in transit. The physical protection requirements for transporting nuclear material are established in DOE M 470.4-2c1.

In the event that the physical protection system is not sufficient to prevent unauthorized access and control of Category 1 and Category 2 nuclear material is lost, there is a backup plan in place to respond to the security events. In this situation, response operations are implemented, which consists of guards responding to an event that may involve recapture, recovery, and pursuit. These requirements are established in Chapter 1 of DOE M 470.4-3c1. Recapture refers to regaining control of nuclear material that is in unauthorized possession within the confines of a DOE site, whereas recovery refers to regaining control of the nuclear material that has been taken off-site, as defined by DOE M 470.4-7. Pursuit is formally called fresh pursuit, which refers to seeking out stolen nuclear material shortly after the control over the material has been lost and the material has been taken off-site. Response operations add yet another layer of protection, which is part of the defense-in-depth strategy.

To fully realize their goal, the DOE cooperates with the IAEA to establish requirements that consider sub-national and national threats to the nuclear security of the United States. The DOE's commitment to work with the IAEA is a substantial step in ensuring national, as well as global, nuclear security and is established in the Non-Proliferation Treaty (NPT), INFCIRC/140. The structure and content of the NPT is provided in INFCIRC/153.

International Atomic Energy Agency

The goal of the IAEA is to assist in the spread of nuclear energy for peaceful purposes while ensuring that nuclear material, equipment, facilities, and information provided by the IAEA to developing nations will not be used to further any military objectives. This goal is stated in INFCIRC/274 and Chapter 1A of INFCIRC/66. To accomplish this goal the IAEA makes recommendations about international requirements for safeguards and security systems to prevent the diversion of controlled nuclear power related resources by national or sub-national threats. The documents that address the IAEA's physical protection recommendations are in INFCIRC/225 and TECDOC-967. The recommendations and requirements that are used to counter sub-national threats will be discussed and used to ascertain the IAEA's high-level physical protection objectives.

The primary objectives of the IAEA's physical protection system are to provide recommendations to member states to mitigate the risk of unauthorized removal of nuclear material and sabotage, as well as to support the recovery of missing or diverted nuclear material. These objectives are stated in Chapter 3 of INFCIRC/225. The IAEA recommends, in Chapter 4 of INFCIRC/225, that member states use IAEA recommendations to influence their national law to establish physical protection regulations that are regularly evaluated by a national regulator. In Article 2 of INFCIRC/274, it is established that by joining the Convention on Physical Protection of Nuclear Material (CPPNM), which results in the establishment of national laws to ensure, as far as practicable, that nuclear material is protected to an established standard, as set by the IAEA and agreed upon by member states, which is stated in Article 3 of INFCIRC/274. CPPNM membership is interpreted as "affecting the sovereign rights of a State regarding the domestic use, storage, and transportation of such nuclear material."

The IAEA recommends the inclusion of high-level principles to accomplish their physical protection goals, which are similar to that of the DOE. There appears to be four key principle strategies that the IAEA uses to make recommendations: utilizing the DBT, instituting graded protection requirements, implementing the defense-in-depth strategy, and readiness to implement recovery operations. The IAEA's first principle strategy is the DBT, which uses characteristics and capabilities of potential adversaries to determine necessary requirements to prevent unauthorized access to nuclear materials and nuclear facilities to mitigate the risks associated with theft of nuclear material and/or radiological sabotage. The recommendation for implementing the DBT is specified in Chapter 4 of INFCIRC/225. When considering the DBT, the IAEA considers two types of scenarios: internally and/or externally initiated events, as described in Chapter 2 of STI/PUB/1271. An internally initiated event occurs when adversaries attempt to gain access to a facility, with or without the assistance of an insider at the site. An externally initiated event occurs when the threat occurs outside of a boundary and does not require the on-site presence of an adversary. Examples of externally initiated events are having an adversary crash a plane into a reactor or shooting a rocket into a nuclear reactor facility. Considering these types of threats, prudent planning involving facility design, security hardware, guards, and procedures should be used to contend with these specified threats.

The second principle strategy used by the IAEA is the implementation of the graded approach to physical protection. This approach establishes physical protection requirements based on possible adversary targets and the potential consequences of losing control of those targets. The IAEA categorizes nuclear material by material type, quantity, physical and chemical form, degree of dilution, radiation level, and the material's self-protecting nature. The categorization requirements for nuclear material are provided in Chapter 5 of INFCIRC/225 and in Annex 2 of INFCIRC/274. Nuclear material of significant strategic value is more stringently controlled. The requirements for graded protection of nuclear material are described in Chapter 4 of INFCIRC/225. The physical protection requirements for the various categories of nuclear material are provided in Chapter 6 of INFCIRC/225, which considers physical protection requirements for transportation, as well as fixed facility requirements.

The defense-in-depth strategy is the third principle strategy that the IAEA utilizes in establishing recommendations, which is established in Chapter 4 of INFCIRC/225. Recommendations for physical protection requirements, for fixed facilities and shipments of nuclear material, are specified in Chapters 6-8 of INFCIRC/225 and Chapters 6-8 of TECDOC-967.

The final and heavily emphasized aspect of the IAEA's physical protection system is recovery operations. Specific recommendations and requirements are established in Chapter 3 of INFCIRC/225 and Article 5 of INFCIRC/274. When a member state joins the CPPNM, the member state has agreed to cooperate internationally to recover lost or diverted nuclear material, upon request. In Article 7 of INFCIRC/274, illegal acts are defined and in Article 11 of INFCIRC/274, foundations are laid to enable extradition of international criminals. Agreements between the IAEA and member states are used to influence national law within the agreement nation. An excellent example of this, in practice, is the relationship between the IAEA and the NRC.

Nuclear Regulatory Commission

The NRC's overarching goal is to license and regulate the United States' civilian nuclear industry, while protecting public health and safety, promoting national security, and protecting the environment. Title 10 Code of Federal Regulations (10CFR), is the guiding document for the NRC. In 10CFR73, the physical protection requirements are established to protect nuclear material and nuclear facilities.

The high level objectives of the NRC, stated in Part 45 of 10CFR73, are to implement the DBT strategy, detect and assess the passage of unauthorized individuals and material across controlled areas, develop and implement a response plan to safeguards contingency events, maintain effective communication networks, and to ensure that a single event cannot destroy the capabilities of the security organization to request off-site assistance. In October 2008, the NRC formally stated, in 10CFR50, the policy that requires concurrent consideration of safety and security in the design of nuclear reactor facilities that result in a security system that requires fewer human actions. Front end loading of the design process, specifically focusing on safety and security, enables a more effective implementation of physical protection systems, as well as other systems. The high level physical protection objectives and lower level requirements are specified in 10CFR73. The NRC's guiding physical protection principle strategies can be reduced to implementing the DBT, graded protection, and layered protection.

The implementation of the DBT and its required use are established in Part 1 and Part 20 of 10CFR73. The material categorization of nuclear material is defined in Part 2 of 10CFR73 and the physical protection requirements for transportation and storage of nuclear material of strategic significance are established in Parts 25, 26, 40, 46, 67 of 10CFR73.

Results and Conclusions

The overarching goals of the IAEA, DOE, and NRC's physical protection systems are to prevent theft of nuclear material, nuclear sabotage, and mitigate consequences of compromised material. The successful achievement of these goals is strived for by reaching established physical protection objectives, which can be achieved by implementing physical protection strategies.

It has been concluded that there are strong similarities in the goals, objectives, and strategies used by the IAEA, DOE, and NRC's physical protection systems. The conclusions in this paper were ascertained by reviewing pertinent physical protection regulatory requirements from each regulatory body. The requirements from each governing body were grouped by the intended objectives of each requirement. After reviewing the IAEA, DOE, and NRC's physical protection requirements and exploring their identified objectives, it was clear that there were three key objectives: detect and assess unauthorized personnel and material, delay and prevent unauthorized intrusion, and initiate response and recovery operations when needed. To achieve these objectives, each regulatory body uses focused physical protection strategies. The IAEA, DOE, and NRC use slightly different strategies to achieve their objectives, but they all use three principle strategies: the DBT, graded protection, and the defense-in-depth strategy. From this type of analysis the similarities between regulatory organizations become apparent, which helps facilitated cooperative efforts and furthers an understanding of requirements.

The most relevant documents, related to safeguards and physical protection, were integrated into a targeted library called the Nuclear Security Reference Library. The documents that are included in the Nuclear Security Reference Library are available in Appendix B. Some of the regulatory documents used in this paper that directly pertain to physical protection systems are briefly summarized in Appendix C.

Appendix B

Nuclear Security Reference Library
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DOE

PHYSICAL PROTECTION

DOE M 470.4-1 Chg 1: Safeguards and Security Program Planning and Management
DOE M 470.4-2 Chg 1: Physical Protection
DOE M 470.4-3 Chg 1: Protective Force
DOE P 470.1: Integrated Safeguards and Security Management (ISSM) Policy
DOE M 470.4-7: Safeguards and Security Program References
DOE P 454.1: Use of Institutional Controls
DOE G 454.1-1: Institutional Controls Implementation Guide for Use with DOE P 454.1, Use of Institutional Controls
DOE M 470.4-1 Chg 1: Safeguards and Security Program Planning and Management
DOE O 470.3B : Graded Security Protection (GSP) Policy
DOE O 420.1B: Facility Safety
DOE G 473.2-1: Guide for Establishment of a Contingency Protective Force
DOE 5480.30: Nuclear Reactor Safety Design Criteria
DOE G 413.3-3: Safeguards and Security for Program and Project Management
DOE O 413.3A Chg 1: Program and Project Management for the Acquisition of Capital Assets
DOE M 470.4-5: Personnel Security

PROLIFERATION RESISTANCE

DOE O 142.2A: Voluntary offer Safeguards Agreement and Additional Protocol with the International Atomic Energy Agency
DOE 470.4-6 Chg 1: Nuclear Material Control and Accountability

IAEA

PHYSICAL PROTECTION

IAEA INSAG-10: Defense in Depth in Nuclear Security
IAEA TECDOC-967: Guidance and Considerations for the Implementation of INFCIRC/225, The Physical Protection of Nuclear Material and Nuclear Facilities
IAEA STI/PUB/1133 Preparedness and Response for a Nuclear or Radiological Emergency
IAEA TECDOC-1357: Management of Disused Long Lived Sealed Radioactive Sources
IAEA TECDOC-1355: Security of Radioactive Sources
IAEA STI/PUB/1272: Nuclear Regulatory Systems
IAEA INFCIRC/225: The Physical Protection of Nuclear Material and Nuclear Facilities
IAEA INFCIRC/274: The Convention on the Physical Protection of Nuclear Material
IAEA INFCIRC/66: The Agency's Safeguards System
IAEA STI/PUB/1271: Engineering Safety Aspect of the Protection of Nuclear Power Plants against Sabotage

PROLIFERATION RESISTANCE

IAEA INFCIRC/153: The Structure and Contents of Agreements Between The Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons
IAEA INFCIRC/140: Treaty on the Non-Proliferation of Nuclear Weapons
IAEA INFCIRC/26: The Agency's Safeguards
GC(49)/17: Nuclear Security – Measures to Protect Against Nuclear Terrorism
IAEA INFCIRC/36: The Text of the Agreement for the Application of Agency Safeguards to Four United States Reactor Facilities
IAEA INFCIRC/540: Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards
IAEA INFCIRC/57: The Text of the Agreement for the Application of Agency Safeguards to the United States Reactor Facilities

NRC

PHYSICAL PROTECTION

NRC NUREG 1614: Strategic Plan
NRC 10 CFR 73: Physical Protection of Plants and Materials
NRC 10 CFR 50: Policy Statement on the Regulation of Advanced Reactors

PROLIFERATION RESISTANCE

NRC 10CFR74: Material Control and Accounting of Special Nuclear Material
NRC 10CFR75: Safeguards on Nuclear Material, Implementation of US/IAEA Agreement

UN

UN Resolution 255 (1968): Question relating to measures to safeguard non-nuclear-weapon States parties to the Treaty on the Non-Proliferation of Nuclear Weapons 20%
UN Resolution 1373 (2001): Threats to international peace and security caused by terrorist acts
UN Resolution 1540 (2004): Non-proliferation of weapons of mass destruction
UN Resolution 1617 (2005): Threats to international peace and security caused by terrorist acts
UN Convention 2005: International Convention for the Suppression of Acts of Nuclear Terrorism
UN General Assembly A/62/156: Measure to Prevent Terrorist from Acquiring Weapons of Mass Destruction

Appendix C

Summaries of DOE, IAEA, and NRC Documents

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DOE O 142.2A: Voluntary offer Safeguards Agreement and Additional Protocol with the International Atomic Energy Agency

The order defines the requirements for the Department of Energy (DOE) to be in compliance with the following agreements: Agreement between the United States and the International Atomic Energy Agency for the Application of Safeguards within the United States, Original Protocol of the Agreement, Additional Protocol, Subsidiary Arrangements, and Voluntary Offer Agreement. The requirements are primarily focused on IAEA access, information security, exceptions to access, and management responsibilities within the DOE.

DOE M 470.4-2 Chg 1: Physical Protection

The manual specifies DOE goals, objectives, requirements, and strategies for the protection of nuclear weapons, components, special nuclear materials and classified information. Physical protection subsystems, which are specifically addressed in the manual, can be grouped into three generic groups: denial, detection, and maintenance. The denial group refers to the requirements associated with preventing unauthorized access to secure areas by the implementation of the following subsystems: physical barriers, locks and keys, layered security areas, access controls, and protective forces. The detection group refers to requirements associated with detecting and assessing unauthorized penetrations into secure areas by using the following subsystems: intrusion detection and assessment systems, communication systems, and alarm management and controls systems. The maintenance aspect of the manual refers to general, corrective and preventive maintenance.

DOE M 470.4-3 Chg 1: Protective Force

The manual specifies management and operational requirements for DOE protective forces, which are based on risk-based management decisions to prevent security events that lead to interruption, disruption or compromise of DOE operations or facilities. Procedures and requirements are specified for protective forces management, as well as for equipment and facilities. The manual also establishes protective forces' duties, operations, training and qualification, and testing. Additionally, requirements associated with special response teams and guidelines for fresh pursuit are specified.

DOE O 452.4A: Security and Control of Nuclear Explosives and Nuclear Weapons

The objective of this order is to prevent the deliberate unauthorized use of U.S. owned nuclear explosives or nuclear weapons by specifying DOE and National Nuclear Security Administration (NNSA) requirements and responsibilities. These responsibilities include development of security and methods to maintain and regain control of U.S. owned nuclear explosives and nuclear weapons.

DOE O 452.3: Management of the Department of Energy Nuclear Weapons Complex

The objectives of the order are to establish the authorities and responsibilities of the National Nuclear Security Administration to maintain and improve the safety, reliability, and performance of the nuclear weapons stockpile by continually improving the capabilities, technical expertise, and infrastructure of the Nuclear Weapons Complex.

DOE P 470.1: Integrated Safeguards and Security Management (ISSM) Policy

The objective of this policy is to provide an all encompassing system that uses risk-based strategies to provide a formal and organized process for planning, performing, assessing, and improving the quality of work, thereby making it more efficient and secure. The framework to accomplish these goals consists of six components, which are: the objective, guiding principles, core functions, mechanisms, responsibilities, and implementation.

DOE M 470.4-5: Personnel Security

The objectives of the manual are to specify requirements for the Personnel Security Program are to grant access to DOE classified matter or special nuclear material, when the determination that access to this material will not endanger security or the common defense. The number of access authorizations will be kept to a minimum and the investigation process will be conducted in a way that ensures timely, efficient, consistent, objective, and fair interpretation of application information. Individuals will be periodically reevaluated to determine access eligibility and continued need for access.

DOE M 470.4-7: Safeguards and Security Program References

The manual provides the definitions for terms used in the Safeguards and Security Program within the DOE.

DOE P 454.1: Use of Institutional Controls

The goal of the policy is to protect human health and the environment by implementing institutional controls to ensure controls are effective, implemented as planned, maintained, reevaluated, and modified as required. The defense-in-depth strategy and property controls were focused on in the discussion of the implementation of institutional controls because of the vital role that they play in mitigating risks.

DOE M 470.4-1 Chg 1: Safeguards and Security Program Planning and Management

The objective of this manual is to specify program planning and management requirements that will be implemented into DOE operations, as determined by line management and sound risk management practices, with the ultimate goal of preventing security events from interrupting, disrupting, or compromising DOE services. The manual establishes the requirements and objectives regarding the DOE's tactical doctrine, graded protection strategies, and management considerations. The requirements associated with the Site Safeguards and Security Plan, Site Security Plan, Self-Assessment Program, and vulnerability assessments are specified. Additionally, the requirements for the safeguards and security training and awareness programs are provided, as well as facility clearances and registration S&S activities.

DOE O 470.3B: Graded Security Protection (GSP) Policy

Classified

DOE M 470.4-6: Nuclear Material Control and Accountability

The manual establishes material controls and accountability for transfers and storage. This manual establishes requirements for equipment and procedures that must be in place to account for material.

IAEA INFCIRC/140: Treaty on the Non-Proliferation of Nuclear Weapons

This is the Nuclear Non-Proliferation treaty between the IAEA and the United States.

IAEA INFCIRC/153: The Structure and Contents of Agreements Between The Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons

This document contains additional information about the agreements established in the Non-Proliferation Treaty that was signed by the United States.

IAEA TECDOC-967: Guidance and Considerations for the Implementation of INFCIRC/225, The Physical Protection of Nuclear Material and Nuclear Facilities

This document is a supplement to INFCIRC/225 and provides detail to established requirements.

IAEA INFCIRC/225: The Physical Protection of Nuclear Material and Nuclear Facilities

The objectives of the INFCIRC/225 document are to establish physical protection recommendations on requirements for nuclear facilities, as well as for the use, storage, and transportation of nuclear material. Recommendations are made with respect to responsibility and authority associated with provided physical protection of nuclear materials at fixed sites or in-transit. Nuclear material types and quantities are categorized into groups based on the potential risks that are associated with the material if it were to be diverted from its intended use.

IAEA INFCIRC/274: The Convention on the Physical Protection of Nuclear Material

INFCIRC/274 specifies the requirements that member states need to adhere to in order to satisfy physical protection requirements for transport or storage of nuclear materials. The material types and quantities of nuclear materials that make up categories 1, 2, and 3 are defined. International collaborative efforts for the recovery and protection of nuclear material are clearly established, as is the international classification of extraditable offenses and related procedures. It is declared that by joining the convention that the sovereign rights of member states are affected, in regards to use, storage, and transport of nuclear material. Import and export requirements are place on member states.

IAEA INFCIRC/66: The Agency's Safeguards System

The INFCIRC/66 document establishes controls to aid in the implementation of their obligations to spread nuclear energy while minimizing, where possible, the risks of nuclear weapons proliferation. The IAEA is looking to enlarge the contribution of atomic energy toward peace, health, and the prosperity throughout the world. Furthermore, their goal is to prevent the diversion of nuclear material, developed with their assistance, for any military purpose. Inspection and report guidelines are specified for the various nuclear facilities with the ultimate purpose of ascertaining if nuclear material has been diverted from its intended purpose. In addition, the provisions are specified for safeguarded nuclear materials in nuclear reactors, reprocessing plants, conversion plants, and fabrication plants.

IAEA STI/PUB/1271: Engineering Safety Aspect of the Protection of Nuclear Power Plants against Sabotage

The publication is specifically tailored to address the issues related to the prevention or mitigation of sabotage risks of nuclear facilities. A plant's physical protection system is designed around the design basis threat and engineering safety aspects are designed to support the physical protection system, which constitutes an additional layer of defense that is part of the defense-in-depth strategy.

Two threat scenarios are specified for the assessment of possible sabotage scenarios. The first is made up of either the insider threat or external adversaries who intend to invade the facility to accomplish their task. The second scenario refers to an external threat outside the plant boundary. This scenario considers adversaries using shoulder launched missiles, truck bombs, and the impact of a fully fueled Boeing 767. The targets that are considered are radioactive materials and nuclear reactors.

The sabotage margin assessment procedure is used to evaluate the capacity of engineering safety provisions to resist the external standoff threat, which may or may not be included in the design basis threat for individual sites. The goal of the sabotage margin assessment is to define success paths that can demonstrate protection against the three scenarios.

NRC 10 CFR 73: Physical Protection of Plants and Materials

This part of the regulatory guide establishes physical protection requirements for in-transit and storage of nuclear material and protection requirements for nuclear facilities.