5-2010

A Safeguards Design Strategy for Domestic Nuclear Materials Processing Facilities.

Jonathan Long
East Tennessee State University

Recommended Citation

Long, Jonathan, "A Safeguards Design Strategy for Domestic Nuclear Materials Processing Facilities." (2010). *Electronic Theses and Dissertations.* Paper 1710. https://dc.etsu.edu/etd/1710

A Safeguards Design Strategy
for Domestic Nuclear Materials Processing Facilities

A thesis
presented to
the faculty of the Department of Technology
East Tennessee State University

In partial fulfillment
of the requirements for the degree
Master of Science in Engineering Technology

---

by
Jon D. Long
May 2010

Dr. W. Andrew Clark, Chair
Dr. Andrew Czuchry
Dr. Gerald L. DeVault
Dr. Hugh K. Rogers

Keywords: Nuclear, Safeguards, Safeguards Design Strategy, Systems Engineering

ABSTRACT

A Safeguards Design Strategy for Domestic Nuclear Materials Processing Facilities

by

Jon D. Long

The outdated and oversized nuclear manufacturing complex within the United States requires its transformation into a smaller, safe, and secure enterprise. Health and safety risks, environmental concerns, and the end of the Cold War have all contributed to this necessity. The events of September 11, 2001, emphasized the protection requirements for nuclear materials within the U.S. as well as abroad.

Current Nuclear Safeguards regulations contain minimal prescriptive requirements relating to the design of new production facilities. Project management and engineering design guides require that design documents contain specific and measureable statements relating to systems requirements. The systems engineering process evaluates alternatives for an effective and integrated solution during project design.

A Safeguards Design Strategy for domestic nuclear materials processing facilities based upon a core "framework" of safeguards regulatory programmatic elements that also use the prescriptive requirements and similar goals of safety, health, and physical security regulations is proposed and justifiable.

DEDICATION

To the entrepreneur, driven by an intense commitment to excel and win. Dissatisfied with mediocrity, opportunities for improvement are obvious in almost any given situation. Failure is but a mere tool used in the selection of appropriate alternatives. Negative individuals are an indicator that perseverance is required. In the face of adversity, you strive for integrity and the desire to do what is right, not what is easy. Belief in making a difference in the final outcome of your life and the lives of others is the driving force in the desire to succeed.

“Unless a variety of opinions are laid before us, we have no opportunity of selection, but are bound of necessity to adopt the particular view which may have been brought forward.”
- Herodotus, 5th century BC, Greek historian

“The world is a dangerous place to live - not because of the people who are evil but because of the people who don't do anything about it.”
- Albert Einstein

ACKNOWLEDGEMENTS

In appreciation to the numerous individuals that have provided personal, educational, and professional guidance, support, encouragement, and prayer.

CONTENTS

Page

Chapter

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Programmatic Responsibility for Material Protection

Protecting nuclear material assets at domestic, government owned facilities is the responsibility of the Safeguards and Security Program within the national government. Security program elements include such disciplines as Physical Protection, Information Security, and Personnel Security. Nuclear Safeguards is comprised of the Material Control and Accountability Program (MC&A), which is then broken down into subelement areas of concentrated responsibility and specialty.

The Physical Security program is a mature program and has received much attention over time. Implementation of extensive requirements, practices, and technologies has ensured the evolution of the program. The program takes a graded approach for the protection of the lowest level of government property or interests and sequentially scaled to the most critical requiring the highest protection levels or most resources.

The MC&A program historically focused upon the operational aspects of manufacturing and accounting of nuclear material as a subset of its production. A new need for controlling and segregating these materials by type and form was realized as the production quantities increased. Governance as a separate discipline became necessary to compile the policies and procedures for storage and inventory of the different forms and isotopes of material.

MC&A Programs are implemented to deter and detect theft and diversion of nuclear material by both outside and inside adversaries (U.S. Department of Energy, 2005). Nuclear Safeguards provides an oversight role and responsibility in assuring that material does not get into the hands of adversaries. If a facility has control of its material, adversaries have less chance of obtaining the material for illicit purposes. Therefore, the facility must ensure the material is in its proper location and in known quantities all the time.

CHAPTER 2

BACKGROUND INFORMATION

United States Nuclear Manufacturing Complex

From 1943 to 1989, The United States (U.S.) Department of Energy (DOE) built and operated a complex of manufacturing facilities comprised of over 120 million square feet at 17 major sites. During this time, the nuclear weapons complex (NWC) produced and processed tons of unique products and materials. Increasing concerns about health, safety, and the environment prompted the temporary cessation of operations at many DOE facilities in the late 1980s and early 1990s. With the ensuing collapse of the Soviet Union, the Cold War came to an end and these temporary operational suspensions became permanent. However, the old and inefficient facility legacy remained along with the responsibility of ownership of the material.

The permanent operational suspensions, along with the requirements of compliance with the technical and administrative terms of international arms control treaties required that the complex be scaled back. The events of September 11, 2001, emphasized the need to protect nuclear materials within the U.S. as well as abroad. Nonproliferation concerns and providing safeguards and security protection to nuclear materials were added to the list of issues.

The shifting mission requirements as well as the outdated and oversized NWC evolved into the need to transform the nuclear materials storage and production capabilities in the U.S. into a smaller, safe, and secure National Security Enterprise (NSE), eliminating the excess capacity and equipment. Environmental concerns, new missions, and programs that require the availability of nuclear materials highlighted the need to pursue integrated production requirements and efficiencies, reducing health and safety risks.

To ensure an adequate supply of material for national security missions such as nonproliferation and nuclear deterrence, nondefense programmatic use such as research and development, and the support of nuclear power generation, new production facilities are required. Facilities may include fabrication, purification, down-blending, enrichment, separation, or recycling. Managing nuclear materials requires highly sophisticated safeguards and security measures (U.S. Department of Energy, 2000).

Personal Perspective

My involvement in Nuclear Safeguards facility modernization efforts began with the assignment to a new processing facility Integrated Project Team (IPT) early in 2005. Conceptual design was on-going at the time. Responsibilities included the preparation of documentation related to the design requirements for safeguards methods and technologies.

In October 2005 I wrote and presented a paper entitled, *Material Control and Accountability in a Lean Manufacturing Environment*. This was presented at the Institute of Nuclear Materials Management, Central Chapter Conference in Oak Ridge, Tennessee. The paper emphasized the opportunity to apply systems engineering practices to new facilities when integrating nuclear safeguards, safety, security, and manufacturing systems. This paper provides the foundation for my thesis and is included in its entirety in Appendix A.

CHAPTER 3

PROBLEM STATEMENT

Deficient Regulatory Design Requirements

The outdated and oversized nuclear complex within the United States has required the transformation of the nuclear materials production capabilities into a smaller, safe, and secure enterprise. Health and safety risks, environmental concerns, and the end of the Cold War all contributed to the required transformation. New missions and programs ensuring an adequate supply of material for national security purposes along with nonproliferation and nuclear deterrence will be provided by new manufacturing facilities in the future. Managing nuclear materials requires safeguards and security measures to meet any threats posed by both the potential external or internal adversary.

Material Control and Accountability regulations contain minimal prescriptive requirements relating to design of domestic, government owned nuclear materials processing facilities. Project management design guides require that engineering documents contain specific and measureable statements relating to systems requirements. Technical MC&A regulatory design standards have neither been compiled sufficiently to be requirements or are nonexistent altogether.

Safeguards measures cannot be unlimited in scope or cost based upon whatever the disciplines' engineers want in a facility. Budgetary expenditures for design and construction are questioned if the regulations are lacking in defined and detailed requirements that engineers need to design the process systems. Therefore, what detailed requirements should design engineers follow to initiate preliminary design and subsequently follow-up with final design to be able to meet the operational intent of current regulations?

Safeguards Design Strategy

A Safeguards Design Strategy (SDS) for domestic nuclear materials processing facilities based upon a core “framework” of safeguards regulatory programmatic elements that uses the prescriptive requirements of safety, health, and physical security regulations is proposed and justifiable. Engineered, facility and operational performance enhancements will be relied upon to reduce administrative and production encumbrances and thereby reduce operating cost. An Information Technology Network (ITN) using new methodologies and technologies within the facility and processes will provide data as soon as available. This information will be uploaded in near real-time (NRT) from production processes to approved users ensuring that the material is in its proper location and in known quantities, all the time as required by integrated requirements.

Current Nuclear Safeguards regulatory requirements are that processing facilities cease operating, clean-up, and perform a complete inventory every 2 months to determine a facility material balance. This results in lost production time. Lost production time can be calculated and equated into potential square footage of floor space based on the production rate depending on the specific type of production facility.

The opportunity exists to integrate multiple regulatory requirements to prove facility and system integration. System performance criteria will be determined after testing and start-up of new facilities and process systems. Safeguards and Security (S&S) facility performance will be graded based upon fundamental principles of risk management criteria established by federal auditors. Regulations allow for facilities that have met the risk-based criteria to relax their inventory frequency. Currently, minimum inventory requirements in processing facilities allow for an annual inventory accompanied by the complete cessation of operations. It is the goal of this SDS to provide the foundation leading to an annual inventory in a new Category I/II processing facility.

Literature Review

Lean Manufacturing

Lean manufacturing is a general philosophy that has been derived mostly from the success that Toyota Motor Corporation has had in achieving success in deploying new products from conception to delivery to the consumer. The Toyota Production System, or TPS as it has become known, was only identified as being "Lean" in the 1990s. The philosophy now considered lean has been used over the years under other names by others in their search to reduce waste. In the modern manufacturing process Toyota focused on the elimination of seven wastes from the manufacturing process in order to improve overall customer value. TPS has grown significantly since 1948 as it responded to the problems it saw within its own production facilities (Liker, 2004).

Types of Waste

Toyota's view to expose, reduce, or eliminate problems was in the systematic identification of waste. The three types of waste are mura (unevenness), muda (non-value-adding work), and muri (overburden). Implementation and use of the tools were only temporary fixes to the problems in the Toyota Production System. While the elimination of waste may seem simple, waste is often very conservatively identified and often misunderstood.

Planning and implementation of waste reduction begins when *muri* focuses on the preparation and planning of the process, or a proactive design. The design can be a new product, process, or a new production facility of new processes to produce new products. Next, *mura* then focuses on how the actual work is implemented and the elimination of fluctuation at the scheduling or operations level. *Muda* is then discovered after the process is in place and is dealt with reactively.

The implementation of smooth flow, planning for smooth flow, or designing a process for smooth flow will exposes problems that already exist, and thus waste reduction naturally happens as a consequence. The advantage claimed by this approach is that it naturally takes a system-wide perspective, whereas a waste only focus views individual problems and, thus, may only shift problems elsewhere.

The original seven TPS *muda* wastes are:

1. Transportation (moving products that are not actually required to perform the processing).
2. Inventory (all components, work-in-process, and finished product not being processed).
3. Motion (people or equipment moving or walking more than is required to perform the processing).
4. Waiting or not maximizing capabilities (waiting for the next production step).
5. Overproduction (production ahead of demand or schedule).
6. Over Processing or Process Design (due to poor tool or product design creating excess activity).
7. Defects (effort involved in inspecting for and fixing defects).

Pull Production System

Lean Manufacturing is comprised of multiple aspects in which the focus is upon improving the efficiency based on optimizing flow or smoothness of the production process, thereby steadily eliminating *mura* or "unevenness" through the system. Techniques to improve flow include various methods to leveling production including among others "pull" production, which is also known as *kanban*. Depending on the type of pull production system implemented, lean can be known as Just-In-Time (JIT). Most new production facilities planned in today’s world are some combination of a lean facility.

Kanban Production Control System

Kanban refers to a Japanese sign shop that used a visual image on a sign to communicate the type of products that are sold. Typically, a kanban system uses visual aids to control the movement of materials between different work cells or locations. Toyota implemented a kanban based system for its transport and storage containers in its production centers. Kanban is basically a card that is attached to the containers to identify the part number and the container capacity as well as any other information necessary (Feld, 2001).

A pull production system is based on customer demand and schedule. Each manufacturing component is typically staged with the demand from adjacent (downstream) production cells in order to build a final part to the customer's specifications. The kanban system is called a pull system because kanban is used to pull parts from one production stage and move them to the next stage when needed. In a pull system the material movement only occurs when the work station needing more materials asks for it. Various types of kanban systems exist depending upon the nature of the product being manufactured.

Kanban methods originally used were visual aids to show that a process has been completed or the process requires more work. Many modern systems employing pull systems use Information Technology systems within the production process. Computer monitors can communicate information directly to specific operators in the production sequence. Downstream and upstream controllers communicate production information directly to specific locations within the production cell.

Research is currently being conducted in the semiconductor industry where multiple production cell configurations are used with the aim to reduce work-in-process and enhance the *kanban* pull communication signal.

Pull production systems are not available for all manufacturing operations because of product types, lead times, and stock holding arrangements; however, when such systems have been implemented, they have been shown to reduce lead times and the costs associated with production systems.

A tool in pull production is the buffer inventory, or work-in-progress, and it is used to create balance in the total production system. Buffer inventories are maintained and used in the local production process cell or unit. In-process inventory is staged locally within the process cells and used to reduce the cycle time of a production unit. The cycle time of a production unit is the amount of time it takes to manufacture a specified product by that production unit.

Lean and Agile implementation is focused on getting the right things to the right place, at the right time, in the right quantity to achieve the right process flow while minimizing wrong waste and being flexible and able to change to maintain a production process that provides a product that meets the customer's expectations (Parsaei & Sarkis, 1999).

Nuclear Facility Complexity and Modeling for Lean

With the complexity of a new nuclear materials processing facility containing multiple new processes, the modeling of the complete facility to optimize required adjacencies of the process rooms is paramount. Modeling of the most overall effective and lean arrangement for space, material moves, and cost effectiveness, as well as time savings in constructing requires a number of layouts to be considered using systems engineering tools (Liker & Morgan, 2006).

Constraints such as cost, size, internal environment, HVAC, piping, ductwork, security systems, quality, and safety policies all enter into the modeling effort. Integrated teams, collocated for the purpose of a project, optimize the strengths of all disciplines during these modeling efforts (Schilling, 2005).

The simulation modeling is an extreme time and cost saving tool. Extensive engineering change orders are avoided by the use of modeling tools as well as the cost and scheduling conflicts over the lifecycle of a project's phases. The conceptualization, definition, design, and construction of a new nuclear material processing facility can take 10 to 15 years. (Project Management Institute, 2008).

Lean Processes in Nuclear Manufacturing Facilities

Essential elements of a lean nuclear manufacturing process include:

- Manufacturing material flow - Manufacturing material flow is essentially planning, scheduling, and controlling the production sequence ensuring material gets where it is needed at the appropriate time with no excessive inventory build-up (buffer) between process steps.
- Functional operational involvement - Functional operational involvement is basically the active responsiveness of the production workers. The operators must be fully engaged in the production process to ensure that materials are fabricated, evaluated, measured, inventoried, and routed in accordance with production requirements. The production control database should "pull" material to the next process, via electronic signal.
- Process control - Process control is monitoring and control of the manufacturing equipment and measurement of material flow. This is often used in conjunction with "Process Monitoring", an anomaly resolution process for nuclear materials.

- Performance measures - Performance measures are those quality control and assurance results based assessments of the production sequence to ensure the accuracy of the production process and that material is not being wasted that must be accounted for.

CHAPTER 4

SOLUTION

Nuclear Safeguards focuses primarily on the internal threat and requires the use of an engineered and integrated systems approach to MC&A to prevent material from being intentionally or unintentionally diverted from within a process, process room, or Material Balance Area (MBA) during active operational hours when personnel are present and actively engaged in material processing. An MBA is a geographical area corresponding to a specific production process where the nuclear materials inventory can be controlled and known. A Material Access Area (MAA) surrounds all the MBAs and is different from the MBA. It forms an outer perimeter where materials are not allowed under normal circumstances and is protected by multiple means. An area encompassing all facilities' outside perimeters is defined as the Protected Area (PA).

Depending upon the facilities' particular manufacturing operations, multiple MBAs will be necessary. When materials are transferred to the next process for continued production operations, materials in known quantities are tracked by applicable means in specific timeframes to the next location. A primary principle and condition of integrated requirements is knowledge of the immediate location of an item of material, identified by its manufacturing process or specific item number. Certain disciplines have the need-to-know and are dependent upon having knowledge of the quantity and form of material at any given time. When items are transferred to another location, MBA, or within a production process, a foundation by which many design analyses can be based is formed. The reason for this is because of the affinities or natural relationships between certain disciplines and the design requirements that are necessary.

Nuclear Safeguards Philosophy

The protection philosophy of nuclear safeguards is at the local level, i.e., where processing occurs or where material is contained. Figure 1, Nuclear Safeguards Protection Containment Layers provides a graphical representation. The protection philosophy is based upon sequential layers of both defensive and offensive protection applied in a manner where the failure of a single feature in a layer does not compromise the protection of the material. The safeguards protection features within a single layer must be effective and integrated with other features in that layer to the degree necessary to ensure the protection required due to the importance of the material.

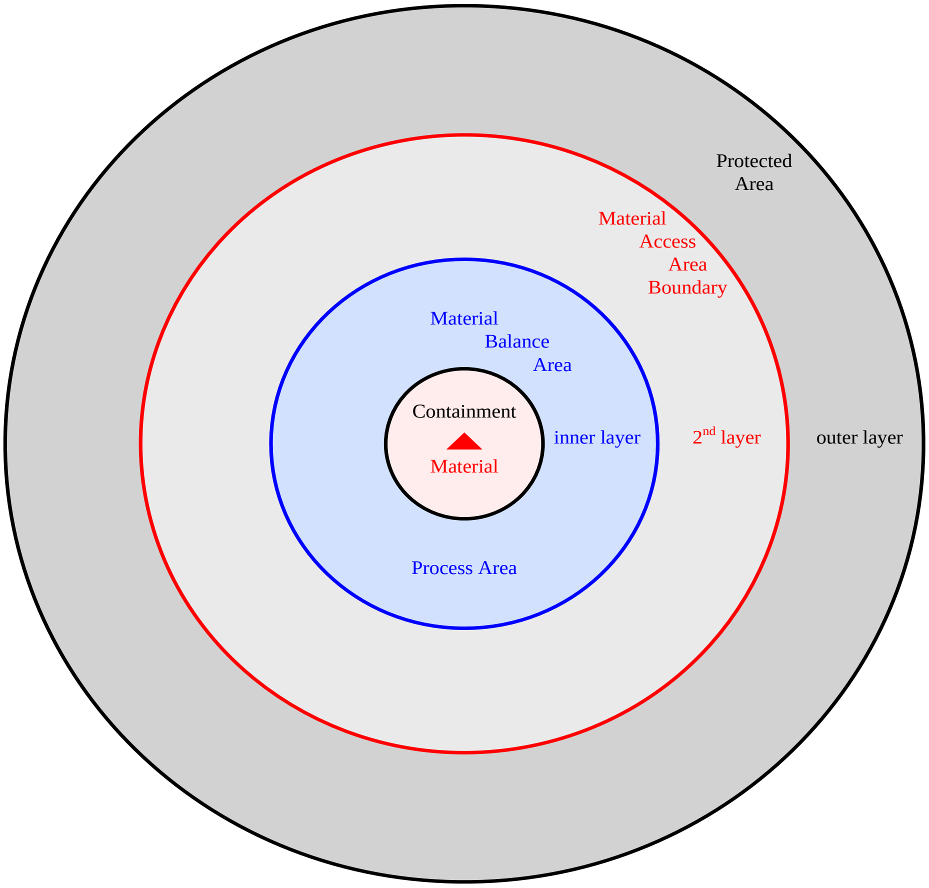


Figure 1. Nuclear Safeguards Protection Containment Layers

Core Safeguards Program Elements

To verify that the material is where it is supposed to be and in the quantities stated, the accounting function of MC&A is required by federal regulatory requirement to provide auditable records for a facility. Measurement systems are required to quantify the amount of materials present. This is an excellent example of defense in-depth and the overlap of the material control and accounting elements within the MBA element.

With engineered physical features in place within new facilities, an MBA maintains the control of the material as part of its integral processing operation. The MBA is also a subsidiary account in the accounting database as required by regulatory reporting requirements. This system of dual use requirements also serves as a check and balance system. This has proven to be an effective regulatory measure of Nuclear Safeguards for many years.

Physical features and engineered systems provide defensive controls and containment. Elements of a system such as material measurement and detection mechanisms as well as material accountability methodologies at the MBA and subunit level provide an offensive capability to deter or detect the loss of material. This methodology also provides an investigative capability to localize any losses inside and between MBAs during transfer operations were they to occur.

Given the various system requirements, design criteria, regulatory standards, and specifications, the opportunity exists to apply systems engineering practices to the design process in these new facilities and processes to fully integrate the MC&A systems required in a manufacturing environment. MC&A systems are not limited to new technologies but encompass new methodologies as well. Systems of the future must integrate technologies and methodologies along with safety, manufacturing, and security systems.

The Systems Engineering Management Process and the Systems Engineering Technical Process can model multiple alternatives to obtain the optimized decisions within the scope of large projects such as a nuclear materials processing and production facility.

Systems Engineering

Systems Engineering Goal

Systems Engineering (SE) is defined as a proven, disciplined approach that supports management in clearly defining the mission or problem, managing system functions and requirements as well as identifying and managing project risk. It establishes the bases for informed decision making and verifying that products or services meet customer needs. The goal of the SE process is to transform mission operational requirements into system architecture, performance parameters, and design details. Systems Engineering is interdisciplinary and holistic in that it focuses on the entire project in defining stakeholders' needs and the required functionality early in the conceptual design phase. It then proceeds with design synthesis and system validation, considering the system life-cycle (U.S. Department of Energy, 2008).

The systems engineering process is used:

- upon approval of mission need to analyze alternative concepts based on user requirements, risks, costs, and other constraints to arrive at a recommended alternative;
- in the Project Definition Phase to integrate requirements analysis' risk identification and analysis, acquisition strategies, and concept exploration to evolve a cost-effective, preferred solution to meet mission need;
- in the Execution Phase to balance requirements, cost schedule, and other factors to optimize the design, cost, and capabilities that satisfy the mission need;
- integration of the design and safety basis; and

- planning, implementation, and completion of a project.

Systems Engineering Process

The systems engineering process is a disciplined process that is applied throughout all stages of a project applied sequentially and iteratively to:

- transform customer needs into defined requirements;
- generate information for effective decisions; and
- provide input for the next level of integrated design development.

As illustrated in Figure 2, the iterative approach to the systems engineering process ensures a system design solution that satisfies customer requirements. The process allows for simultaneous solutions for process and facility or product and technology development. Multiple alternatives to a solution can be modeled for the unique solution set to meet all specifications, requirements, and constraints within project scope.

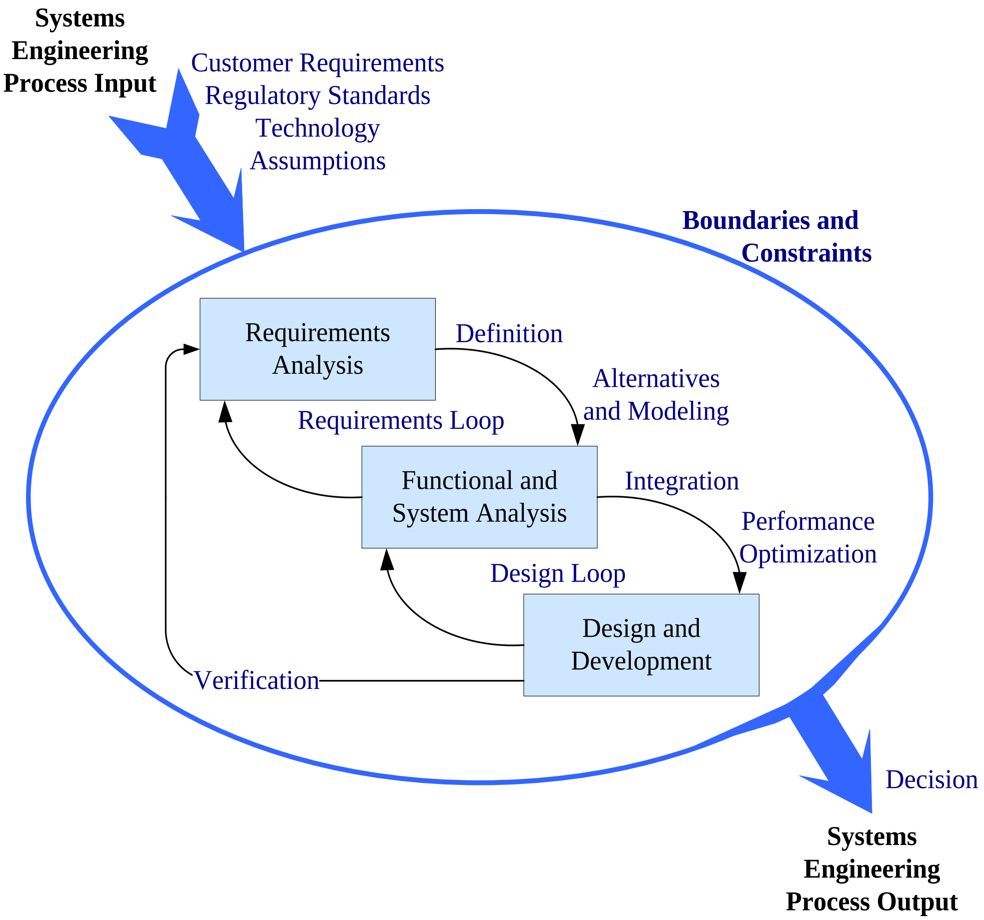
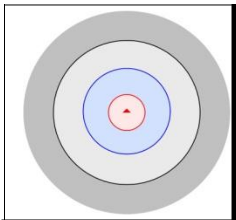


Figure 2. The Systems Engineering Process
(adapted from Systems Engineering Fundamentals, 2001)

Material Protection and Graded Safeguards

A domestic safeguards system can be designed so that it will provide varying degrees of physical protection, material control, and accountability to ensure the input data into the accounting database is corroborated. The different types, quantities, physical forms, and chemical or isotopic compositions produced and tracked by regulatory requirement as indicated in Table 1 – Graded Safeguards have been assigned an Attractiveness Level. The Attractiveness Levels are consistent with the potential consequence of malevolent acts associated with the convenience of access to the materials by potential adversaries.

Table 1. *Graded Safeguards*

	Attractiveness Level	Pu/U-233 Category (kg)				Contained U-235/Separated Np-237 Separated Am-241 and Am-243 Category (kg)				All E Materials Category IV
		I	**II**	**III**	**IV**[1]	**I**	**II**	**III**	**IV**[1]	
Weapons Assembled weapons and test device	**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 (≥ 25g/L) etc.; fuel elements and assemblies; alloys and mixtures; UF_4 or UF_6 (≥ 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); UF_4 or UF_6 (≥ 20% or < 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[2] (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 as required by DOE M 470.4-6 chg. 1

[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.

MC&A Structures, Systems, and Components

Engineered, facility, and operational performance enhancements are the most important in reducing administrative and production encumbrances and, thereby, reducing operating cost. It is imperative that cost-effective MC&A structures, systems, and components (SSCs) are used to determine the safe, secure, and effective means in meeting the design requirements for future facilities.

As was seen in Table 1, Graded Safeguards, Category I and II quantities of material require the most protection due to their applicability in weapons. Thus, the MBA where they are located within a facility requires the most comprehensive protective complement of SSCs. The features within the facility are integrated where necessary such that they provide a defensive barrier or offensive alarm response capability. The level of defense-in-depth required for a facility becomes clear as the design detail evolves and systems become more defined. The quantity of SSCs necessary to provide a corresponding reduction in risk to the material from potential adversaries decreases if design solutions and systems are integrated. This is shown graphically in Figure 3.

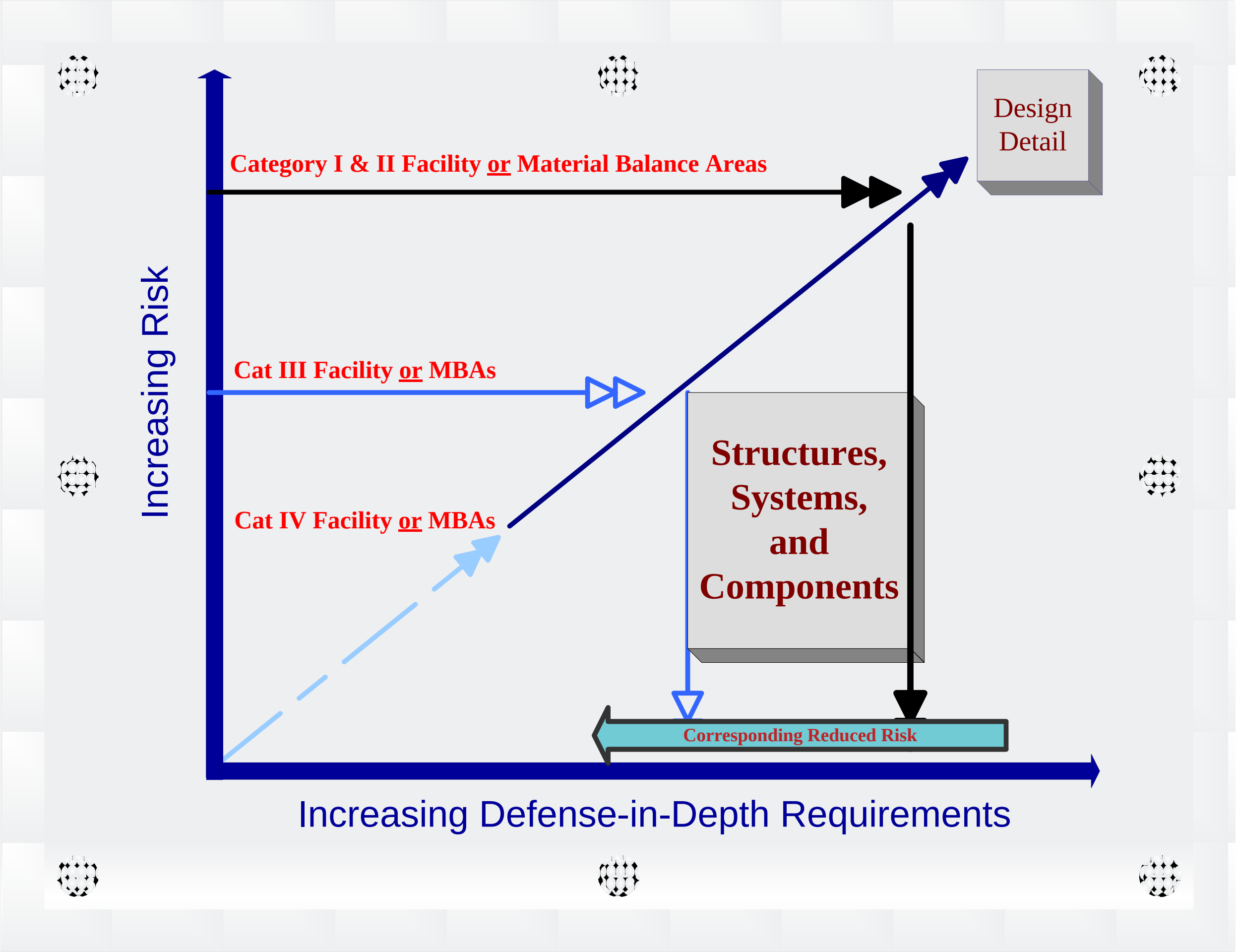


Figure 3. SSC Requirements for Graded Safeguards

MC&A SSC Selection Strategy

The selection strategy to address MC&A measures is based on the following order of preference at all stages of facility design and operation. Consideration must be given to the type of facility (storage or processing). Additional considerations include personnel interaction in facility operations, i.e., (do they provide one level of protective measures that are not administrative).

1. Minimization of impact to personnel safety is the first priority.
2. Structures, systems, and components (SSCs) are preferred over Administrative Controls.
3. Passive SSCs are preferred over active SSCs.
4. Active SSCs are complementary to passive SSCs (consider type of facility).

5. Preventative measures are preferred over mitigative measures (i.e., response).
6. Integrated facility safety SSCs are to be considered and can be complementary (i.e., Criticality Safety, Radiation Protection, and Accountability).
7. Controls closest to the source (MBA or subunit) may provide protection to the largest population of material.
8. Integrated protective mechanisms that are effective for multiple control measures (i.e., containment, surveillance, access) can be resource effective.

Interfacing MC&A measurement and material control SSCs provide significant leveraging opportunities where the multiple disciplines' requirements can be met. Use of such opportunities also provides significant cost avoidance in addition to the enhanced support for the integrated systems effectiveness.

System Design and Lean Process Material Flow

During the design process, application of "Lean Techniques" by the architects to a facility's layout and by the engineers to a facility's various process areas can provide an enhanced structured system of material control and accountability measures. Process control is also enhanced. Lean implementation is focused on getting the right things, to the right place, at the right time, in the right quantity to achieve the right process flow while minimizing wrong waste and being flexible and able to change.

Nuclear Safeguards, Physical Security, and the various safety disciplines often use similar terms and have common goals but different methods. The natural affinity between these disciplines is important, and the systems engineering process will ensure those common goals are achievable through the iterations of alternative selection and the design decision process.

Integration With Physical Security

The Physical Security program is a mature program and an organizational counterpart of Nuclear Safeguards. Implementation of extensive requirements, practices, and technologies have ensured the evolution of the physical and protective actions of the security discipline. The program takes a graded approach for the protection of the lowest level of government property or interests and layered to the most critical.

Nuclear material must be well protected but remain accessible to the level necessary for work activities to accomplish manufacturing operations. Figure 4 shows the protection layers and the general spatial relationship between the complementary disciplines of Nuclear Safeguards and Physical Security.

Nuclear Safeguards focuses primarily on the internal threat to the nuclear materials and uses an engineered and integrated systems approach to MC&A to prevent material from being intentionally or unintentionally diverted from within a process, process room, or Material Balance Area (and thus the facility). The focus of this threat is primarily during active operational hours when personnel are present and actively engaged in material processing and transfer activities.

Physical features and engineered systems provide defensive controls and containment. Material detection and measurement systems as well as material accountability methodologies at the MBA and Process Unit level also provide additional capabilities to deter or detect the loss of material. These systems will also localize any losses inside or between MBAs as well identify losses that were to occur during internal facility transfers.

These measures are designed for both normal and emergency conditions. The systems in place must be functional for both normal facility processing operations as well as during periods of anomalous conditions when activities are outside of the normal conditions of operations. The integrated systems maintain an overlap of capabilities or redundancy of sensor input points necessary for a complete risk-based assessed coverage for the appropriate level of protection required for the material. This combined and integrated network ensures no single point failure can compromise the system either during normal operations or anomalous conditions. Appropriate technologies are selected to capture data into the appropriate modules of the Information Technology Network (ITN) for information reporting and management.

Increased risk management protocols require the physical security model of early detection, denial, and delay of adversaries at greater distances for modern facilities from the traditional security boundaries. Integrated process technologies used for the state or condition and Nuclear Safeguards systems data can easily be used for the security posture of a facility. The Facility Information Management System easily becomes a tool for use by response teams as necessary. Using facility design features, enhanced command and control, communication, facility-based information, and technologies that are well interspersed within the facility, the efficiency and survivability of protective forces that are protecting the nuclear materials from threat in modern nuclear facilities is realized.

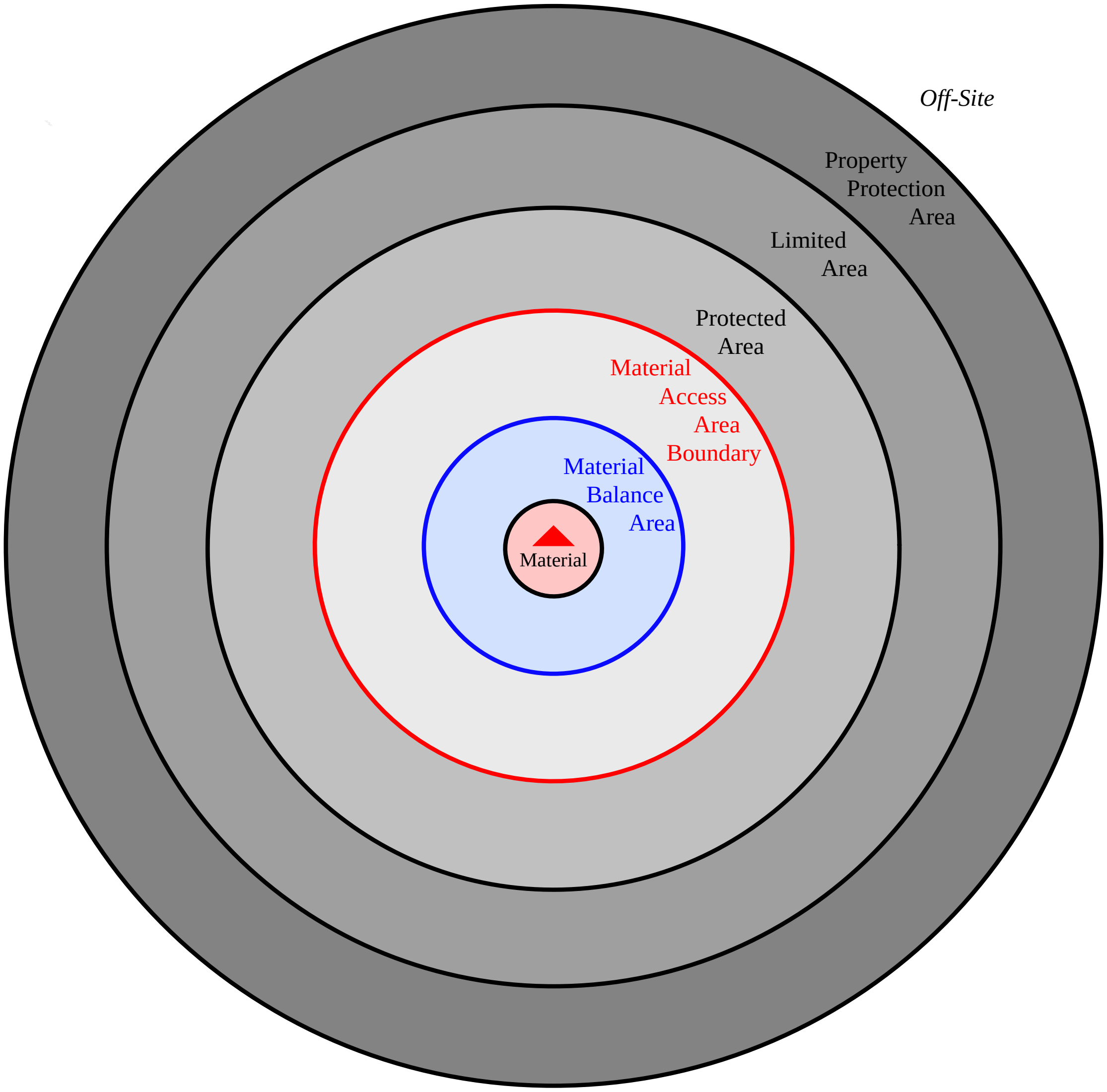


Figure 4. Nuclear Safeguards and Physical Security Spatial Relationship

Integration With Safety-In-Design

A Safety Design Strategy is required to guide the design and support the safety basis documents at each phase of the project. The safety design strategy provides the safety guidance policies, significant discipline interfaces from a safety perspective, and the safety goal considerations as well as the safety basis.

To provide the guidance necessary in formulating an overall safety strategy, A DOE Standard (U.S. Department of Energy, 2008) (the Standard) has been developed to show how project management, engineering design, and safety analyses can interact successfully to implement a successful overall strategy in implementing core components and an overall systems view. These interactions are a fundamental element necessary in the integration of safety.

The Standard describes the Safety-in-Design philosophies to be used with the project management requirements of multiple regulatory requirements (U.S. Department of Energy, 2005) as a key foundation for Safety-in-Design determinations.

The basic Safety-in-Design precepts are as follows:

- appropriate and reasonably conservative safety structures, systems, and components are selected early in project designs;
- project cost estimates include these structures, systems, and components; and
- project risks associated with safety structures, systems, and components selections are specified for informed risk decision-making by the Project Approval Authorities.
- The methods by which safety SSCs are designated (either safety class, safety significant, or defense-in-depth) during project phases must be documented and justified.

The provisions of the Standard when implemented in conjunction with other applicable requirements (U.S. Department of Energy, 2005) are consistent with the core functions and guiding principles of Integrated Safety Management (ISM) (U.S. Department of Energy, 2005).

The Standard provides guidance on a process of integration of Safety-in-Design intended to implement the applicable ISM core functions—define the work, analyze the hazards, establish the controls—necessary to provide protection of the public, workers, and the environment from harmful effects of radiation and other such toxic and hazardous aspects attendant to the work.

The Standard does not instruct designers how to design nor instruct safety personnel how to perform safety analyses. Rather, the Standard provides guidance on how the disciplines and project management can interface and work together to incorporate safety into the design process and design outputs.

Program Elements of Material Control and Accountability

MBA Access Controls

Access control mechanisms must ensure that unauthorized or unaccompanied personnel cannot enter the processing areas undetected when the MBA access door is unlocked, unprotected by alarm mechanisms, or accessible to approved process personnel for manufacturing operations. MBA personnel access and egress points shall be separate from nuclear material entrance and exit points (i.e., vestibules for material and equipment).

Material Balance Areas

With engineered physical features in place within new facilities, an MBA maintains the control of the material as part of its integral processing operation. The MBA is also a subsidiary account in the accounting database as required by regulatory reporting requirements. This system of dual use requirements also serves as a check and balance system. This has proven to be an effective regulatory measure of Nuclear Safeguards for many years. This is also an excellent example of the defense in depth concept.

The focus of nuclear safeguards is at the local level, i.e., where processing occurs. Therefore, material containment measures include the MAA, MBA, gloveboxes, and where necessary, other material enclosures. Transfer pathways into and out of the MBAs and gloveboxes are identified. Systems must be in place to detect and assess the unauthorized removal of nuclear materials consistent with graded safeguards and to localize removal from authorized locations.

Defense in depth measures work together in processing operations to:

- deter the removal of material by inside adversaries due to multiple observable and unobservable obstacles,
- alert personnel to unauthorized removal of material,
- quickly localize any removal if it does occur.

The measures are designed for both normal and emergency conditions. The systems put in place must be functional for both normal facility processing operations as well as during periods of anomalous conditions.

Material Transfers

Measurements and a system of records of measurements are required to reflect the flow of material between MBAs within a facility as well as other facilities on the same site. Transfer activities between MBAs must be controlled and monitored as part of an overall deterrence and theft detection methodology for the prevention of unauthorized nuclear material removals.

Nuclear materials being transferred may be part of the facility-specific approved controls if the following typical conditions are approved:

1. The item has been appropriately identified and characterized for the transfer and entered into the production control module of the ITN.
2. The item is in a protective transfer device such as a Rapid Transfer Port (RTP) authorized for the transfer of nuclear material removed from a glovebox.
3. The item was placed in the transfer device at an authorized loading location such as connected to the glovebox by personnel authorized to place nuclear material in the transfer device.
4. The item and transfer device was placed into the transfer cart or other approved means and entered into the production control module.
5. The transfer device is operated by personnel authorized to operate the device and to transfer nuclear material and has received chain-of-custody approval.
6. The transfer device is placed en route on an authorized route within the ITN production module between the loading point and the authorized destination.
7. The transfer device makes no unauthorized stops while en route, and the transfer time between source and destination does not exceed the maximum authorized transfer time as timed by the production control module.
8. The item is removed from the transfer device only at the authorized destination and by personnel authorized to remove nuclear material.

Chain-of-Custody Transfer Requirements

An MBA custodian of the receiving MBA cannot be the custodian of the shipping MBA. The facility control system [IT production control and the nuclear material inventory management module] must be designed to work in concert with personnel such that abnormal situations are flagged (e.g., inappropriate transfers of quantities, materials, unauthorized personnel performing transfers or inappropriate timing of moves). Custodial transfer shall occur at the MBA transfer control point or Key

Measurement point (KMP). A KMP is a location where nuclear material appears in such a form that it may be measured to determine material flow or inventory. Typically, it is a transfer such as an input or output and specifically identified items. Several types of KMPs are typically used such as MBA boundaries. Transfer locations may be KMPs such as in-process transfers, external in-coming shipments, or out-going shipments including waste containers. An exact mass determination is generally necessary accompanied by a gamma spectroscopic signature at KMPs.

Key Measurement Point (KMP) in the MBA Transfer of Nuclear Material

Measurements form the accounting basis for inventory and transfer operations, providing assurance that no nuclear material is missing. Measurements provide vital information on quantities (i.e., volume or weight), isotopic composition of uranium, concentration (i.e., grams uranium per gram of material or grams uranium per liter), and enrichment or weight percent of U-235 determination material in given locations. This information is essential to determining category levels and protection requirements within each MBA of the facility.

Inventory Data Updates

Accountability data are maintained by MBA and reflect quantities of nuclear material inventories. Therefore, transfers between MBAs must be accurately recorded, and as custody changes, the information is updated accordingly. The MBA account structure must sort data by material types, processes, and function. Facility nuclear material accounts consist of MBAs such that the location and quantity in each MBA is easily determined by the database when necessary. Therefore, accurate data recording is necessary to meet Near Real-Time (NRT) requirements.

Material Containment (In-Process Staging)

The nuclear material processed or staged for processing within each MBA is controlled in accordance with the graded safeguards concept. In-process staging is generally located within racks within the process room. During normal operations approved quantities of nuclear material not being actively processed are located within criticality and seismically safe in-process staging units or specifically approved areas in accordance with specific security plans.

Material Surveillance

Material surveillance methods assure that detection equipment or measures are in place to detect and deter a lone individual from diverting or removing material. These methods and measures (1) assure that material is in its location of record and (2) detect unauthorized activities. Each MBA uses material surveillance measures that have been designed for use within the facility. Surveillance and access control mechanisms must ensure that unauthorized or unaccompanied personnel cannot enter the processing areas undetected when the MBA access door is unlocked or open. MBA personnel access or egress points shall be separate from nuclear material entrance and exit points (i.e., vestibules for material and equipment).

All personnel with material surveillance responsibilities are required to have the appropriate clearance, included in the Human Reliability Program (HRP), and trained on the material surveillance procedures and knowledgeable of the area operations.

The surveillance program has been established to provide the capability of detecting unauthorized activities or anomalous conditions and reporting material status. The methods used to investigate, notify, and report anomalies may include maintaining process logs, inventory records, or other information where available. The surveillance program addresses normal and emergency conditions.

Material Surveillance Mechanisms

Employment of automated systems, visual surveillance or direct observation, and other alternative safeguards measures as material surveillance mechanisms are allowed by regulatory requirements. The automated means used for material surveillance include but are not limited to space alarms, door (balanced magnetic switch) alarms, MAA closed-circuit television (CCTV), key and combination controls, voice identification access, portal monitoring, shelf monitors, and process instruments that may show abnormal readings during unauthorized activities.

Surveillance and access control mechanisms must ensure that unauthorized or unaccompanied personnel cannot enter the processing areas undetected when an MBA access door is unlocked or open.

Detection and Assessment Systems: Tamper-Indicating Device (TID) Plan

TIDs are used to provide assurance that a container, door, or item is intact and containment integrity has not been violated. Typically, a two-member team is used for TID application, verification, and removal. The two-member team is responsible for verifying the contents of a container prior to initial TID application. TIDs are used to maintain chain-of-custody as well.

A TID Plan specific to any new facility will have to be approved. The opportunity exists to prove-in new technologies or methods of protecting those items and locations such that the arduous administrative requirements for their use are avoided. A system of SSCs may be provided that can alleviate some of these administrative controls.

Vestibules

The purpose of airlocks or vestibules is to aid in maintaining space pressure differentials within a confinement facility during personnel and material entry and egress to the facility and also assist in other areas such as HVAC, Radiation Protection, Security, Safeguards (MC&A), and Operations. Vestibules are a part of the building that creates a transitional space that can serve a number of functions. To ensure the proper functionality of the confinement ventilation system, vestibules (or air locks) are used to maintain the zone pressure differentials during personnel traffic and material transfer into the zone. Therefore, this location is a Key Measurement Point for material transfers.

Measurement and Measurement Control

Measurements play a key role in nuclear material safeguards because they form the basis for inventory and transfer operations, providing assurance that no nuclear material is missing. Measurements also provide vital information on quantities (i.e., volume or weight), isotopic composition of uranium, concentration (i.e., grams uranium per gram of material or grams uranium per liter), and enrichment or weight percent U-235 determination material in given locations. This information is essential to determining category levels and protection requirements within the MBA.

The measurement and measurement control program is the responsibility of multiple organizations. Safeguards (MC&A) is the lead organization and establishes the measurement and measurement control program and has responsibility for administering and communicating requirements to functional organizations performing accountability measurements and for monitoring measurement performance to ensure requirements are implemented.

MC&A statisticians are responsible for establishing criteria to be used to qualify measurement systems, for approving measurement systems for accountability use, and for approving the measurement control program. The MC&A Inventory Analysis statistical staff is responsible for overseeing the measurement control program and for quantifying estimates of the random and systematic error variances based on the measurement control data. The statisticians monitor trends and biases and, based on their impact on inventory “limits of error” (control limits) which determine the appropriate actions to minimize the control limits.

Destructive and nondestructive measurements of nuclear materials are performed by an analytical chemistry organization. The ACO is responsible for selecting measurement methods for analytical and nondestructive measurements in consultation with Safeguards (MC&A), qualifying measurement systems for accountability use, ensuring that measurement systems are calibrated by standards traceable to the national measurement system, and performing and reporting the results of measurement control activities. ACO and nondestructive analytical staff are also responsible for demonstrating acceptable measurement performance prior to making accountability measurements.

Production personnel are responsible for weight and volume measurements and the sampling of bulk materials to determine accountability values. The Metrology Organization calibrates scales, balances, and standards check weights for the measurement of nuclear materials. The activities are governed by accepted procedures for calibration and control of measurement and test equipment. Production personnel are responsible for demonstrating acceptable measurement performance prior to making accountability measurements.

Multiple organizations may be responsible for the nondestructive analysis (NDA) measurement of nuclear materials in processing equipment and ventilation systems. Some of the nuclear material is classified as holdup (nuclear materials remaining in equipment after cleaning) and some is classified as in-process. The measurement staff selects measurement methods in consultation with other staff experts, qualifies measurement systems for accountability use, and performs measurement control activities for accountability measurement systems.

Accounting

Material Control Validation

Essentially, the accounting function serves to ensure that the material control function of MC&A has been fully integrated. Accountability data are maintained by each MBA within the data module and reflects quantities of nuclear material inventory. The account structure must sort data by material types, processes, and function. Facility nuclear material accounts consist of MBAs such that the location and quantity in each MBA is easily determined by the database when necessary. Therefore, accurate data recording is necessary on a timely basis.

In-Process Measurement Systems (Process Monitoring)

Modern processing facilities require an extensive in-situ process measurement system for evaluating special nuclear material during processing. Typically, this practice has been known as Process Monitoring for quantifying the material. Process monitoring is typically designed to identify any activity outside normal process variations. The purpose of this active in-process measurement system will also enhance the inventory portion of the MC&A program. By establishing process units, or small mini-balance units, identifying processing anomalies for nuclear materials around a specific items or processes, variations in the process are more easily identified. Figure 5 shows a representative Process Unit.

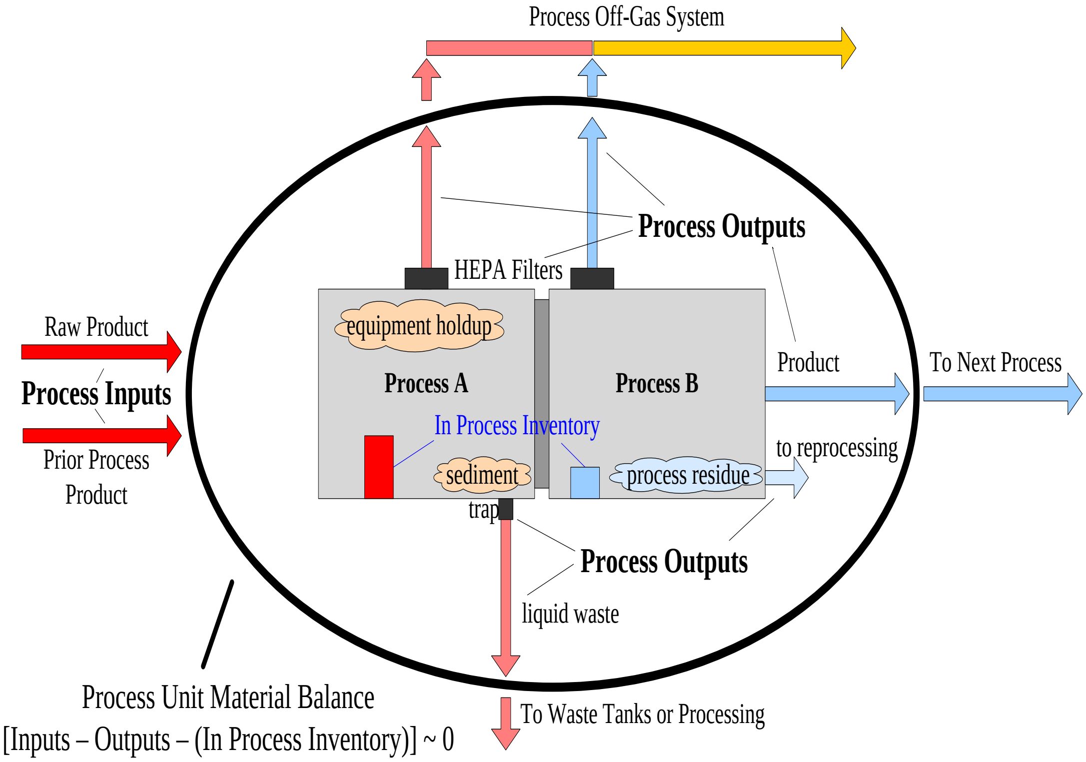


Figure 5. Graphical Representation of Process Unit

Division of MBAs into smaller units called process units helps to evaluate the overall process inventory where there are many different processes within an MBA. Providing in process measurements points to measure the material entering and leaving each manufacturing process determines the local material inventory and a “running inventory” for the facility when all process units are added up. These measurement points in the process are located where materials typically change form and can most easily be measured. This process is based upon the mass flow rate of the process systems. The flow rates are very dynamic, meaning that the throughput to a process may be as little as a few minutes, or could be as much as a week. Therefore, for modern processing facilities, a “dynamic inventory” accounting methodology is expected. However, the data input at the in process measurement point is captured in “near real-time” as the material is at a KMP as previously described.

A hypothetical MBA is depicted in Figure 6 where a manufacturing process is to be conducted. All materials enter and exit through the vestibule in the transfer cart. A gamma spectroscopic signature is obtained along with the Identification (ID) assigned to the RTP and item on the item on incoming and outgoing transfers. An item within a can that needs some type limited fabrication enters the hood in Process Unit A-1. It exits through Process Unit A-3 with the new weight recorded in the process control module along with the gamma spectrum and ID.

The same type component can be assembled to another part that is loaded into the glovebox from the other end of Process Unit A-1. The parts are radiographed prior to assembly of the components. A final weight is obtained after assembly. A gamma spectrum and ID are entered into the production control module. The assembly is then packaged with chain-of-custody procedures followed. The package is scanned at the Vestibule and transferred to somewhere else.

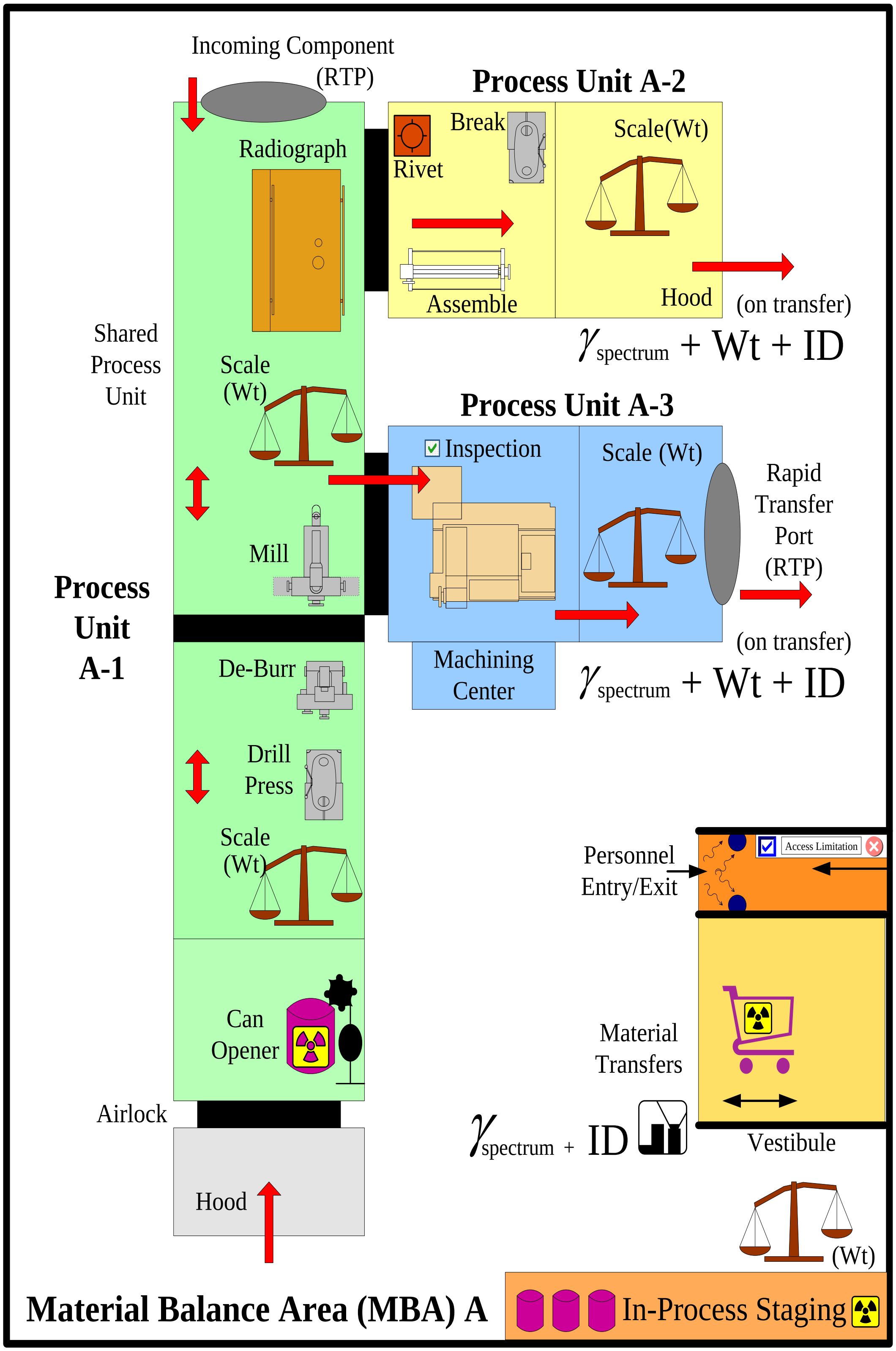


Figure 6. Hypothetical Material Balance Area with Glovebox Process Units

Each time a process removes a quantity of material, it is collected for recycling. It is also weighted separately each time material is removed. This is the concept behind process monitoring. Materials that are removed provide the checks and balances for the main production materials. Each step of the process requires the entry of the process step into the production control module before the sequence can continue.

A system that contains in-process measurements at each of the process steps to validate the material mass, form, isotopic composition or enrichment of the material undergoing processing, as well as the MBA boundary key measurement points in accordance with materials safeguards (MC&A) requirements is generally considered a near real-time (NRT) accountability system. Data logging must be maintained within an ITN.

Data uploading may be automatic due to the manufacturing process control system interface. Data may also be input by an operator after obtaining data by weighing material on a scale. Other information may be gamma spectrum data confirming the enrichment of the material. Scales or enrichment verification equipment within many processes are connected to the IT enterprise system and the operator simply presses the upload button to transmit the data. A material transfer and unspecified manufacturing process is represented in Figure 7 to show the various time delay elements associated with a manufacturing process.

The times (t) can vary significantly between processes. Depending on the specific process and the time necessary to handle material, the time to obtain quantifiable data may be as little as less than a second to more than a few minutes. Some processes require a lot of time to complete and data may not be available for more than a week in some cases.

Therefore, the time for the data to be input is dependent on each individual process. No specific time limit can be imposed because of the manufacturing time component that limits the input of the data. The data must be input as soon as available after the material has completed its processing step.

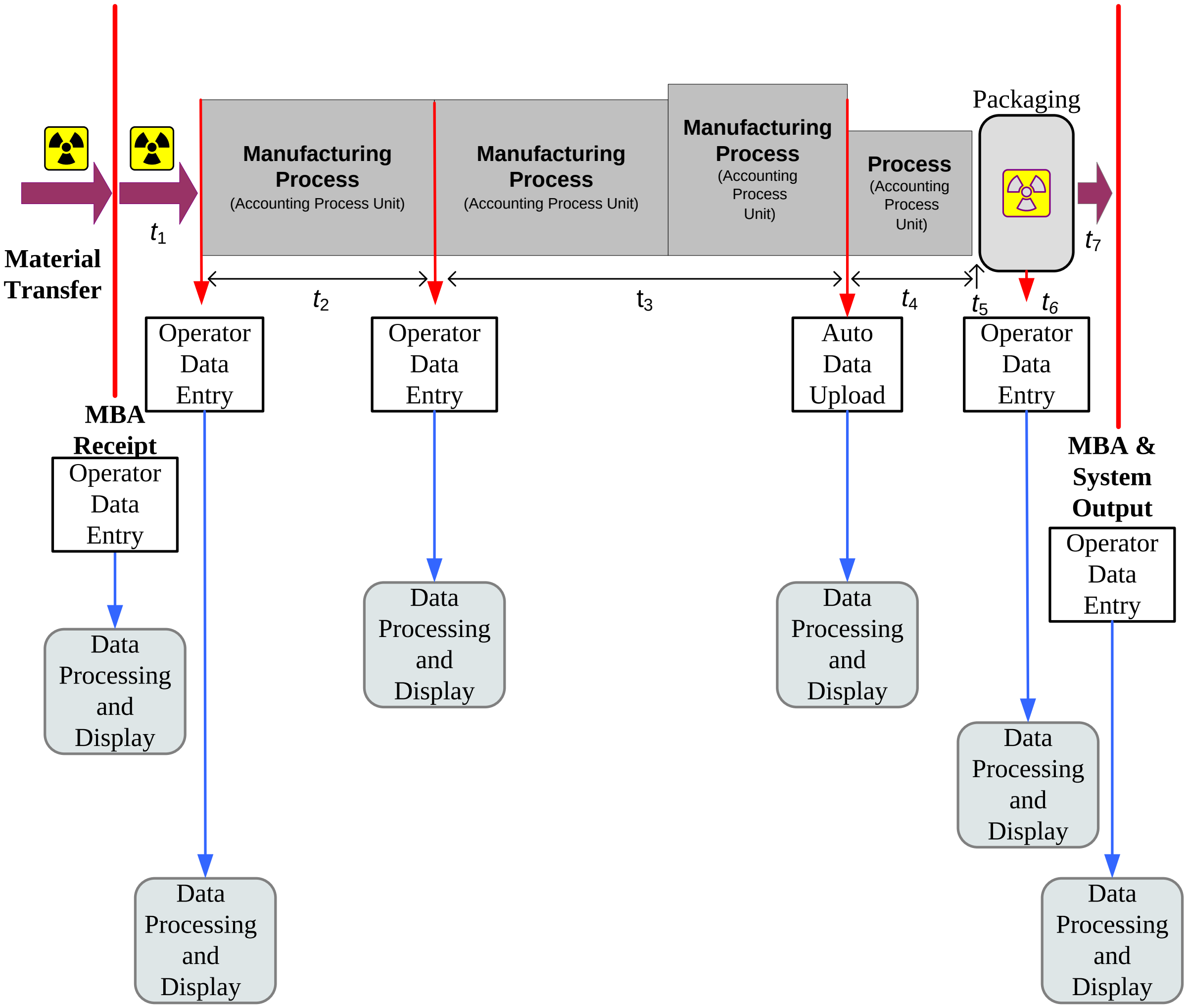


Figure 7. Time Delay Elements Associated with a Near Real-Time Accountability System (Materials Processing and Data Processing)

Information Technology Enterprise System

Near Real-Time Information Technology Enterprise System

A modern information technology enterprise system that implements a near real-time (NRT) system for the control and accountability of all materials used within a facility is required. This is especially true for nuclear materials. Near real-time reporting (NRTR) incorporates the delay elements of operational processes and events where quantitative data are obtained at KMPs by operations personnel and can have auto-upload capabilities and input into the information processing system. The information processing (internal) and data presentation as performed by the computer system are performed in real-time once the data have been manually uploaded by operations personnel or captured automatically through technological means. The data are then presented (output) in usable format for approved personnel for viewing and review.

A facility material enterprise system must be designed to work in concert with personnel such that abnormal situations are flagged (e.g., inappropriate transfers of quantities, materials, unauthorized personnel performing transfers, or inappropriate timing of moves). Thus, multiple types of measurements and their respective equipment types are required for the measurement and documentation for the transfer of materials between MBAs to meet regulatory requirements for an overall safeguards strategy in the protection of special nuclear materials. MBA boundaries provide one layer of Key Measurement Points (KMPs) in a defense in-depth safeguards strategy for the control of nuclear material within the facility.

The Information Technology (IT) Enterprise Control system is the overall backbone in a dynamic lean-pull production control system. Instead of listing the steps in job routings and expecting the operators to “push” the completed component to the next step of the manufacturing process in the production control system queue, the production control system will be able to recognize the state of overall manufacturing operations within the facility, including material in-process due to production requirements within material balance areas, individual glovebox production units, and process cells.

Establishing this in-process production relationship between all process cells is part of the pull production system. Dynamic communication with each production operating group in the adjacent manufacturing step is paramount in establishing a somewhat smooth flow in a process as complex and unique as any future domestic material processing facility. The product manufacturing control system will maintain an active communication link with the adjacent production process steps directly connected to it supply chain. The system will signal the input side of the production sequence that the process is waiting for product input. The overall production sequence will be monitored for overall process loading and throughput quantities.

Within the overall enterprise system, there are distinct and separate databases that will be used by multiple professional disciplines. Criticality Safety, Waste Operations, Industrial Hygiene, Radiological Protection, as well as Nuclear Material Control and Accountability are just a few of the organizations that will have individualized and protected information requirements. The IT production control system is the primary interface communication link where data are gathered from the production environment. Specific information required by individual disciplines is routed from the manufacturing interface to the necessary protected historical database to be used by that organization for its unique purpose.

Certain active databases are expected to collaborate within the production control system to implement limited shared data requirements that are complementary between various disciplines. An example of this is a criticality safety and material control location information system within glovebox production lines. See Figure 8, IT Enterprise System Architecture.

Process manufacturing units, where data are uploaded via scale or other device, are subject to material loading limits. The production control system receives the data into an active processing module as well as supplying the necessary information to additional modules as historical records. The local active module for the process cell and process units will be manipulated as part of the production control system.

Using input and output parameters of weights and other data from specific locations and product and container IDs queued from the production control system within an enclosed environment such as a glovebox line will actively provide a lower-cost, safe, and efficient limited information sharing material tracking database to enhance both criticality safety and material control needs. Container loading and material location within a production process will be provided to the production operators (and other approved personnel) within the active production control system without intruding on the respective disciplines’ historical database. A glovebox having its regulatory required safety, mechanical, operational, and various other sensors and alarm systems in addition to the production database material warning limits at the local level will inject another layer of defense in depth for material safeguards in a modern processing facility.

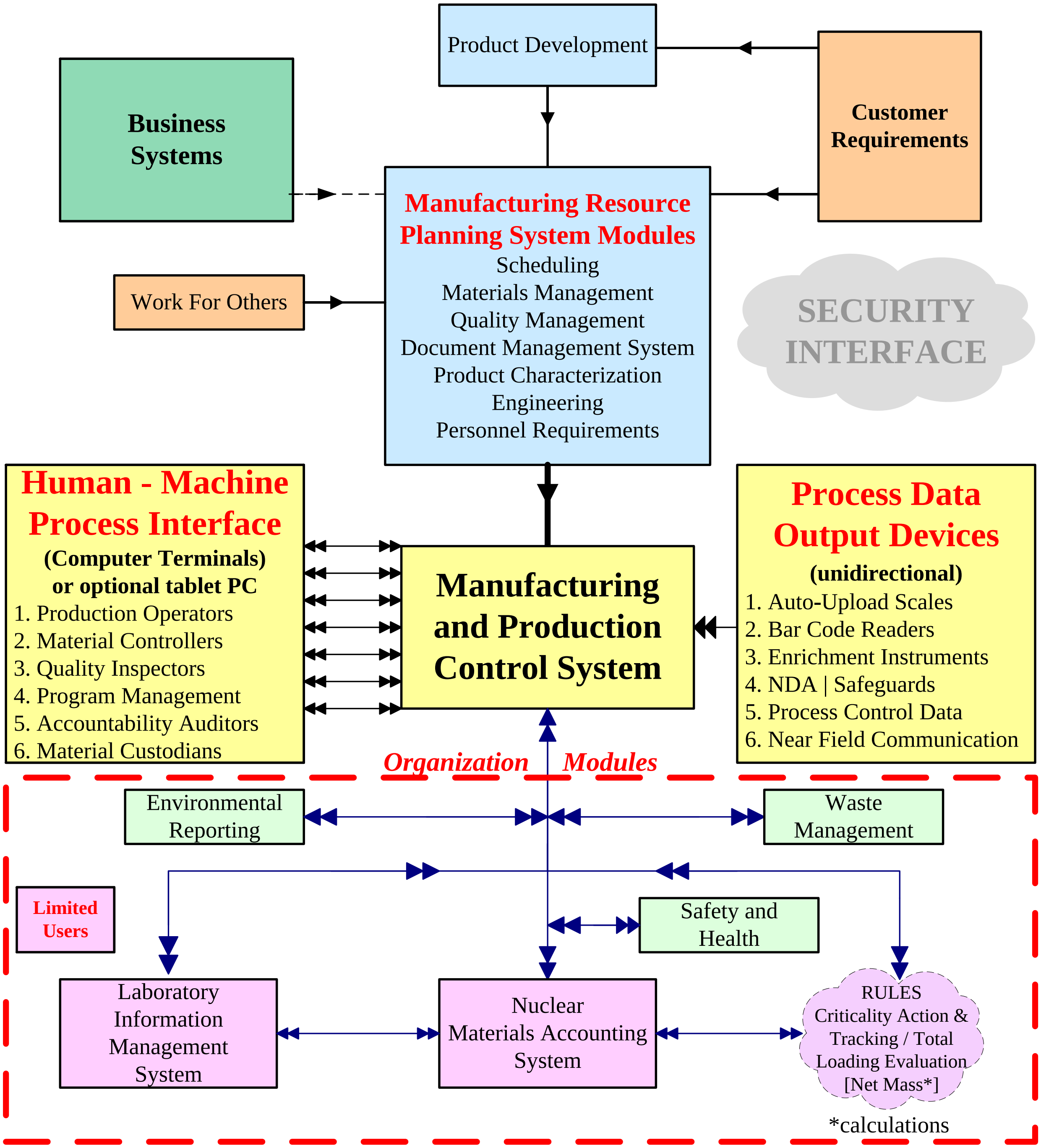


Figure 8. IT Enterprise System Architecture

CHAPTER 5

DISCUSSION

Geopolitical Perspective

As previously indicated, many nuclear facilities within the United States were shut down in the late 1980s and early 1990s. Since that time, multiple issues have initiated the revival of the nuclear industry. Included in the revival is the defense industry, nuclear power, and the supporting nuclear processing manufacturing facilities.

The desire for nuclear power as well as the political and military might associated with nuclear weapons is sought after by many countries. The concerns and challenges associated with the potential proliferation of technology used in the enrichment of nuclear materials used both for fuel in nuclear power plants and in nuclear weapons components pose many challenges for the International Atomic Energy Agency (IAEA).

The agency has the responsibility for assuring compliance with international treaties on the nonproliferation of nuclear weapons. Resources such as people, processes, and technology are needed to address these challenges. In September 2008 the Next Generation Safeguards Initiative (NGSI) was officially introduced by the Department of Energy, the primary supporter of the IAEA.

NGSI is a broad and comprehensive effort aimed at addressing many issues. However, an immediate programmatic goal is to institutionalize the concept of “Safeguards-by-Design” (SBD). SBD is an approach that has the goal to optimize safeguards implementation at nuclear facilities by designing safeguards requirements into new facilities at the earliest stage of conceptual design and following through into construction and operation.

Literature Review of Complementary Work

A project team of principal specialists was assembled by the DOE Program Manager to address SBD issues. A number of papers have been presented in both national and international forums on the SBD subject since the process began. It has evolved quickly due to the number of resources and degree of urgency. One paper (Bjornard et al., 2009) described by one of the principal authors as the best and most thorough on the subject is used for comparison purposes of my thesis.

The similarity of core requirements between my thesis and the SBD process is striking, even though the SBD process is focused primarily upon international facilities. Discussions surrounding the necessity to include MC&A, physical security and safety as well as integrating facility process controls in formulating and executing the overall SBD process are included. The SBD approach has adopted technical institutionalization processes of requirements definition, design processes, and technology and methodology and identifies them as part of it project and systems engineering processes. Again, these core concepts are in agreement with the structure of the Domestic Safeguards Design Strategy. High-level requirements specifying the use of project management tools and MC&A elements such as MBAs, KMPs, accounting, measurements, and process monitoring methodologies are listed. All the core components to a comprehensive design program are similar. All work was conducted independently.

CHAPTER 6

CONCLUSION

Modern, safe, and secure nuclear materials processing facilities will become a reality. And it can be done so in a cost effective manner. It requires a commitment to integrate safeguards, security, and safety requirements along with the willingness of all organizational entities to accept the program management integrated tools of doing business. Organizational turf battles must give way to the willingness to implement systems engineering evaluations and the benefits that can be gained from opportunities afforded by them.

An all-encompassing IT System Architecture, or ‘backbone”, providing all organizational operating conditions at the touch of a few fingers, provides the surety that the facility is operating as it was designed to do. Shared information from strategic locations within the facility and processes provide the interface from technology and personnel interface and key measurement points are the key element of an all-encompassing system.

It is this writer’s judgment that justification of the approach taken to an integrated safeguards design strategy based upon a core “framework” of safeguards regulatory programmatic elements that also use the prescriptive requirements of safety, health, and physical security regulations that have similar goals. Design of new facilities is proceeding forward based upon this criterion.

A safeguards authorization basis must be provided for new facilities. A new facility must receive approval from the DOE after undergoing a thorough assessment of the integrated facility safeguards and security design features, procedures, personnel qualifications, and operational requirements prior to the facility receiving nuclear materials. System performance criteria will be determined after testing and start-up of these new facilities and process systems. Safeguards and

Security (S&S) performance will be graded based upon fundamental principles of established risk management criteria.

Regulations allow for facilities that have met the risk-based criteria to relax their inventory frequency after having proven integrated operational, safeguards, and security capabilities after a period of time. Minimum requirements for a complete cessation of operations allow for an annual inventory in processing facilities once the criteria established for the systems by the auditors have been met.

It is the ultimate goal of this SDS to provide the guidance and foundation for an integration model leading to an annual inventory in Category I/II processing facilities. Final proof of this Safeguards Design Strategy will be in an approved authorization basis document and extended inventory frequency in a new facility.

REFERENCES

Bean, R., Hebditch, D., & Hockert, J. (2009). *Integrating safeguards and security with safety into design.* 19th Annual EFCOG Safety Analysis Workshop. Retrieved February 10, 2010 from http://www.inl.gov/technicalpublications/Documents/4235647.pdf

Bjornard, T., Bari, R., Hebditch, P., & Schanfein, M. (2009). *Improving the safeguardability of nuclear facilities*. Received via e-mail February 10, 2010 from T. Bjonard. Available at: http://www.inl.gov/technicalpublications/Documents/4310590.pdf

Bjornard, T., Bean, R., DeMuth, S., Durst, P., Ehinger, M., Golay, M., et al. (2009). *Safeguards-by-design: Early integration of physical protection and safeguardability into design of nuclear facilities*. Proceedings of Global 2009, Paris, France, September, 2009. Retrieved February 10, 2010 from http://www.inl.gov/technicalpublications/Documents/4384039.pdf

Bjornard, T., Bean, R., & Hebditch, D. (2009). *Safeguards-by-design: An element of 3S integration*. IAEA Symposium on Nuclear Safety. Retrieved February 10, 2010 from http://www.inl.gov/technicalpublications/Documents/4235645.pdf

Bjornard, T., Bean, R., Hebditch, D., DeMuth, S., Ehinger, M., Hockert, J., et al. (2008). Achieving the benefits of *safeguards-by-design.* Proceedings of the 49th Annual Conference of the Institute of Nuclear Materials Management, July, 2009, Nashville, TN. Retrieved February 10, 2010 from http://www.inl.gov/technicalpublications/Documents/4045030.pdf

Boyer, B., DeMuth, S., Dixon, E., Thomas, K., Tobin, S., & Wallace, R. (2008). *Increased proliferation resistance for 21st century nuclear power*. Retrieved February 10, 2010 from http://www.worldenergy.org/documents/p001308.pdf

Durst, P. (2008). *Advanced safeguards approaches for new reprocessing facilities*. Retrieved February 10, 2010 from http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2007/cn1073/Papers/2.2%20Ppr_%20Durst%20-%20Advanced%20Safeguards%20Approaches%20for%20New%20Reprocessing%20Facilities.pdf

Feld, W. (2001). Lean manufacturing – Tools, techniques, and how to use them. Boca Raton, FL: CRC Press.

Gauthier, J., Jorant, C., Massimo, M., & Stein, M. (2009). *Safety, security, and safeguards by design – An industrial approach*. Proceedings of Global 2009, Paris, France, September, 2009. Available at http://www.gen-4.org/GIF/About/ProceedingsofGIFSymposium.htm

Liker, J. (2004). The Toyota way. New York, NY: McGraw-Hill.

Liker, J, & Morgan, J. (2006). The Toyota product development system. New York, NY: Productivity Press.

Long, J. (2009). *MC&A system integration in processing facilities during conceptual and preliminary design*. Proceedings of the 50th Annual Conference of the Institute of Nuclear Materials Management, July, 2009, Tucson, AZ. Available at http://osti.gov./

Long, J. (2009). *Lean nuclear materials supply chain management for safeguards/MC&A enhancement in processing facilities design*. Proceedings of the 50th Annual Conference of the Institute of Nuclear Materials Management, July, 2009, Tucson, AZ. Available at http://osti.gov./

Long, J. (2005). *Material control and accountability in a lean manufacturing environment.* Proceedings of the Fall Meeting of the Institute of Nuclear Materials Management - Central Chapter, October, 2005, Oak Ridge, TN. Available at http://osti.gov./

Project Management Institute. (2008). A guide to the project management body of knowledge (PMBOK Guide). Newtown Square, PA: Project Management Institute, Inc.

Parsaei, H., & Sarkis, J. (1999). Advanced manufacturing systems – Strategic management and implementation. Amsterdam, The Netherlands: Gordon and Breach Science Publishers.

Scheinman, A. (2009). Calling for action - The next generation safeguards initiative. *NonProliferation Review*, 16, 257-267. Retrieved February 10, 2010 from http://pdfserve.informaworld.com/989371_731506231_912327996.pdf

Schilling, M. (2005). Strategic management of technological innovation. New York, NY: McGraw-Hill/Irwin.

U.S. Department of Defense. (2001, January). *Systems engineering fundamentals*. Fort Belvoir, VA: Defense Acquisition University Press. Available at http://spacese.spacegrant.org/SEModules/Reference%20Docs/DAU_SE_Fundamentals.pdf

U.S. Department of Energy. (2000, June 30). A strategic approach to integrating the long-term management of nuclear materials. The Department of Energy's integrated nuclear materials management plan, *A report to Congress*. Retrieved February 12, 2010 from http://www.pi.energy.gov/documents/inmm.pdf

U.S. Department of Energy. (2006, August 14). DOE Manual (M) 470.4-6, Change 1, *Nuclear material control and accountability*. Retrieved June 1, 2008 from http://www.directives.doe.gov

U.S. Department of Energy. (2008, September 23). DOE Guide (G) 413.3-1, *Managing design and construction using systems engineering for use with* DOE O 413.3A. Retrieved June 1, 2009 from http://www.directives.doe.gov

U.S. Department of Energy. (2008, March). DOE Standard (STD) 1189-2008, Integration of safety into the design process. Retrieved June 1, 2008 from http://www.hss.energy.gov/nuclearsafety/techstds/

U.S. Department of Energy. (2006, July 28). DOE Order (O) 413.3A, Change 1, *Program and project management for the acquisition of capital assets*. Retrieved June 1, 2008 from http://www.directives.doe.gov

U.S. Department of Energy. (2005, December 22). DOE Order (O) 420.1B, *Facility safety*. Retrieved June 1, 2008 from http://www.directives.doe.gov

U.S. Department of Energy. (2006, November 1). DOE Manual (M) 450.4-1, *Integrated safety management system manual*. Retrieved June 1, 2008 from http://www.directives.doe.gov

APPENDIX

Material Control and Accountability in a Lean Manufacturing Environment (U)

Jon Long

BWXT Y-12, Y-12 National Security Complex

Oak Ridge, Tennessee USA 37831

Abstract

Material Control and Accountability (MC&A) modernization efforts have previously been focused primarily on technological solutions to bring MC&A into compliance with current regulatory requirements with a desire to shorten inventory periods or even the relaxation of inventory requirements. Therefore, one has to question what future regulatory requirements may be and just how flexible MC&A technologies being developed and deployed will be to those undetermined requirements.

With facility modernization efforts on-going throughout the Department of Energy (DOE) complex, the opportunity exists to apply systems engineering practices to potential new facilities and processes to fully integrate the MC&A systems necessary in a lean manufacturing environment. MC&A systems are not limited to new technologies, but encompass new methodologies as well. MC&A systems of the future must integrate those technologies and methodologies with safety, manufacturing and security systems. The cost of deploying and integrating technologies must also be considered. This paper presents the concepts and system engineering approach necessary to deploy the most efficient, reliable and cost effective MC&A system possible.

Historic Background

Uranium processing facilities in their basic configuration were designed in the 1940s and 1950s. Design alterations to the processing equipment have been on-going since the equipment was initially designed and installed. The ultimate goal was the production of metal with insignificant regard for the byproduct streams other than eventual recovery. Past production requirements focused on the end product with secondary concerns paid to efficiency in material processing or control and accounting practices. MC&A principles as a part of overall nuclear materials management consists of control, accounting, statistical analysis, and measurement of nuclear materials with all distinctive components contributing equally to the overall function. The material control, inventory and accounting systems have in most recent times been driven by regulatory requirements requiring that processes be shut down bimonthly so that the inventory process could be completed. This is time consuming and expensive as well as impacting production requirements.

Lean Manufacturing

By adapting lean manufacturing techniques and methods, many companies are improving cycle times, reducing in-process inventories and machine set-up times, as well as reducing waste during processing. Lean manufacturing is aimed at elimination of waste at every stage of the production process, incorporating less human effort, less inventory, and less floor space while producing a final high quality product in the most economical manner possible. In its purest sense, lean manufacturing is production efficiency without waste.

The events of September 11, 2001 coupled with the significant production requirement curtailments over the past decade as well as federal budget constraints require nuclear materials manufacturing facilities to evaluate current manufacturing processes to uncover and implement efficiencies where appropriate as well as increased attention to the security of the material.

For nuclear materials processing, essential elements of a lean manufacturing process include:

- Manufacturing material flow
  Manufacturing material flow is essentially planning, scheduling and controlling the production sequence ensuring material gets where it is needed at the appropriate time with no excessive inventory build-up between process steps.

- Functional operational involvement
  Functional operational involvement is basically the active responsiveness of the production workers. That the operators are fully engaged into the production process to ensure that materials are fabricated, inventoried, evaluated, and routed in accordance with production requirements.

- Process control

Process control is monitoring, controlling and measuring manufacturing equipment and material flow.

- Performance measures
  Performance measures are those quality control and assurance results based assessments of the production sequence.

Process Equipment Design Characteristics

For new facilities under consideration, first and foremost is ensuring that the facility is designed appropriately for processing and handling nuclear materials. Nuclear material accumulates in cracks, pores, low points, and regions of poor circulation within process equipment. Examples of equipment where material accumulates are: pipes, tanks, ducts, furnaces and gloveboxes. Process equipment design and construction techniques must minimize features that allow for the accumulation of material inside the equipment.

The term “holdup” refers to the accumulation of nuclear material inside the processing equipment at nuclear facilities. The material that remains after system cleaning (e.g., acid leaching and rinsing) is typically referred to as fixed holdup and must be accounted for in the plant inventory system. The prevention of material accumulation is paramount to safeguard against theft or diversion, enhancing criticality safety and personnel radiation protection as well as minimizing the amount of time required for inventory measurement and accounting for material.

Manually measuring the quantity of material in process equipment is difficult, time-consuming, and expensive. It also impacts the health and safety of employees measuring the holdup. Measuring holdup is subject to many uncertainties. Determining holdup in processing equipment is required for inventory purposes. Process equipment design must allow for the application of sensor/measurement systems and provide spacing for personnel to physically access the mechanical systems to take measurements in support of a holdup survey program. Piping geometry should be designed to provide a simplified field of view for holdup measurements. Equipment should be designed to minimize residue, fines, turnings, chips, slag, salvage, slugs, etc. where possible. The equipment should be designed so that efficient cleaning and filtration can be accomplished on a continuous basis. Systems should be included that allow for collection of any excess materials as they are produced where possible. A facility designed with these requirements will enable process measurements to be conducted as safely and efficiently as possible.

Material Balance Areas and Process Units

Multiple Material Balance Areas (MBAs) are envisioned within modern processing facilities that correspond to process streams or compartments. Process units shall be established corresponding to specific processes, equipment and material type or stream that will aid in tracking and maintaining a running inventory. Process unit is a material control and accountability term used to define a local area within a MBA where a balance is determined. Process streams or process compartments may be further segregated into areas enhancing MC&A purposes.

Each MBA and process unit must:

- be formally documented;
- be identified by geological boundaries, process, operation, and function;
- describe the administrative controls for each MBA;
- define custodial responsibilities for SNM within each MBA;
- identify personnel authorized to handle, receive, or transfer SNM;
- identify the material flow into and out of the MBAs; and
- ensure that SNM transferred across MBA boundaries is based on measured values.

Process Monitoring

Commercial facilities must conform to 10 CFR 74.53, *Process Monitoring*, and 10 CFR 74.55, *Item Monitoring*. Process monitoring is a continuous practice that allows immediate discovery and recovery, if necessary, of nuclear materials during processing. Process monitoring used in this sense essentially utilizes functional elements of the lean manufacturing process: material flow, operational involvement, process controls, and performance measures. A process monitoring program can mitigate inventory differences resulting in a more efficient process flow. It can also reduce the amount of time spent accounting for materials in an inventory period.
To implement process monitoring techniques, each MBA should be subdivided into appropriate process units based upon material type, form, or method of process. As the material passes through each stage of the process, it is accounted for as input(s) and output(s) to verify MC&A requirements. Measurements must be made on the material leaving and entering process units and subsequently entered into the MC&A database. Normal processing gains and losses are expected and will be built into established control limits for each process unit. Cumulative losses will also be tracked for detection of any attempt at a protracted diversion of nuclear material. See figure 1 for a general example of process unit material balance determination.

Current DOE regulatory requirements do not require process monitoring, but does recognize that it exists. Current regulations also do not explicitly allow for the utilization of process monitoring techniques for a relaxation of inventory frequencies. Utilization of process monitoring techniques, aided by modern technology in the tracking and surveillance of material, hopefully, should allow for the eventual relaxation of physical inventory requirements once it is shown that a facility can provide a near real-time accounting of its material in process. Near real-time may essentially be maintaining a daily inventory balance of each process unit.

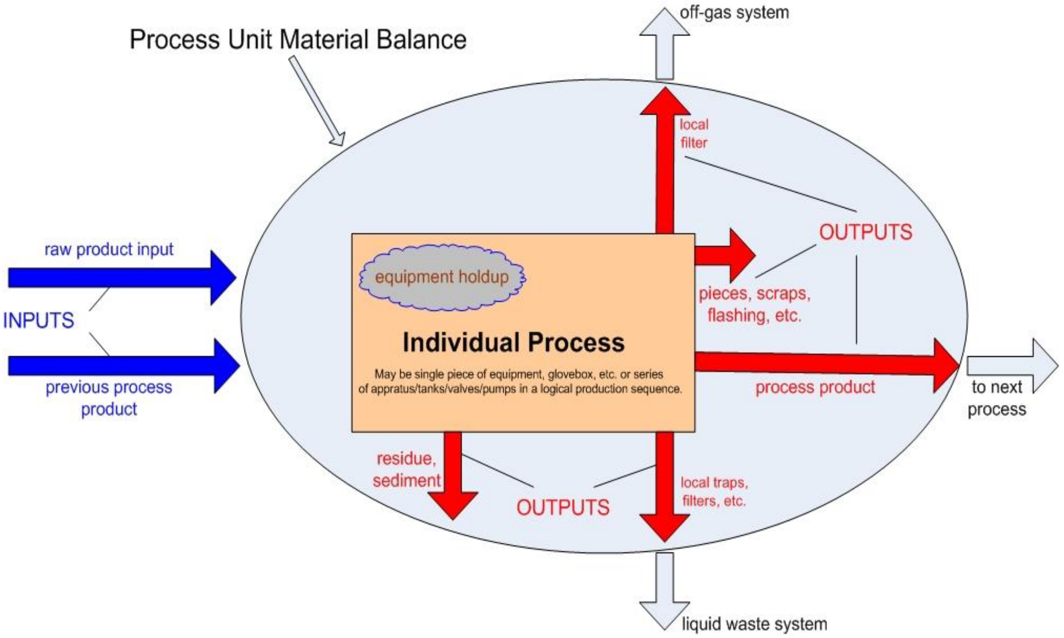


Figure 1. General Example of Process Unit Material Balance Determination

Inventory of SNM and Regulatory Flexibility

In accordance with regulatory requirements, a nuclear materials processing facility shall perform periodic and special physical inventories according to the strategic importance of the material and the consequences of its loss. Inventories must be based on measured values, including measurements or technically justifiable estimates of holdup.

Physical inventories are currently to be performed bimonthly in Category I and II material balance areas where processing occurs. At least annually, a simultaneous physical inventory must also be performed in all Category I and II MBAs for which the established inventory frequency is annual or more frequent.

Inventory frequencies are approved by the DOE/National Nuclear Security Administration (NNSA) field element manager. The desired goal to meeting inventory requirements in an effective, responsive and accurate inventory system in any modern facility would be near real-time. However, there has not been a completely integrated system identified or evaluated that will accommodate the various methods and configurations of materials, processing equipment, and containers planned for any modern processing facility. Cost considerations will have significant bearing when evaluating the individual components of a fully integrated system. The determination of an inventory frequency above the bimonthly minimum, subject to NNSA approval, will be dependent upon the inclusion of alternate inventory control methods and measures.

Examples of alternate measures include:

- continuous monitoring of physical or mechanical parameters,
  e.g., weight sensors, gamma spectroscopy, etc. ,
- continuous item observation and monitoring by video or imaging,
- laser/fiber optic systems, or
- other technologies.

In-process storage areas will house materials that are in the process of being packed, unpacked, or transferred into or out processing areas or into the next process stream. The materials may be either solid or liquid. Factors that will need to be considered in making inventory frequency determinations will include:

- material category and attractiveness levels,
- personnel radiation exposure,
- criticality safety measurements and systems
- the operational mode of the facility,
- credible protracted diversion scenarios, and
- technology utilization in the monitoring of material movement and location.

Measurement Systems

Material processing facilities will require in-process measurement systems that can generate data in near-real time on the shop floor to maintain an inventory at the local level as well as for the entire facility. Measurement systems and technologies will be required to:

(1) monitor discrete item transfers and determine the specific location between process areas and in-process storage as well as time within the approved transit pathways;
(2) collect weight information for material at specific locations on process manufacturing equipment. Measurement at each location may be a fixed or mobile weigh station with data capable of being uploaded directly to the MC&A accountability database as well as a material management system;
(3) estimate the amount of material utilizing techniques such as active neutron interrogation, passive gamma measurement or custom designed systems where weight determinations cannot be made;
(4) collect and quantify the amount of material in byproduct and waste streams at each process location;
(5) accurately determine the quantity of material transferred between each manufacturing process, including processes where changes occur in material form and to detect unauthorized material removal during transfer;
(6) accurately quantify material in-process as well as holdup; and
(7) monitor all exit pathways from the MAA. Exit pathways include doors, pipes, ducts, conduits, etc where material could be intentionally diverted, i.e., to detect unauthorized material flows.

Technology is a tool to accomplish the methodology of process monitoring in a lean manufacturing environment. It is not the all-purpose solution by which all accountability data can be collected. Technology must be used judiciously to enhance the production process as well as performing MC&A functions. Any development activities must be applications focused to solve specific needs.

Materials Surveillance

The graded nuclear materials surveillance program must be capable of detecting unauthorized activities or anomalous conditions and reporting material status. The surveillance program must address both normal and emergency conditions and provide for periodic testing. Testing for material surveillance must be performed and documented in accordance with regulatory requirements.

- Only appropriately authorized and knowledgeable personnel (i.e., individuals who are capable of detecting incorrect or unauthorized actions) must be assigned responsibility for surveillance of SNM. Technological development applications will be required to detect and provide response information for unauthorized actions.
- Controls must be sufficient to ensure that one individual cannot gain access to a secure storage area.
- Procedures to ensure constant surveillance of all persons in secure storage areas must be in effect anytime the storage area is not locked and protected by an active alarm system.
- Surveillance technologies must be sufficient to ensure that unauthorized or unaccompanied authorized personnel cannot enter the storage area undetected when the door in unlocked or open. Tracking and recognition technologies will need to be deployed to enhance surveillance technologies if determined to be cost effective.
- When two persons are assigned responsibility for maintaining direct control of item(s) outside an alarmed storage area within an MAA, two authorized Q-cleared Human Reliability Program (HRP) persons must be physically located where they have an unobstructed view of each other and/or the item(s) and can positively detect unauthorized actions or access to the material (e.g., two-person rule). The alternative is a system of applied technologies, engineered controls, and administrative controls sufficient to ensure no unauthorized accumulation of a Category I quantity without timely detection.

Inclusion of technological advancements into physically enhanced facilities should also allow for the relaxation of internal facility surveillance requirements in future regulations.

Information Technology and Materials Management

A nuclear materials accountability database will be one of many functional modules required for a complete materials and facility management information technology system in future facilities. Other modules where a MC&A system overlap and contribute actionable information include criticality safety and physical security. Modules will interface where appropriate to provide necessary information to manage modernized facilities. Any shop floor scheduling and production management system will be required to submit data as necessary to the accountability module for inventory and tracking purposes. Material transfers should be made by pre-electronic approvals and automated electronic confirmation after transfers are complete. Digital signatures and biometric identification technologies will become the norm. Wireless technologies will be deployed to provide automated data uploads where feasible. A complete information technology and materials management system will be the foundation upon which modernized facilities will operate efficiently.

Summary

Future processing facilities must employ methods and technologies that complement each other if a cost effective, responsive and accurate material control, surveillance, and accountability system is to be realized for the purposes of nuclear materials management. An automated database program will be essential to sustain a process control program in any modernized facility. An interactive shop floor materials control system is essential for active operator input/output of material measurements and automated sensor systems for just-in-time production in a lean manufacturing facility.

References

1. D. Reilly, N. Ensslin, H. Smith, Jr., and S. Kreiner, *Passive Nondestructive Assay of Nuclear Materials*, NUREG/CR-5550, LA-UR-90-732, March, 1991.
2. A. McCormack, R. Hayes, "Implementing Modern Process Monitoring Techniques At The Y-12 National Security Complex", Institute of Nuclear Materials Management Meeting, Orlando, Florida, July 18-22, 2004.

VITA

JON D. LONG

Education:	A.S. Nuclear Engineering Technology Chattanooga State Technical Community College June, 1981
	B.S. Engineering Science (Nuclear / Mechanical Systems Design Emphasis) University of Tennessee May, 1995
	M.S. Engineering Technology East Tennessee State University May, 2010
Professional Experience:	Nuclear Safeguards and Materials Security Lead Y-12 National Security Enterprise Uranium Processing Facility Project Oak Ridge, TN 2004 - Present
	Program Engineer - Nuclear Material Packaging Program Y-12 National Security Enterprise Oak Ridge, TN 1997 - 2004
	Emergency Management Coordinator K-25 Site Oak Ridge, TN 1991 - 1997
	Health Physics and Safety Surveys Technician Oak Ridge National Laboratory Oak Ridge, TN 1983 - 1991

Publication List:

Long, Jon D. (2009). *MC&A System Integration in Processing Facilities During Conceptual and Preliminary Design.* Proceedings of the 50th Annual Conference of the Institute of Nuclear Materials Management, July, 2009, Tucson, AZ.

Long, Jon D. (2009). *Lean Nuclear Materials Supply Chain Management for Safeguards/MC&A Enhancement in Processing Facilities Design.* Proceedings of the 50th Annual Conference of the Institute of Nuclear Materials Management, July, 2009, Tucson, AZ.

Geist, William H., Tobin, Steve J., and Long, Jon D. (2008). *A Monte Carlo Evaluation of the Performance of Non-destructive Assay Systems for Quantitative Measurements of Enriched Uranium Metal Turnings*. Proceedings of the 49th Annual Conference of the Institute of Nuclear Materials Management, July, 2008, Nashville, TN.

Tobin, Steve J., Geist, William H., and Long, Jon D. (2008). *Monte Carlo Modeling Evaluation to Determine the Most Accurate Measurement System for Quantifying the Enriched Uranium Mass of Machine Turnings Collected Within a Small Can*. Proceedings of the 8th International Conference on Facility Operations – Safeguards Interface, April, 2008, Portland, OR.

Long, Jon D. (2005). *Material Control and Accountability in a Lean Manufacturing Environment.* Proceedings of the Fall Meeting of the Institute of Nuclear Materials Management - Central Chapter, October, 2005, Oak Ridge, TN.

Long, Jon D. (2005). *Assessment of Pulse Reactor Fuel for Packaging and Accountability.* Proceedings of the 46th Annual Conference of the Institute of Nuclear Materials Management, July, 2005, Phoenix, AZ.