LA-UR-10-06569

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Title: Safeguards Design Strategies: Designing and Constructing New Uranium and Plutonium Processing Facilities in the United States

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Intended for: IAEA Symposium on International Safeguards
Preparing for Future Challenges
November 1-5, 2010
Vienna, Austria

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Safeguards Design Strategies: Designing and Constructing New Uranium and Plutonium Processing Facilities in the United States

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Abstract. In the United States, the Department of Energy (DOE) is transforming its outdated and oversized complex of aging nuclear material facilities into a smaller, safer, and more secure National Security Enterprise (NSE). Environmental concerns, worker health and safety risks, material security, reducing the role of nuclear weapons in our national security strategy while maintaining the capability for an effective nuclear deterrence by the United States, are influencing this transformation. As part of the nation's Uranium Center of Excellence (UCE), the Uranium Processing Facility (UPF) at the Y-12 National Security Complex in Oak Ridge, Tennessee, will advance the U.S.'s capability to meet all concerns when processing uranium and is located adjacent to the Highly Enriched Uranium Materials Facility (HEUMF), designed for consolidated storage of enriched uranium. The HEUMF became operational in March 2010, and the UPF is currently entering its final design phase. The designs of both facilities are for meeting anticipated security challenges for the 21st century. For plutonium research, development, and manufacturing, the Chemistry and Metallurgy Research Replacement (CMRR) building at the Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico is now under construction. The first phase of the CMRR Project is the design and construction of a Radiological Laboratory/Utility/Office Building. The second phase consists of the design and construction of the Nuclear Facility (NF). The National Nuclear Security Administration (NNSA) selected these two sites as part of the national plan to consolidate nuclear materials, provide for nuclear deterrence, and nonproliferation mission requirements. This work examines these two projects' independent approaches to design requirements, and objectives for safeguards, security, and safety (3S) systems as well as the subsequent construction of these modern processing facilities. Emphasis is on the use of Safeguards-by-Design (SBD), incorporating Systems Engineering (SE) principles for these two projects.

1. Introduction

The United States' Department of Energy (DOE) is transforming its aging nuclear material facilities into a smaller, safer, and more secure National Security Enterprise (NSE) [1]. Environmental concerns, worker health and safety risks, and material security are significant reasons for this transformation. Additionally, reducing the role of nuclear weapons in a national security strategy while maintaining the capability for an effective nuclear deterrence by the United States, are influencing facility capabilities as well. Furthermore, there is an international need in "promoting the peaceful use of nuclear energy, strengthening non-proliferation and international safeguards, advancing disarmament, and keeping nuclear material out of the hands of terrorists" [2].

DOE's Y-12 National Security Complex's Uranium Processing Facility (UPF) and Los Alamos National Laboratory's Chemistry and Nuclear Facility (NF) are part of the transformation of the old nuclear complex into a new modern complex viable well into the 21st century.

2. Designing in Safeguards, Security, and Safety

2.1 Nuclear Safeguards Philosophy

The material 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 basis for the protection philosophy is sequential layers, both defensive and offensive protection. Additionally, failure of a single feature in a layer does not allow the compromise of 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 nuclear material.

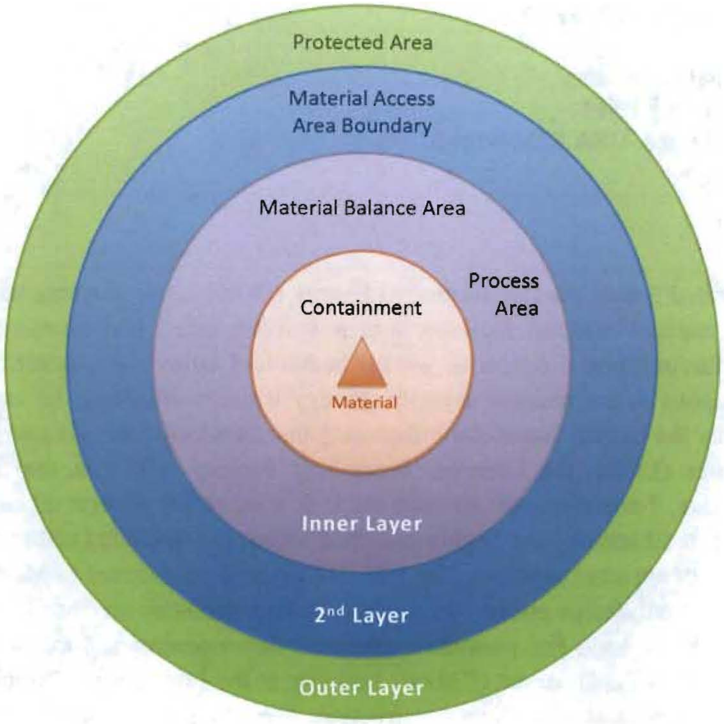

Figure 1. Nuclear Safeguards Protection Containment Layers

2.2 Systems Engineering Process in Design

The Systems Engineering (SE) Management Process and the Systems Engineering Technical Process can model multiple alternatives to obtain an optimized decision within the scope of large multi-discipline projects, such as nuclear materials processing or a nuclear production facility [3]. 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 SE process allows for simultaneous solutions for process and facility or product and technology development. Modelling multiple alternatives to a solution supports selecting the unique solution set to meet all specifications, requirements, and constraints within the project scope. 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 Material, Control & Accounting (MC&A) systems required in a manufacturing environment. Engineering an MC&A system is not limited to new technologies, but encompasses new methodologies as well.

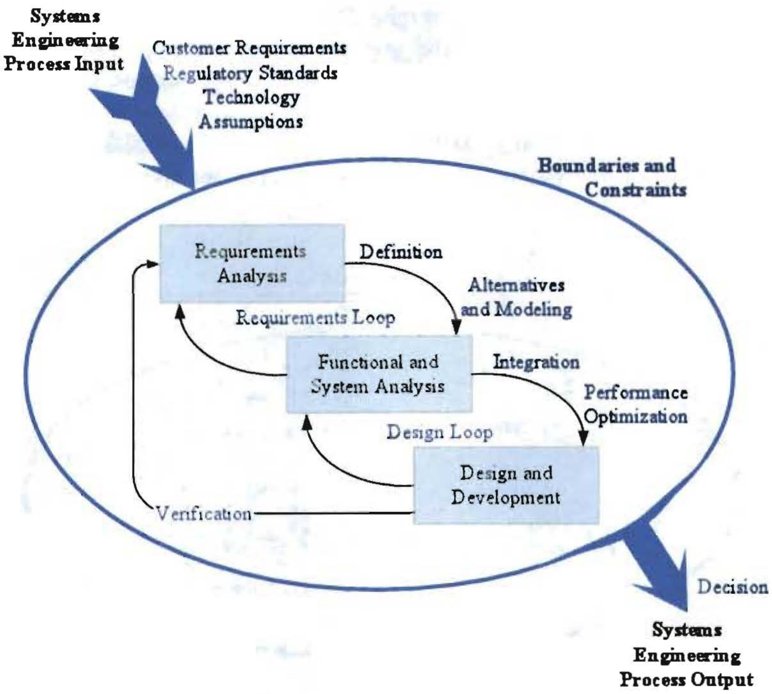

Figure 2. The Systems Engineering Process is sequential and iterative.

2.3 Modelling Provides Decision Support throughout the Facility Life-Cycle

Design and process simulation models and databases support manufacturing and integrated planning for design of new nuclear facilities. A primary purpose of the modelling is to assure that new nuclear facilities meet or exceed production requirements while reflecting stringent requirements for safety, security, flexibility, and efficiency. Modelling and updating design documentation occurs continuously throughout the lifecycle of the facility and into decommissioning [4]. Figure 3 describes the life cycle of a nuclear facility, and some requirements at each level.

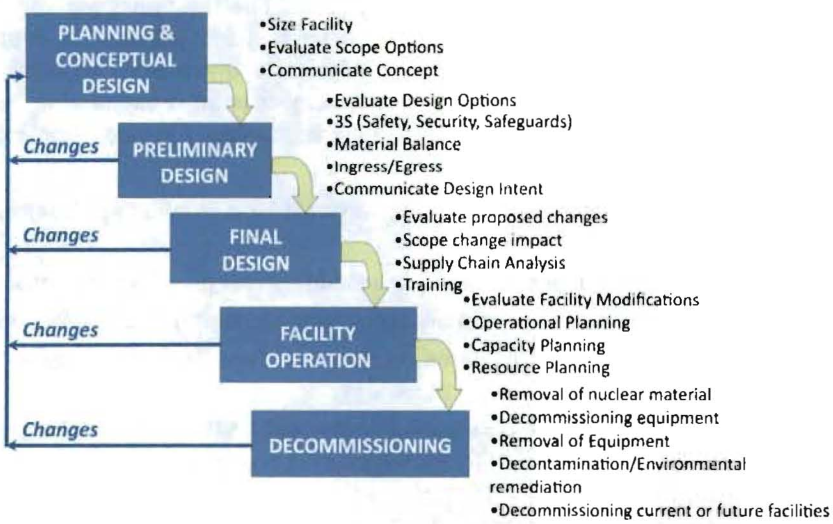

Figure 3. Modeling provides decision support throughout the life-cycle of the facility.

2.4 In-Process Measurement Systems (Advanced Process Monitoring)

Modern processing facilities require an extensive in-situ process measurement system for quantifying special nuclear material during processing, known as Process Monitoring [5]. Process monitoring can identify any activity outside normal process variations in old facilities where processes and materials are easily accessible. With the extensive requirement to use gloveboxes for safety purposes and material control, material is confined to the process. The purpose of active in-process measurement systems will enhance the inventory portion of the MC&A program. The nuclear material measurements are a basis for material control and accounting (MC&A), but also support processing requirements and Criticality Safety as well. Establishing material balance areas (MBAs) and sub MBAs, around specific items or processes, further supports and maintains nuclear materials accountability throughout operation processes. Also, process monitoring easily identifies when variations in the process are outside of acceptable. Monitoring waste lines and off-gas lines, supports material balance closures for the plant. Figure 4 is a graphical representation of a process unit.

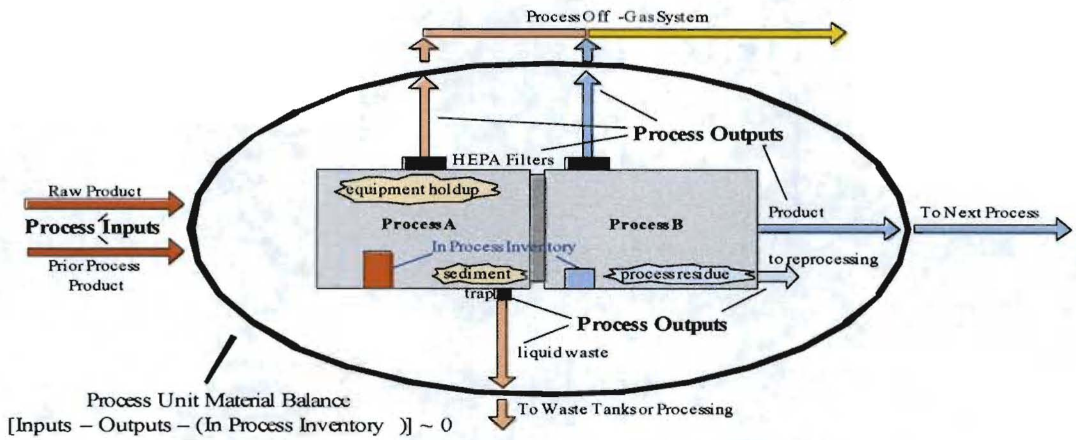

Figure 4. Graphical Representation of a Process Unit

2.5 Near Real-Time Accountability (e.g., Dynamic Inventory System)

Modern nuclear facilities will need to have near real-time nuclear material accountability [5]. Utilization of process units within MBAs at in-process measurement locations or key measurement points (KMP) where materials typically change form during processing, including gaining or losing mass due to the chemical or physical nature of the process. Measurement data collected at one KMP is input to another process. This forms the foundation for the subdivision of MBAs into smaller accounting units that provide a "running inventory" based upon the mass flow rate of process systems. The flow rates are very dynamic, meaning that the throughput in an individual 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". See Figure 5 for a graphical representation of a near-real time accountancy system. Some of the benefits of a Dynamic Inventory Accounting system are as follows:

- Extensive in-situ process measurement system for evaluating nuclear material during processing,
- Process monitoring can identify activities outside normal process variations,
- Integration of Criticality Safety and the accounting element of the MC&A program,
- Provides a "running inventory" based on the mass flow rate of process systems: an active or "dynamic inventory" accounting methodology,
- Data input at the *in-process measurement points* and KMPs; data is "near real-time" because of various delay elements produced by manufacturing processes,
- Accounting System Module of the Information Technology Enterprise System updates the data as it uploads, and
- Material Management System presents inventory data in "real-time" (a reference point in time).

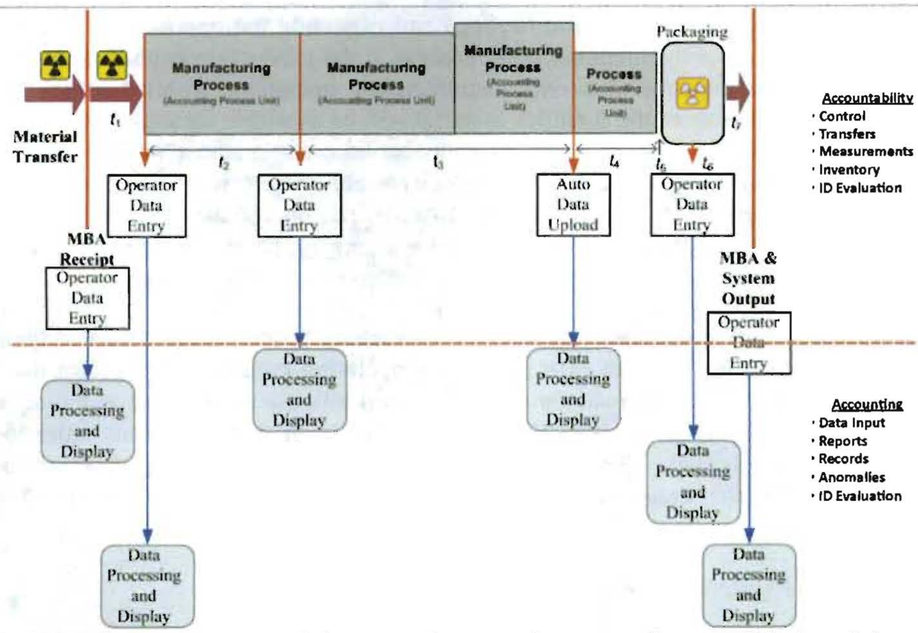

Figure 5. Near real-time accountability, e.g., Dynamic Inventory System, with time delay elements.

2.6 Information Technology Enterprise System for Facility Control

The information technology network (ITN) Material Management System is the overall backbone in a dynamic lean-pull processing facility. Within the overall enterprise system, there are distinct and separate data modules utilized by multiple professional disciplines. Criticality Safety, Waste Operations, Industrial Hygiene, Radiological Protection, as well as Nuclear Safeguards are just a few of the organizations that have individualized and protected information requirements. The Manufacturing Execution System (MES) is the interface communication link that gathers data from the production environment. The MES routes specific information required by individual disciplines to the necessary module utilized by that organization; see Figure 6.

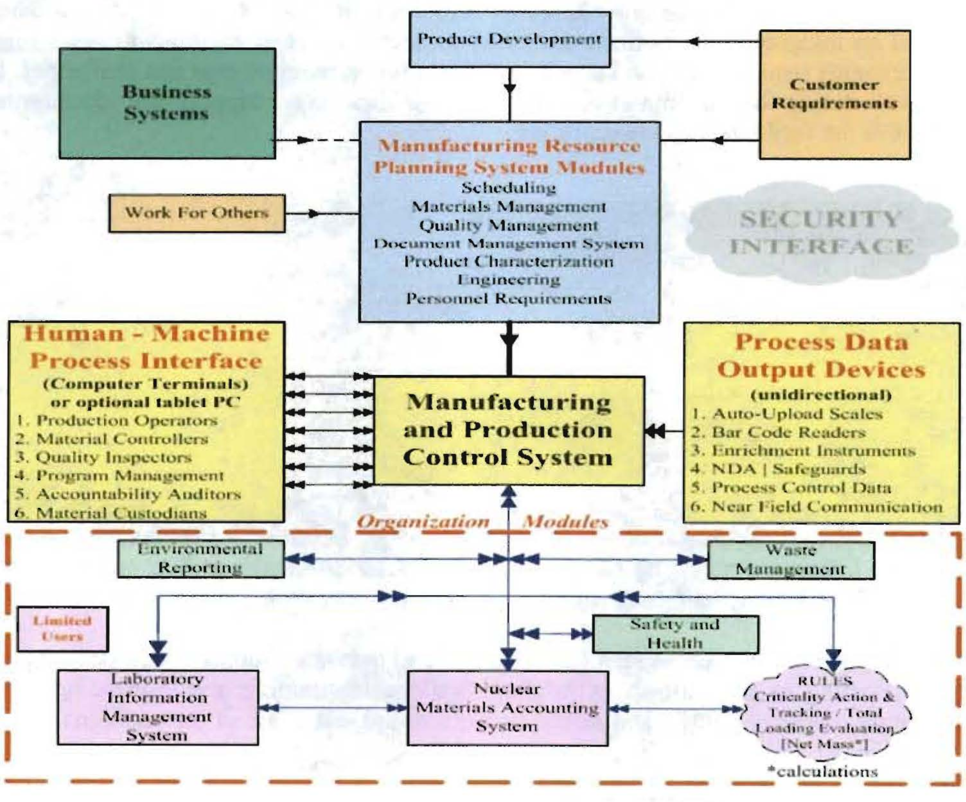

Figure 6. Information Technology Architecture

Instead of the MES 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 MES will be able to recognize the state of overall manufacturing operations within the facility and individual process cells. The overall state of the facilities material will be available through the ITN. Certain modules collaborate within the MES to share data requirements between complementary disciplines. An example of this is a criticality safety and material control location information system within glovebox production lines. A glovebox having its regulatory required safety, mechanical, operational and various other sensors and alarm systems in addition to the production material warning limits at the local level will inject another layer of defence-in-depth for material safeguards in a modern processing facility.

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 material processing facility such as UPF. The MES will maintain an active communication link with the adjacent production process steps. The system will signal the input side of the production sequence that the process is waiting for product input. The production sequence will be monitored for overall process loading and throughput quantities.

2.7 Integration with Physical Security

Increased risk management protocols require the physical security model of early detection, denial, and delay of adversaries at greater distances for modern facilities from traditional security boundaries. Integrated process technologies describing the state or condition and nuclear safeguards systems data can support the security posture of a facility. The Facility Information Management System easily becomes a tool for use by security or safety response teams as necessary. Utilizing facility design features, improved command and control, communication, facility-based information, and technologies interspersed within the facility, enhances the efficiency and survivability of protective forces protecting the nuclear material in modern nuclear facilities.

3. New Nuclear Facilities in the DOE Complex

DOE's Y-12 National Security Complex's Uranium Processing Facility (UPF) and Los Alamos National Laboratory's Chemistry and Metallurgy Research Replacement (CMRR) facility design teams, shown in Figure 7, used an integrated approach in designing these new nuclear facilities to meet current security, safety and safeguards requirements, and also to anticipate future requirements and challenges. Incorporating lessons learned during design initiatives of new facilities may support the decommissioning and dismantlement of the facilities they are replacing.

Figure 7. The Uranium Processing Facility and HEU Material Facility at Y-12 on the left, and LANL's Nuclear Facility and Radiological Laboratory/Utility Office Building on the right.

For the UPF Project design, process simulation models and databases support manufacturing and integrated planning [6]. Staffing levels, start-up, scheduling, bottlenecks, training, job sequencing maintenance, in-process inventory, resource control and safety evaluations are just a few of the additional modelling efforts planned for the integrated models [7].

For the CMRR, integration of environmental, safety, and security features are part of the facility design. The design team uses a systems engineering approach to design the facilities for the CMRR, covering planning through decommissioning, integrating safety, security, and safeguards. Criticality safety and security is an engineering feature of the long term and short-term storage vaults [8]. For the Nuclear facility, the design team is incorporating MC&A subject matter experts in designing a near real time nuclear material accountability system. The design team is incorporating process flow diagrams, into material flow diagrams, and using these to address materials-at-risk (MAR) for the Nuclear Facility.

4. Summary

These new nuclear facilities will require a modern ITN enterprise system that implements a near real-time (NRT) system for the control and accountability of all materials within the facility. This requirement is especially true for nuclear materials. Near real-time reporting (NRTR) incorporates the delay elements of operational processes and events where quantitative data is obtained at KMPs, which is then input into the ITN. Real-time data processing (internal) and data reporting by the ITN occurs at this point. Presentation of the data (output) for approved personnel to view is in a usable format, that personnel can readily react on.

New safeguards approaches used by the DOE Nuclear Security Enterprise have direct application for the IAEA. An example is a modern ITN for the overall control of a nuclear facility, which provides an opportunity for the IAEA to implement information driven safeguards. With an approval to obtain data directly from the facility ITN, remote safeguards inspections can occur, thus enhancing confidence in compliance with safeguards obligations. Through a greater cooperation between facilities and the IAEA, inspections can become more effective and efficient. Safeguards-by-Design techniques and methodologies can support preparations for the global nuclear expansion and increased safeguards workload. The DOE NSE is currently using Safeguards-by-Design techniques and methodologies for transforming its' old nuclear complex into the new National Security Enterprise of the 21st century.

5. Acknowledgments

The authors gratefully acknowledge support provided by the Next Generation Safeguards Initiative through the Department of Energy's National Nuclear Security Administration Office of Nuclear Safeguards and Security and the NNSA Office of Defence Programs.

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