

MANAGING THE DEPARTMENT OF ENERGY'S URANIUM HEXAFLUORIDE INVENTORY

Scott Harlow, U.S. Department of Energy NE-40
Michael Taylor, Bechtel Jacobs Company LLC

ABSTRACT

The Department of Energy (DOE) owns about 700,000 metric tons of uranium hexafluoride (UF₆) generated from more than 45 years of operating uranium enrichment plants at Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth Ohio. About 99 percent of the inventory is depleted in the U²³⁵ isotope, a resultant by-product from operating the enrichment plants. The remaining inventory is natural assay UF₆, 0.711 percent U²³⁵ and enriched assay UF₆, greater than 0.711 percent U²³⁵.

The long-term management strategy for the depleted UF₆ inventory is under review by DOE through the National Environmental Policy Act. While under review, the mission for the inventory management is safe storage. This mission will continue until the storage inventory has been fully deployed (i.e., recycled or converted).

Through the 1990's, the storage project has incurred some unique drivers that have assisted in accomplishing the mission thus far. These drivers stemmed from the initial 1990 discovery of breached cylinders. The unique drivers include (1) Defense Nuclear Facility Safety Board Recommendation 95-1 and the (2) Director's Final Findings and Orders from the Ohio Environmental Protection Agency (OEPA).

These drivers have placed the project in the fore front of many initiatives within DOE including (1) the creation of Work Smart Standards (WSS) and (2) the implementation of Integrated Safety Management. These initiatives coupled with the compliance to the drivers mentioned above have structured a project with the necessary decision making tools and control processes to successfully continue the storage mission throughout the deployment of the UF₆ inventory.

HISTORY

The DOE UF₆ inventory is stored in about 60,000 unfired pressure vessels (cylinders) constructed of mild steel. The cylinders in storage vary in design and capacity. A typical cylinder is 4 ft in diameter and 12 ft. long and is constructed with a 5/16 inch steel wall thickness. The typical cylinder has a storage capacity of 12 metric tons. The inventory of UF₆ owned by DOE is what remains from the federal government's working inventory from operating the enrichment plants. The balance of the inventory was transferred to the United States Enrichment Corporation (USEC) prior to privatization.

The depleted UF₆, most of the DOE inventory, was generated as a by-product from enriching uranium for commercial and government applications. Typically, the process to make a pound of commercial grade enriched UF₆ requires six pounds of natural assay feed and produces five pounds of depleted UF₆. The depleted UF₆ was and continues to

be stored for future use. Some commercial and government applications have been found over the years for the depleted UF₆ with a small amount of the inventory deployed compared to what is available. In addition, several depleted UF₆ refeed or recycle campaigns were found advantageous in the operation of the enrichment plants. The objective of the recycle campaigns was to strip more of the U²³⁵ isotope from the depleted UF₆ inventory.

As the depleted UF₆ inventory grew in the 1960s, cylinders slated for storage were designed and economized with a thinner wall, 5/16 inch, instead of the 5/8 inch wall thickness for cylinders used in routine filling and emptying operations. Minor design modifications were made over the years with continuous procurements of new storage cylinders. In addition, capital funds were provided to periodically expand the storage yards to meet the growing demand for storage capacity. Until the 1990 breached cylinders were discovered in the Portsmouth storage yards, no surveillance and maintenance program existed for the cylinders in long-term storage. However, cylinders in long-term storage were periodically verified to meet nuclear material accountability requirements.

The natural UF₆ owned by DOE is a government strategic reserve. The enriched UF₆ owned by DOE is the balance of the inventory that was not transferred to USEC. The enriched inventory has some operational constraints with readily using it to meet commercial grade orders. These constraints include the following:

- the condition of the cylinder requires special processing,
- a small quantity of UF₆ in the cylinder (i.e., heel quantity) is not readily retrievable,
- the constituents of the UF₆ require purification or special blending to meet American National Standards Institute specifications.

The UF₆ cylinder inventory is stored at the East Tennessee Technology Park in Oak Ridge, Tennessee and the gaseous diffusion plants in Paducah, Kentucky and Portsmouth, Ohio. About 60 percent of the cylinder inventory is stored at the Paducah plant, 30 percent at the Portsmouth plant and 10 percent at ETTP.

Cylinders are stored outside in gravel and concrete storage yards. The typical storage configuration has cylinders stacked in two-tiered rows with about 4 ft aisle spacing. The bottom tier cylinders are placed on concrete or wooden saddles.

THE HAZARDS

Uranium hexafluoride is a solid white crystal under ambient conditions. This chemical form was naturally selected for the enrichment process because its physical properties allowed the uranium compound to be heated and easily processed as a liquid or gas. Also aiding the enrichment process was the level of chemical purity (99.97 percent UF₆) with which this compound could be easily manufactured.

This chemical compound also presents some specific hazards. If exposed to moisture in air, UF_6 readily reacts to produce hydrofluoric (HF) gas and soluble uranyl fluorides. The discovery of breached cylinders in the storage system verified a reduction/oxidation reaction naturally occurs with the uranium and the iron from the mild steel cylinder. This reaction transfers electrons reducing the uranium to the tetravalent state forming UF_4 . The UF_4 compound has comparatively low solubility in water. Evidence of this reaction and its self-sealing properties were found in the investigation of the breached cylinders. For example, the investigation determined that a cylinder had a breach exposed to the environment for 13 years and lost less than 1 percent of the uranium content or an upper bound of about 112 lbs. uranium during the exposure. At the time of discovery, the breach had grown to about 2 sq. ft. in size. The investigation determined that neither the HF nor the uranium EPA reportable quantities were exceeded or approached. In addition to this naturally occurring control that minimizes exposure of the uranium hazard to the environment, the human sense of smell has the ability to detect HF below measurable quantities and below immediate danger to life and health thresholds. This sense of smell provides additional control for limiting human exposure.

As stated earlier, most of the DOE UF_6 inventory is depleted in the U^{235} isotope reducing the radiological hazard. In general, industry considers UF_6 with assay less than 1 percent U^{235} to have a higher chemical hazard than radiological hazard. In addition to the radiological and chemical hazards, UF_6 storage operations have to manage typical industrial facility hazards, primarily moving heavy loads.

A physical hazard inherent to the UF_6 compound when being processed is the volume expansion when heating the solid form to make a liquid. The expansion coefficient, under normal operating conditions, is around 1.3. Heating has to be controlled so the UF_6 does not exceed the volume and pressure rating of the equipment or cylinder. Excessive heat could result in a hydraulic rupture of the containment device. The volume expansion hazard is only of concern during the deployment of the UF_6 inventory (i.e., emptying the cylinder contents through liquefaction).

In summary, these hazards make for a comparatively low-risk project within the DOE complex. The combination of relative low risk, large inventory (greater than 1.5 billion pounds of UF_6 in 60,000 cylinders), and little market demand challenges project management to sustain sufficient federal resources to meet DOE's mission.

UNIQUE DRIVERS

Unique drivers for the project began developing with visibility from the breached cylinders discovered in the early 1990's. These incidents brought the involvement of the OEPA in 1992 and the DNFSB in 1994. These events lead to the creation of two unique drivers applicable to the depleted UF_6 .

The involvement of the OEPA lead to an agreement document between the State of Ohio and DOE for managing the Portsmouth inventory with a specific level of rigor in a surveillance and maintenance program to assure environment safety. The agreement

basically involves OEPA in the management of the cylinders and commits to a ten year period of searching for useful applications, while completing some upgrades in the storage configuration, and preparing for deployment of the depleted UF₆ inventory. The agreement is legally binding with potential financial fines for violations. The agreement on depleted UF₆ was part of a larger agreement negotiated with OEPA including other projects at the Portsmouth site. The agreement took about five years to become final.

The involvement of the DNFSB lead to formal Recommendation 95-1, which DOE accepted. The recommendation was to implement a systems approach to ensure cylinders, while in storage, were safely managed. By inference, the Board recognized the uncertainty as to when the cylinder inventory would be retired and what would become of the uranium inventory. The recommendation included three sub-recommendations:

- Begin an early program to paint cylinders
- Implement other operational improvements
- Study other uranium forms to see if another form is more suitable

The commitment in the DOE Implementation Plan was to develop a systems engineering approach and provide specific documents:

- System Requirements Document (SRD),
- Systems Engineering Management Plan (SEMP),
- Engineering Development Plan (EDP),
- Project Management Plan (PMP), and
- Safety Analysis Reports (SARs).

These documents provided the evidence that the approach was implemented. The documents were all submitted on time. Recommendation 95-1 remains open with periodic interfaces with the Board and their staff.

IMPLEMENTING SYSTEMS ENGINEERING

A graded approach to applying systems engineering was mandatory, as the storage system already existed, and had no driver (relatively low risk) for performing a complete system redesign. The graded approach is based on prioritization of improvements to the storage system relative to the mission of safe storage. The approach outlined in Figure 1 required the development of a series of documents that structured how project management and the storage system would meet the mission. The development of the documents was an iterative process beginning with the identification of bounding assumptions and followed by a decomposition of the mission into major objectives and mission requirements. Following the identification of requirements was the identification of standards for which the requirements would be met. In later iterations of identifying the standards, the Project took the lead in implementing DOE's WSS through a defensible, structured approach. The structured approach to the WSS initiative required the further breakdown of routine tasks to identify hazards of the tasks and applicable standards for managing those hazards. The mission requirements and standards for the Project are documented in the

SRD. These requirements form the basis for how upgrades to the storage system are prioritized. The SRD is an agreement document between the contractor and DOE with appropriate change control.

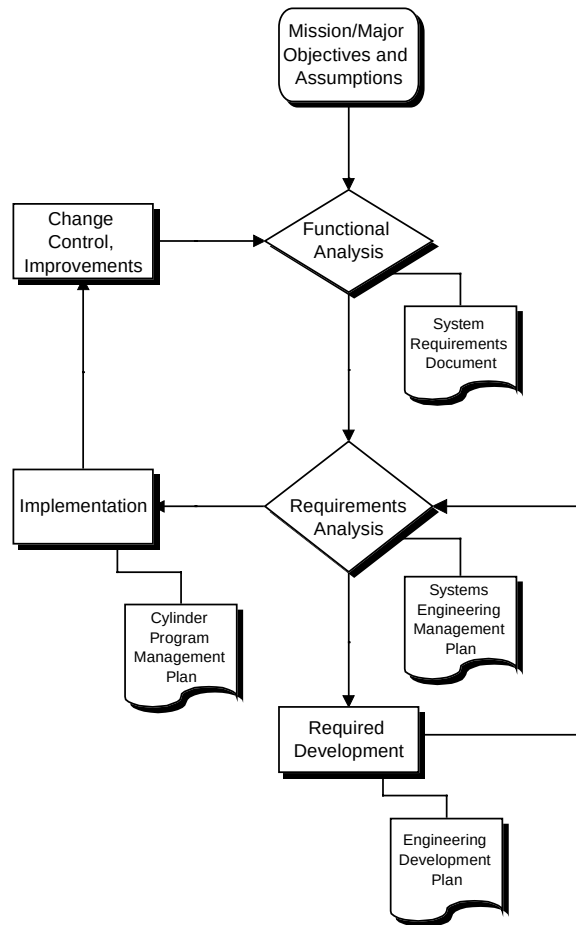


Figure 1. Systems Engineering Development

The second document in this series is the SEMP. This document is also a signed agreement document between DOE and the prime contractor. The SEMP specifies the level of rigor the prime contractor will follow to assure compliance of the requirements and standards agreed to in the SRD. The agreement describes overall systems engineering approach and articulates the tools and processes project management uses to execute the tasks within the storage system. These tools and processes include how risk management, control of interfaces, configuration management and prioritization of tasks are executed. A key reference document in the SEMP is the contractor's description and commitment to an Integrated Safety Management System. Also key to project execution is the SEMP section describing the requirement analysis process. This process analyzes the requirements to determine the required actions for meeting the requirement. This process is based on the Kepner-Tregoe decision-making model and allows for a graded approach to decision making within the project. This process was used in the further

iteration of the mission requirements, breaking them down into required actions of the project. The complete listing of required actions, also provided in the SEMP, articulates all of the actions that need to be completed to meet the major objectives and storage mission. As new information and situations arise the requirements analysis process is used to create defensible changes within the required actions.

Next in this series of documents is the PMP. Typical of any project, whether applying systems engineering or not, the project management plan contains the work breakdown structure (WBS), performance metrics, projected budget requirements, and schedule for implementation of tasks. The WBS organizes all of the required actions in the SEMP in a structure for execution (i.e., budgeting, planning, monitoring, and controlling). Configuration management, or change control and improvements to the system, is managed through this command media. Also included in the PMP are the roles and responsibilities of the project management team and the command media for executing the tasks. The PMP is a contractor document revised annually to recognize the tasks completed the previous year and accommodate the schedule changes due to available funding.

The final systems engineering document is the EDP. This document describes in more detail the control of development tasks necessary to sustain the storage system, such as monitoring corrosion rates, technical evaluation of paint performance, and valve characterization studies. The document provides a more-detailed description of the development tasks planned within the fiscal year and a method for verifying completion of the task. The rationale for having an EDP is to ensure the intent of development tasks is clear before releasing them and to ensure sufficient documentation of the findings from the development effort. Most of this documentation becomes technical basis for decisions within the project. This documentation has proven essential to justifying budget requests.

The application of a systems approach to managing the cylinders has increased the cost of administering the system. However, the overall cost of executing the project has been reduced while the earned value has increased. Within the first 18 months of implementing the approach, the project recognized an overall 40 percent cost savings. This savings is attributed to limiting the project to required actions, negotiating prices for key tasks, and implementing specific project controls. In short, focusing on the mission of the project.

SUMMARY

Implementation of a graded approach to systems engineering has given the project the tools necessary to comply with the unique drivers and secure funding to sustain compliance with DOE's safe storage mission. The approach has reduced overall costs by focusing the management of the project on required tasks. Grading the approach to systems engineering has minimized the impact on costs for administering the system.