Successful Deployment of System for the Storage and Retrieval of Spent/Used Nuclear Fuel from Hanford K-West Fuel Storage Basin-13051

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ABSTRACT

In 2012, a system was deployed to remove, transport, and interim store chemically reactive and highly radioactive sludge material from the Hanford Site's 105-K West Fuel Storage Basin that will be managed as spent/used nuclear fuel. The Knockout Pot (KOP) sludge in the 105-K West Basin was a legacy issue resulting from the spent nuclear fuel (SNF) washing process applied to 2200 metric tons of highly degraded fuel elements following long-term underwater storage. The washing process removed uranium metal and other non-uranium constituents that could pass through a screen with 0.25-inch openings; larger pieces are, by definition, SNF or fuel scrap. When originally retrieved, KOP sludge contained pieces of degraded uranium fuel ranging from 600 microns (μm) to 6350 μm mixed with inert material such as aluminum hydroxide, aluminum wire, and graphite in the same size range.

In 2011, a system was developed, tested, successfully deployed and operated to pre-treat KOP sludge as part of 105-K West Basin cleanup. The pretreatment process successfully removed the vast majority of inert material from the KOP sludge stream and reduced the remaining volume of material by approximately 65 percent, down to approximately 50 liters of material requiring management as used fuel. The removal of inert material resulted in significant waste minimization and project cost savings because of the reduced number of transportation/storage containers and improvement in worker safety. The improvement in worker safety is a result of shorter operating times and reduced number of remote handled shipments to the site fuel storage facility.

Additionally in 2011, technology development, final design, and cold testing was completed on the system to be used in processing and packaging the remaining KOP material for removal from the basin in much the same manner spent fuel was removed. This system was deployed and successfully operated from June through September 2012, to remove and package the last of the SNF fragments from the 105-K West Basin, ending the long and complex history of the KOP sludge materials.

The planning and execution of this project demonstrated how the graded application of DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*[1], DOE-STD-1189-2008, *Integration of Safety into the Design Process*[2], and DOE G 413.3-4, *U.S. Department of Energy Technology Readiness Assessment Guide*[3], can positively affect the outcome of project implementation in the DOE Complex. Provided herein are relevant information, ideas, and tools for use by other projects facing similar issues in managing high risk waste streams in a complex regulatory environment. Positive aspects are also provided of appropriate time spent in detailed planning, design, and testing in non-hazardous environments to

reduce project risks in both cost and safety performance, as well as improving confidence in meeting project goals through predictable and reliable performance.

INTRODUCTION

A primary objective at the Hanford Site is cleanup of the River Corridor. This portion of the site includes former laboratory, waste disposal, and reactor facilities bordering the Columbia River. One of the last facilities containing nuclear material within the river corridor is the 105-K West Reactor Fuel Storage Basin (Figure 1), where highly radioactive sludge remains from the long-term storage and degradation of SNF. This sludge material needed to be removed from the 105-K West Basin so that final deactivation, removal of shielding cover water, and D&D of the basins can be completed to enable remediation of chemical and radioactive plumes present underneath the basin structure and perform remediation of 100-K Area.

The KOP sludge was particularly troublesome because of its unique consistency of coarse uranium metallic grit that is highly erosive and reactive, corrosion products that contain chemically bound water, and high levels of radioactivity. The KOP sludge in the 105-K West Basin was a legacy issue resulting from the SNF washing process applied to 2200 metric tons of highly degraded fuel elements following long-term underwater storage. The KOP sludge will be managed as SNF along with the previously removed spent fuel and spent fuel scrap.

Fig. 1. K East and K West Reactor Basins
and the Cold Vacuum Drying Facility.

BACKGROUND

The spent fuel pools initially received SNF from the Hanford Site's 105-KE and 105-KW Reactors. The reactors were shut down and the spent fuel was processed in the late 1960s. Beginning in the late 1970s, the 105-K East and 105-K West Basins were upgraded and stored the overflow of stored SNF from 100-N Reactor. Highly radioactive sludge and fuel fragments formed in the basins during fuel storage operations from fuel corrosion.

The SNF and scrap that had been stored in pools near the Columbia River at the Hanford Site were previously processed by cleaning, dewatering, and drying and then moved to storage in a helium atmosphere in stainless steel containers called multi-canister overpacks (MCO). Each MCO contained several metric tons of fuel and are approximately 2 feet in diameter and nearly 14 feet tall. Each MCO contains up to six baskets to hold fuel and scrap in critically safe configurations. The MCOs were placed and remain in a below ground dry storage location in central Hanford away from the Columbia River. These MCOs have been in dry storage for up to 12 years. The primary technical requirement for long-term storage was to assure that little water remained in the MCO that might pressurize the stored MCO beyond an established design limit over the assumed 40-year storage period.

The fuel processing operations were performed at the 105-K West Basin and included cleaning and packaging of the fuel. The sludge generated from fuel cleaning and packaging operations flowed into process equipment including strainers, KOPs, and settler tanks. These process steps were intended to capture increasingly smaller sludge material by physical separation and/or settling. KOP material (which also includes material from the strainers) is functionally represented by sludge that passed through the 0.25-in. screens of the fuel cleaning machine, but did not pass through downstream 600 µm strainers.

PROJECT EXECUTION

The planning and execution of this project demonstrated how the graded application of DOE O 413.3B[1], DOE-STD-1189-2008[2], and DOE G 413.3-4[3] can positively affect the outcome of project implementation in the DOE Complex. Key tailored elements included:

- Development of a formal "Major Modification" determination using application of DOE-STD-1189-2008 along with the overall Sludge Treatment Project's (STP) Safety Design Strategy. This project did NOT meet the major modification definition, so a parallel approval process was established within CH2M HILL Plateau Remediation Company (CHPRC) for each of the project elements that would have been subject to formal DOE approval.

- A technology maturation strategy plan was developed and the Project utilized a formal test planning, test execution, and test reporting subject to the STP's Joint Test Group review and approval. A formal DOE-approved technology readiness assessment was not required for this project; however, CHPRC applied the Joint Test Group Process to formally assess technology readiness.

- Completion of conceptual design, preliminary design, and final design reports and conduct of a formal design review at each design stage.

- Establishment of a CHPRC formal Project Review Board and a design/gate approval process. This CHPRC-level decision process was applied at each design level and provided Company-level approval to proceed with the next phase of project execution.

Challenges

Technical challenges for packaging KOP material into MCOs in a manner similar to SNF centered on revising and establishing a nuclear safety basis to account for physical differences between KOP material and SNF. The key differences are the much smaller uranium metal sizes that result in much higher uranium reactivity because of increased surface to volume ratios. Uranium metal reacts exothermically with water and water vapor and produces hydrogen gas. Thermal stability and control of gas generation are key safety parameters. The reaction of uranium with water also produces uranium oxides that are small in size and must be controlled to limit the amount of radioactive material at risk for transportation and safe storage safety analysis. To meet the long-term storage criteria in the MCO and the Canister Storage Building, the KOP material must be conditioned. Free water is easily removed by cold vacuum drying. However, the non-uranium material can contain chemically bound water that can produce pressurizing gas and flammable gas mixtures through radiolysis of any remaining bound water. To be successful, the project had to demonstrate that it could limit the total amount of bound water to prevent over pressurization and flammable gas build up in a sealed MCO.

Functional requirement challenges to condition the KOP material for loading into MCOs included removal of uranium-bearing material less than 600 µm, and removal of non-uranium metal (uranium oxide and metallic hydroxides such as aluminum hydroxide). Application of stringent process control for product quality also had to be applied to the underwater operation that was done under nearly 17 feet of water by personnel using long handled tools from a grated work platform above the basin pool.

The cost of fabrication, loading, drying, transporting and long-term storage is very significant. Only a limited number of MCOs from SNF processing remained and the number of storage locations was fixed. The quantity and composition of the KOP material were not well known. Preliminary evaluations revealed that additional MCOs would need to be procured and treatment of the KOP to remove chemically bound water components and material less than 600 µm would be needed in order to fit within available storage space.

Project Scope

Processing and packaging of KOP product material was patterned after the successful packaging and processing of SNF and scrap. Newly designed systems and the adaptation of some existing systems were necessary for packaging KOP material.

The scope of the KOP Disposition Subproject included the following activities:

- Retrieval, washing, and inspection of the KOP material to characterize its physical properties
- Design, fabrication, testing and installation of the required KOP processing equipment in the 105-K West Basin
- Sorting of the KOP material by density and size

- Loading of the processed KOP material into MCOs
- Transporting the MCOs to the drying facility and drying the contents of the loaded MCOs
- Transporting the MCOs to interim storage.

Key engineering aspects and analysis to support the disposition of KOP material demonstrated that:

- The use of a copper block insert, with a centrally milled slot to contain the KOP product material along with screens at the top and bottom to allow drying was successful in limiting the volume available to receive KOP product material, enhanced heat conduction, and functioned as a heat source and sink during drying operations. This resulted in stable thermal behavior during cold vacuum drying.
- A similar proof-of-dryness test that was used for previous SNF MCOs could be applied to the KOP MCOs and that the KOP material contained in the copper inserts would dry readily.
- A bulk wet density measurement of the KOP product material before loading could be used to establish a bounding value for the chemically bound water content of the KOP product material. The bounding water inventory for each loaded KOP MCO does not exceed the bounding value that was used for fuel/scrap MCOs.
- Intimate contact of uranium and water bearing material in the KOP product material during interim storage results in competing reactions of oxygen generation through radiolysis and oxygen consumption through uranium oxidation. Additional limits were placed on the uranium loading as a function of bulk density to assure that oxygen concentrations and MCO internal pressure are acceptable throughout interim storage.

Nuclear Safety

An evaluation to determine whether the KOP activities constituted a “major modification” under DOE-STD-1189-2008[2] was conducted early in the project lifecycle, and formed the planning for the design and installation of the KOP equipment in the basin under the existing K Basin authorization basis. The evaluation showed that the hazards being controlled were identical to those associated with the processing and loading of SNF and scrap. Loading KOP material into SNF scrap baskets, loading the baskets into MCOs, and processing the MCOs comparable to fuel processing was determined not to be a major modification using the criteria in Reference [2].

One noteworthy outcome from the iterative nuclear safety analysis and design process was the establishment of an intrinsic thermal stability design of the MCO configuration by design modifications to the copper insert used to hold the KOP material in the MCO. During drying of the KOP material, uranium water and uranium water vapor reactions must be controlled to maintain thermal stability. When SNF loaded in MCOs was dried, process control measures were applied to assure thermal stability through the drying process. During the safety analysis it was shown that a change in the geometry of the slot used to hold the KOP material in the copper insert would establish an intrinsically thermal stability design.

Risk and Opportunities

A risk and opportunity assessment was prepared consistent with DOE-STD-1189-2008[2]. Opportunities to mitigate technical and programmatic uncertainties and challenges were identified and addressed early into the design process.

For example, the estimated final number of MCOs required to complete the mission covered a wide range because of uncertainties concerning the effectiveness of the removal of non-uranium materials. The number of MCOs required was important because not only are the MCOs expensive to fabricate, the procurement lead time was relatively long. In addition, the operations schedule was driven by the number of MCOs processed. As a risk mitigation measure, the project procured three additional MCOs with options to procure additional MCOs to assure that project completion would not be dependent on MCO availability. The procurement time was long enough that this risk decision was made early in the project lifecycle and was successful in helping mitigate the uncertainty of MCO availability.

In-basin inspections were initiated to confirm material composition, quantities, and technical feasibility to separated non-uranium material for the spent fuel uranium. A decision to separate the original process into separate pretreatment and final treatment campaigns was made to remove non-uranium components and provide quantification and reduce the uncertainty of the final process feed stream.

Full-Scale Testing and Process Development

A full-scale testing facility in a production setting (under water with mock-up grating and long handled tools) was established at an onsite facility to assist in the development, demonstration, and the design of the inspection, pretreatment, and final packaging of the KOP equipment (Figure 2). KOP simulants were established based on critical characteristics and process parameters and used throughout the process development and design process. The use of a full-scale facility mock-up allowed operations and maintenance personnel to work the design concepts with the lead engineers early in the design process to identify needed features and refine the equipment to improve the ability to install, maintain, and operate the equipment. Operator involvement and operation of full-scale test equipment played a key role in refining process equipment and tools for a nearly flawless field execution. By the time the final equipment had been demonstrated, there were several opportunities to gain input from the field operations personnel. The field operations personnel had ownership of the systems that were installed and were able to complete the processing and packaging without any significant operational issues. The full-scale test platform was also used to train operators and develop operating procedures.

Full scale testing provided equipment refinement, design verification, operator training and ownership that enabled the project to complete ahead of schedule and within budget. Typical readiness and startup issues associated with design completeness and operation personnel process knowledge, and operational learning curves were not encountered.

Fig. 2. KOP Full-Scale Test Facility.

PROCESS DESCRIPTION AND OPERATION

KOP Material Origin

KOP material originated from SNF corrosion in the storage basins and was collected during the fuel and scrap cleaning process used in the SNF process at K Basins. Fuel was cleaned in the primary cleaning machine (PCM), which provided mechanical agitation and flushing to remove particulate from fuel by slowly tumbling the fuel canisters past high-pressure water jets. Particulate material in the canisters, small uranium metal fragments and internal fuel particulate from damaged fuel assemblies, and coatings on fuel assemblies and canisters were also removed during the cleaning process.

KOP Material Characteristics

KOP material consists primarily of uranium, Grafoil®[1], and aluminum and iron compounds between 600 µm (0.0236-in.) and 6350 µm (0.25-in.) particle sizes, and short strands of aluminum wire. Grafoil® seals were used on nearly 4000 fuel canisters in the 105-K West Basin. Aluminum and iron compounds resulted from corrosion of basin equipment and aluminum canisters used to hold the spent fuel during storage. The source of the aluminum wire was the screens on the “open-bottomed” fuel canisters. Although KOP material had not been directly chemically characterized, the components that make up the KOP material had been identified and characterized for chemical, physical, and radiochemical properties during previous K Basin fuel and sludge characterization activities.

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[1] Grafoil is a registered trademark of Graftech International Holdings, Inc., Parma, Ohio.

In-basin inspection of KOP material was a key element of the technical basis for the design of the pretreatment and processing of KOP material. These inspections established values for material properties and demonstrated that size and density-based separation processes were viable. The observations also supported the technical viability of cold vacuum drying and interim storage of the KOP material. The inspection work:

- Determined quantities and bulk density of KOP materials
- Evaluated and determined feasibility of particle size and density separations
- Demonstrated friability of non-uranium components for size reduction
- Confirmed expected components of KOP material
- Confirmed expected particle size distribution of KOP material
- Confirmed that removal of non-uranium components was necessary to package within reasonable number of MCOs
- Confirmed that additional laboratory characterization for chemical composition was not necessary.

Pretreatment

The KOP material stream contained significant quantities of non-uranium-based compounds that had the potential to contribute to the bound water content of the material; therefore, affect the amount of material that could be stored in a single MCO. The KOP material was pretreated in 2011 to remove the undesirable material to the extent practicable.

The existing spent fuel cleaning process was used as the core of the KOP pretreatment process. The density separation process was used to first segregate non-uranium materials that are much less dense than uranium metal. The low density material was then washed in the existing fuel cleaning machine process. The low density material consisted primarily of Grafoil®, and aluminum and iron hydroxides, which are friable and could be size reduced to less than 600 µm.

Sufficient low-density material was removed from the KOP material such that the pretreated high-density material achieved a bulk wet density greater than the target 9 kg/L. The inventory of KOP material was reduced from 137 liters with an average bulk wet density of 5.6 kg/l to 53 liters with an average bulk wet density of 9.8 kg/l. This optimization enabled a more cost-effective packaging of the product stream (uranium-metal based materials) as SNF. As shown in Figure 3, the original volume of KOP material was estimated to require approximately 16 MCOs. Removal of the non-uranium components reduced the projected number of MCOs to 5.

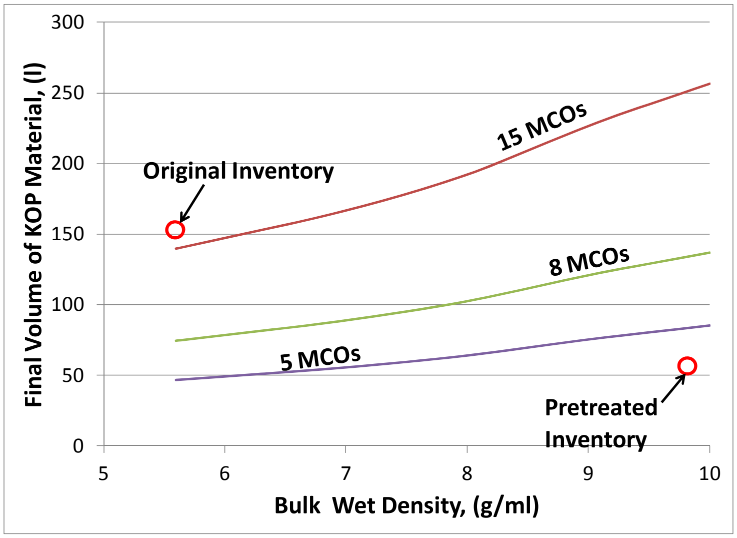


Fig. 3. Number of Multi-Canister Overpacks Required.

Pretreatment activities were carried out in three phases: density separation, size reduction of the less dense non-uranium bearing fraction and friable portions of the KOP material, and aluminum wire separation. The pretreatment process flow diagram is presented in Figure 4.

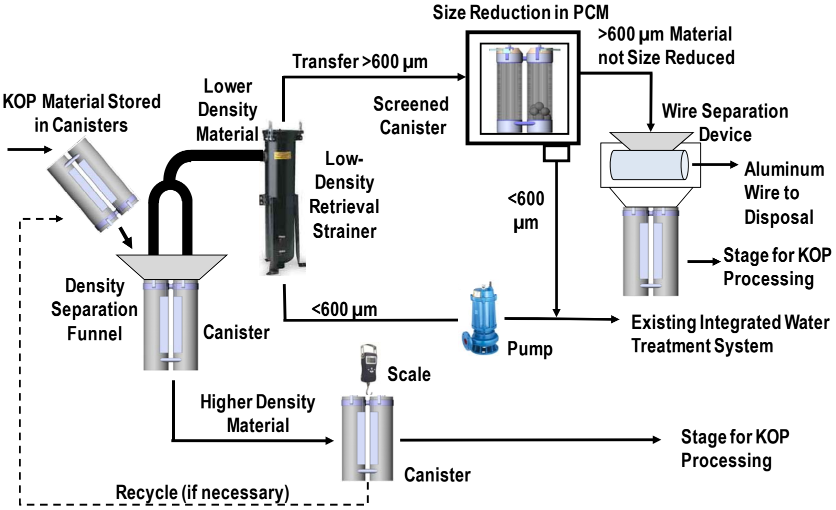


Fig. 4: Pretreatment Simplified Process Flow.

Density separation was accomplished with an elutriation process that included a density separation funnel with dual suction wands and a low-density retrieval strainer and pump skid. Particles whose settling rates were less than the upward water flow through the suction wands were removed and captured in the low-density retrieval strainer. Conversely, solids whose settling velocities were greater than the upward water velocity would not be carried over and settled into the canister. The density separation funnel was positioned over a standard fuel canister to collect the high density uranium rich stream.

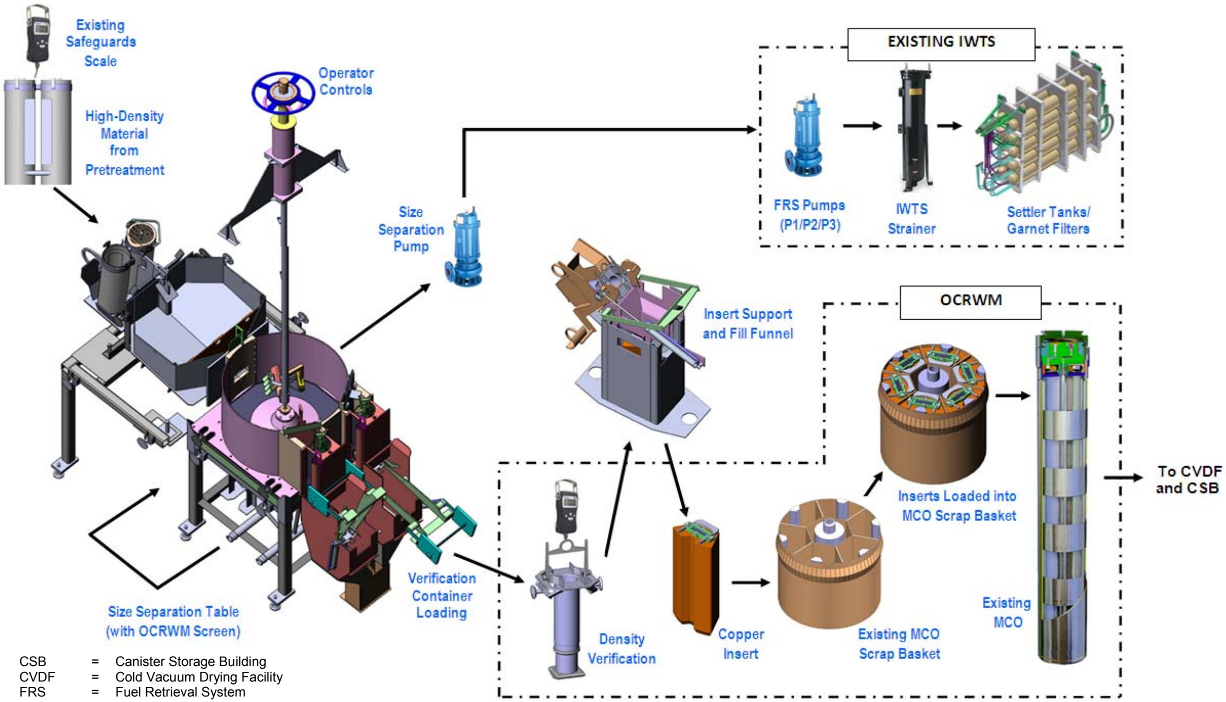
The lower density material separated from the base KOP material within the density separation funnel was captured in a retrieval strainer and was transferred to a screened canister for size reduction. Size reduction equipment consisted of a screened canister, agitators, and the existing fuel cleaning machine. The size reduction step physically broke-down a portion of the non-uranium based components to less than 600 µm so that it could pass through the screen and be removed from the process.

The remaining material in the screened canisters was processed through the wire separation device. The wire separation step removed aluminum wire. Following wire separation, the wire remaining in the drum of the wire separation device was removed, confirmed as non-fuel, and segregated as debris.

KOP Processing System

The uranium metal product from pretreatment was processed using the KOP Processing System (KPS) (shown in Figure 5) in the summer of 2012. The process was comprised of the following three main process steps: (1) size separation, (2) verification container loading, and (3) packaging.

The size separation process removed particles less than 600 µm in size from the KOP material before the material was transferred to the verification container loading equipment. The size separation equipment included a screened size separation table, nozzle array unit, pump skid, flow meter skid, and miscellaneous long pole tools.



CSB = Canister Storage Building
CVDF = Cold Vacuum Drying Facility
FRS = Fuel Retrieval System
OCRWM = Office of Civilian Radioactive Waste Management

Fig. 5. KPS Process Flow Diagram.

Pretreated KOP material was first placed on a 600-µm screened surface for particle size separation on the size separations table. The pretreated KOP material was distributed onto the screened surface in a thin layer and agitated with spray nozzles. Material with particle sizes less than 600 µm passed through the screen and exited the process.

The pretreated KOP material that did not pass through the screen was placed into verification containers at the verification container fill station. Once filled, the verification containers were weighed and volume measurements were taken. Based upon these values, a bulk wet density was calculated, with adjustments to account for measurement uncertainty.

The KOP product was then packaged into specially designed MCO basket inserts, which were then loaded into SNF scrap baskets. The MCO basket inserts (Figure 6) were designed to contain the KOP material, which when placed within existing MCO scrap baskets, permitted drying, facilitated heat transfer, and ensured adequate mass and appropriate void space in the MCO. The MCO basket inserts are 260 pound copper blocks with a full-length cavity down the middle. The cavity cross section was approximately 0.75 inch by 4.5 inch. The size and shape of the cavity ensured thermal stability of the KOP material during drying operations. The 20.5-inch height of the block and cavity permitted the insert to hold approximately 0.95 liters of KOP material with some allowance for head space.

Once the KOP product was loaded into SNF scrap baskets, the remaining process was mechanically the same as the process previously used for the SNF Project. MCOs were loaded in a specific sequence with empty scrap baskets and with the scrap baskets containing MCO basket inserts with KOP product. The MCOs were dewatered, dried and transported to interim storage on the Hanford Central Plateau.

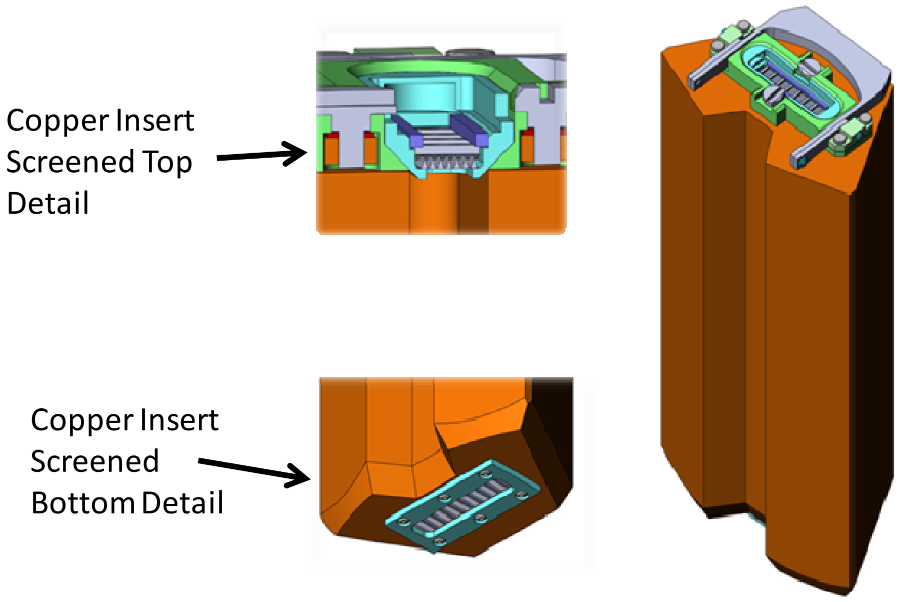


Fig. 6: Copper Inserts.

CONCLUSIONS/LESSONS LEARNED

The conclusion of the project was the highly successful processing of all of the KOP material in the summer of 2012 (Figure 7 and Figure 8). A total of five KOP MCOs were produced, which was consistent with pretreatment projections. All operations were completed ahead of schedule, with no required modifications to the equipment. The procedures developed during full scale pilot system were followed without significant changes. No operational upsets due to equipment design or procedural errors were encountered, which is attributed to an excellent operations crew and operator buy-in and design inputs obtained during process development and testing.

The project moved the most troublesome sludge from near the Columbia River to safe storage on the Hanford Central Plateau paving the way for removal of remaining sludge from the 105-K West Basin so that final deactivation, removal of shielding cover water, and D&D of the basins. The *Hanford Federal Facility Agreement and Consent Order*[4] Milestone related to final completion was met ahead of schedule.

The planning and execution of this project demonstrated how the graded application of DOE O 413.3B[1], DOE-STD-1189-2008[2], and DOE G 413.3-4[3] can positively affect the outcome of project implementation in the DOE Complex. The development of a technology maturation plan/strategy early in the project, along with test planning and test reporting overseen by a formal project test review panel improved the rigor of the testing done; and resulted in improved test qualification and identification of design and development issues early in the development/design cycle.

Establishing a full-scale testing facility in a production style setting (under water with mock-up grating and long handled tools) to assist in the development, demonstration, and the design of the inspection, pretreatment, and final packaging resulted in Operator involvement and operation of full-scale test equipment played a key role in refining process equipment and tools for a nearly flawless filed execution of the process.

Identification and mitigation of technical and programmatic uncertainties and challenges in the early into the design process led to successful completion of the project.

The KOP Disposition Subproject was completed within budget and on time. The initial total cost estimate for the project established at preliminary design was \$35.6M. The final project cost was \$36.8M. The differences in initial project cost estimate and final cost estimate are primarily due to rate changes and overhead allocation adjustments. The project schedule established during conceptual design forecast a completion date of April 30, 2012 for completing removal of KOP material from the K Bain to interim storage on the Hanford central plateau. The *Hanford Federal Facility Agreement and Consent Order*[4] Milestone related to final completion, was September 30, 2012. A reduction of force within CHPRC was necessary in the fall of 2011 due to reduction of CHPRC funding following the American Recovery Act efforts at Hanford. Although this adjustment did not affect he KOP Disposition Subproject funding profile it did result in a loss of trained personnel necessary to perform the KPS operations. Labor agreements at Hanford allow for union member transfers between Hanford Contractors and projects within the contractors. New personal were transferred to the project, trained and KPS completed September 13, 2012 ahead of the regulatory milestone.

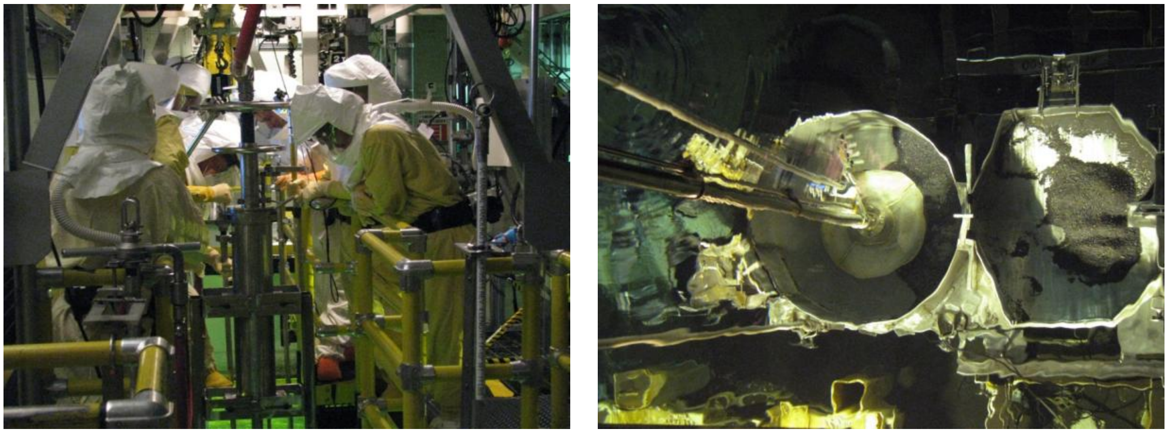


Fig. 7. KPS Processing in 105-K West Basin.

Fig. 8. Final and 5th MCO on Trailer Leaving 105-K West Basin.

REFERENCES

1. DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets* (2010).
2. DOE-STD-1189-2008, *Integration of Safety into the Design Process* (2008).
3. DOE G 413.3-4, *U.S. Department of Energy Technology Readiness Assessment Guide* (2009).
4. *Hanford Federal Facility Agreement and Consent Order* (1989).