

**Technology Development and Deployment of Systems for the
Retrieval and Processing of Remote-Handled Sludge
from Hanford K-West Fuel Storage Basin**

Abstract No. 12195

Roger Quintero*, Sahid Smith*, Mike W. Johnson**, Richard Raymond**, Dennis Hamilton**, Neal Sullivan**, Eric Erpenbeck**, and Wally Rutherford**

*U.S. Department of Energy, Richland Operations Office, Richland, Washington 99352

**CH2M HILL Plateau Remediation Company, Richland, Washington 99352

ABSTRACT

In 2011, significant progress was made in developing and deploying technologies to remove, transport, and interim store remote-handled sludge from the 105-KW Fuel Storage Basin on the Hanford Site in south-central Washington State. The sludge in the 105-KW Basin is an accumulation of degraded spent nuclear fuel and other debris that collected during long-term underwater storage of the spent fuel. In 2010, an innovative, remotely operated retrieval system was used to successfully retrieve over 99.7% of the radioactive sludge from 10 submerged temporary storage containers in the KW Basin. In 2011, a full-scale prototype facility was completed for use in technology development, design qualification testing, and operator training on systems used to retrieve, transport, and store highly radioactive K Basin sludge. In this facility, three separate systems for characterizing, retrieving, pretreating, and processing remote-handled sludge were developed. Two of these systems were successfully deployed in 2011. One of these systems was used to pretreat Knockout Pot (KOP) sludge as part of the 105-KW Basin cleanup. Knockout pot sludge contains pieces of degraded uranium fuel ranging in size from 600 μm to 6350 μm mixed with pieces of inert material, such as aluminum wire and graphite, in the same size range. The 2011 pretreatment campaign successfully removed most of the inert material from the sludge stream and significantly reduced the remaining volume of KOP product material. Removing the inert material significantly minimized the waste stream and reduced costs by reducing the number of transportation and storage containers. Removing the inert material also improved worker safety by reducing the number of remote-handled shipments. Also in 2011, technology development and final design were completed on the system to remove KOP material from the basin and transport the material to an onsite facility for interim storage. This system is scheduled for deployment in 2012. The prototype facility also was used to develop technology for systems to retrieve remote-handled transuranic sludge smaller than 6350 μm being stored in underwater containers. After retrieving the sludge, the system will be used to load and transport the sludge for interim storage. During 2011, full-scale prototype systems were developed and tested to a Technology Readiness Level (TRL) 6 as defined by U.S. Department of Energy (DOE) standards. This system is scheduled for deployment in 2013. Operations also are scheduled for completion in 2014.

INTRODUCTION

The 105-KW Basin, used to store spent nuclear fuel, is situated about 274 m (300 yd) from the pristine Columbia River on the Hanford Site in south-central Washington State. Highly radioactive sludge containing up to 300,000 Ci of actinides and fission products remains from the long-term storage and degradation of spent nuclear fuel. The sludge is being stored in temporary containers in the KW Basin. [1]

By definition, sludge is material that can pass through a 0.64 cm (0.25-in) screen; larger pieces are defined as fuel or fuel scrap. As of 2009, the sludge was stored in three types of receptacles: large underwater temporary storage containers called engineered containers, ten 3 m (10-ft)-long underwater cylindrical settler tubes, and several underwater filter canisters called knockout pots. The sludge varies from submicron sized uranium oxide particles to 0.64 cm (0.25 in) or smaller pieces of uranium metal. [2]

Retrieving, processing, transporting, and storing the K Basin sludge represents a significant technical challenge, resulting from the varied physical, radioactive, and chemical properties of the sludge. Physically, the sludge is a highly abrasive non-Newtonian solid with densities ranging from 1 to 19 kg/L. Its radioactive properties caused by degradation of irradiated fuel elements, result in radiolysis and potential criticality concerns. The sludge also contains hazardous chemicals and the continuing corrosion of uranium metal produces hydrogen and uranium oxides. A further complication is that the sludge is stored under water at the bottom of a 5 m (17 ft) basin. [3] Meeting this challenge required developing innovative technologies and techniques.

METHOD

Settler Tank Retrieval

As part of KW Basin cleanup, the accumulated sludge needed to be removed from ten 0.5 m diameter by 5 m long settler tanks, shown in Figure 1 below, and transferred approximately 45 m to an underwater container for sampling and waste treatment. The abrasive, dense, non-homogeneous sludge was the product of washing corroded nuclear fuel. It consists of uranium metal, uranium oxide, and other constituents as particles smaller than 600 μm that have potentially agglomerated or become cohesive after 10 years of storage.

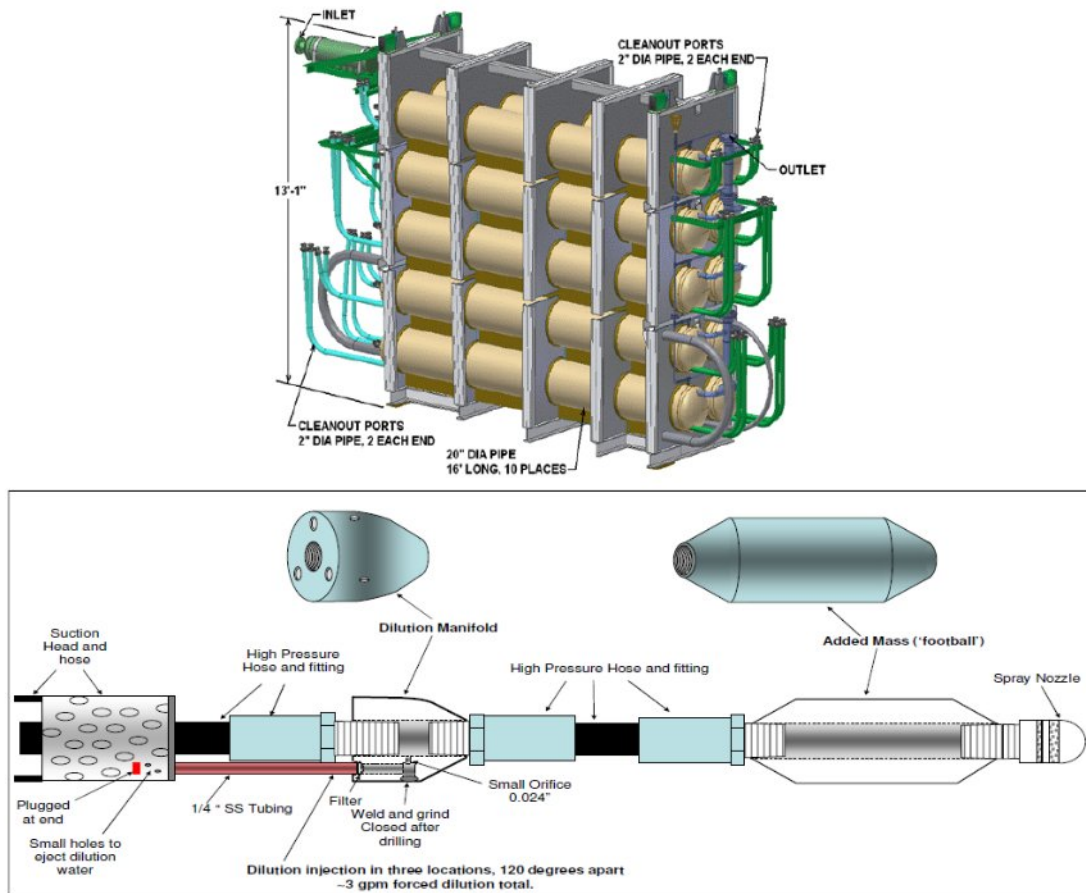


Fig 1. Settler Tanks & Settler Tank Retrieval Tool.

The Settler Tank Retrieval System (STRS) was developed to access, mobilize, and pump the sludge from each tank using a standardized process of retrieval head insertion, periodic high-pressure water spray, retraction, and continuous sludge pumping. Remote operations were guided by monitoring flow rate, radiation levels in the sludge stream, and solids concentration. The technology developed and employed in the STRS can potentially be adapted to empty similar problematic waste tanks or pipes that must be remotely accessed to mobilize and retrieve the sludge within. In 2010, the STRS was deployed to successfully retrieve over 99.7% of the radioactive sludge from the settler tanks.

Unique Retrieval Head (Suction and High-Pressure Spray Head Assembly)

Spray nozzles used for clearing plugged pipes are used commercially in the sewer and pipeline cleanout industries. Nozzles are readily available that effectively mobilize sludge and provide burrowing thrust to move a hose down a pipe. Typically, dislodged solids can be removed from a pipe simply by inserting a hose into the top of the pipe and pumping out at a high flow rate. However, the combination of very dense sludge and large "pipe" diameter make it impossible for this approach to overcome the sludge

settling velocity. As a result, a suction device must be co-located with the sludge mobilization spray.

Development of such a device focused on a retrieval head design that carried both the spray nozzle and the suction device in one assembly. An iterative development and testing process with attention to all design constraints was undertaken to obtain a flexible retrieval head assembly. The resulting configuration is shown in Figure 1.

Key features of the retrieval head are as follows:

- **Flexibility.** The retrieval head must be able to pass through the 50 mm-diameter cleanout pipe 90-degree sweep. The design meets this requirement by using sections of flexible (high pressure) hose to link segments of rigid parts, as seen in the lower section of Figure 1.
- **Spray Nozzle.** Nozzles with various sizes and numbers of orifices set at a variety of angles were tested to optimize both sludge mobilization and thrust to self-propel the head to the end of the tank. The selected commercial spray nozzle contains thirteen 0.69 mm (0.027-in) orifices (4 facing backward at a 45-degree angle, 8 facing backward at a 25-degree angle to horizontal, and 1 facing forward). The orifices are sized to operate at 200 bar (~3000 psi) to achieve maximum cleaning effectiveness. The water being ejected under high pressure through the backward-facing nozzles provides thrust to advance the retrieval head down the tank.
- **Stabilization Mass.** This added mass enables the retrieval head to go down the tank without veering off course or curling back on itself when spraying.
- **Dilution Manifold.** A small percentage of the high-pressure water is bled off and directed into the suction screen as dilution water to reduce the potential for hose plugging.
- **Suction Screen.** A stainless steel perforated screen with 0.64 cm (0.25-in)-diameter holes is located approximately 40 cm (16 in.) behind the spray nozzle and connected to the outer coaxial hose. The inner high-pressure water hose passes through a hole on the end of the screen. Development testing with sludge simulants showed that the backward-facing orifices would “throw” the high-density solids back to this location. Therefore the screen was located for optimal efficiency. Although the settler tanks were not supposed to contain any solids larger than 0.64 cm, the potential existed for agglomerations that could plug the system if allowed to enter.

Full-Scale Prototype Facility Construction

In 2011, a full-scale prototype facility was completed. The facility is being used for technology development, design qualification testing, and operator training on systems for retrieval, transport, and storage of K Basin sludge.

To design and develop the one-of-a-kind systems needed to retrieve, mobilize, and capture K Basin sludge, full-scale rigorous hardware testing and development were essential. The U.S. DOE contractually required the Sludge Treatment Project to obtain a TRL 6 before starting fabrication, installation, and operation of the new systems and equipment needed to accomplish the mission.

DOE G 413.3-4A, Technology Readiness Assessment Guide [1], defines TRL 6 as the following: "Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing an engineering-scale prototypical system/environment and analysis of what the experimental results mean for the eventual operating system environment. Technology Readiness Level 6 begins true engineering development of the technology as an operational system. The major difference between Technology Readiness Level 5 and Technology Readiness Level 6 is the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the operating system. The prototype should be capable of performing all the functions that will be required of the operational system. The operating environment for testing should closely represent the actual operating environment."

These rigorous testing requirements called for a specialized facility in which to conduct the tests. To create that facility, the STP acquired ownership of the 437 Maintenance and Storage Facility (MASF) in calendar year 2008 before it was decommissioned. The MASF, a multi-purpose high-bay facility, supports project development and acceptance testing of sludge-handling components and systems and training of Operations personnel. The complex consists of a main building and a two-story service wing. The main building is 88 m (290 ft) long by 29 m (95 ft) wide and provides approximately 2601 m² (28,000 ft²) of area for mockup fabrication and engineering-scale testing. The entire area of the main building is serviced by a 54 metric ton (60 ton) overhead bridge crane with a 9 metric ton (10 ton) auxiliary hoist. The main building is divided equally into high and low bay sections with heights of 32 m (105 ft) and 15 m (49 ft), respectively. The high-bay section is serviced by a 115-ton overhead bridge crane with a 25-ton auxiliary hoist and below-grade cells for specialized test activities. The high- and low-bay overhead cranes incorporate control circuit interlocks to prevent movement of either crane unless one crane is in the stowed position. The two-story service wing is physically separated from the main building by a rated fire wall. The process equipment room, process control room, personnel support areas, and main lobby are located on the first floor of the service wing.

The second floor of the service wing includes office space, a lunch/conference room, and the mechanical equipment room. The mechanical equipment room contains major heating, ventilating, and air conditioning equipment such as the air handling unit, return air fan, return air high-efficiency particulate air filters, and the energy recovery unit.

To meet the contractual requirements and the testing fidelity needed to satisfy the TRL 6 requirements, modifications to the facility were needed. The project entered into a fixed price construction contract for the modifications. The contract scope was to modify the existing MASF to create a mock-up of the KW Basin pool structure for future underwater testing activities. The work scope included removing 2 existing inert vessels, each 15 m (40 ft) long and 4 m (12 ft) in diameter, located in an 18 m (60-ft)-deep cell under the facility operating deck. Once the tanks were removed 15 m (40 ft) of controlled-density fill were poured into the cells to achieve a final operating surface (30 cm [1 ft]-thick concrete slab with water stops) placed at exactly 6.25 m (20 ft 6 in. from the operating deck, identical to layout of the K Basin pools. On removal of the tanks, and installation of the controlled density fill, two 1.5 m (5-ft)-thick concrete slabs

weighing approximately 99790 kg (220,000 lb) each had to be saw cut and removed from the operating deck so a single rectangular pool (5 m by 15 m [16 ft by 40 ft]) could be constructed from the two cells.

After removing the deck and internal wall separating the two cells, the pool was lined and filled with water. To cover the open pool, a superstructure that included monorail beams, trolleys, and floor grating supported by the superstructure was fabricated. This allowed operator access on top of the pool identical to the KW Basin layout. To complete the construction, a water filtration system including two pump skids was installed to maintain water quality and clarity during testing activities.

In this facility, three separate systems for characterizing, retrieving, pretreating, and processing remote-handled sludge were developed and, in some cases, deployed in 2010 and 2011.

RESULTS

Characterization Systems

The sampling system used an “isolation tube,” which is a special metal tube inserted into the sludge isolating a representative vertical core of the sludge from the sludge bed. The isolation tube has water inlet ports high above the bulk sludge bed to allow ingress of basin water during the sampling process. The isolated core of sludge was vacuum transferred with a special extraction tube or wand into a set of 4 L sample bottles located in a lead-shielded cart above the pool on the basin grating. Water and entrained sludge were vacuumed into the sample bottles.

The design of the sample isolation tubes precluded collection of any particles larger than 0.64 cm (0.25 in.) in diameter. The sample is extracted from the isolation tube and placed in the sample bottle. The sample bottles collected all the transport water required to vacuum and mobilize the sludge sample into the bottles, as well as the associated sludge solids. Suctioning started at the top of the core and the extraction tube was gradually worked downward toward the bottom of the core or isolation tube. Once a set of two bottles was filled, the sampling was stopped. If additional sludge remained to be pulled to complete removal of a core sample, additional sets of bottles were used until the extraction tube or wand reached the bottom of the isolation tube.

The sampling equipment was designed to handle high-density nuclear fuel materials, such as uranium metal (19 g/ml), as well as lower density particulate found in the K Basin sludge. The sampling system was designed and qualified in accordance with its design requirements in a set of “cold” (non-radioactive) tests. These included demonstrating recovery of at least 85 wt% of sludge material representative of the entire sludge core. The cold tests used representative sludge simulants, including materials with a range of particle diameters similar to the sludge (i.e., from 1 μm to approaching 0.64 cm [0.25 in.] in diameter), as well as densities representative of various sludge components, including the high-density uranium.

Knockout Pot Pretreatment

A system was developed and successfully deployed and operated in 2011 to pretreat KOP sludge as part of KW Basin cleanup. The KOP sludge contains pieces of

degraded uranium fuel larger than 600 μm and smaller than 6350 μm mixed with inert material such as aluminum wire and graphite in the same size range. The 2011 pretreatment campaign successfully removed the vast majority of the inert material from the sludge stream and significantly reduced the remaining volume of KOP material. Removing inert material resulted in significant waste minimization and cost reduction by reducing the number of transportation and storage containers. It also improved worker safety by reducing the number of remote-handled shipments.

Because only a limited amount of water-bearing material can be placed in the transportation and storage containers, 15 containers would have been required to load this material without pretreatment. The starting inventory consisted of 137 L of heterogeneous material with an average bulk wet density of 5.6 kg/L. The inventory of material following pretreatment consisted of 53 L of material with an average bulk wet density of 9.8 kg/L. This material can be loaded into approximately five transportation and storage containers.

The removed material consists of the following:

- 20 L of settler-type sludge, with an average bulk wet density of 3.4 kg/L collected in strainers.
- 12 L of wire, with an average bulk wet density of 3.0 kg/L to be disposed of as low level waste.
- 52 L of sludge, with an estimated bulk wet density of 2.4 kg/L collected in the settler tanks in the water treatment system.

The three phases of the pretreatment process are density separation; size reduction of low-density, friable material; and wire separation.

Density separation was achieved through the use of a density separation funnel. Density separation equipment includes a density separation funnel, dual suction wands, and a low-density retrieval strainer and pump. The density separation funnel sits over a standard fuel canister. Figure 2 below illustrates the density separation funnel.

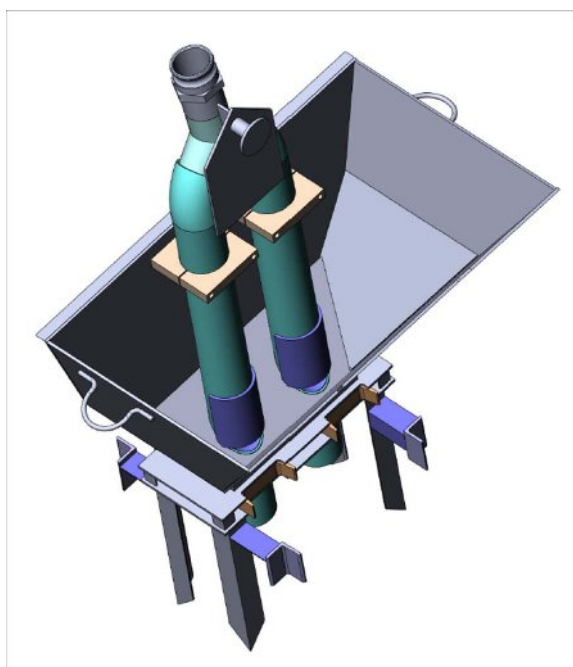


Fig 2. Density Separation Funnel.

Each suction wand extends into a canister barrel. The density separation step removed low-density material, such as Grafoil¹, aluminum wire, aluminum hydroxides, and iron hydroxides, from the KOP material stream. Removing the low-density material reduces the overall volume and increases the overall density of the product material placed into a container.

Density separation is based on particle settling characteristics, which are directly related to particle's size, shape, and density. The solids removal principle is that individual solid particles with settling rates of less than the upward flow of water through the suction wands will be removed. Conversely, solids with settling velocities greater than the upward velocity of the water will settle into the canister.

Only the low-density material removed by the density separation process was subjected to the two additional steps of size reduction and wire removal.

The size-reduction equipment consists of a screened canister, agitators, and the existing primary cleaning machine, which was designed to clean the fuel during spent nuclear fuel processing. The size reduction step physically broke down a portion of the non-uranium-based components to less than 600 μm so it could be removed from the process and captured in the Integrated Waste Treatment System.

¹ Grafoil is a trademark of Graftech, Inc., Lakewood, Ohio.

The low-density material collected in the low-density retrieval strainer during density separation was transferred via a funnel into a screened canister with the same overall dimensions as a standard K Basin double-barreled canister so it could be placed in the primary cleaning machine. The difference between the screened canister and the standard canister is that, rather than solid walls, the screened canister cylinder walls, bottoms, and lids are fabricated with nominal 600 μm stainless steel wedge wire screen. Wire separation was devised because aluminum wire was present. The wire broke off some fuel canisters with wire mesh bottoms. The wire pieces that were retained in the KOP material inventory were typically up to 3.18 cm (1.25 in.) long and 0.16 cm (0.0625 in.) in diameter. In addition to reducing the density of the KOP material, the wire caused challenges in handling and loading the material.

The wire separation device was designed to allow small particles to pass through the device, while retaining the wire. However, because the material staged for wire separation consisted almost entirely of wire, the device tended only to separate longer wire from shorter wire. Both the material retained by the device and its product stream were determined to be debris.

Engineered Container Retrieval

The prototype facility, shown in Figure 3 below, also was used in 2011 for technology development of systems to retrieve remote-handled transuranic sludge stored in underwater containers with particle sizes less than 6350 μm and load the sludge into containers for transportation and interim storage. During 2011, full-scale prototype systems were developed and tested to TRL 6.



Fig 3. Engineered Container Retrieval and Transfer System Prototype.

Sludge is retrieved from the KW Basins by using a newly developed XAGO HydroLance and its associated pump skid. The HydroLance is a combined fluidizer and jet pump system. An adjustable annular jet pump provides both suction and motive force to move the slurry; a low-pressure Coanda fluidizer head entrains solids at the suction end of the HydroLance. The HydroLance has a set of high-pressure nozzles used to break up high-shear-strength materials.) The retrieval system pump skid is fitted with two booster pumps, connected to the Hydrolance. The fluidizing pump provides water through the Hydrolance at up to 159 L/min (42 gal/min) and 1127 kg/cm (385 lb/in²). The motive flow pump is rated for a capacity of 155 L/min (41 gal/min) at 623 kg/cm (213 lb/in²). The system has check valves (safety-significant systems, structures, or components) to prevent sludge back-flowing into the ion exchange module (IXM) water service header, is supplied with basin IXM water.

Retrieved sludge slurry is transferred to a booster (peristaltic) pump via a 3.8 cm (1.5-in.)-diameter flexible hose. The booster pump is needed to overcome pressure loss in the over 76 m (250-ft) of in-basin flexible hose and 11 m (35 ft) change in elevation to deliver sufficient solids concentration in the retrieved sludge slurry to the Sludge Transport and Storage Container (STSC). Sludge is transferred at nominally 5 vol% solids and approximately 264 L/min (70 gal/min).

Retrieved sludge is transferred to a STSC located in a sludge transport system cask on the transport trailer. After each sludge transfer, the line is flushed with 1.5 times the line volume of water (approximately 189 L [50 gal]) into the STSC. The hose-in-hose slurry transfer line connects to an STSC. A coaxial hose-in-hose connector, mates to the container nozzle. The connector includes integral leak detection.

After the STSC is filled with a batch of retrieved sludge slurry, the sludge slurry is allowed to settle by gravity for approximately 16 hr. A turbidity probe is installed in the STSC to indicate whether the suspended solids content is low enough to decant the supernate. Flocculant can be added to the supernate to facilitate sludge settling.

Once the supernate turbidity has reached acceptable levels, supernate is decanted from the STSC and transferred through a sand filter back to the KW Basin. The process is repeated until the required mass of sludge has been transferred to the STSC. Following retrieval of the final batch of sludge, the solids captured in the sand filter are back flushed into the STSC.

At mission end, the sand filter media will be retrieved from the sand filter to a separate STSC, which also will be transported to T Plant for interim storage because the sand filter media will likely contain residual sludge particles. All water used in the sludge transfer process is recycled back to the KW Basin except for the relatively small amount left in the STSC to provide radiation shielding.

The STSC will be transported to T Plant for interim storage. After interim storage, sludge will be retrieved from the STSCs for final packaging for long-term storage at the Waste Isolation Pilot Plant. Several tools have been developed to facilitate removal of sludge from the STSC. One retrieval tool, which is permanently installed inside the STSC, uses direct suction in conjunction with a mobilization spray nozzle to pull sludge out of the STSC. The tool is connected to a water supply line that provides dilution

water to the tool during sludge transfer. A high-pressure pump provides fluidization water to mobilize the sludge for transfer.

DISCUSSION

The U.S. DOE, Richland Operations Office, has developed a road map, the 2015 Vision [2], for finishing the cleanup activities on the 570 km² (220 mi²) River Corridor portion of the Hanford Site by the year 2015. The 2015 Vision reflects the desire shared by officials of the DOE, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology to protect the Columbia River from contamination originating at the Hanford Site. As part of the plan, approximately 500 facilities will be decommissioned, deactivated, decontaminated, and demolished; approximately 1,000 waste sites will be remediated; and approximately 1.4 metric tons of waste and debris will be sent to the Site's landfill, the Environmental Restoration Disposal Facility. Expediting removal of the sludge from the KW Basin and transferring it away from the Columbia River Corridor provides a lower risk path forward in support of the DOE's 2015 Vision; removes an environmental, safety, and health risk to the public and the Columbia River; and supports the DOE Environmental Management's Environmental Strategic Goal 4.1, Environmental Cleanup: Complete cleanup of the contaminated nuclear weapons manufacturing and testing sites across the United States [3]. The technology development, testing, and training programs established at the MASF have been instrumental in advancing processes and systems to remove sludge from the KW Basin.

REFERENCES

1. HNF-1728, 1998, *Analysis of Sludge from Hanford K West Basin Canisters*.
2. DOE/RL-2010-52, 2011, *Remedial Design and Remedial Action Work Plan for the K Basins Interim Remedial Action: 105-K West Basin Deactivation*.
3. DOE/RL-2010-63, 2011, *Remedial Design and Remedial Action Work Plan for the K Basins Interim Remedial Action: Removal of K Basin Sludge from the River Corridor to the Central Plateau; and Removal of Knockout Pot Contents*.
4. DOE G 413.3-4A, 2011, *Technology Readiness Assessment Guide*, U.S. Department of Energy, Washington, D.C.
5. DOE, 2011, *The 2015 Vision Hanford Site Cleanup*, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
6. DOE-EM, 2006, *U.S. Department of Energy Strategic Plan*, U.S. Department of Energy, Washington, D.C.