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A COMPARISON OF CHALLENGES ASSOCIATED WITH SLUDGE REMOVAL, TREATMENT & DISPOSAL AT SEVERAL SPENT FUEL STORAGE LOCATIONS

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
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A Comparison of Challenges Associated with Sludge Removal, Treatment and Disposal at Several Spent Fuel Storage Locations

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ABSTRACT

Challenges associated with the materials that remain in spent fuel storage pools are emerging as countries deal with issues related to storing and cleaning up nuclear fuel left over from weapons production. The K Basins at the Department of Energy's site at Hanford in southeastern Washington State are an example. Years of corrosion products and piles of discarded debris are intermingled in the bottom of these two pools that stored more 2,100 metric tons (2,300 tons) of spent fuel. Difficult, costly projects are underway to remove radioactive material from the K Basins. Similar challenges exist at other locations around the globe. This paper compares the challenges of handling and treating radioactive sludge at several locations storing spent nuclear fuel.

INTRODUCTION

The disposition path for spent nuclear fuel is an issue around the globe. Without an available disposal route through geological repositories or reprocessing facilities, many nuclear complexes use wet storage as a default solution to their spent-fuel-storage issues until alternate paths become available. Wet storage facilities for spent fuel are placed in service using assumptions for design life and fuel conditions available at the time of initial operations. It is possible, however, that as disposal pathways via geological repositories are postponed and reprocessing facilities experience operating delays, wet storage will be required beyond the original planned design life.

According to the International Atomic Energy Agency (IAEA), *"At the end of 2004 there were over 400 operational nuclear power plants in IAEA Member States. There were also 274 research or test reactors in operation, as well as ten under construction and six planned. In addition, there are 97 independent power reactor storage facilities, wet and dry, that are not directly attached to a reactor building and 57 away from reactor spent fuel storage facilities at research reactors. The need to understand and manage ageing of systems, structures and components has emerged as a priority as the ages of these storage facilities increase, in some cases well beyond their originally expected lifetimes."* (Ref. 1)

First-generation spent fuel storage facilities, put in service at the dawn of the nuclear age, are now being decommissioned. At the time these facilities began operations, design assumptions typically included a 20-year operating period. These assumptions proved false, as the wet storage basins have remained in service long after their assumed 20-year design life. Examples include wet-storage basins in the United States, the United Kingdom, France, and Russia. In the United States, the K Basins at the Hanford Site in Washington State are prime examples, as are the spent fuel pools at the Idaho National Engineering and Environmental Laboratory (INEEL), also in the U.S, Marcoule in France, and Sellafield in the United Kingdom.

HANFORD K BASINS

The two K Basins spent fuel storage facilities at Hanford, Washington, were placed into service in the 1950s as temporary holding facilities for spent fuel from the K reactors. Each K Basin measures 38 meters (125 feet) by 20 meters (67 feet) and holds 4 million liters (1.1 million gallons) of water. The basins were originally unlined concrete with a design life of 20 years. The K East (KE) and K West (KW)

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defense production reactors were shut down in 1971. When the last of the Hanford reprocessing facilities went into refurbishing shutdown between 1972 and 1983, the storage capacity for the spent fuel exceeded that available at Hanford's N Reactor fuel storage basin. After minimal upgrades, the KE basin started receiving N reactor fuel in 1975. The fuel was shipped and stored in open containers originally designed to dissipate heat after discharge from a reactor. Corrosion was not expected to be an issue when the fuel canisters were designed because of the planned short turn around time prior to processing. (Ref. 2)

With the KE basin approaching capacity and the reprocessing facility still not available, the KW basin was prepared to receive fuel in 1981. Though the focus was still on short-term storage, the KW basin was modified to incorporate lessons learned at the KE basin. For example, the KW basin was drained and sealed with epoxy to make the surface less porous and make it easier to remove surface contamination. Water filtration and heat-exchange systems were also installed. In addition, the fuel canisters were upgraded to include a closed lid with an ability to vent gas generated during storage.

When the Hanford reprocessing facility was placed on standby status in December 1990, the K basins were left holding the United State's largest concentration of stored spent nuclear fuel. The KE basin held 3600 open canisters, while the KW basin hosted some 3800 canisters – a total of 2,100 metric tons of heavy metal.

A significant fraction of the fuel stored in the KE Basin degraded due to breaches of the cladding that occurred not only from physical handling during reactor discharge, but also from corrosion during long-term underwater storage in open canisters. Over time, corrosion products from degrading fuel rods, storage racks, concrete basin walls, organic material and environmental particulates accumulated as sludge in fuel canisters, on the floor, and in the pits of KE Basin (see Figure 1). Sludge in the K Basins is defined as material less than 0.635-cm (0.25-inch) diameter.



Fig. 1. Hanford's 105 K East Basin had badly corroded fuel (left) and sludge (right).

In addition to sludge, a significant amount of other debris accumulated in the two K Basins over the years. Radioactive contamination was initially contained within the water of the basins and the operating spaces were relatively free of contamination. Equipment or waste material that came into contact with the contaminated water tended to stay in the water to avoid contaminating the operating area. In other words, a conscious decision was made to not impact immediate plans by pausing to establish contamination areas and airborne-radiation areas for removing broken tools and debris. As a result, these items were routinely dropped into the basin for later disposition.

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Over the years, water has leaked from the KE Basin through a construction joint. This release of radioactive material to the environment has increased the urgency for removing the fuel, sludge, debris and water from the KE Basin so that it can be demolished and the soil under the facility can be remediated.

Removing fuel from the K Basins and placing it in dry storage took slightly less than four years: December 2000 to October 2004. Fuel was first transferred from the KE to the KW Basin before cleaning and drying operations began. Then the dried fuel was transferred to a separate facility for storage pending shipment to the national spent fuel repository. The transfer of fuel, as well as the cleaning operations added sludge to the inventory of the KW Basin. Though pieces of fuel accounted for over 99% of the basin's curie content, approximately 50 cubic meters of sludge remained to be removed before the basins could be demolished.

Depending on its location, sludge in the K Basins can contain from 4 % to 90% uranium metal by weight. Particles of uranium metal in the sludge can exist up to 0.635-cm (0.25-inch). Sludge in the KW Basin contains a higher concentration of radionuclides due to fuel cleaning operations that occurred there.

Sludge began to be removed from the KE Basin in October 2004. The sludge-retrieval process uses submersible pumps to pump sludge to newly constructed submerged steel containers. Operators handle debris and manipulate specially designed vacuum heads with long pole tools from a grating suspended above the basin water. The pumping system includes a strainer to ensure material greater than 0.635 cm (0.25-inch) does not reach the containers. The containers include components designed to minimize carryover of finer sludge particles back into the basin water. These components include an inlet distribution manifold, flocculent injection system, and sloped settler tubes on the tank top where water flows out of the tank.

Retrieving the sludge from the KE Basin has been more difficult and has taken longer than originally predicted. The first major challenge that had to be overcome was higher levels of airborne radioactivity resulting from work that disturbed the fuel and the sludge. This situation evolved from occasionally requiring respiratory protection to a full-time requirement. Using respiratory masks and hoods increases preparation times, limits work stay times and reduces worker productivity.

The second significant challenge was a loss of visibility from the operating deck. When the sludge was agitated, the water became murky and workers could not see the working end of their long-pole tools. The challenge was largely overcome by using underwater cameras connected to monitors at the working deck level. Working with cameras and monitors has also slowed progress and increases resource requirements. An additional worker is required to manipulate the camera position, and worker movements are slowed as they operate via remote viewing systems.

The most significant challenge, however, has been separating the debris material from the sludge. The quantity of debris found in the KE Basin sludge-debris matrix was much greater than expected, and it interfered with the ability to vacuum sludge. The project ultimately learned that to remove the sludge, debris must be removed; and to see all of the debris, sludge must be removed. The problem became akin to an archeological dig in reverse, as the goal was to remove the small material and leave items larger than 0.635-cm (0.25-inch). To overcome the debris-interference problem, the project delayed retrieving sludge and focused on removing large pieces of debris to make the sludge more accessible. In addition, several specialized "end effector" vacuum heads were designed to effectively vacuum a wide variety of sludge and debris mixtures.

After the sludge in the KE Basin has been collected in engineered containers submerged in the KE Basin, it will be pumped to new submerged containers in the KW Basin via a hose-in-hose system. The hose-in-hose transfer system began operating in October 2006. Sludge in the KW basin will also be vacuumed into new containers where it will be stored pending treatment.

Sludge from the K Basins must be treated due to its high Uranium metal content with the potential to generate hydrogen gas in excess of limits during planned shipment to the Waste Isolation Pilot Plant (WIPP). Treatment will include heating the sludge under moderate pressure to accelerate corrosion of

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uranium metal to extinction, and then grouting the sludge in 208-liter (55-gallon) drums. The resulting waste will be disposed of as remote-handled transuranic (RH-TRU) waste. In general, transuranic waste is radioactive waste containing more than 3700 Becquerels (100 nanocuries) of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years. Approximately 1300 drums are estimated to result from the treatment of K Basin sludge.

INEEL CPP-603

The Idaho National Engineering and Environmental Laboratory (INEEL) CPP-603 Fuel Receiving and Storage Facility went into operation in 1952. It was one of the first facilities operating in what was then the Idaho Chemical Processing Plant (the name was changed to the Idaho Nuclear Technology and Engineering Center [INTEC] in 1998).

CPP-603 has three interconnected water-filled basins (north, middle and south). The north and middle basins are 18 meters (60 feet) long, 12 meters (40 feet) wide, and 6.5 meters (21 feet) deep. The storage basins and interconnecting canals are unlined concrete and contain about 5.3 million liters (1.4 million gallons) of water.

Over its operating period, CPP-603 held a variety of irradiated metallic (aluminum, zirconium and stainless steel) clad fuels. The fuel came from a variety of sources: the Experimental Breeder Reactor-II operated by Argonne National Laboratory-West at INEEL, nuclear Navy operations, the three test reactors operated at the Test Reactor Area, and other government reactors at INEEL and around the country. When reprocessing facilities at the INTEC were shut down in 1992, transfers from CPP-603 stopped. (Ref. 3)

The north and middle basins stored spent fuel suspended from a monorail on hangers that kept the fuel in the proper location. Over the years, the carbon steel hangers and fuel containers corroded significantly. The south basin kept the spent fuel units in racks that sat on the basin floor. By 1996, all the fuel had been removed from the north and middle basins by transferring fuel that was still in good condition to the new pool at CPP-666, and by consolidating the fuel that needed additional treatment in the south basin. The remaining fuel in the CPP-603 basin was repackaged into new storage cans or buckets and transferred to other facilities. Between 1994 and April 2000, 1,340 units of spent fuel were transferred.

Undissolved solids from desert sand and dust, corrosion particles, metal particles from past cutting operations and dead microorganisms created sludge on the bottoms of the CPP-603 basins. Approximately 42 cubic meters (1467 cubic feet) of sludge required disposition. The uranium content of the sludge was less than 0.1% by weight, and there were no large uranium particles. Therefore, hydrogen generation was not a concern for waste disposal.

The initial baseline for cleanup of CPP-603 sludge assumed workers would clean the basins using long-pole tools. Industrial divers, however, were found to be a more cost effective and safer solution (Ref 4). Sludge was removed by pumping, with divers manipulating local vacuuming tools. Approximately 50,000 kilograms (110,200 pounds) of sludge was removed from the CPP-603 basin in April 2006 (Ref. 5). The sludge was dewatered, grouted, and disposed of as low-level radioactive waste. Transuranic radioisotope content of the grouted sludge averaged 9.25 Becquerels (0.25 nanocuries) per gram.

MARCOULE

The UP1 reprocessing plant commissioned at Marcoule, France in 1958 handled roughly 20,000 metric tons of fuel from gas-cooled and research reactors. UP stands for "*usine de plutonium*" (plutonium factory). The UP1 plant ended commercial reprocessing in December 1997.

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Storage basins #7 and #14 are among the oldest storage facilities located at the Marcoule Nuclear Fuel Decladding Building. Basin #7 is 7.3 meters by 4.6 meters and 6.78 meters deep with a volume of 200 cubic meters. This basin is covered with a 1-meter thick concrete slab. Its walls and floor are covered with an epoxy coating. Approximately 45 cubic meters of sludge was stored in Basin #7. Basin #14 is slightly larger: 9.8 meters by 4.9 meters and 7.6 meters deep with a volume of 357 cubic meters. A 1.5-meter concrete slab covers the basin and it is lined with a stainless steel liner. Approximately 71 cubic meters of sludge was stored in Basin #14.

The Marcoule sludge consists mainly of graphite and zeolites with some iron oxide, magnesium oxide, ion-exchange resins and diatomaceous earth. Uranium content ranges from 1% to 6% by weight.

Recent projects have been successful in removing sludge from these basins. Sludge was removed by pumping through a 350-meter long pipe and consolidated in safer interim storage basins. The retrieval process utilized a suction head that included water spray nozzles to locally mobilize sludge. The vacuum head was manipulated through a shielded movable plate and rotating sphere device mounted in the basin cover plate. The pump is submerged and all above basin piping is shielded. This configuration minimizes the need for operator protective equipment, such as respirators.

Before the sludge-pumping system was put into service, a full-scale demonstration test was conducted and the proven system was installed in 2004 in Basin #14. Average retrieval rates up to 600 kg of sludge per day were achieved. The sludge will be grouted using an advanced batch-grouting process. (Ref. 6)



Fig. 2. Operators pumping sludge at Marcoule required little protective equipment. (Ref. 6)

SELLAFIELD PILE FUEL STORAGE POND

The Pile Fuel Storage Pond (PFSP) began operations in 1952 as an open-air storage and cooling facility for the United Kingdom's Windscale Pile military reactor fuel. Operations at the pond included the receipt, storage and removal of the outer casing (known as decanning) from fuel elements from early U.K. reactors.

Increasing need for commercial nuclear power generation resulted in larger-capacity facilities for recycling fuel and the 100-meter-long PFSP was superseded by the larger Magnox Storage and Decanning Facility in 1962. The PFSP was then used to store intermediate-level waste (ILW) together with some other fuel. Operations ceased in the 1970s.

The volume of sludge in the PFSP is estimated at 325 cubic meters. The PFSP sludge contains a significant proportion of biologically derived material such as guano, algae and wind-blown debris.

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Analysis of sludge samples indicates that it generally contains lower radionuclide content than other Sellafield sludge.

The U.K.'s Nuclear Decommissioning Authority (NDA) has made the cleanup of the sludge in the Pile Fuel Storage Pond a priority and the Nuclear Installations Inspectorate (NII) has instituted a regulatory specification that requires 90% of the sludge (300 cubic meters) be removed to interim steel containment tanks by August 2009. Recent progress on cleanup has been made with the installation of a local effluent treatment plant (LETP), capable of cleaning 125 cubic meters of pond water per day. Future plans call for installing a local sludge treatment plant (LSTP) adjacent to the PFSP. The LSTP will include shielded tanks to store the sludge prior to treatment (Ref. 7).

SELLAFIELD MAGNOX STORAGE AND DECANNING FACILITY

The First Generation Magnox Storage and Decanning Facility (MSDF) operated from 1959 to 1985. It stored irradiated Magnox (magnesium oxide) fuel in a 140-meter-long concrete open-air pond before stripping the fuel of its cladding (decanning) prior to reprocessing at a separate Sellafield facility (Figure 2). The facility handled approximately 2.5 million fuel elements, or 27,000 metric tons of fuel. It received its last batch of fuel in 1992.

In the mid 1970s, Magnox Reprocessing Plant outages coupled with increased throughput of fuel used for generating electricity resulted in fuel residing in the open-air pond longer than expected. This extended residency resulted in increased corrosion and significant quantities of sludge, higher levels of radiation, and extremely poor underwater visibility in the pond. Pond activity levels in MSDF in the 1970s were as high as 10^6 Megabecquerels per cubic meter (Ref. 8).

Actions were taken to counter problems associated with the sludge, including washing the fuel before decanning, and using ion-exchange resins to reduce radiation levels in the pond water. These actions were only partially successful. The MSDF continued to operate under difficult conditions until a replacement facility was commissioned in 1986. An estimated 1,200 cubic meters of sludge accumulated in the MSDF pond (Ref. 9).

Poor visibility and high radiation and contamination conditions that exist in the MSDF pond make inspection and monitoring using conventional methods difficult. Remotely operated submersible vehicles (ROVs) were used to assess the condition of stored fuel, sludge, debris, radiation levels and structural conditions. More than 5,000 hours of video footage was generated, providing valuable information to help develop the plan for removing the pond's contents. The survey showed that the fuel was in better condition than expected and engineers were able to prototype the retrieval process on a selected container, or "skip" of fuel (Ref. 10, 11).

A container of fuel has been transferred to the Sellafield Fuel Handling Plant to test this method of removal for reprocessing, as has a container of sludge. Knowledge of the residual fuel and sludge inventory has been enhanced by deploying an ROV. The MSDF pond contains approximately 400 metric tons of decaying spent fuel debris; 1,200 cubic meters of highly radioactive sludge; and 1,500 cubic meters of solid ILW scrap (Ref. 9).

Current plans are to remove the MSDF sludge to local temporary steel containment vessels to await future treatment and disposal. The significant quantity of spent fuel still in the pond must be moved repeatedly within the basin to allow access to sludge material.

Sludge treatment processes have not yet been defined. A range of technologies are currently being evaluated, including high temperature vitrification, immobilization in grout matrixes (both in drum and out of drum mixed) and sludge drying followed by high force compaction. The technology selection is due during 2007. The facility to receive and treat the waste streams is planned for 2015 operations, and it is likely that the waste will stay at the Sellafield site in a new storage facility.

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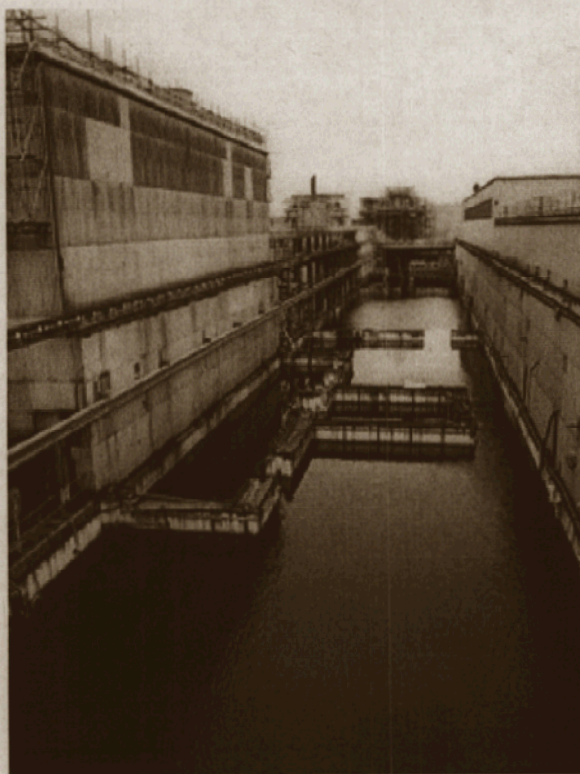


Fig. 3. The MSDF pond at Sellafield is not enclosed. (Ref. 7)

CONCLUSION

Review of several first-generation storage basins for spent fuel reveals a wide range of physical characteristics (Table 1), and a collection of commonalities. The basins vary widely in size, radionuclide content, and level of containment. Typically, fuel was stored much longer than originally planned due to a lack of exit paths to reprocessing or disposal facilities. Original designs did not anticipate fuel residence times or corrosion products at the levels experienced. Given the increasing amount of spent fuel in wet storage in international nuclear facilities, and the uncertainties related to waste repositories and reprocessing facilities, it is likely that we will continue to hold spent fuel in wet storage beyond durations originally planned.

Operational practices commonly accepted during historical operations, such as dumping debris into the storage pool, become unacceptable in hindsight and make cleanup more difficult. In most cases, it is impossible to understand the extent of debris material in the sludge matrix without digging it out. Poor record keeping and the inherent variability associated with long-term corrosion make accurate knowledge of sludge constituents difficult. Sampling of the material is costly and physically challenging due to material properties, locations and dose rates. The result of these variables is an increase in the uncertainty of key parameters needed to accurately plan cleanup activities. Regulatory agencies are elevating priorities for cleanup of these basins, adding pressure to accelerate cleanup schedules and driving project managers to find innovative solutions to these complex challenges.

It is therefore important not only to share cleanup experiences and lessons learned during sludge retrieval, treatment and disposal with similar ongoing cleanup efforts at first generation storage basins, but to incorporate lessons learned into management strategies for newer spent fuel wet storage facilities.

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Table 1. Comparison of Sludge Parameters at Selected Spent Fuel Storage Facilities^a

Site	Hanford		INEEL	Sellafield		Marcoule	
Location	Washington, USA		Idaho, USA	Cumbria, UK		Gard, France	
Basin Name	105 KE	105 KW	CPP-603	MSDF	PFSP	Basin #7	Basin #14
Year operations began	1955	1955	1952	1952	1959	1958	1958
Water Volume (megaliters)	4.16	4.16	5.3	13.7	16	0.2	0.36
Sludge Density (kg/m ³)	1400	2400	1187	1500	1055	933	775
Sludge mass (metric tons)	58	26	50	1560	343	42	55
Sludge Volume (cubic meters)	42	11	42	1200	325	45	71
Uranium (metric tons)	4.2	12.8	0.005	46.8	0.2	2.4	0.3
Uranium % by wt.	7.2%	49%	0.01%	3%	0.07%	6%	1%
Sludge Treatment	Hot Water Oxidation, Grouting	Hot Water Oxidation, Grouting	Grout	TBD	TBD	Grout	Grout
Waste Class	RH-TRU	RH-TRU	LLW	ILW	ILW	Interim Storage	Interim Storage

^a Table 1 contains approximations due to variability and uncertainties in sludge and is based on best available information.

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