DESIGNING AND CONSTRUCTING HANFORD’S WASTE TREATMENT PLANT - CHALLENGES AND PROGRESS IN THE NATION’S LARGEST CONSTRUCTION PROJECT

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ABSTRACT

There are many challenges in the design and construction of the Department of Energy’s (DOE’s) $5.7 billion Hanford Tank Waste Treatment and Immobilization Plant (WTP) that is rising above ground at the Hanford site. Being built to process radioactive waste from cold war plutonium production operations contained in 177 underground tanks, engineering is about 85% and construction is at about 45% complete. The project, comprised of 3 large process buildings - the Pretreatment (PT) facility, High Level Waste (HLW) facility, and Low Active Waste (LAW) facility, is scheduled to complete construction in 2008 and hot commissioning in early 2011.

Design challenges have included staffing for and performing extensive design for a close-coupled design/construction project, completion of the process design with a large confirmatory testing program, and the successful employment of the “black cell” design approach involving operating spaces for which no entry in a process cell is presumed in 40 years of plant operation.

Construction on the 57-acre site started with first concrete in July 2002. Ultimately some 250,000 cubic yards of concrete with 40,000 tons of rebar and 27,000 tons of embeds will be placed and 200 miles of mostly small-bore piping will be installed in the three facilities [1]. A key construction hurdle is installing the mazes of piping associated with the process vessels. Many vessels have 30 to 40 piping penetrations on the head, creating very congested areas for installation and inspection and the need to use advanced examination techniques.

Other challenges specific in the PT facility include proving that the resin used in the crucial cesium ion exchange process will perform adequately, use of fluidic pulse jet mixers (PJMs) on high rheology non-Newtonian wastes, and the precision installation of remote jumpered equipment in the hot cell. In LAW, the fabrication and installation of the huge melters is a challenge, and in HLW the design and testing of the remotely operated and maintained melters is a key challenge.

INTRODUCTION

On the Department of Energy’s (DOE) Hanford site, a few miles west of the Columbia River 53 million gallons of radioactive and chemical wastes from cold war plutonium production are stored in 177 underground tanks. At least a million gallons of this waste has leaked. The DOE has awarded Bechtel National, Inc. (BNI) a 10-year, $5.7 billion contract to design and construct the world’s largest radioactive waste treatment plant to turn the waste into glass and place it in stainless steel canisters for safe and permanent disposal. The WTP will process some 50 million gallons of radioactive waste from 177 underground tanks. Engineering is about 85% and construction is at about 45% complete. The plant is well along in construction (Figure 1) and is scheduled to complete hot commissioning in early 2011.

Fig. 1. Lifting a 475,000 gallon feed receipt vessel into the pretreatment facility

The Waste Treatment Plant (WTP) is comprised of three main facilities: The Pretreatment (PT) facility performs separation and concentration of the waste received from the underground tanks. The High Level Waste (HLW) Vitrification facility immobilizes the high level fraction of the waste in glass using melters. Similarly, the Low Active Waste (LAW) facility vitrifies the low-level waste fraction. A large separate analytical lab building performs all the process chemistry analyses necessary to ensure good glass is being produced.

This paper reviews the general challenges that have been encountered in designing and constructing the facilities and examines some specific and novel challenges in each of the three main process facilities relating to process systems design, equipment design, equipment fabrication, and equipment installation.

General Challenges

Some key general design challenges include supporting a close-coupled project, completion of the process design incorporating input from the research and test program, and the design of no-access "black cells".

With the start of the current project in January 2001 based on an advanced conceptual design and no site work, the design must support the completion of the plant and completion of hot commissioning in early 2011. The design output some covers some 250,000 cubic yards of concrete with 40,000 tons of rebar and 27,000 tons of embeds, 200 miles of mostly small-bore piping, design and procurement of 100 large, high-alloy vessels, and the development of an extensive integrated control network. To meet the end date the design is "close-coupled" to construction: design of upper elevations in the buildings is in progress as the lower elevations are being built. This requires careful planning and the imposition of some compensatory measures

when not all of the information needed to complete the design is available at the time the design is released for construction. The schedule also required a rapid ramp-up from the 300 or so engineers that had worked on the conceptual phase of the project under a previous contractor to over 1300 engineers a year after contract award.

The facility process design has been under development for years, but the final design details and design confirmation are in the WTP project scope. An extensive research and technology (R&T) program supports the project to provide confirmatory information for the various processes. An R&T group manages this effort and uses the services of Battelle in Richland, and the Savannah River National Lab (SRNL) in South Carolina. The engineering department works closely with the R&T group to ensure the test information being developed supports engineering needs that the test results are correctly interpreted, and that occasional adjustment from the testing program is properly implemented in the design. One key testing effort has been the operation of the LAW pilot melter. The pilot is full-scale in height and width and one-third in length. Operation over several years has proven the design and provided valuable design information for the melter-associated systems.

"Black cells" are operating spaces for which no entry is presumed in 40 years. While concept is employed extensively at British Nuclear Fuels Limited's (BNFL) Sellafield facility, it is novel in the American nuclear complex. The advantage is a considerably reduced plant footprint and the elimination of a large amount of remote handling equipment for major capital cost savings. In compensation, limits are placed on what is in such cells: all components are passive and nothing that will require examination, maintenance, or replacement is located in the cells. Extra measures are specified to assure equipment reliability, such as extensive non-destructive examination of welds and materials. Engineering performs extensive evaluations to ensure that process conditions and material selections will preclude equipment degradation or failure.

The large concrete, steel, and piping quantities noted above present a big challenge to build on an aggressive schedule, with all major facilities under construction simultaneously. Construction on the 57-acre site started with first concrete in July 2002. Key construction hurdles include installing the mazes of piping associated with the 100 large process vessels. A combination of stick-built and modular construction is being employed to achieve piping installation rates necessary to stay on schedule.

Many vessels have 30 to 40 piping penetrations on the head, creating very congested areas for installation and inspection. Performing nondestructive examination in such congested spaces requires the development and proof of novel and leading-edge approaches including vacuum-box testing in lieu of hydrostatic testing in some cases, and the use of automated ultrasonic testing (AUT) rather than radiography.

In summary, there are considerable design and construction challenges in the three facilities: a demanding design effort, R&T input developed for all three facilities, black cell design in the PT and HLW facilities, and large amounts of concrete, rebar, and pipe that need to be designed and installed on all three.

There are additional challenges specific to each of the facilities. In Pretreatment, major challenges include developing an effective and reliable cesium ion resin, qualifying pulse jet mixers for high-rheology non-Newtonian service, and accurately positioning and installed hot cell equipment. In LAW the major challenge is the design and installation of the world’s largest radioactive waste melters. In HLW, a principal challenge is the design and installation of a remotely maintainable melter. Each of these is discussed in more detail below.

Pretreatment Facility

This facility receives the waste from the tank farm and preconditions it for delivery to the melter plants. LAW feed is concentrated by an evaporator, excess cesium is removed in an ion exchange system, and then the feed is further concentrated in another evaporator before delivery to the LAW facility. HLW feed is first washed and leached to remove unwanted non-radioactive constituents then filtered to concentrate the feed. Cesium extracted from LAW feed is added to the concentrated HLW stream. PT is sized to produce feed to support production of 6 metric tons of HLW glass and 80 metric tons of LAW glass per day.

The PT footprint is the size of two football fields and is arranged with a central hot cell the length of the building The hot cell houses the maintainable equipment (pumps, valves, etc.) for the cesium ion exchange system, the ultrafiltration system, and the evaporators. The hot cell is surrounded by black cells on both sides that contain the process tanks.

Three of the significant challenges in PT are:

- Proof of viability of the cesium ion exchange process
- Qualification of PJMs for mixing of process vessels
- Precision installation of remotely-maintained equipment in the PT facility

These are discussed below.

Cesium Ion Exchange Resin

A cesium ion exchange system removes excess cesium from the LAW feed stream. WTP uses a unique proprietary elutable organic ion exchange resin called Superlig®644 [2]. The resin has not been used on a commercial scale before and several key issues needed to be resolved to confirm technical adequacy and to complete the design. These included:

- Showing the resin meets the design throughput requirements for cesium (Cs) removal for the different waste streams
- Demonstrating adequate resin durability, chemical and radiological, and determining gas generation rates under various process conditions

- Demonstrating that the resin can be manufactured in large quantities with batch-to-batch consistency necessary to meet the resin performance and usage predictions
- Confirming that spent resin can meet land disposal requirements and have sufficiently low residual Cs content to qualify as low-level waste

The testing program also helped develop the final requirements of the column design, including the length-to-diameter or aspect ratio, resin expansion pressures, and flow direction (a fully flooded downflow design is used), and fluid volume above the bed (to allow slurrying of the resin for removal). Testing also indicated that upflow bed expansion after regeneration is helpful to remove fines and reset the bed which and extends the useful resin life.

Twenty-eight separate investigations were conducted over several years by the Savannah River National Laboratory (SRNL) and the Battelle Pacific Northwest Division (PNWD) to resolve the issues identified above. The result showed that the resin will perform adequately: Cs is removed sufficiently in each of the waste streams, the resin holds up and maintains acceptable hydraulic characteristics, it can be commercially manufactured, and the spent resin can be land-disposed [3]. Based on these results the ion exchange system equipment is being procured. Separately, DOE has asked WTP to investigate the use of an alternate resin that will work in the same equipment. That effort is underway.

Pulse Jet Mixers

Mixing is required in the waste receipt and processing vessels to keep solids suspended and to avoid a dangerous buildup of hydrogen in the waste that is evolved in the waste. There are some 38 vessels in black cells that require mixing. A proprietary passive mixing technology is employed using the PJMs. A PJM is simply a cylinder with a conical nose pointing downward in the vessel. The vessel contents is drawn up into the cylinder under vacuum and then expelled under air pressure. A typical suction/discharge cycle may take several minutes. Sensors detect the end of the discharge cycle and terminate the discharge before air exits the PJM avoiding an "overblow".

PJMs have been used very successfully at British Nuclear Fuels Limited (BNFL) Sellafield facility since the 1970's. With no moving parts and a simple design, they are very reliable and ideally suited for black cell applications. The preponderance of experience with PJMs has been with dilute Newtonian fluids. At WTP, 33 of the vessels contain Newtonian fluids. The adequacy of the mixing design (the number, size, arrangement, and discharge velocity of the PJMs) is confirmed using computational fluid dynamics (CFD).

Five of the PJM-mixed vessels contain non-Newtonian fluids, which like ketchup, develop an appreciable shear strength or "gel" when the fluid is not moving. Mixing these fluids is more of a challenge and CFD analysis is insufficient to confirm adequate mixing. Accordingly, the WTP developed a testing program to finalized and confirm the design. This program first did tenth-scale testing using a clear clay simulant and then did large-scale confirmatory testing at a Battelle PNWD facility near the project offices in Richland, Washington. A photo of the large-scale PJM array being installed in the 10,000-gallon test tank is shown below (Figure 2).

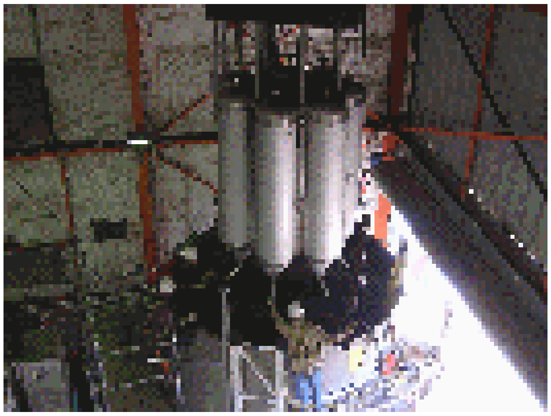

Fig. 2. PJM test assembly being installed in test tank.

The testing program revealed that the most efficient design for non-Newtonian applications was to use a combination of PJMs and sparger tubes [4]. The PJMs provide off-bottom suspension while the sparger tubes (typically 30 per vessel) keep the upper regions turbulent. The testing showed the combination of PJMs and spargers provided very good mixing with a good deal of mixing overlap. A crucial test was to simulate the production of hydrogen within the liquid (using hydrogen peroxide) and measure how fast the gas would be released after mixing was started from a gelled condition. The results showed the gas was released very quickly, confirming the safety function is achieved quickly once mixing is started or resumed.

Pretreatment Remotely Maintained Equipment

Another challenge is the precision installation of remote jumpered equipment in the PT hot cell. Some 550 rigid and 1100 flexible jumpers are employed in the design to make the fluid, electrical and controls connections to processing equipment. A process equipment platform and wall nozzle platform approach was developed to facilitate the installation and fit-up of the rigid jumpers with the equipment and wall penetrations in the cell [5].

This equipment in the hot cell will become contaminated with radioactive materials to a point where remote handling is required. To facilitate the remote handling and maintenance activities, the process equipment will be mounted on removable skids called process equipment platforms (PEPs). Remotely removable and replaceable process piping, services (water, air, etc.), and electrical wiring for power supply, instrumentation, and controls (collectively referred to as jumpers) connect the process equipment to permanently installed nozzles located on the PT facility hot cell walls.

Nozzles on both the process equipment and the walls must be placed to close tolerances to ensure reliable mating. Wall nozzle platforms (WNPs) will be used to simultaneously locate multiple nozzles along the wall to machine shop tolerances with the placement of one WNP.

Figure 3 below illustrates the basic configuration of a PEP, WNP, process equipment, jumpers, and associated positioning and retention features.

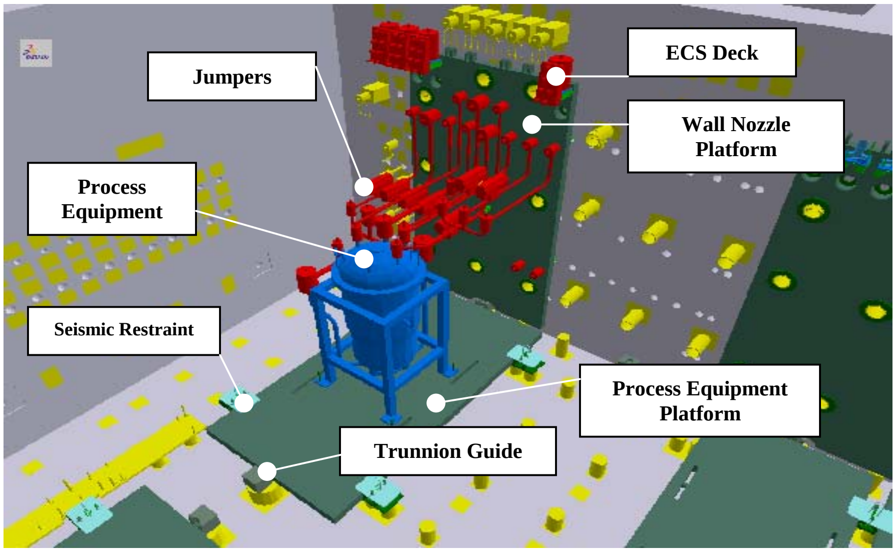

Fig. 3. PEP/WNP configuration.

PEPs provide a remotely replaceable structural mounting surface for process equipment, and jumper supports within the PT facility hot cell. The process equipment varies in size from small pumps up to 30 ton Reboilers. Each PEP has been permanently mounted, locating dowels and threaded studs for securing the process equipment and associated jumper supports [6].

There are a total of 36 PEPs in the hot cell and all are 21 feet long. There are three widths that vary between 9 and 12 feet. All PEPs feature a carbon steel structure with stainless steel cladding for decontamination and corrosion resistance.

WNPs provide the ability to accurately locate a large number of process, service, and electrical nozzles on the hot cell walls with the placement of one item. WNPs are permanently mounted and reduce the volume of precision fieldwork necessary to achieve the desired nozzle placement accuracy and precision.

There are 29 WNPs in the hot cell that come in three heights between 19 and 21 feet. They are either 11feet-9 inches or 12feet-9 inches wide. The number of WNPs required is less the number of PEPs since they are only used in areas where there were enough nozzles to justify the use of a WNP rather than individual nozzle boxes. The construction combination of carbon steel with stainless steel cladding is similar to the PEPs.

A variety of nozzle types and sizes are attached to the WNPs. In general, any pipe end on the face side of the WNP is referred to as a nozzle. Nozzle types include PUREX remote clamp connectors, and flanged connections specially modified for use in remote environments.

The electrical connector support (ECS) decks provide a platform for the location and support of an electrical nozzle for connection of remote electrical jumpers.

Trunnion guides are permanently installed items that provide a method of establishing location and orientation of PEPs. Trunnion guides located near the hot cell wall also provide a common locating point between the PEPs and its associated WNP. Each of the PEPs has two trunnion guides.

Law Facility - Melter Fabrication and Installation

The LAW facility houses two melters sized to produce 15 metric tons of glass per day. Feed is received by pipeline from the PT facility, mixed with glass formers in the LAW facility, and then fed to the melters. The melters boil off the water in the feed and create a homogenous blend of melted glass formers and sodium and radioactive constituents in the feed. The offgas in the melter headspace is highly toxic and is cooled and treated before exhausting from the stack. The glass is poured into 6-ton cylindrical stainless steel containers, which, after cooling, are capped and decontaminated. The containers are then trucked to a disposal trench on the Hanford site and buried.

As the construction phase ends in mid-2008 the melters will be installed. After assembly on site, the melters will be rolled into the facility for installation.

The two LAW melters are the largest radioactive waste melters ever developed at 330 tons each (empty). Shown in Figure 4, they are nearly 30 feet long, 16 feet high and 21 feet wide and weigh 330 tons empty. The LAW melters are locally shielded and have an integral containment and radioactive shield surrounding the inner refractory-lined glass pool. They have a nominal life of five years and must be moved to install and replace them [7].

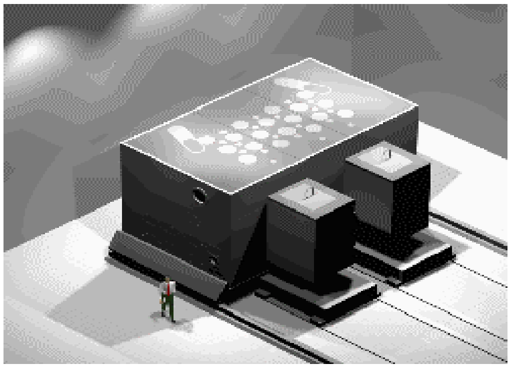

Fig. 4. LAW melter

The melters were designed by (Duratek Technical Services) and BNI has contracted a fabricator to pre-assemble components of the melters using the Duratek drawings. The fabricator will preassemble and ship the base and wall assemblies, the lids, and the cooling panels. BNI construction forces will complete the assembly at the site.

Installation of the refractory will be by a specialty contractor to perform the precision installation of the refractory bricks and some final in place refractory casting.

The melters are assembled in a weather enclosure adjacent to the LAW facility on rails that lead to their final position within the building. After a melter is assembled, it is rolled into the building on the rails [8]. The facility is designed around the melters so that a new melter only needs to be moved horizontally, never lifted.

Moving the melter is challenging because of the weight and the fact that the refractory bricks are placed together but not bonded together in any way. This is because the refractory has to expand as it heats up. The refractory design involves leaving precision gaps in to allow the bricks to expand and not become damaged or leave leakage paths for the melted glass. Consequently, movement of the melter is in accordance with strict limits on acceleration (no greater than 0.1g) and deflection (62 mils maximum combined deflections on the rails and 1/16" corner to corner relative vertical racking). The 28-foot gauge rails are designed to support these requirements, being made of high alloy, high strength head-hardened steel that are nearly four feet tall by six inches wide.

Once the melters have been secured in position in the building, they are "plugged in" to the interfacing systems. This involves connecting 25 pipes and ducts, 162 flex hoses, and 63 electrical connections for each melter. As noted above, the melters are locally shielded allowing personnel access to the melter during operation. The feed tanks and offgas systems are located in shielded rooms behind the melters.

Once the melters are installed they are baked out to remove any moisture in the refractory. Next they are loaded with glass frit and energized (consuming over 1 megawatt each during production). Once a melter is heated up, it must remain hot with the glass pool melted.

HLW Facility – Remotely Installed and Maintained Melter

The HLW facility houses two melters sized each to produce 3 metric tons of glass per day. Feed is received by pipeline from the PT facility, mixed with glass formers in the HLW facility, and then fed to the melters. As with LAW, the water in the feed is boiled off in the melter and a homogenous blend of melted glass formers and the radioactive constituents in the feed is created. The glass is poured into 2-foot diameter by 14 feet high cylindrical stainless steel canisters, which, after cooling, are capped and decontaminated. The containers are then trucked to an interim storage facility on the Hanford site pending shipment for final disposal at the national high-level waste depository in Nevada.

The same as LAW, as the construction phase ends in mid-2008 the melters will be installed. After assembly on site, the melters will be rolled into the facility for installation.

The two HLW melters are comparable in size to other high-level waste melters at West Valley and the Defense Waste Processing Facility (DWPF). The HLW melters are located in shielded melter cells, as their radioactive levels require remote operation. The same as LAW, they have a nominal life of five years and must be moved to install and replace them [9].

These melters are also designed by Duratek and are fabricated and assembled in the same fashion as described for the LAW melters above [10]. The difference is that the ability to remotely maintain the melters and eventually remove them requires demonstration of that capability before hot operations can commence.

The melter caves are equipped with various remote handling equipment - an overhead crane with a power manipulator attached, and through-wall manipulators. Shield windows and television camera's are provided for viewing. The adequacy of the remotable design is first confirmed during the design phase using IGRIP™ software operating on the 3-D design model that confirms that viewing capability is adequate to observe the various remote operations. The IGRIP™ simulation also confirms that the remote equipment can access the places it needs to without interference from other items installed in the cell. The software also quantifies the time it takes to perform a given remote evolution.

The design activities provide substantial assurance that the remote design will function correctly. Nevertheless, all remote operations, including melter installation and removal, will be demonstrated during the startup testing phase: the melter will be installed, connected to other equipment, disconnected, and removed all using the remote equipment. Remote operations planned or possible during plant operations are also confirmed. These include replacing thermowells and bubbler tubes on the melters, and servicing the mixing equipment on the feed vessels.

The melter caves also contain the melter feed preparation vessel (where the glass formers are added) and the melter feed vessel, as well as the offgas equipment including the submerged bed scrubber and the high-efficiency mist eliminator (HEME). Between the scrubber and (HEME) is a wet electrostatic precipitator (WESP), located in a cell above the melter cell. Some 200 connections are provided, through jumpers, to connect the melters to this equipment. As above, the ability to perform these connections and disconnections remotely is first checked during design and then confirmed in startup.

Progress Summary

Process Confirmation Status

The process development and confirmation program is largely complete; the design is confirmed, with some design details continuing to be worked out. Some follow-up R&T is in progress examining an alternate cesium ion exchange resin and some issues related to hydrogen hazards in the facility.

Design and Procurement Status

Overall, design is about 85% complete. The civil/structural, mechanical, and piping design is on track to be largely complete at the end of 2005. Piping design is currently some two years ahead of installation. The electrical and controls an instrumentation design will be largely complete at the close of 2006. More than 80% of all bulks and equipment procurements have been placed and materials and completed equipment are steadily arriving at the site.

Construction Status

Construction is proceeding steadily:

- All major buildings (PT, HLW, LAW, and the Laboratory) are above grade and the second elevation above grade is proceeding on PT.
- Many of the major process tanks have been received and some are placed, including the four 475,000 gallon feed receipt tanks.
- Piping assemblies are being delivered and installed.

The project is on track to complete on schedule in early 2011.

CONCLUSIONS

There are considerable challenges in the design and construction of the nation's largest construction project underway at the Department of Energy's Waste Treatment Plant on the Hanford site. Some of these are described above. As described in this paper, in each case the project has met the various challenges and developed effective design and construction approaches to keep the project on track to completion in 2011. The challenges to date are more in the design, R&T, and procurement arenas. Future challenges will grow in completing the construction and completing the extensive startup and cold and hot commissioning; planning for these is already underway.

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