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Revision 0

Lessons Learned From Cleaning Out The Sludge From The Spent Fuel Storage Basins At Hanford

ICEM-07

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

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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LESSONS LEARNED FROM CLEANING OUT THE SLUDGE FROM THE SPENT FUEL STORAGE BASINS AT HANFORD

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ABSTRACT

Until 2004, the K Basins at Hanford, in southeastern Washington State, held the largest collection of spent nuclear fuel in the United States Department of Energy (DOE) complex. The K East and K West Basins are massive pools – each holding more than 4 million liters of water – that sit less than 450 meters from the Columbia River. In a significant multi-year campaign that ended in 2004, Fluor Hanford removed all of the fuel from the two Basins, over 2,300 metric tons (4.6 million pounds), dried it, and then placed it into dry storage in a specially designed facility away from the River.

Removing the fuel, however, did not finish the cleanup work at the K Basins. The years of underwater storage had corroded the metallic uranium fuel, leaving behind a thick and sometimes hard-packed layer of sludge that coated the walls, floors and equipment inside the Basins. In places, the depth of the sludge was measured in feet rather than inches, and its composition was definitely not uniform. Together the Basins held an estimated 50 cubic meters of sludge (42 cubic meters in K East and 8 cubic meters in K West). The K East sludge retrieval and transfer work was completed in May 2007.

Vacuuming up the sludge into large underwater containers in each of the Basins and then consolidating it all in containers in the K West Basin have presented significant challenges, some unexpected. This paper documents some of those challenges and presents the lessons learned so that other nuclear cleanup projects can benefit from the experience at Hanford.

INTRODUCTION

The K Basins are two 4 million liter concrete pools that were built to temporarily store spent nuclear fuel from former plutonium production reactors. The Basins are indoor, concrete rectangular pools 38 meters by 20 meters, and are located about 56 kilometers north of Richland, Washington, on the DOE's Hanford Site. They sit less than 450 meters from the Columbia River.

Until 2004, the K Basins held the largest collection of spent nuclear fuel in the United States Department of Energy (DOE) complex, over 1.8E6 TBq (50 million curies) of radioactivity. Removal of over 100,000 fuel elements was safely completed in late 2004. The 2,100 metric tons (4.6 million pounds) of fuel were placed into dry storage. Fluor then turned its focus on the remaining sludge.

However, removing the fuel did not finish the cleanup work at the K Basins. Years of underwater storage corroded the fuel, leaving behind radioactive sludge that was a mixture of windblown sand, fuel-corrosion products, spalled concrete, rocks, work debris, metal rack and storage canister corrosion products, and ion-exchange resin beads. In addition, the fuel-cleaning process itself generated sludge that had concentrated radionuclides.

An estimated 50 cubic meters of sludge were contained in the Basins (42 m^3 in K East and 8 m^3 in K West). Sludge retrieval began in K East in October 2004 and was completed in October 2006. Sludge transfer from K East to K West began in November 2006 and was completed in May 2007. Sludge retrieval is in process at K West and will be completed by January 2008.

NOMENCLATURE

DOE	United States, Department of Energy
HiH	Hose-in-hose
KBC	K Basins Closure
TBq	TeraBequerels
UT	Ultrasonic Test

Retrieval and transfer of the K East sludge provided many valuable lessons. Fluor and its subcontractors, with support and participation by the DOE customer, conducted several formal and informal lesson learned sessions. Discussed below are several of the key lessons learned.

- Fast track project caused less than adequate planning and estimating
- Erosion testing, contingency planning and erosion monitoring provided much needed operational flexibility
- Pump fouling resulted from less than adequate clearances for the maximum particle size
- Dilution and mobilization of the sludge was more of a technical challenge than anticipated
- Schedule recovery efforts were effective at mitigating delays caused by technical issues

The original scope for the K Basins Sludge Project was to design and fabricate a retrieval and storage system to retrieve sludge from the K Basins and package it in containers that would be stored at Hanford's T Plant for later treatment (~2015 time period). Originally, the treatment of the 50 cubic meters of sludge was planned to be encompassed within the treatment of over 2000 cubic meters of other Hanford waste. Thus, the K Basins Project competitively sought and awarded in October 2003, a contract to design and fabricate the Sludge Retrieval and Storage System. This contract was for the design of a system to retrieve K East and K West sludge into Large Diameter Containers for shipment and interim storage at T Plant for later treatment.

Simultaneously, DOE performed a review of the T Plant facility for this work. Based on that review, DOE urged that the sludge be handled only once and be treated sooner rather than later. DOE also questioned the use of the aging T Plant facility for this new mission. In response to the DOE's request, Fluor embarked on a revised plan to only send the low radioactivity sludge (about 4-6 cubic meters of sludge in the North Load Pit area of K East) to T Plant for direct grouting (no oxidation of uranium metal). For the remaining sludge, Fluor and DOE decided to consolidate the remaining sludge underwater in the K West basin (one kilometer away from the K East Basin) for later treatment.

The K West Basin was selected to receive the sludge since the basin was never known to have leaked The K East Basin had leaked millions of gallons of contaminated basin water to the underlying soil in the early 1980s and early 1990s. This made it a priority to empty the K East Basin, demolish the basin and begin remediation of the underlying contaminated soil.

Fluor began to evaluate three options to transfer the sludge from the K East Basin to the K West Basin. The three options considered were:

1. Transfer the sludge in small rectangular boxes (about 0.5 cubic meters in size) inside the already designed and built fuel transfer cask.
2. Transfer the sludge via dilute slurry and pumping through a hose-in-hose (HiH) pipeline.
3. Pump the sludge into larger containers at K East and transfer in a special transfer cask.

Fluor chose option two due to the following major factors:

1. The HiH technology was being used on the Hanford Site for transfer of High Level Tank Waste and was accepted by the DOE customer and regulators.
2. A substantial amount of nuclear safety analysis foundation existed from the tank waste nuclear safety basis.
3. Pumping operations were expected to be the least labor intensive method of transfer

During this evaluation and selection process, design was proceeding on the retrieval system and Large Diameter Containers. By December 2003, Fluor had briefed DOE on the options and was moving toward option two. In January 2004, the subcontractor delivered an informal design of the original design, minus the T-Plant portion. In March 2004, Fluor revised the SOW by adding the K East to K West Basins sludge transfer system scope using HIH design and to provide a preliminary study on sludge treatment options. Since the 60% informal design-review deliverable for the balance of the original contract scope had been submitted, Fluor and subcontractor agreed that the HIH design would only be subjected to a 30% and 90% design review.

A new project plan (baseline), shifting the project to Option 2, was developed from January to May 2004. In parallel, Fluor began to modify the subcontract to build containers and transport the sludge to T Plant. It was systematically modified to be a subcontract to transfer the sludge to the K West basin via HiH.

Schedule pressure caused less than adequate planning during the baseline update in May 2004. Optimistic dates were chosen and little or no contingency was built into the new plan. This created what is referred to as a fast-track project. Fast tracking, combined with midstream, wholesale modification of the design contract from Large Diameter Containers to a HiH system set the stage for numerous project pitfalls.

Needless to say, there were significant scope changes before the 100% design was issued. More than 30 technical changes to the contract and three revisions to the statement of work were issued.

The subcontractor awarded a sole-source subcontract to fabricate portions of the HIH equipment in July 2004. Fluor received the 90% design deliverables in August 2004, after which the fabricator started planning and material purchases using the 90% design documents. The review by Fluor personnel generated many comments. Obviously, the design changes occurring due to the shift in strategy and subcontract modifications were too much for the change control process to handle. Based on the extent of 90% comments, there were significant changes between the 90% and 100% documents, resulting in major changes in fabrication of the equipment, using 100% design documents. Cost over runs and schedule delays began to develop. This situation continued to deteriorate. The fabricator had numerous questions on drawings that were not complete. Meanwhile the designer was still redlining and changing drawings to reflect design changes and Fluor comments. This was further exacerbated by the results of erosion testing.

Due to concerns over potential erosion of the flexible hose by the abrasive sludge traveling at fairly high velocities (14-16 feet per second), the subcontractor commissioned a test of the hose. In September 2004, erosion testing demonstrated that the steel braided, EPDM rubber hose withstood the erosion very well. However, the test pump failed due to erosion after only eight hours of pumping. This situation raised concerns over excessive erosion of the pump that was intended for the booster pump station of the HIH transfer lines.

Fluor corporate technical experts recommended the design be modified to use a positive displacement slurry pump to solve the erosion issue. The lead time to procure the desired positive displacement pump was nearly 18 months. There were other disadvantages of the positive displacement pump. Specifically, the high discharge pressure would cause a large jump in the quality and cost of the transfer hoses. Secondly, the high discharge pressure made the spray release accident scenario significantly worse. Due to the fast track nature of the project, and the two issues discussed above, less than adequate time was available to procure the best suited pump. The fast-track schedule allowed less than one year for equipment procurement, fabrication, installation, testing and start up.

Fluor and the subcontractor jointly decided to minimize schedule impact, and use a modified centrifugal pump. A new test pump constructed with duplex stainless steel was tested with sludge stimulant. The test results indicated that pump had much higher resistance to erosion. However, the test data predicted the pump would approach minimum wall thickness by the end of the project. Functional design criteria for the pumping system required a safety margin of two times design life. Based on this a second pump was required to be added to each of four booster stations. This installed spare could then be valved in rapidly if the primary pump approached minimum wall thickness (Figure 1). This also drove the need for installed ultrasonic (UT) probes on the eight pumps in those areas where wear was expected to be high. The addition of the second pump in each booster station, as well as the UT measurement equipment, caused another perturbation in the design and major fabrication changes. Cost increases and schedule delays continued to climb.

In late May 2005 Fluor stopped funding the design subcontract and closed out the HIH contract and assumed all subcontracts due to continued issues with cost and schedule performance. To minimize further cost overruns, Fluor accelerated reviews of final fabrication data packages and in some instances took over minor remaining fabrication work in order to have all of the equipment delivered in July 2005 for installation.

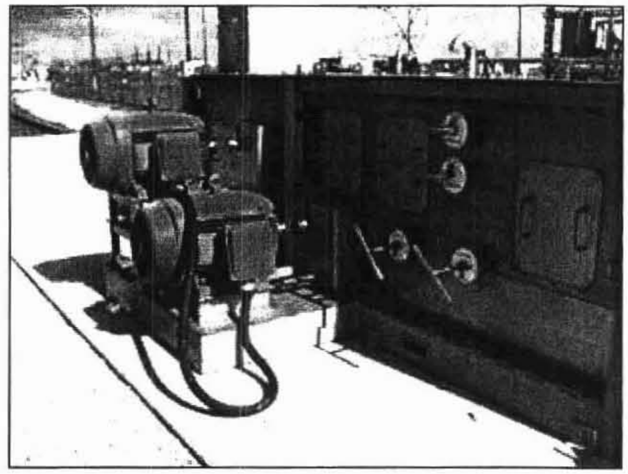

Figure 1 – Sludge Transfer Booster Station (one of four)

Based on this and other DOE projects, new DOE leadership decided that fast-track projects, especially for highly complex, first-of-a-kind projects like the K Basins sludge project, were not how DOE wanted to do business. Thus, in the fall of 2005, DOE and Fluor decided to re-baseline this project. Fluor performed a robust risk evaluation on all remaining portions of this project using Fluor's Business Risk Management Framework (BRMF) tools. A revised baseline that contained a detailed risk mitigation plan and cost and schedule contingency was delivered to DOE in November 2005. Equipment installation occurred from July 2005 to the summer of 2006. Testing and startup were completed by October 2006 and transfer of the sludge occurred from November 2006 through May 2007. After completion of this new baseline, technical challenges continued to arise; however, through the use of risk mitigation plans and contingency funding in the new baseline, the project was completed by the legal and contractual deadline of May 31, 2007. The lesson learned is to avoid fast-track projects, especially when they are complex and first-of-a-kind. Also, to avoid major shifts in technical approaches late in the planning cycle without adding adequate time for replanning and rebaselining.

The second major lesson learned was that good erosion testing, contingency planning and erosion monitoring provided much needed operational flexibility. Erosion testing indicated that the transfer pump would just reach minimum wall thickness at the end of the expected duty cycle. A safety factor of two was required by the Fluor pumping system design specification. This led to the decision to install a spare booster pump in each booster station and to allow it to be valved in from outside the booster station enclosure. The enclosure provides spray tightness in the case of an unexpected leak or rupture disk over pressurization (see Figure 1). The project also decided to install ultrasonic (UT) probes on the eight pumps in those areas where wear was expected to be high. The addition of the UT sensors would allow on line monitoring of pump wall thickness to ensure field performance was consistent with test results and to ensure the shift to the spare pump occurred prior to reaching the minimum allowed wall thickness. This contingency planning proved invaluable. The primary booster pump in Booster Station #2 was taken off line due to vibration and the secondary pump was placed in service early in the project. Thus the contingency to have a second pump for erosion protection saved the project when pump vibration arose as a technical issue. Now making this secondary pump last the life of the project without approaching minimum wall thickness was a challenge. While Booster Station #2 was open for inspection, additional UT measurements were taken to confirm that the location of the four installed UT probes did in fact represent the location of maximum erosion (which was determined in the earlier erosion tests). This revealed that there were several locations that exhibited higher wear than the installed probes. These locations appeared to coincide with the heat affected zone (HAZ) of the discharge nozzle. The base metal and weld filler erosion was low; but, the HAZ erosion was higher. This is consistent with predicted behavior for duplex stainless steel when higher heat is applied during welding. Three additional UT probes were mounted on the booster pumps to add these new areas to the monitoring scheme for a total of seven UT probes per pump housing (Figure 2).

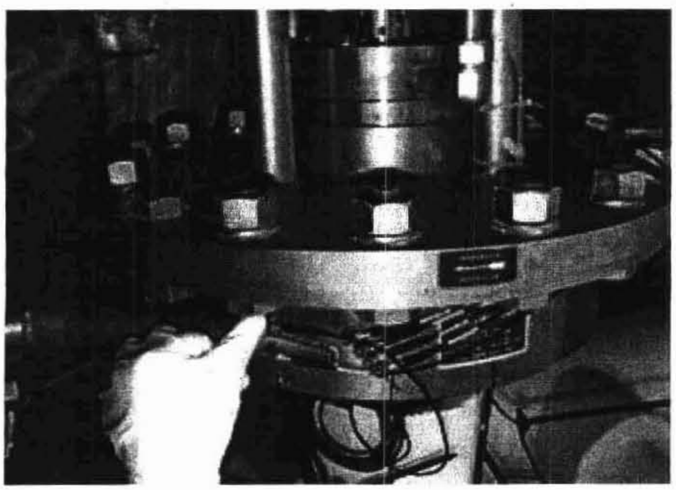

Figure 2 – Additional Ultrasonic Probes on Booster Pump

Monitoring procedures were changed to increase the frequency of monitoring. In the end, all pumps lasted to completion without reaching the allowed minimum wall thickness.

The lesson learned is that without the spare pumps the project would have taken a large delay. Without the UT probes and wall thickness monitoring, Fluor and the DOE customer would not have had the confidence in the pumps integrity to run to completion. Erosion rates were very close to that predicted by the testing program. The location of highest erosion varied slightly due to differences in the geometry and fabrication of the production pump compared to the test pump. Erosion was consistent between all production pumps indicating that geometry and fabrication techniques are consistent enough in production pumps to have little effect on erosion rates.

The third major lesson learned stemmed from the last minute changes in design to the centrifugal pumps used in the booster stations. Recall that the redesigned test pump manufactured from duplex stainless steel withstood erosion fairly well. The test pump was a smaller scale version of the pump with lower head requirements. Eight large pumps were ordered (two per booster station) with the same velocity requirement but higher discharge head. The specification required that the pump be able to pump sludge particles up to ¼ inch in diameter. Shortly after startup of the HiH system and before a significant amount of sludge was transferred, the primary pump in one booster station began to show excessive vibration. Detailed inspections of mountings, balance and a fiber-optic inspection of the internals was conducted. These inspections revealed that a bridge of deposits had formed between two vanes of the impeller (Figure 3). Additionally, the back side of each impeller blade had a build up of deposits over a short distance about three fourths of the way to the outer radius (Figure 4). This buildup appeared to be fairly uniform when comparing the five impeller blades.

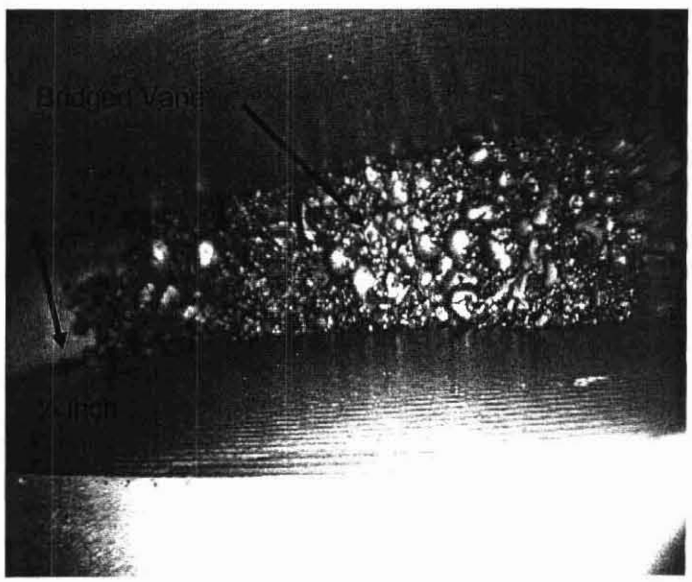

Figure 3 – Sludge Deposits Bridging Two Impeller Vanes

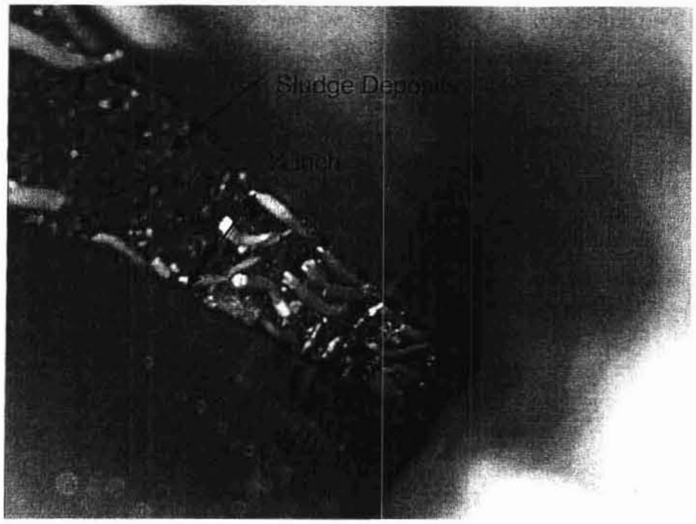

Figure 4 – Uniform Sludge Deposits on Back of Impeller Blade

In order to troubleshoot this problem, Fluor requested the pump vendor's proprietary drawings of the pump impeller. Upon receipt of these drawings, Fluor learned that the impeller clearance was only one quarter inch, not the 3/8 – 3/4 inch that would be expected for a slurry pump designed for up to 1/4 inch particles. Discussion with the vendor indicated that the clearance was reduced in order to add 1/8 inch wiper vanes on the back of the impeller. Fluor also learned that the impeller vanes had been significantly lengthened and flattened by the vendor when compared to the test pump. The pump vendor based this on his model to create the needed discharge head. Fluor commissioned finite element modeling of the existing impeller and predicted the flow vectors on the impeller blades. The finite element modeling confirmed the prediction that tangential velocities went to zero on the backside of the impeller blade. This appeared to explain the uniform deposits on the back side of the vanes; however, the uniform deposits were not likely the cause of the vibration. The bridge between two vanes was the likely initiator of the vibration. Fluor speculated that this bridge was likely caused by one or two particles of approximately 1/4 inch size jamming between the impeller blades, potentially aided by the deposit buildup on the impeller back side. Once a particle jammed, other particles began to dam up behind this and caused the bridge. Additionally, early sludge transfers were plagued by "slugging". Slugging occurred when a large slug of sludge overwhelmed the dilution controller and put a "slug" of sludge into the transfer line. The resulting pressure transient often tripped the pumps off on pressure protection interlocks that were built into the system to protect against this predicted event. In response to this discovery, Fluor put the following corrective actions in place:

1. A new impeller was designed that eliminated the low flow regime and opened up the impeller clearances to be consistent with common slurry pump clearance design guidance.
2. The spare pump was placed in service in the booster station with the fouled pump.
3. A new strainer was placed upstream of the booster stations to screen the sludge through a 3/16 inch screen. This would restore adequate clearance in the existing pumps.
4. Replacement pumps were ordered in case the new strainer failed to protect the remaining pumps. Wholesale pump replacement would be much easier than replacement of an impeller in a highly contaminated pump (dose readings inside the pump were approximately 3-5 rem/hour when the pump fouled). The first new pump was not expected for five to seven weeks.
5. Replacement impellers were ordered since the lead time was fairly short (two weeks). This was a backup plan if the other pumps fouled in the next five weeks.
6. Vibration monitoring frequency was increased and action setpoints were established for increasing vibration (>0.28 inches/second RMS demanded increased monitoring as long as vibration was increasing. >0.48 inches/second required pump shutdown).
7. Dilution control changes were implemented. This included physical system modifications as well as software settings and procedures.

The shutdown to investigate this problem and putting the above actions in place caused a loss in schedule of one full month. Replacement impellers and pumps were received but were never needed. The revised dilution control scheme greatly reduced the number of slugging events and pressure trips. This reduced the likelihood of heavy concentrations of sludge in the impellers and thus the likelihood of fouling. The reduced maximum particle size in the system due to the new strainer is also attributed with the protection of the remaining pumps.

The lesson learned in this case is to more closely monitor and inspect the work of vendors. Do not trust that they will adequately modify or scale up equipment based on their assumed expertise in their line of business. Consider full scale testing for complex projects, especially when equipment replacement and maintenance are so difficult due to high radiation fields.

The fourth major lesson learned was that Dilution and mobilization of the sludge was more of a technical challenge than anticipated. The dilution scheme consisted of:

1. A suction pipe from the tank at the bottom of the sloping portion of the tank
2. Inside the tank, a resuspension dilution lance that provided variable flow of sludge-free water close to the tank outlet
3. Outside the tank, dilution water inlet connection to inject sludge-free water in the pump suction, upstream of the dilution control valve
4. A dilution controller measuring suspended solids and controlling dilution water flow

Slurry content at the first pump (and hence downstream) was controlled by adjusting the dilution water rate.

Early operations were plagued by inconsistent slurry concentration and system trips on pump suction or discharge pressure interlocks. Fluor determined that the dilution issues stemmed either from deviations from the original design or weaknesses in the initial design. One deviation was the position of the suction pipe dilution water inlet. It was moved further from the tank outlet during system installation due to operation efficiencies that would be gained when switching the pumping hardware from tank suction to tank suction (sludge was stored in four underwater tanks in K East that were pumped in series). This condition was corrected and dilution control improved but was not solved. The second deviation occurred in the height of the resuspension dilution lance inside the tank. The lances were installed several inches too high due too integration of the design of the deck grating penetration collars (provided by Fluor) and the lances (provided by subcontract). The lances were lowered and dilution control improved further. Additionally, the dilution control valve was being overdriven in the closed direction by approximately 10%. Over time, this caused the valve operator to slip on the valve drive shaft. Investigation revealed that the input signal to the dilution control valve needed to be limited to prevent overdriving the valve operator.

The operability of the suspended solids meter and instrument control loop were also weak and needed software adjustments, timing changes and procedure modifications to tune the dilution control system performance. Once these system adjustments were completed, dilution control improved dramatically and slugging and pressure transients and system trips were reduced dramatically. Fewer slugs of sludge being sent into the pumps and the smaller maximum particle size resulting from the new strainer basket helped protect the pumps from fouling. Vibration problems were mitigated and controlled by these changes.

The lesson learned is that the design performance can be quickly lost, with significant consequences, due to small and innocent modifications. Expected schedule improvements resulting from the modifications can be completely erased by degraded system performance. Design changes resulting from less than adequate integration of facility modifications and installed equipment modifications need to be avoided via interface control documents. Any system that relies on a feedback loop will require some fine tuning and period of time to find the proper settings to avoid hunting. Lastly, when mobilizing heterogeneous sludge, consideration should be made for a stirrer or recirculation loop to achieve a more dilute and constant suspended solids concentration.

The last major lesson stemmed from the recovery effort needed to mitigate the delays caused by early problems with dilution control, slugging, pressure transients, pump trips, fouling, vibration and erosion. As previously mentioned, a month was lost in February 2007 due to the vibration issue and the added vibration and UT monitoring that resulted from the investigation and repair. In February, Fluor delivered a new working schedule to DOE that forecast a June 14 completion. This would be 14 days later than the May 31 legal and regulatory deadline for completing this work. At the same time, Fluor delivered a recovery plan to DOE that established all the actions and contingencies that Fluor would pursue to recover lost schedule. The recovery plan included numerous actions. A few of the more important actions were:

1. Establishment of a multidisciplined "war room" team, manned 24 hours a day, seven days a week to keep work planning, implementation of improvements, development of contingency plans, procurement of spares, etc, well ahead of the operational effort. The team included a senior manager who could exercise influence to spur action. The goal was to ensure that paperwork and parts were never causing a delay. This was quite effective. Dozens of contingency work packages were generated and waiting on the shelf in case of further equipment failure. Some were used, many were not. Those that were used saved many days of further delay.
2. Procurement of spares
3. Twice daily teleconferences between the war room project staff, functional support organizations (e.g. procurement) and the DOE customer.
4. Assignment of expediters to ensure spare parts were delivered and received quickly.
5. Transfer of larger particle sludge caught in the strainers by fuel transfer cask

These actions, coupled with numerous other recovery plan actions, recovered more than 14 days on the critical path and allowed the project to complete by the May 31, 2007 legal/regulatory milestone. The recovery efforts were supported well by Fluor senior management and DOE.

Recovery plans, when well planned and executed, can dramatically improve performance and recover lost schedule time. Despite numerous technical hurdles, the project personnel persevered and achieved the desired result.

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My sincerest thanks to the project managers, engineers, workers, shift managers, administrative staff and support personnel who persevered to make this project happen and overcome many technical hurdles and to the DOE customer for their faith and support.

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