This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-09SR22505 with the U.S. Department of Energy.

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Life Extension Program for the Modular Caustic Side Solvent Extraction Unit at Savannah River Site – 13179

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ABSTRACT

Caustic Side Solvent Extraction (CSSX) is currently used at the U.S. Department of Energy (DOE) Savannah River Site (SRS) for removal of cesium from the high-level salt-wastes stored in underground tanks. At SRS, the CSSX process is deployed in the Modular CSSX Unit (MCU). The CSSX technology utilizes a multi-component organic solvent and annular centrifugal contactors to extract cesium from alkaline salt waste. Coalescers and decanters process the Decontaminated Salt Solution (DSS) and Strip Effluent (SE) streams to allow recovery and reuse of the organic solvent and to limit the quantity of solvent transferred to the downstream facilities. MCU is operated in series with the Actinide Removal Process (ARP) which removes strontium and actinides from salt waste utilizing monosodium titanate. ARP and MCU were developed and implemented as interim salt processing until future processing technology, the CSSX-based Salt Waste Processing Facility (SWPF), is operational. SWPF is slated to come on-line in October 2014. The three year design life of the ARP/MCU process, however, was reached in April 2011. Nevertheless, most of the individual process components are capable of operating longer. An evaluation determined ARP/MCU can operate until 2015 before major equipment failure is expected. The three year design life of the ARP/MCU Life Extension (ARP/MCU LE) program will bridge the gap between current ARP/MCU operations and the start of SWPF operation. The ARP/MCU LE program introduces no new technologies. As a portion of this program, a Next Generation Solvent (NGS) and corresponding flowsheet are being developed to provide a major performance enhancement at MCU.

This paper discusses all the modifications performed in the facility to support the ARP/MCU Life Extension. It will also discuss the next generation chemistry, including NGS and new stripping chemistry, which will increase cesium removal efficiency in MCU. Possible implementation of the NGS chemistry in MCU accomplishes two objectives. MCU serves as a demonstration facility for improved flowsheet deployment at SWPF; operating with NGS and boric acid validates improved cesium removal performance and increased throughput as well as confirms Defense Waste Processing Facility (DWPF) ability to vitrify waste streams containing boron. NGS implementation at MCU also aids the ARP/MCU LE operation, mitigating the impacts of delays and sustaining operations until other technology is able to come on-line.
INRODUCTION

The mission of the Savannah River Site (SRS) Tank Farms is to receive, store, transfer and manage high-level radioactive liquid waste generated at SRS. The waste tanks receive radioactive liquid waste, prevent escape of radionuclides to the environment, provide salt disposal feed, and provide feed for immobilization of high level waste in vitrified glass at the Defense Waste Processing Facility (DWPF).

Since SRS began operations in early 1950, its uranium and plutonium recovery process have generated liquid radioactive waste (LRW). Currently, approximately 36 million gallons of LRW are stored in underground tanks at SRS.

The Salt Waste Processing Facility (SWPF) is a new SRS facility that is being built to utilize monosodium titanate (MST) treatment and Caustic Side Solvent Extraction (CSSX) technologies to treat the salt portion of the LRW inventory. The treatment will allow the resulting waste streams to be disposed of through vitrification at DWPF and by incorporation into grout at the Saltstone Processing Facility (SPF). SWPF is not scheduled to begin operations until 2014.

In the interim, DOE has provided direction to maximize the use of existing infrastructure to perform actinide removal and develop a CSSX capability to facilitate Tank Farm storage space gain and support continued operation of DWPF. Two existing facilities were modified to provide the Actinide Removal Process (ARP). A new facility, Modular Caustic Side Solvent Extraction Unit (MCU), was constructed to provide CSSX. Together, these facilities form the Integrated Salt Disposition Project (ISDP). A summary of this process is shown in Figure 1.

The ARP decontaminates low-curie salt solution via adsorption of strontium-90 (Sr-90), actinide radionuclides, and entrained sludge solids in the salt solution onto MST followed by filtration. The actinide, Sr-90, and MST laden sludge waste stream are transferred to DWPF for vitrification and the remaining clarified salt solution is transferred to the MCU process. The MCU process extracts Cs from the clarified salt solution using caustic side solvent extraction (CSSX) chemistry. The low Cs-137/low actinide DSS is subsequently transferred to Tank 50 for feed to the SPF, and the strip effluent (SE) solution of cesium nitrate from the CSSX process is transferred to DWPF for vitrification.

ISDP was originally expected to have a design life of five years and an operating life of no more than three years and would only stay in service until the SWPF was brought on-line. SWPF will be needed to complete processing the large salt waste inventory. The primary goals of the ARP/MCU process are to (1) treat salt solution prior to the start of SWPF; (2) dispose of less than 200,000 Ci of Cs to Saltstone (Permit value is 0.2 – 0.3M Ci); and most importantly (3) provide operational experience and lessons learned for the SWPF project. Being interim facilities, there was strong incentive to keep costs down for the design and construction of MCU.
DEMONSTRATED PERFORMANCE

The ARP/MCU process was validated during the initial first months of operation. As a first-of-a-kind nuclear operation, ARP/MCU was started up after a series of reviews to validate readiness. Operations proceeded very deliberately to ensure initial performance per the safety basis and operational requirements. “Sample and hold” requirements were enforced to ensure that all acceptance criteria would be met until confidence was established in facility baseline performance and to ensure collection of key operational data to inform SWPF design.

ARP/MCU processed an average of 23,000 gallons per month of Salt Batch 1 solution from Tank 49 with a peak performance of 64,700 gallons per month yielding a total of 142,000 gallons of salt waste processed from Tank 49 for Salt Batch 1. Improvements based upon experience and lessons learned from Salt Batch 1 reduced risk and increased productivity with Salt Batch 2 processing. Enhancements and improvements in process chemistry, process efficiency, and overall attainment / throughput resulted in record processing rates (on two occasions) of more than 40,000 gallons within one week during 2009 / 2010 Salt Batch 2 processing. In addition, the ARP/MCU process has performed better than expectations for decontamination factor requirements for Cesium 137, and solvent carryover performance. These factors are summarized in the following Table 1.

Actions taken since startup of ARP/MCU in 2008 have demonstrated an increased processing rate from the original design of 1 million gallons per year to approximately 1.4 million gallons per year. Enhancements and improvements include chemistry adjustments at tank 49, reduced cycle-times, redesign and replacement of the secondary filter at 512-S. A 12hr strike time was
implemented at ARP, along with a 6 gpm processing rate increase at MCU which reduced the overall processing cycle-time.

Table 1: Summary of Select ARP/MCU Performance Parameters

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<tbody>
<tr>
<td>Cs-137 DF</td>
<td>&gt;12</td>
<td>100-350</td>
<td>100-450</td>
<td>100-400</td>
<td>N/A</td>
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<tr>
<td>Sr-90 DF</td>
<td>54.4</td>
<td>&gt;190</td>
<td>~205</td>
<td>N/A</td>
<td></td>
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<tr>
<td>Pu DF</td>
<td>14.4</td>
<td>&gt;100</td>
<td>~139</td>
<td>N/A</td>
<td></td>
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<tr>
<td>Gallons Processed</td>
<td></td>
<td>142000</td>
<td>730000</td>
<td>684,000 (in progress)</td>
<td>~1.7M gallons</td>
</tr>
<tr>
<td>Curies Processed</td>
<td></td>
<td>~40000</td>
<td>~180000</td>
<td>~180000</td>
<td>~400K curies</td>
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Although the overall attainment has significantly improved from SB1 to SB2, equipment reliability issues have limited the overall attainment hence overall throughput. The majority of the affected equipment has been repaired, replaced, and or redesigned commensurate with the failure causes identified. Efforts continue to improve equipment reliability, reducing unexpected downtime to improve overall attainment. In addition to equipment and processing upgrades, alternative system planning is being done to more efficiently qualify subsequent salt batches to reduce downtime between batches. A summary of the downtime hours and consequent ISDP enhancements/lessons learned is shown in Error! Reference source not found.
Specific efforts to increase ARP/MCU throughput include:

- Improvements to the ARP filtration cycle to support a MCU processing rate of 2 million gallons per year, such as:
  
  - Installation of an improved ARP secondary filter with increased solids handling capacity.
  
  - Improved temperature controls increasing overall ARP filtration rate.
  
  - Improved process shutdown controls to minimize solids formation.
• Implementation of an ARP/MCU blend tank capability reducing the time for salt batch makeup outages by 5 weeks. This configuration has been deployed and proven for Salt Batch 3.

• Upgrades to shielded sampler system, eliminating the potential for sample cross contamination and thereby reducing costly re-sampling evolutions.

• Improvements to pre-filter installation and coalescer cleaning reducing the accumulation of solids, reducing coalescer pressure differential, and extending media life.

• Improvements to solvent quality controls ensuring process performance and eliminating process interruptions resulting from degraded solvent.

• Automation of control systems to be installed, improving MCU startup consistency and reducing shutdown conditions.

• Improvements to the durability of the pumps.

The combination of the completed improvements, planned improvements, and the increasing process confidence commensurate with more experience provide the basis for achieving a throughput of 2M gal/year. The ARP/MCU continues to provide valuable information to SWPF but is also functioning remarkably well as a salt processing capability in the liquid waste system.

LIFE-EXTENSION

Processing approximately 97 million gallons of salt solution from the Tank Farms is planned over the life of the program. The ARP/MCU process was constructed and permitted initially for a three-year service period, bridging the crucial period before the startup of the SWPF. SWPF will be needed to complete processing the large salt waste inventory. LW System Plan, Rev. 15 also included an Alternative Analysis to specifically assess the impact of SWPF startup being delayed to September 2015. A twenty-eight month delay in the start-up of SWPF operations would directly impact those processes that depend on expeditious treatment and disposal of salt waste. The immediate results would be a delay in the salt waste retrieval campaign, affecting at least five tanks. While this results in a day-for-day slip in accelerated waste retrieval and closure of these tanks, the tanks would still be able to meet the FFA commitments for closure. Such delay would also reduce by half the available capacity of the tank farm system to support sludge washing for DWPF feed. The result would be a canister rate reduction from the accelerated 400 canisters per year back to the current 200 canisters per year. Delays in salt removal would also delay future waste retrieval from Type III tanks.

Actions to address ARP/MCU life extension beyond the three-year period include:
• Implement process and equipment upgrades and improvements.
• Evaluate and procure spare parts.
• Adjust preventive maintenance.
• Increase equipment performance monitoring.
• Obtain appropriate regulatory approvals.

ARP/MCU will process approximately four million gallons of DSS during extended operation to April 2015, creating approximately one million gallons of tank space. The total curies disposed at SDF during interim salt processing, using the ARP/MCU process, would remain below the projection in the SRS LW Strategy and the §3116 Basis.

The design life of the ARP / MCU Cesium removal process is three years of operation which would have been reached in 2012. Due to delays in the startup of SWPF, a better understanding of the actual service life of ISDP facilities was needed. Both active and passive components form ISDP. The scope of the evaluation was the structures, systems, and components (SSC’s) that comprise the operating capability of ISDP. Active components are consumable and degrade in performance over time. They include motors, pump rotating assemblies and seals, actuators, and instruments in that nature. Passive components are not considered consumable; however, they will degrade over time. Passive components include cell coatings, building structures, tanks and vessels, piping, pump casings, heat exchangers, and etc.

Most of the individual components comprising the process, however, are capable of a longer operating life than three years. An evaluation concluded that ARP/ MCU could operate until 2015 before major equipment failure was expected. The passive process components, such as piping and structures, were determined to have service life in excess of 2025.

While the original design life basis for ISDP had been validated, extending the life of ISDP required that some process equipment be replaced due to radiological or chemical failure. ISDP operating experience has demonstrated that non-radiological/chemical issues may require shutdown and repair of process equipment more often than anticipated. Radiological and chemical issues would only lessen the ability of ISDP to meet its required availability and throughput. To successfully operate ISDP for longer than the original design life of 3 years (2012), equipment at high risk of failure should be monitored to give early warning of impending failure, i.e. motors and equipment in high radiation areas.

The MCU process vessels consist of the following: Salt Solution Receipt Tank 1 and 2, Salt Solution Feed Tank, DSS Decanter, DSS Decanter, DSS Hold Tank, Solvent Hold Tank, Strip Effluent Decanter, Strip Effluent Hold Tank and Contactor Drain Tank.
Process vessel components that are exposed to significant dose rates from high radiation include submersible pumps and their power cables, which are both located inside the tanks. Other components include flow elements, radiation sensors, electrical power and instrument cables, air operated valves, and vertical shaft pumps. The motors on these pumps are located outside the tanks but inside the process cells. The dose rates for these components can vary, depending on the activity level of material being handled in the process vessel; e.g., salt solution activity is 1.1 Ci/gal; strip solution activity is 16.5 Ci/gal. The Decontaminated Salt Solution (DSS) and Caustic Wash Streams have low radiation exposure rates. Due to the low rates for this process streams, it is possible for equipment in or near this process stream to not experience any radiological or chemical related failures. The Contactor Drain Tank (CDT), Solvent Hold Tank (SHT), Salt Solution Receipt Tank (SSRT), Salt Solution Feed Tank (SSFT) streams have moderate to high radiation exposure rates. There may be radiation-related failures to equipment located in, or near, these streams. The Strip Effluent (SE) stream would be exposed to high radiation rates, due to waste concentration potentially as high as 16.5 Ci/gallon. It was expected that equipment in this stream would experience radiation induced failures.

Motors that are designed to operate in a harsh radiation environment, such as that found in nuclear power plants, are qualified for total exposures in the range of 1 to 200 Mrad. When an electric motor receives a chronic dose of high radiation, a number of things deteriorate: lubricants, varnish coatings on the windings, lamination bondings, and motor lead insulation. It is reasonable to expect that non-hardened motors would not be able to survive a radiation exposure much beyond the lower end of this dose range. Since not all pumps were procured with a radiation hardened motor, a dose of 37 Mrad was assumed to result in motor failure. SEHT motors and wiring, near the SE Hold Tank, would receive this dose by 2015, SSRT motors and wiring in the SSRT by 2021, and CDT, DSS Decanter, DSSHT, SSFT and SHT motors and wiring would not reach 37 Mrad through 2025. SSRT wiring outside the SSRT is not expected to exceed 37 Mrad through 2025.

Motors installed at MCU were supplied with high quality poly-urea grease in sealed bearings. Most bearings were expected to last 5-6 years of continuous service (2012-2013). Taking into account two pumps being employed one in use at a time, bearings may last until 2017 to 2019, before radiological effects are taken into account before radiological effects are taken into account. This type of bearing has a radiation resistance of 10 Mrad to 100 Mrad. The Strip Effluent Hold Tank Pump Motor bearings would receive a 50 Mrad dose by 2015 (Intermittent Operation). The Strip Effluent Coalescer Pump Motor bearings would receive a 50 Mrad dose by 2015 (Continuous operation). The Decontaminated Salt Solution Hold Tank pumps are required approximately 50 percent of the time. Other process pumps are limited in use to approximately 1 to 2 hours per day.
It was estimated that between 2015 and 2017, The Strip Effluent Hold Tank Pump Motor, Strip Effluent coalescer Pump Motor and Contactor bearings would have failed. Contactor bearings would have been at risk of failures beginning 2014, as they have no alternate and run when the process operates. Bearings in the Strip Contactors would have been at increased risk of even shorter life due to their higher radiological exposure. Bearing grease would have oxidized faster in these areas, resulting in poor lubrication. Metal fatigue failures in motor bearings are not likely in intermittent use pumps and motors. However, bearing metal fatigue failure is possible in those motor bearings running continually.

The Salt Solution Feed and Receipt process streams will experience moderate radiation exposure. The pair of submersible pump motors that is located inside each Salt Solution Receipt Tank (SSRT) is potentially susceptible to radiation damage. Each motor receives a gamma dose of 389 rad per hour based on an activity level of 1.1 Ci/gal in the salt solution. This equates to a dose of 3.41 Mrad per year. Exposure of components in wetted contact with the feed solution would reach 23 Mrad through 2017. Non-wetted components will experience approximately 12 Mrad through 2025. It is possible that the SSRT pump elastomer seal might fail by 2013 due to radiation damage, and subsequently at 3 year intervals with 1.1 Ci/gallon feed material. There is also the risk of SSRT motor bearing failure as early as 2013, due to operating time and radiation dose. Salt Solution Feed Tank B Pump experienced problems in January 2009 and failed in May 2009.

The Contactor Drain Tank and Solvent Hold Tank wetted equipment will experience moderate to high dose rates. These areas would have received a radiation dose rate of 10 Mrad through 2010 and 100 Mrad through 2019. SHT pump B and CDT Pump B experienced failures in February 2009. These failures were not attributed to process chemistry. Solvent Hold Tanks flow elements are also at risk from radiological damage.

The Strip Effluent process stream will see the high radiological exposures. The Strip Effluent process stream may experience up to 16.5 Ci/gallon at the maximum feed value of 1.1 Ci/gallon. However, the design maximum feed value of up to 1.1 Ci/gallon may not be realized. Pumps and equipment in contact with the Strip Effluent stream would have begun to experience radiation induced failures as early as 2012. During 2013, valves and equipment in intermittent contact with the Strip Effluent stream could experience radiation doses exceeding 100 Mrad. Motors and equipment (i.e. Strip Effluent Hold Tanks flow elements and Strip Effluent Decanter radiation sensors) near the SEHT stream could reach 100 Mrad exposure in 2022.

Since the beginning of radiological operation in April 2008, the following pumps and equipment have failed: Cell Sump Pump Motor (Motor failure was due to frequent starts. Motor/pump was replaced and measure implemented to reduce frequent motor starts.), SHT pump, CDT pump,
and SSFT pump). All process tank pump failures had been lutz shaft pumps. Lutz pump and flow meter replacements were being pursued as system viability enhancements.

Most valves in the process cell are expected to not fail by 2025 based on assumed radiation rates. The failure threshold for MCU valves was assumed to be 100 Mrad. Most valves are self-draining and only in contact with waste intermittently. CDT valves that are constantly immersed may reach the 100 Mrad threshold by 2020. SHT valves may be exposed to 100 Mrad by 2019. All other valves are not expected to reach the 100 Mrad threshold through 2025.

The contactor system is subdivided into several system segments: extraction contactors, scrub contactors, strip contactors, caustic wash contactors, and the caustic wash tank. The contactor skid was determined by the vendor to be capable of 5 years of operation without any maintenance being performed.

Each set of contactors makes up a system segment that includes component groups such as drive motors with speed and vibration monitoring equipment. Components in the contactor package consist of those placed inside the contactor enclosure that are exposed to high radiation and components located outside the contactor enclosure that are exposed to normal background radiation. The highest component dose rates are found in locations inside the enclosure building where solution with an activity as high as 16.5 Ci/gallon flows through the strip contactor number 7. A dose rate calculation for seals on the connector ends of the flexible hoses shows that seals in contact with this solution would receive 10 Mrad, which is the nominal service life of Kalrez gasket material, by 2021. This is a conservative assumption.

Contactor bearing was a limiting factor as well. Assuming 75 percent utility, contactor bearings should have lasted 5-6 years, not having taken radiological degradation into account. However, radiological exposure would have shortened the bearing life further. Strip contactors were especially at increased risk of failure due to the elevated radiation rates in these contactors. It was estimated that the SEHT motors would receive a cumulative dose of 37 Mrad, the assumed motor failure dose, in 2014.

ISDP life extension is expected to increase operational and maintenance doses based on radioactivity buildup in cells/enclosures and on components. The facility demonstrated the ability to decontaminate and shield work areas effectively. The original Radiological Design Summary Report assumed a 3 year operating life for the various facilities. Extension of ISDP service life included revision of the Radiological Design Summary Reports for ISDP facilities.

CONCLUSIONS

While the original design life basis for ISDP had been validated, extending the life of ISDP required that some process equipment be replaced due to radiological or chemical failure. To
successfully operate ISDP for longer than the original design life of 3 years, equipment in high radiation areas which were at high risk of failure were monitored for early warning of impending failure.

Some equipment that was anticipated to fail and so was replaced was: Solvent Hold Tank Pumps A & B, Aqueous DSS Decanter Pumps 1 & 2, DSS Hold Tank Pumps A & B, DSS Coalescer Pumps A & B, and Process Enclosure Sump Pump. Contactor bearings have been replaced as well. From 2015 onward, currently installed pumps, motors, flow elements, valves are at an increasing risk of failure. Equipment monitoring will increase the ability to predict impending equipment failure. This will allow repairs or replacements to be scheduled during planned outages, reducing system downtime.