HIGH-LEVEL WASTE MANAGEMENT AT THE DEPARTMENT OF ENERGY SAVANNAH RIVER SITE

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The Savannah River Site (SRS) is a Department of Energy (DOE) site located on 300-square miles in South Carolina. Since it became operational in 1951, the site has produced nuclear material for national defense, research, medical, and space programs. The separation of fissionable nuclear material from irradiated targets and fuels resulted in the generation of over 150 million gallons of radioactive waste. Originally, 51 tanks were constructed and utilized to support the mission. Six tanks have been operationally closed and taken out of service and two are currently undergoing the closure process. Most of the tank waste is a complex mixture of chemical and radioactive waste generated during the separation of special nuclear materials and enriched uranium from irradiated targets and spent fuel using the Plutonium Uranium Reduction Extraction (PUREX) process in the F-Canyon separation facility and the modified PUREX process in the H-Canyon separation facility (HM process). Waste generated from the recovery of Pu-238 in H-Canyon for the production of heat sources for space missions is also included. The waste was converted to an alkaline solution; metal oxides settled as sludge (iron, aluminum, uranium, manganese, nickel, and mercury), and supernate evaporated to form saltcake. The Liquid Waste System is a highly integrated operation involving safely storing liquid waste in underground storage tanks; removing, treating, and dispositioning the low-level waste fraction in concrete; vitrifying the higher activity waste at the Defense Waste Processing Facility (DWPF); and storing the vitrified waste in stainless steel canisters until permanent disposition. Continued long-term storage of these radioactive wastes poses a potential environmental risk. Therefore, since 1996, DOE and its contractors have been removing waste from tanks, pre-treating it, vitrifying it, and pouring the vitrified waste into canisters for long-term disposal in a permanent repository. As of December 31, 2014, DWPF had produced 3,917 vitrified waste canisters.

I. LIQUID WASTE TANKS

There are four types of waste tanks which were placed into operation between 1954 and 1986 — Types I through IV.

- Type I "old-style" tanks were constructed in 1952 through 1953; have partial secondary containment and cooling. There are 12 Type I tanks.
- Type II "old-style" waste tanks were constructed in 1955 through 1956; have partial secondary containment and cooling. There are 4 Type II tanks.
- Type III "new-style" tanks were placed into operation between 1969 and 1986. These tanks have full secondary containment and have no leakage history. There are 27 Type III tanks.
- Type IV "old-style" tanks, constructed in 1958 through 1962 are single shell tanks without secondary containment or cooling. There are 8 Type IV tanks.

Fourteen "old-style" tanks without full secondary containment have a history of leakage. As a result of program progress to date, of these tanks with leakage history:

- 4 are operationally closed and grouted (Tanks 5, 6, 19, and 20)
- 2 have been cleaned, pending further evaluation (Tanks 12 and 16)
- 4 contain essentially dry waste, with little or no free liquid supernate (Tanks 1, 9, 14, and 15)
- 4 contain liquid supernate at a level below known leak sites (Tanks 4, 10, 11, and 13)

Of the remaining 10 old-style tanks (none of which have any known leakage history):

- 2 are operationally closed and grouted (Tanks 17 and 18)
- 2 contain essentially dry waste, with little or no free liquid supernate (Tanks 2 and 3)

6 contain liquid supernate (Tanks 7, 8, and 21 through 24).

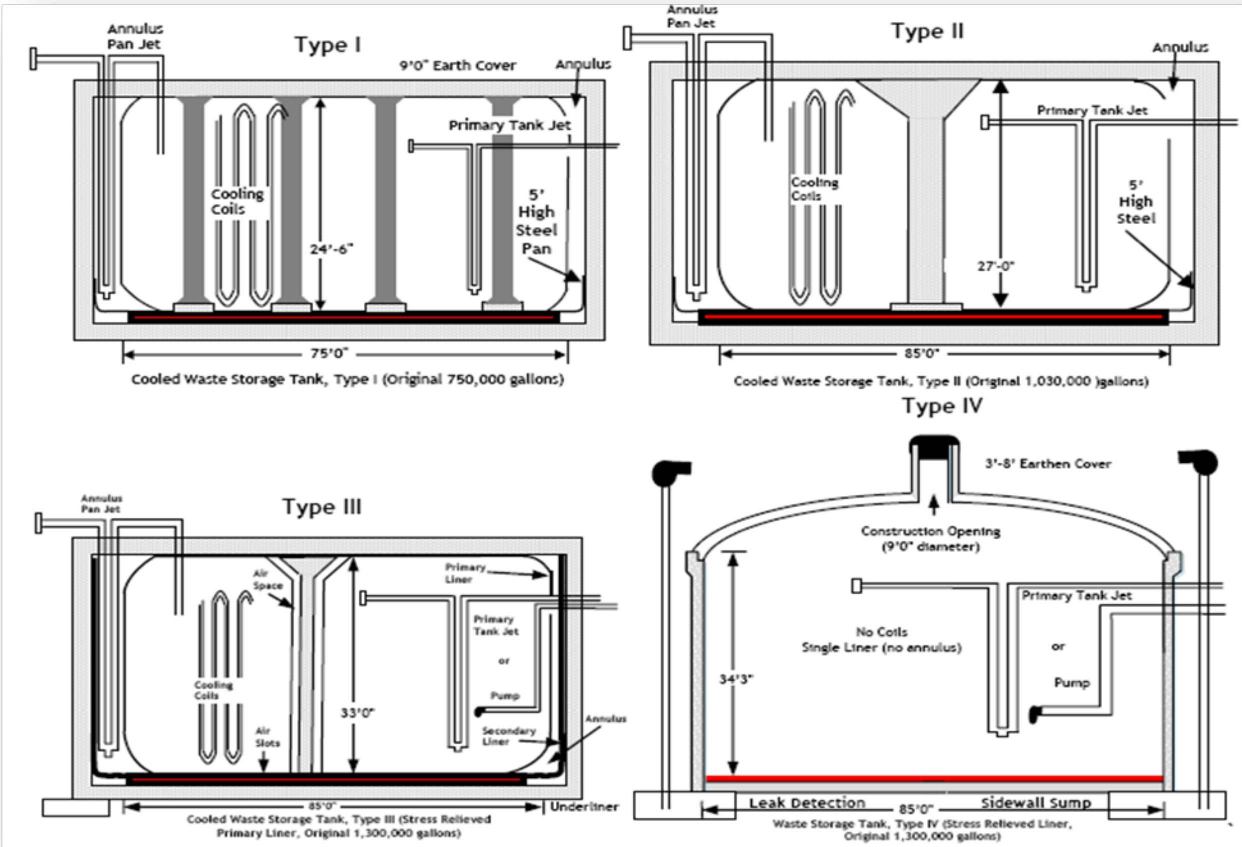

Fig. 1. Liquid Waste Tank Types

When DWPF began operation in 1996, the inventory of waste in the SRS tank system contained approximately 550 million curies. Currently, 36 Mgal of radioactive waste, containing 268 million curies (MCi) of radioactivity, are stored in 43 active waste storage tanks located in two separate locations, H-Tank Farm (27 tanks) and F-Tank Farm (16 tanks). This waste is a complex mixture of insoluble metal hydroxide solids, commonly referred to as sludge, and soluble salt supernate. The supernate volume is reduced by evaporation, which also concentrates the soluble salts to their solubility limit. The resultant solution crystallizes as salts. The resulting crystalline solids are commonly referred to as saltcake. The saltcake and supernate combined are referred to as salt waste.

The sludge component of the radioactive waste represents approximately 2.7 Mgal (7% of total) of waste but contains approximately 137 MCi (48% of total). The salt waste makes up the remaining 34.6 Mgal (93% of total) of waste and contains approximately 150 MCi (52% of total). Of that salt waste, the supernate accounts for 18.7 Mgal and 138 MCi and saltcake accounts for the remaining 15.9 Mgal and 12 MCi. The sludge contains the majority of the long-lived (half-life > 30 years) radionuclides (e.g., actinides) and strontium. The sludge is currently being stabilized in DWPF through a vitrification process that immobilizes the waste in a borosilicate glass matrix while the salt is being separated in the ARP/MCU process into a higher level component being stabilized in DWPF and a lower level component dispositioned in SPF.

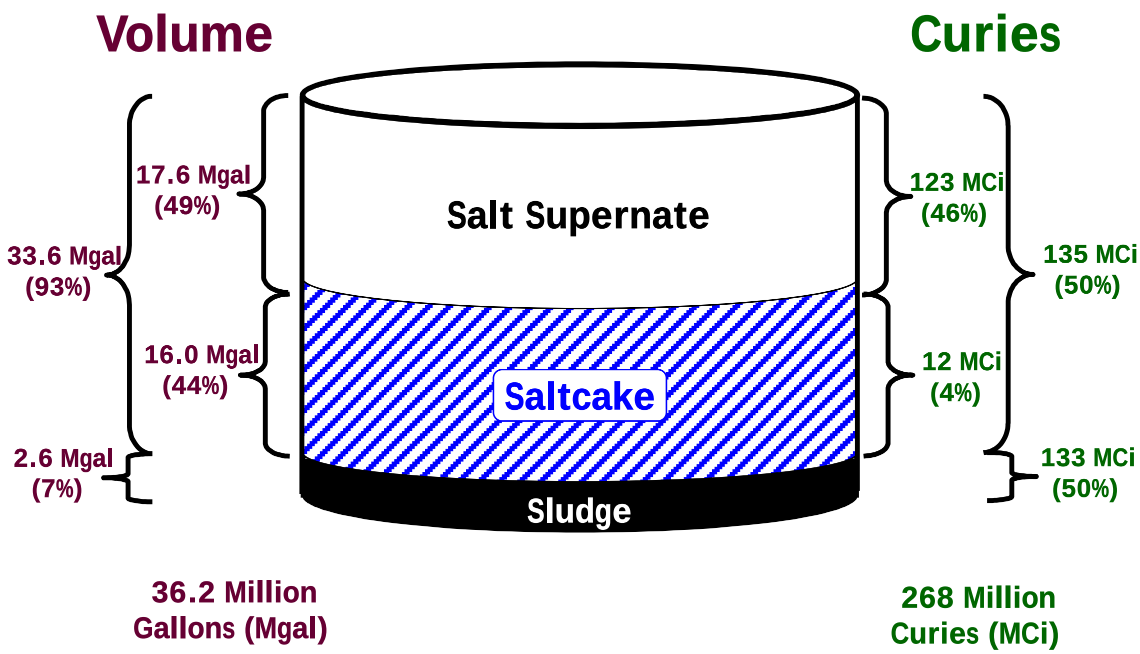

Fig. 2. Liquid Waste Tank example

I.A. Waste Tank Space Management

To make better use of available tank storage capacity, incoming liquid waste is evaporated to reduce its volume. This is important because most of the SRS Type III waste storage tanks are already near full capacity. Since 1951, the Tank Farms have received over 150 Mgal of liquid waste, of which over 110 Mgal have been evaporated, leaving approximately 37.3 Mgal in the storage tanks. Projected available tank space is carefully tracked to ensure that the Tank Farms do not become "water logged," meaning that so much of the usable Type III tank space has been filled that normal operations and waste removal and processing operations cannot continue. A contingency allotment of 1.3 Mgal is not included as working space. This amount is equivalent to the size of the largest tank and is reserved for the unlikely event that a full tank failed such that all its material had to be removed. Waste receipts and transfers are normal Tank Farm activities as the Tank Farms receive new or "fresh" waste from the H-Canyon stabilization program, liquid waste from DWPF processing (typically referred to as "DWPF recycle"), and wash water from sludge washing. The Tank Farms also make routine transfers to and from waste tanks and evaporators. Since initiation of interim salt waste treatment, the working capacity of the Tank Farms has been maintained. Two evaporator systems are currently operating at SRS — the 2H and 3H systems.

Space in Type III tanks is used for various operations for waste processing and disposal. Tank space is recovered through evaporator operations, DWPF vitrification, ARP/MCU Treatment, and saltstone disposal. This valuable space has been used to: (1) retrieve waste from and clean old-style tanks; (2) prepare, qualify, and treat sludge waste for disposal; (3) prepare, qualify, treat, and dispose salt waste; and (4) support nuclear materials stabilization and disposal through H-Canyon. The Tank Farm space management strategy is based on a set of key assumptions involving projections of DWPF canister production rates, influent stream volumes, Tank Farm evaporator performance, and space gain initiative implementation. The processing of salt and sludge utilizes Type III tank space to retrieve and prepare waste from old-style tanks, and therefore nominal empty space in Type III tanks will increase only after all waste in old-style tanks is processed. Sludge processing through the DWPF removes the highest risk material from the old-style tanks. However, for every gallon of sludge processed, 1.3 gallons of salt waste is formed due to sludge washing and DWPF processing operations to return the resulting low hazard salt waste to the Tank Farm. Similarly, salt waste retrieval, preparation, and batching typically require the use of four gallons of tank space per gallon of salt waste treated. Given these parameters, the "key to reducing the overall risk is processing high-level waste as expeditiously as possible and managing the total tank space efficiently," as recognized by the Defense Nuclear Facilities Safety Board (DNFSB) letter dated January 7, 2010.

New-style tank space is used to prepare for permanent immobilization and disposition of high level waste in a vitrified waste form and low-level waste in a grouted waste form. Additionally, some "old-style" tanks (e.g., Tank 21–Tank 24) support immobilization and disposition of high-level waste. The tank space management program maintains sufficient space to allow continued DWPF operations. The tank space management program also provides the necessary tank space to support staging of salt solutions to sustain salt waste disposition currently through ARP/MCU and subsequently through SWPF. Of the 27 new-style tanks (with a total nominal volume of 35.1 million gallons) in the SRS Liquid Waste System:

- Five (Tanks 38, 41, 43, 49, and 50) are dedicated to salt batching, qualification, and disposition (including DWPF recycle beneficial reuse and the 2H Evaporator)
- Six (Tanks 29, 30, 32, 37, 40, and 51) are dedicated to sludge batching, qualification, and disposition (including the 3H Evaporator)
- One (Tank 39) is dedicated to uninterrupted H-Canyon waste receipts
- 15 (Tanks 25, 26, 27, 28, 31, 33, 34, 35, 36, 42, 44, 45, 46, 47, and 48) are dedicated to safe storage of legacy liquid waste pending retrieval and disposition.

There are currently ~6 Mgals of empty space (~17 percent) in these new-style tanks:

- 2.4 Mgals is margin as defense-in-depth operational control coupled with SC/SS SSCs to facilitate reasonably conservative assurance of more than adequate dilution and ventilation of potentially flammable vapors
- 1.3 Mgals is procedurally-required minimum contingency space for recovery from the unlikely event of a bulk waste leak elsewhere in the system
- 2.3 Mgals is operational “working” space variously used to provide:
    - Additional contingency transfer space as operational excess margin above the procedurally-required minimum
    - Excess margin to preserve salt batch quality and maintain uninterrupted treatment and disposition through ARP/MCU and Saltstone
    - Excess margin to preserve sludge batch quality and maintain uninterrupted immobilization through DWPF
    - Excess margin to preserve uninterrupted support for H-Canyon

I.B. Waste Removal from Tanks

The first step in the disposition of sludge and salt waste is bulk waste removal efforts (BWRE). Sludge is removed from the tank and transferred to a feed preparation tank ensuring sludge waste is continuously available for treatment at DWPF. Salt is dissolved, removed, and staged for treatment at ARP/MCU or SWPF.

To reduce the two-to-four year period required for installation of substantial structural steel and large mixing and transfer pumps — with their attendant infrastructure — required for BWRE, a Waste on Wheels (WOW) innovation was developed. The WOW concept minimizes new infrastructure. Portable and temporary equipment meet tank infrastructure needs. Additional purchased pumps and WOW equipment perform accelerated BWRE operations concurrently in both Tank Farms. The primary components of the WOW system are:

- Reusable Submersible Mixer Pumps (SMPs)
- A portable field operating station containing pump drives and controls
- A portable substation to provide 480-, 240- and 120-volt power to the WOW equipment
- Disposable commercial transfer pumps

WOW equipment is deployed at the tank as a field operating station, providing temporary power and control for BWRE equipment. When BWRE is completed on one tank, the WOW equipment is reconfigured to support waste removal on the next tank. Pumps are sized to fit through 24-inch openings in old style tanks. To the extent that risers are available, pumps are set in optimal configurations within the waste tanks. Product lubricated bearings and motor cooling eliminate the need for bearing and seal water supply. These pumps have exterior fittings and fixtures so the pumps can be decontaminated, minimizing radiation exposure to personnel during relocation to another tank. Disposable transfer pumps transfer the waste to a receipt or hub tank using existing underground transfer lines and diversion boxes. If the transfer system is degraded or non-existent, above-grade hose-in-hose technology is deployed, rather than investing in costly repairs. Temporary shielding is supplied as necessary to reduce exposure to personnel.

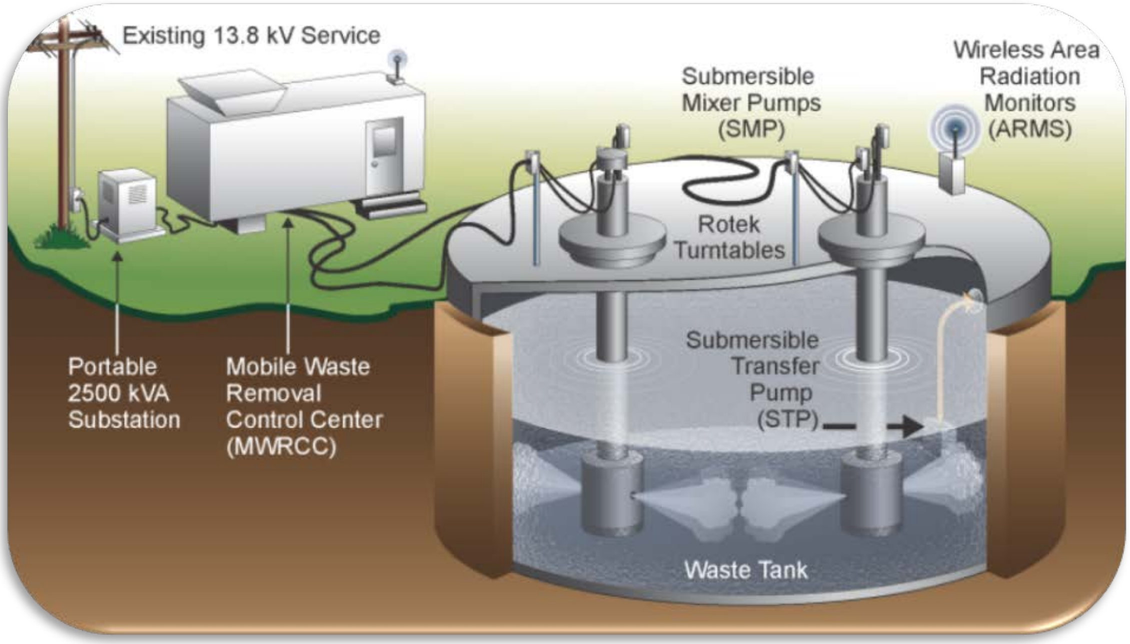

Fig. 3. Waste on Wheels Deployment for Bulk Waste Removal Efforts

I.C. Safe Disposal of Waste

The goal is to convert all of the waste into one of two final waste forms: Glass, which will contain over 99 percent of the radioactivity, and Saltstone Grout, which will contain most of the volume. Each of the waste types at SRS needs to be treated to accomplish disposal in these two waste forms. The sludge must be washed to remove non-radioactive salts that would interfere with glass production. The washed sludge can then be sent to DWPF for vitrification. The salt must be treated to separate the bulk of the radionuclides from the non-radioactive salts in the waste. Starting in 2018, this separation will be accomplished in SWPF. However, until the startup of SWPF, ARP/MCU accomplishes this separation.

II. SALT PROCESSING

Four different processes are used to treat salt:

Deliquification, Dissolution, and Adjustment (DDA) – **D**eliquification (i.e., extracting the interstitial liquid) is an effective decontamination process because the primary radionuclide in salt is Cs-137, which is highly soluble. To accomplish the process, the salt was first deliquified by draining and pumping. The deliquified salt was then **D**issolved by adding water and pumping out the salt solution. The resulting salt solution was aggregated with other Tank Farm waste to **A**djust batch chemistry for processing at SPF. For salt in Tank 41 as of June 9, 2003, which was relatively low in radioactive content, treatment using DDA-solely was sufficient to meet the SPF WAC. Tank 41 has since received additional salt dissolution from Tank 25 and there is no longer any qualified feed for the DDA-solely process. No further DDA-solely is planned.

Actinide Removal Process (ARP) – For salt, even though extraction of the interstitial liquid reduces Cs-137 and soluble actinide concentrations, the Cs-137 or actinide concentrations of the resulting salt are too high to meet the SPF WAC. Salt from these tanks first will be sent to ARP. In ARP, MST is added to the waste as a finely divided solid. Actinides are sorbed on the MST and then filtered out of the liquid to produce a low-level waste stream that is sent to MCU. The MST, containing the actinides, is sent to DWPF.

Modular CSSX Unit (MCU) – The ARP low-level waste stream requires reduction in the concentration of Cs-137 using the CSSX process. MCU is a solvent extraction process for removal of Cs-137 from caustic salt solutions. The solvent used is a four-part solvent with the key ingredient being the cesium extractant (previously BoB Calix but, beginning September 2013, the NGS is Max Calix). This solvent is fed to a bank of centrifugal contactors while the waste is fed to the other end in a counter-current flow. The solvent extracts the cesium, with each successive contactor stage extracting more, resulting in a DSS stream and a cesium-laden solvent stream. The solvent stream is stripped of its cesium, washed, and the solvent is reused. The cesium-laden strip effluent is transferred to DWPF. MCU has a dual purpose:

- demonstrating the CSSX flowsheet
- treating salt waste to enable accelerated closure of Type I, II, and IV tanks and uninterrupted vitrification of HLW at DWPF

Salt Waste Processing Facility (SWPF) – This is the full-scale CSSX process. This planned facility will incorporate both the ARP and CSSX processes in a full-scale shielded facility capable of handling salt with high levels of radioactivity.

III. SALT PROCESSING

Sludge is washed to reduce the amount of non-radioactive soluble salts remaining in the sludge slurry. During sludge processing, large volumes of wash water are generated and must be volume-reduced by evaporation or beneficially reused. Over the life of the waste removal program, the sludge currently stored in tanks at SRS will be blended into separate sludge batches to be processed and fed to DWPF for vitrification.

IV. DWPF VITRIFICATION

Final processing for the washed sludge and salt waste occurs at DWPF. This waste includes MST/sludge from ARP or SWPF, the cesium strip effluent from MCU or SWPF, and the washed sludge slurry. In a complex sequence of carefully controlled chemical reactions, this waste is blended with glass frit and melted to vitrify it into a borosilicate glass form. The resulting molten glass is poured into stainless steel canisters. As the filled canisters cool, the molten glass solidifies, immobilizing the radioactive waste within the glass structure. After a canister has cooled, it is sealed with a temporary plug, the external surfaces are decontaminated to meet United States Department of Transportation requirements, and the canister is then permanently sealed. The canister is then ready to be stored on an interim basis on-site. A low-level recycle waste stream from DWPF is returned to the Tank Farms. DWPF has been operational since 1996.

V. SALTSTONE DISPOSITION

The Saltstone Facility consists of two facility segments: the Saltstone Production Facility (SPF) and the Saltstone Disposal Facility (SDF). SPF is permitted as a wastewater treatment facility per SCDHEC regulations. SPF receives and treats the salt solution to produce grout by mixing the LLW liquid stream with cementitious materials (cement, flyash, and slag). A slurry of the components is pumped into Saltstone Disposal Units (SDU), located in SDF, where the Saltstone grout solidifies into a monolithic, non-hazardous, solid LLW form. SDF is permitted as an Industrial Solid Waste Landfill site.

Future salt waste processing will impose significantly greater production demands. After SWPF startup, feed of decontaminated salt solution to the SPF could reach as high as 12.8 Mgal/year. In anticipation of this future demand, SRS completed installation of Enhanced Low Activity Waste Disposal (ELAWD) improvements. The ELAWD Phase 1 improvements provided equipment modifications to increase operating margins, reliability, and controls. Also, during the ELAWD Phase 1 outage, the Mixing and Transfer System was modified to connect SPF to SDU-2.

ELAWD Phase 2 will modify the dry feeds system and connect SPF to new larger capacity salt solution feed receipt tanks. Lastly, modifications that support converting from the present day-shift staffing to 24/7 operations are planned.

The SDF will contain several large concrete SDUs. Each of the SDUs will be filled with solid Saltstone grout. The grout itself provides primary containment of the waste, and the walls, floor, and roof of the SDUs provide secondary containment.

Approximately 15 feet of overburden were removed to prepare and level the site for SDU construction. All SDUs will be built at or slightly below the grade level that exists after the overburden and leveling operations are complete. The bottom of the Saltstone grout monoliths will be at least five feet above the historic high water table beneath the Z-Area site, thus avoiding disposal of waste in a zone of water table fluctuation. Run-on and run-off controls are installed to minimize site erosion during the operational period.

The first SDU (Vault 1) is approximately 100 feet wide by 600 feet in length by 25 feet in height, divided into six cells and the second SDU (Vault 4) is approximately 200 feet wide by 600 feet in length by 26 feet in height, divided into twelve cells. Neither is planned for future use in emplacing contaminated grout.

SDU-2, SDU-3, and SDU-5, currently in use, consist of two cells, each cell nominally 150 feet diameter by 22 feet high each. This design is used commercially for storage of water. After accounting for interior obstructions (support columns, drainwater collection systems, etc.) and the requirement for a two-foot cold cap, the nominal useable volume of a cell is 2,300 kgal. Recent operating experience has resulted in approximately 1.76 gallons of grout being produced for each gallon of DSS feed, yielding a nominal cell capacity of approximately 1,290 kgal of DSS.

The next generation of units, SDU-6 through SDU-13 will be a 375-foot diameter 43-foot tall single-cell design. The vaults will hold 30 Mgal of contaminated grout or 17.1 Mgal of DSS feed.

Closure operations will begin near the end of the active disposal period in the SDF, i.e., after most or all of the SDUs have been constructed and filled. Backfill of native soil will be placed around the SDUs. The present closure concept includes two moisture barriers consisting of clay/gravel drainage systems along with backfill layers and a shallow-rooted bamboo vegetative cover.

Construction of the SDF and the first two vaults were completed between February 1986 and July 1988. The SDF started radioactive operations June 12, 1990. SDU-2 is filled. SDU-3 and SDU-5 began filling in October 2013. Construction began in December 2013 for SDU06.

Future SDUs will be constructed on a "just-in-time" basis in coordination with salt processing production rates.

Fig. 4. View of the Saltstone Facility

Fig. 5. Saltston Disposition Units Locations

II. SUMMARY

The radioactive waste contained in the F and H-Tank Farms at the Savannah River Site poses a potential environmental risk. The Department of Energy and its liquid waste contractor, Savannah River Remediation, are safely receiving, storing, treating, and stabilizing this waste and in order to reduce the risk to human health, and the environment.

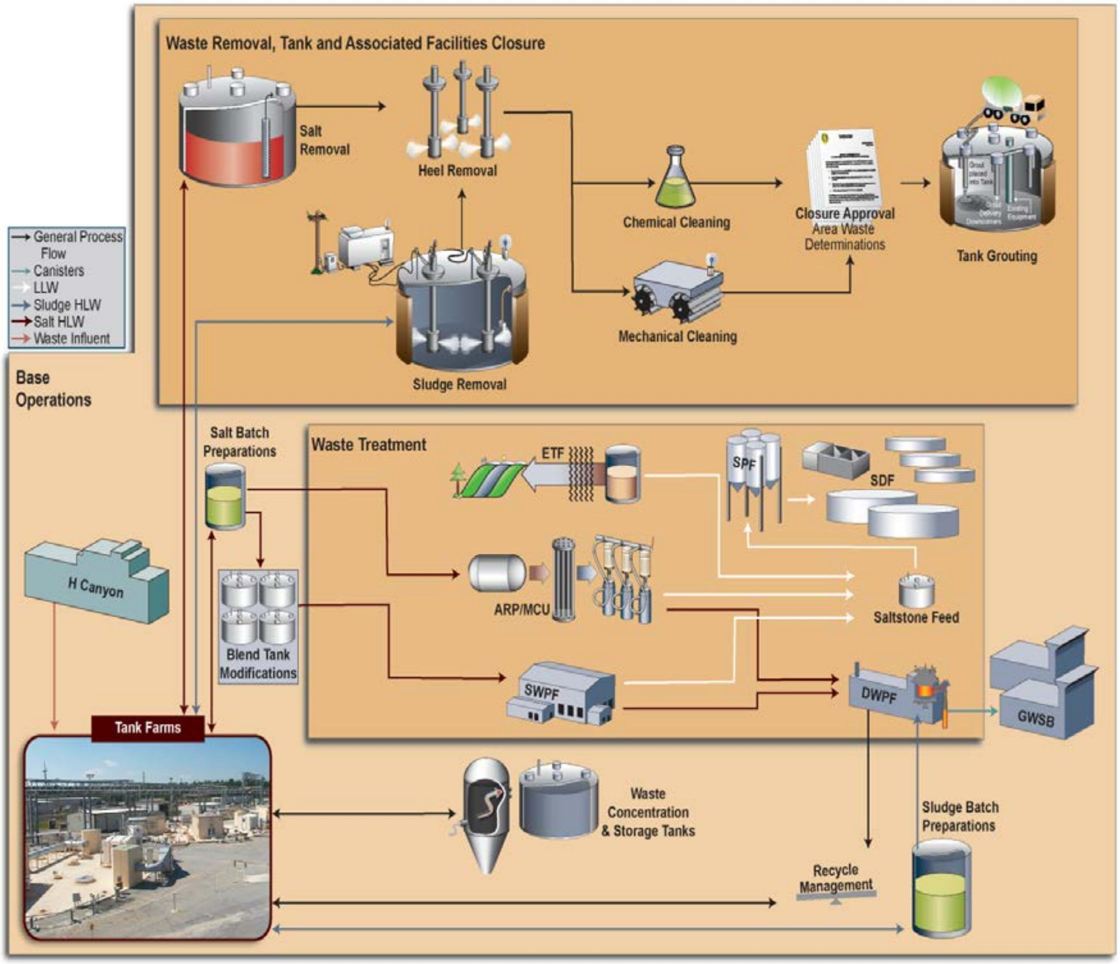

Fig. 6. Process Flowsheet

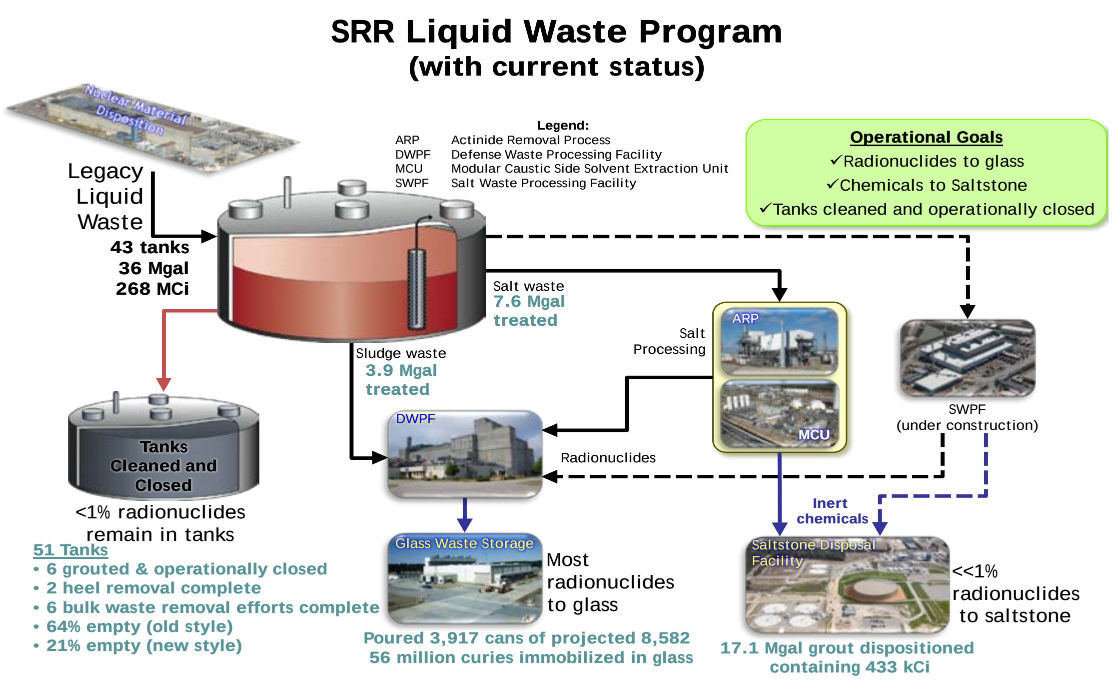

Fig. 7. SRR Liquid Waste Program with current status