DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

June 18, 2012 to August 17, 2012

Saltstone Processing of Low-Level Waste at Savannah River Site

Principal Investigators:

Joshua Emmanuel Midence (DOE Fellow)
Florida International University

Alex Cozzi, Mentor
Savannah River National Laboratory

Acknowledgements:

Marissa Reigel
Brad Pickenheim
Vicky Williams
Tony Burckhalter

Florida International University Program Director:

Leonel Lagos Ph.D., PMP®

Prepared for:

U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology
Under Grant No. DE-EM0000598

ABSTRACT

The Saltstone Production Facility (SPF) at the Savannah River Site in Aiken, South Carolina, receives low level waste (LLW) salt solution from Tank 50H for treatment and disposal. Tank 50H receives transfers from the Effluent Treatment Project (ETP), the H-Canyon General Purpose Evaporator, and the Actinide Removal Process/Modular Caustic Side Solvent Extraction Unit (ARP/MCU) Decontaminated Salt Solution Hold Tank (DSS-HT). At the Saltstone Production Facility, the low level waste is mixed with premix [a cementitious mixture of portland cement (PC), blast furnace slag (BFS) and Class F fly ash (FA)] in a Readco mixer to produce fresh (uncured) saltstone that is transferred to the Saltstone Disposal Facility (SDF).

The saltstone formulation (mix design) must produce a grout waste form that meets requirements for both placement and performance properties. In previous simulated saltstone studies, multiple compositional factors were identified that drive the performance properties of saltstone made from the projected ARP/MCU salt solution. This composition was selected as the salt solution simulant since ARP/MCU is the primary influent into Tank 50H. The primary performance property investigated was hydraulic conductivity since it is a variable input property to the saltstone performance assessment (PA) transport model. Also, the porosity, also referred to as void structure, is another variable that impacts the PA response. In addition, Young's modulus and cured density are other performance properties analyzed in this report; however, they are indicators of the performance of saltstone and not direct inputs into the performance assessment of the concrete mixture.

Performance testing of the saltstone will be conducted in order to determine the best mixture of premix/cementitious mixture for filling tanks that need to be closed. Some of the factors that need to be investigated include *pH levels* of surrounding groundwater (to determine the effect of the saltstone mixture in the future*), strength of the concrete*, *hydraulic conductivity*, and *porosity* of the mixture (all of which are contributing factors to the overall performance of the saltstone grout in the vaults).

Testing to determine the ideal premix ratio for the saltstone that will be poured into the vaults includes:

- Leach testing - percolating sample for pH, conductivity and release of contaminants
- Concrete compression testing - strength of sample
- Blaine fineness testing - measures air permeability of dry cementitious materials
- Hydraulic conductivity testing - measures the capability of a medium to transmit water
- Moisture content analysis – performance for bulk drying

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The Saltstone facilities safely stabilize and dispose of low-level radioactive liquid salt wastes produced and stored at the Savannah River Site. The Saltstone facilities consist of two facility segments: the Saltstone Production Facility (SPF) and the Saltstone Disposal Facility (SDF). Construction of SPF and the first two disposal vaults of SDF were completed between February 1986 and July 1988 and began radioactive operations on June 12, 1990. The facilities immobilize and dispose of salt waste from the site's tank farms, which process waste from the site's two chemical separation facilities. Most of the site's tank farm waste will be immobilized within two waste forms: glass, which will contain about 99 percent of the radioactivity, and cement-like grout, which will contain most of the volume. The highly radioactive, insoluble tank sludge is sent to the Defense Waste Processing Facility (DWPF) to be turned into glass. Soluble salts, primarily sodium nitrate (similar to fertilizer), must be treated to remove radionuclides contained in the salt solution.

This separation will be accomplished in the Salt Waste Processing Facility (SWPF) when the facility is constructed and placed into operations, currently scheduled for the 2015 timeframe. Until the SWPF begins operations, several interim treatment processes will be used for a small volume of salt waste. Radioactive contaminants (cesium, strontium, actinides) removed from the salt waste will be sent to DWPF, where they will be combined with sludge, turned into glass and stored in sealed stainless steel containers until permanently disposed in a federal repository. SPF receives the low-radioactive treated salt solution and stabilizes it by mixing the salt solution with cement, fly ash and slag. The resulting grout mixture, or slurry, is mechanically pumped into concrete disposal vaults that make up the SDF. There, the grout solidifies into a non-hazardous low-radioactive waste form called "saltstone."

Figure 1. Saltstone Facility located at the Savannah River Site.

After filling, the vaults will be capped with clean concrete to isolate it from the environment. Final closure of the area will consist of covering the vaults with engineered closure caps, backfilling with earth and seeding to control water infiltration and erosion. Extensive testing and analysis have concluded that the waste planned for disposal in the SDF will not result in releases of radioactive material to the environment that would exceed the U.S. Environmental Protection Agency drinking water standards. Wells near the edge of the disposal site are used to monitor groundwater to ensure that it meets the applicable standards established by the South Carolina Department of Health and Environmental Control.

> "Saltstone facility operations are a critical component of DOE closing the circle on treatment of tank waste," said Terrel Spears, Assistant Manager for Waste Disposition Project, DOE-Savannah River Operations Office, "The liquid waste program employees are demonstrating real progress in the safe removal and permanent disposition of this low-activity salt waste, which supports DOE's ultimate priority to permanently close our tank farm system and reduce risk."

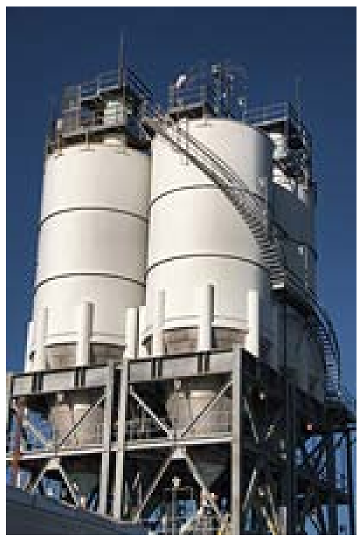


Figure 2. A portion of the Saltstone facilities.

This facility processes other waste from the tank farms as well as from the site's two chemical separation facilities. Each cell is 100 feet long, 100 feet wide and 25 feet tall. Currently, two vaults exist at the facility, one with 12 cells and one with six cells (each vault is partially full). Construction was completed of the Saltstone Facility and the first two vaults between February 1986 and July 1988 at a cost of $45 million. Since the saltstone facility started radioactive operations it has processed approximately 3.1 million gallons of low-activity waste. The facility was recently modified to process higher curie levels of material, and is now waiting for permission from DHEC to start up.

The Saltstone Facility safely treats and disposes of low-level liquid radioactive wastes produced and stored at the Savannah River Site. Soluble salts, primarily sodium nitrate (similar to fertilizer), make up about 93 percent of the 37 million gallons of material in the radioactive waste storage tanks in the high level waste (HLW) storage tanks at the site. Pretreatment of this HLW will separate soluble salts from insoluble sludge to generate about 100-120 million gallons of salt solution. This salt solution will be treated to remove cesium and strontium. These two contaminants are sent to the Defense Waste Processing Facility, where they are combined with the sludge, turned into glass and poured into canisters.

> “Our employees are safely moving this salt waste from storage to disposal, reducing risk and opening the door to more salt waste processing,” said Dave Olson, SRR’s President, “Sending this material through Saltstone is instrumental in performing our mission to close the waste tanks.”

Removal of the cesium and strontium converts the majority of the salt solution to low-activity waste containing less than 0.01 percent of the total radioactivity now present in the waste. This salt solution is sent to the Saltstone Facility for immobilization. In addition to receiving low-level waste from the tank farms, Saltstone also receives a similar waste stream from the Effluent Treatment Project.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Office of Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2012, a DOE Fellow intern (Mr. Joshua Emmanuel Midence) spent 9 weeks doing a summer internship at Savannah River National Laboratory under the supervision and guidance of Mr. Alex Cozzi. The intern's project was initiated on June 18, 2012, and continued through August 17, 2012.

This report focuses on the performance testing of saltstone. This performance testing will be conducted in order to determine the best mixture of premix/cementitious mixture for filling tanks that need to be closed. Some of the factors that need to be investigated include *pH levels* of surrounding groundwater (to determine the effect of the saltstone in the future) via Leach Testing. The leach testing process submerges a 3" x 6" cylinder sample in a vat of water which then will be analyzed in order to find the overall effect of the low level waste to the environment. *Strength of the Concrete* via Concrete Compression was observed in order to compare the samples to each other in terms of overall strength.

Hydraulic conductivity via calculations was a technique that had been used previously at Savannah River National Laboratory using *Steady State Centrifugation Unsaturated Flow Apparatus.* The results that were analyzed in terms of Hydraulic Conductivity were sent out for testing to ***AMEC Environment & Infrastructure Co.*** where they have used *ASTM D5084-03 Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter*. Last but not least, the *porosity* of the mixture via Blaine Fineness was determined as a cost effective manner for determining the state of the cement before actual mixing was performed (all of which are contributing factors to the overall performance of the saltstone grout in the vaults).

3. RESEARCH RESULTS AND ANALYSIS

Blaine Fineness Testing

The testing conducted at the Savannah River National Laboratory was followed using the *ASTM C 204-00* Standard Test Method for Fineness of Hydraulic Cement by Air Permeability Apparatus.

This test method determines the fineness of hydraulic cement, using the Blaine air-permeability apparatus, in terms of the specific surface expressed as total surface area in square centimeters per gram (or square meters per kilogram) of cement. Although the test method may be, and has been, used for the determination of fineness of various other materials, it is mainly used to find relative values and not absolute values.

The *ASTM C 204-00* method is known to work well for Portland cement but it has been clearly stated that the test should be conducted with the user's judgment in determining the suitability with regard to the fineness measurements with the densities or porosities given in a Standard Compliance sheet.

Figure 3. Blaine fineness apparatus.

Nature of the Apparatus – The Blaine air-permeability apparatus consists of the following parts:

- Permeability Cell
- Perforated disk
- Filter Paper
- Manometer
- Manometer Liquid
- Timer

The Blaine air-permeability apparatus consists of a means of drawing a definite quantity of air through a prepared bed of cement of definite porosity. The number and size of the pores in a prepared bed of definite porosity is a function of the size of the particles and determines the rate of airflow through the bed. This apparatus is being used in order to determine the air permeability of the in-house Portland cement that is being used to make the saltstone grout.

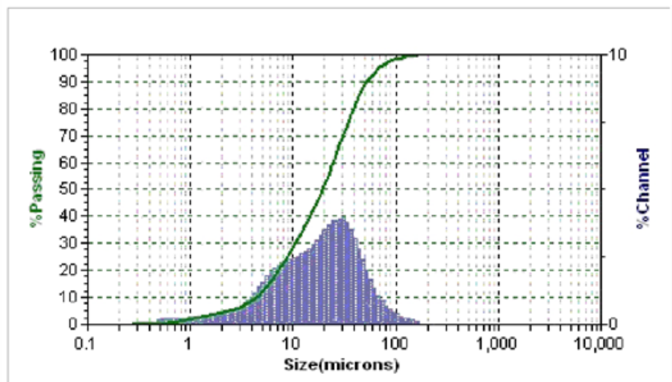
One of the main reasons why this apparatus was chosen to determine the porosity of the Portland cement is because sample testing that is sent out to determine the difference between NIST standard Portland cement and the Holcim Portland cement is expensive (approximately $1600) and can take several days to get results. The NIST standard Portland cement and the Holcim Portland cement that were sent out to be tested yielded the following results that are shown below:

Figure 4. Analysis of NIST standard cement.

Particle Size Analysis		
Microtrac Inc. A Unit of Nikkiso Co., Ltd	300335 Cozzi NIST Standard Cement	
	2012/07/03 07:42	S3000/S3500 S3754

Distribution:	Volume	Run Time:	30 Sec	Fluid:	WATER		
Progression:	Geom 8 Root	Run Num:	Avg of 3	Fluid Ref. Index:	1.333	Loading Factor:	0.044
Upper Edge:	1408	Particle:	CRAWFORD ABS	Above Residual:	0	Transmission:	0.93
Lower Edge:	0.243	Transparency:	Absorbing	Below Residual:	0	RMS Residual:	5.72E-03
Residuals:	Disabled	Part. Ref. Index:	N/A			Flow:	40 %
Num. Channels:	100	Part. Shape:	Irregular	Cell ID:	0595	Usonic Power:	N/A
Analysis Mode:	S3000					Usonic Time:	N/A
Filter:	Enabled	DB Record:	9414	Recalc Status:		Serial Num:	S3754
Analysis Gain:	Default	Database:	C:\Program Files\Microtrac FLEX 10.3.0\Databases\IntegratedTest.MDB				

Size(um)	%Chan	% Pass	Size(um)	%Chan	% Pass	Size(um)	%Chan	% Pass	Size(um)	%Chan	% Pass
1408	0.00	100.00	74.00	1.08	95.99	3.89	0.87	8.59			
1291	0.00	100.00	67.86	1.35	94.91	3.57	0.75	7.72			
1184	0.00	100.00	62.23	1.67	93.56	3.27	0.64	6.97			
1086	0.00	100.00	57.06	2.02	91.89	2.999	0.56	6.33			
995.6	0.00	100.00	52.33	2.42	89.87	2.750	0.49	5.77			
913.0	0.00	100.00	47.98	2.82	87.45	2.522	0.44	5.28			
837.2	0.00	100.00	44.00	3.21	84.63	2.312	0.40	4.84			
767.7	0.00	100.00	40.35	3.54	81.42	2.121	0.36	4.44			
704.0	0.00	100.00	37.00	3.81	77.88	1.945	0.34	4.08			
645.6	0.00	100.00	33.93	3.94	74.07	1.783	0.32	3.74			
592.0	0.00	100.00	31.11	3.92	70.13	1.635	0.30	3.42			
542.9	0.00	100.00	28.53	3.88	66.21	1.499	0.29	3.12			
497.8	0.00	100.00	26.16	3.83	62.33	1.375	0.28	2.83			
456.5	0.00	100.00	23.99	3.70	58.50	1.261	0.27	2.55			
418.6	0.00	100.00	22.00	3.50	54.80	1.156	0.26	2.28			
383.9	0.00	100.00	20.17	3.31	51.30	1.060	0.26	2.02			
352.0	0.00	100.00	18.50	3.13	47.99	0.972	0.25	1.76			
322.8	0.00	100.00	16.96	2.96	44.86	0.892	0.25	1.51			
296.0	0.00	100.00	15.56	2.82	41.90	0.818	0.24	1.26			
271.4	0.00	100.00	14.27	2.69	39.08	0.750	0.23	1.02			
248.9	0.00	100.00	13.08	2.60	36.39	0.688	0.22	0.79			
228.2	0.00	100.00	12.00	2.52	33.79	0.630	0.21	0.57			
209.3	0.00	100.00	11.00	2.46	31.27	0.578	0.21	0.36			
191.9	0.00	100.00	10.09	2.41	28.81	0.530	0.15	0.15			
176.0	0.13	100.00	9.25	2.35	26.40	0.486	0.00	0.00			
161.4	0.19	99.87	8.48	2.29	24.05	0.446	0.00	0.00			
148.0	0.21	99.68	7.78	2.20	21.76	0.409	0.00	0.00			
135.7	0.24	99.47	7.13	2.09	19.56	0.375	0.00	0.00			
124.5	0.30	99.23	6.54	1.94	17.47	0.344	0.00	0.00			
114.1	0.37	98.93	6.00	1.76	15.53	0.315	0.00	0.00			
104.7	0.45	98.56	5.50	1.58	13.77	0.2890	0.00	0.00			
95.96	0.56	98.11	5.04	1.38	12.19	0.2650	0.00	0.00			
88.00	0.69	97.55	4.62	1.20	10.81						
80.70	0.87	96.86	4.24	1.02	9.61						



Data Item	Value
MV(um):	25.39
MN(um):	0.875
MA(um):	8.39
CS:	7.15E-01
SD:	18.56

%Tile	Size(um)
10.00	4.37
16.00	6.13
25.00	8.79
40.00	14.68
50.00	19.51
60.00	24.83
70.00	31.02
75.00	34.65
90.00	52.61
95.00	68.35

Dia	Vol%	Width
19.51	100.0	37.12

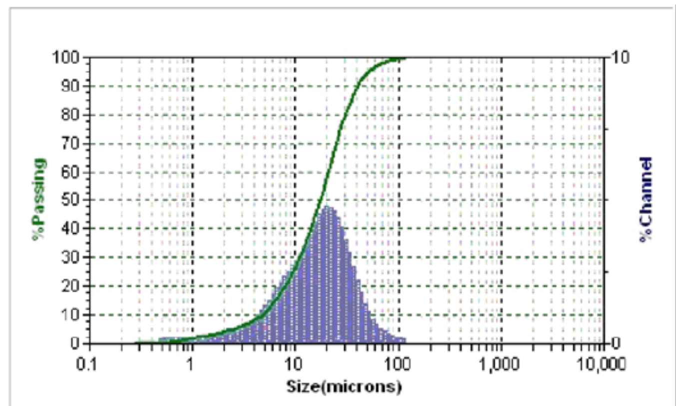
Size(um)	%Tile
0.800	1.20

Figure 5. Analysis of Savannah River Holcim cement.

Particle Size Analysis	
300336 Cozzi Holcim Cement	
2012/07/03 07:32	S3000/S3500 S3754

Distribution:	Volume	Run Time:	30 Sec	Fluid:	WATER		
Progression:	Geom 8 Root	Run Num:	Avg of 3	Fluid Ref. Index:	1.333	Loading Factor:	0.038
Upper Edge:	1408	Particle:	CRAWFORD ABS	Above Residual:	0	Transmission:	0.93
Lower Edge:	0.243	Transparency:	Absorbing	Below Residual:	0	RMS Residual:	5.84E-03
Residuals:	Disabled	Part. Ref. Index:	N/A			Flow:	40 %
Num. Channels:	100	Part. Shape:	Irregular	Cell ID:	0595	Usonic Power:	N/A
Analysis Mode:	S3000					Usonic Time:	N/A
Filter:	Enabled	DB Record:	9418	Recalc Status:		Serial Num:	S3754
Analysis Gain:	Default	Database:	C:\Program Files\Microtrac FLEX 10.3.0\Databases\IntegratedTest.MDB				

Size(um)	%Chan	% Pass	Size(um)	%Chan	% Pass	Size(um)	%Chan	% Pass	Size(um)	%Chan	% Pass
1408	0.00	100.00	74.00	0.52	98.39	3.89	0.73	7.87			
1291	0.00	100.00	67.86	0.67	97.87	3.57	0.64	7.14			
1184	0.00	100.00	62.23	0.86	97.20	3.27	0.56	6.50			
1086	0.00	100.00	57.06	1.10	96.34	2.999	0.50	5.94			
995.6	0.00	100.00	52.33	1.41	95.24	2.750	0.45	5.44			
913.0	0.00	100.00	47.98	1.77	93.83	2.522	0.40	4.99			
837.2	0.00	100.00	44.00	2.21	92.06	2.312	0.37	4.59			
767.7	0.00	100.00	40.35	2.67	89.85	2.121	0.34	4.22			
704.0	0.00	100.00	37.00	3.17	87.18	1.945	0.31	3.88			
645.6	0.00	100.00	33.93	3.65	84.01	1.783	0.30	3.57			
592.0	0.00	100.00	31.11	4.09	80.36	1.635	0.28	3.27			
542.9	0.00	100.00	28.53	4.42	76.27	1.499	0.27	2.99			
497.8	0.00	100.00	26.16	4.63	71.85	1.375	0.26	2.72			
456.5	0.00	100.00	23.99	4.75	67.22	1.261	0.25	2.46			
418.6	0.00	100.00	22.00	4.79	62.47	1.156	0.25	2.21			
383.9	0.00	100.00	20.17	4.70	57.68	1.060	0.24	1.96			
352.0	0.00	100.00	18.50	4.51	52.98	0.972	0.24	1.72			
322.8	0.00	100.00	16.96	4.27	48.47	0.892	0.24	1.48			
296.0	0.00	100.00	15.56	3.98	44.20	0.818	0.23	1.24			
271.4	0.00	100.00	14.27	3.68	40.22	0.750	0.23	1.01			
248.9	0.00	100.00	13.08	3.40	36.54	0.688	0.21	0.78			
228.2	0.00	100.00	12.00	3.14	33.14	0.630	0.21	0.57			
209.3	0.00	100.00	11.00	2.91	30.00	0.578	0.21	0.36			
191.9	0.00	100.00	10.09	2.71	27.09	0.530	0.15	0.15			
176.0	0.00	100.00	9.25	2.51	24.38	0.486	0.00	0.00			
161.4	0.00	100.00	8.48	2.33	21.87	0.446	0.00	0.00			
148.0	0.00	100.00	7.78	2.14	19.54	0.409	0.00	0.00			
135.7	0.00	100.00	7.13	1.94	17.40	0.375	0.00	0.00			
124.5	0.14	100.00	6.54	1.74	15.46	0.344	0.00	0.00			
114.1	0.22	99.86	6.00	1.53	13.72	0.315	0.00	0.00			
104.7	0.23	99.64	5.50	1.33	12.19	0.2890	0.00	0.00			
95.96	0.27	99.41	5.04	1.15	10.86	0.2650	0.00	0.00			
88.00	0.33	99.14	4.62	0.99	9.71						
80.70	0.42	98.81	4.24	0.85	8.72						



Data Item	Value
MV(um):	21
MN(um):	0.866
MA(um):	8.43
CS:	7.12E-01
SD:	13.61

%Tile	Size(um)
10.00	4.73
16.00	6.71
25.00	9.44
40.00	14.20
50.00	17.48
60.00	21.04
70.00	25.26
75.00	27.82
90.00	40.57
95.00	51.53

Dia	Vol%	Width
17.48	100.0	27.22

Size(um)	%Tile
0.800	1.18

The test results yielded a final Holcim cement surface area of 2.2773 m^3/g and a final Standard NIST Portland cement surface area of 1.9365 m^3/g.

The Blaine method is now by far the most commonly used method, mainly because of the ease of maintenance of the apparatus and simplicity of the procedure. Through this testing, it has been determined that the Blaine air-permeability apparatus seems to be a rudimentary but effective method to determine the quality of the material being tested.

Leach Testing

The leach testing method is used to determine what kind of effect the saltstone grout mixture will have after it has stabilized the cesium located in the waste tanks. The samples will be determined using a chromium sample in the laboratories to simulate the effects that can be done to the environment around the Savannah River Site.

The leach testing method can be used to measure the release of a component from a cylindrical solidified waste form (3” x 6” cylinder) into water at a reference temperature of 72°F and can be evaluated at elevated temperatures that accelerate the rate and extent of leaching relative to the values measured at room temperatures and different time intervals. This test method can be used to:

- Compare releases of waste components from various types of solidification agents and formulations.
- Determine the diffusion coefficients for the release of waste components from waste forms at any specific temperatures.
- Promote greater extents of reaction than can be achieved under expected service conditions within a laboratory time frame to provide greater confidence in modeled diffusive releases.
- Determine the dependence of time for diffusive release.

Fitting the experimental results with a mechanistic model allows diffusive releases to be extrapolated to long timeframes and to full-scale waste forms under the following constraints:

- Results of this test method address an intrinsic property of a material and should not be presumed to represent releases in specific disposal environments. These tests can be conducted under conditions that represent a specific disposal environment (for example, by using a representative groundwater) to determine an effective diffusion coefficient for those conditions.

- Projections of releases over long times require that the waste form matrix remain stable, which may be demonstrated by the behavior of the specimen in different soaking periods. The mechanism must have the same standard temperatures and time used in the extrapolation in order to have the best results moving forward in determining the amount of damaging waste.

- The quality of the analytical results depends upon the quality of the standards provided, that is why this year the results were provided using a *Thermo Scientific Orion 4-Star Plus pH/Conductivity Meter* that derives the quality of the water through an electrode sensor that is connected to a swing arm and submerged in the leachate. This machine then gives a read out of each of the samples that were tested. As an example of this, a table with the results for each of the leach test samples will be provided as shown:

Table 1. pH Results

Leachate Exchange	Date/Time	6.0 - 4	6.0 - 5	6.0 - 6	Blank
	30s	9.07	9.16	8.54	8.47
1	2 hour	10.09	10.13	9.99	7.50
2	7 hour	10.35	10.33	10.08	8.25
3	24 hour	10.55	10.60	10.22	8.50
4	2 day	10.16	10.48	10.21	8.60
5	3 day	10.16	10.34	10.14	8.77
6	4 day	10.44	10.60	10.27	8.04
7	5 Day	10.48	10.38	10.35	8.96

Table 2. Electric Conductivity Results

Leachate Exchange	Date/Time	6.0 - 4	6.0 - 5	6.0 - 6	Blank
	30s	56.4	67.8	50.5	1.07
1	2 hour	176.2	197.5	168.0	1.03
2	7 hour	340	342	211.5	0.99
3	24 hour	543	544	236.0	1.12
4	2 day	236.5	426	223.3	1.23
5	3 day	200.0	317	182.3	1.22
6	4 day	199.3	280.8	129.7	1.26
7	5 Day	269.9	223.0	229.7	0.99

Hydraulic Conductivity/Permeability via Calculations:

In prior testing techniques done at the Savannah River National Laboratory, the use of a ***Steady State Centrifugation Unsaturated Flow Apparatus*** was used in order to determine the hydraulic conductivity of the saltstone mixtures. This testing used many variables to produce he equations that are shown below:

Water flux density, q, is given by Darcy's Law as the product of the hydraulic conductivity, K, and the fluid driving force. Under a centripetal acceleration in which water is driven by both a matric potential gradient and the centrifugal force per unit volume, Darcy's Law is given as follows:

$$q = -K\,[d\psi/dr - \rho\omega 2r] \qquad \text{(Equation 1)}$$

where: K = hydraulic conductivity (cm/s)

r = distance from axis of rotation (cm)

ρ = water density (gm/cm3)

ω = rotation speed (radians/s)

ψ = matric potential

dψ/dr = matric potential gradient

pω2r = centrifugal force per unit volume

Hydraulic conductivity is a function of either the matric potential or the volumetric water content. Above speeds of about 300 rpm, provided that sufficient water flux density exists, the matric potential gradient can be much less than the acceleration, $d\psi/dr \ll \rho\omega 2r$. Therefore, under these conditions, Darcy's Law is given by:

$$q = -K\,[-\rho\omega 2r] \qquad \text{(Equation 2)}$$

Rearranging Darcy's Law, the equation becomes:

$$K = q/(\rho\omega 2r) \qquad \text{(Equation 3)}$$

Laboratory Testing via AMEC Environment & Infrastructure

The hydraulic conductivity of the samples in question was determined by ***AMEC Environment & Infrastructure Co.,*** where they have used *ASTM D5084-03 Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter*. AMEC Environment & Infrastructure Co. has provided a full report regarding the hydraulic conductivity of the samples that have been tested at SRNL. Results from their report include the following information:

Table 3. Hydraulic Conductivity Results

SAMPLE #	Water Content (%)	Saturated Weight (pcf)	Dry Weight (pcf)	Hydraulic Conductivity (cm/sec)
0.5 - 1	43.7	106.4	74.0	**1.6×10^{-9}**
0.5 - 2	44.9	105.9	73.1	**4.2×10^{-9}**
0.5 - 3	44.1	107.6	74.7	**3.1×10^{-9}**
1.0 - 1	44.3	106.0	73.5	**4.0×10^{-8}**
1.0 - 2	44.1	106.1	73.7	**2.4×10^{-7}**
1.0 - 3	43.8	105.9	73.6	**1.8×10^{-7}**
3.0 - 1	44.8	107.1	74.0	**2.3×10^{-9}**
3.0 - 2	44.5	107.5	74.4	**2.0×10^{-9}**
3.0 - 3	44.4	108.7	75.3	**1.4×10^{-9}**
6.0 - 1	44.1	105.8	73.4	**5.9×10^{-11}**
6.0 - 2	43.4	107.2	74.8	**1.6×10^{-9}**
6.0 - 3	44.0	107.0	74.3	**2.6×10^{-10}**

Hydraulic conductivity describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation of the material (in our case, the saltstone).

Concrete Compression Testing

The concrete compression testing conducted at SRNL was followed using the *ASTM C39/C39M – 12 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. This test method determines the compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. This testing method is limited to concrete having a density with an excess of 800 kg/m^3 or 50 lb/ft^3.

The *ASTM C39/C39M – 12* test method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. The results of this test method are used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of the compliance with specifications; control for evaluating effectiveness of mixtures; and other similar uses.

Care must be exercised in the interpretation of the significance of compressive strength determinations by this test method since strength is not a fundamental or intrinsic property of concrete made from given materials. Values obtained will depend on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, and fabrication and the age, temperature, and moisture conditions during curing.

Figure 6. Concrete compression machine.

A total 12 samples were provided that simulate real life pouring techniques that can exemplify the strength of different cylinders with different layers or joints. The samples provided include (0.5-7,8,9), (1.0-7,8,9), (3.0-7,8,9), and (6.0-7,8,9) respectively; these specimens will have 1, 2, 6, and 12 joints. The reason these cylinders have a different number of joints is to better describe the amount that will be poured into the waste tanks on the day of the vault enclosure.

The results were obtained from the concrete compression testing that was conducted on saltstone samples (0.5-7,8,9), (1.0-7,8,9), (3.0-7,8,9), and (6.0-7,8,9). The following information has been provided through the use of graphs which include maximum stress (psi), maximum loading (lb), and avg. stress (g) of each of the concrete cylinder samples.

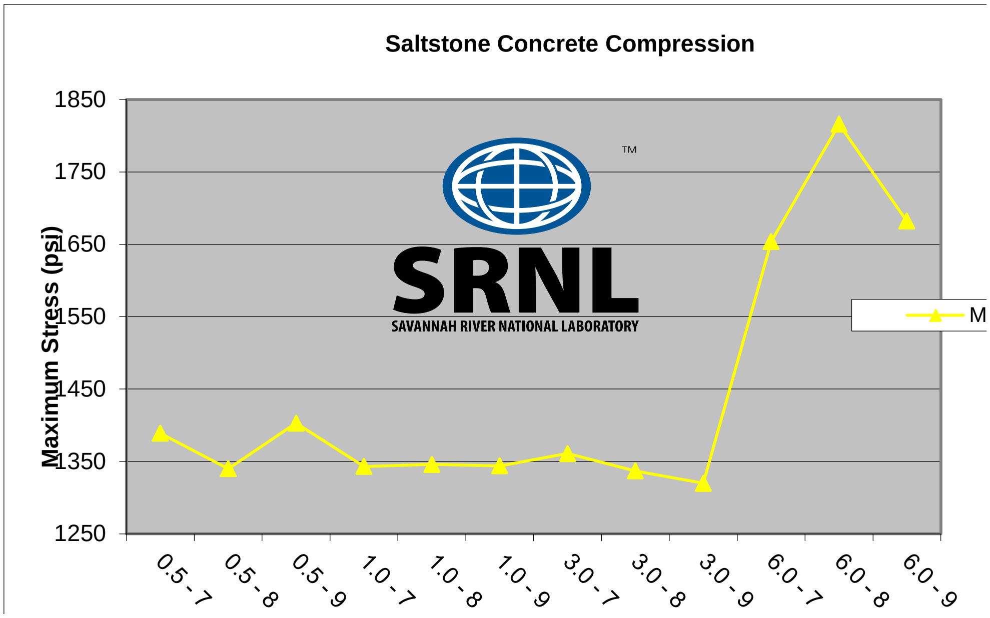


Figure 7. Maximum stress/concrete compression.

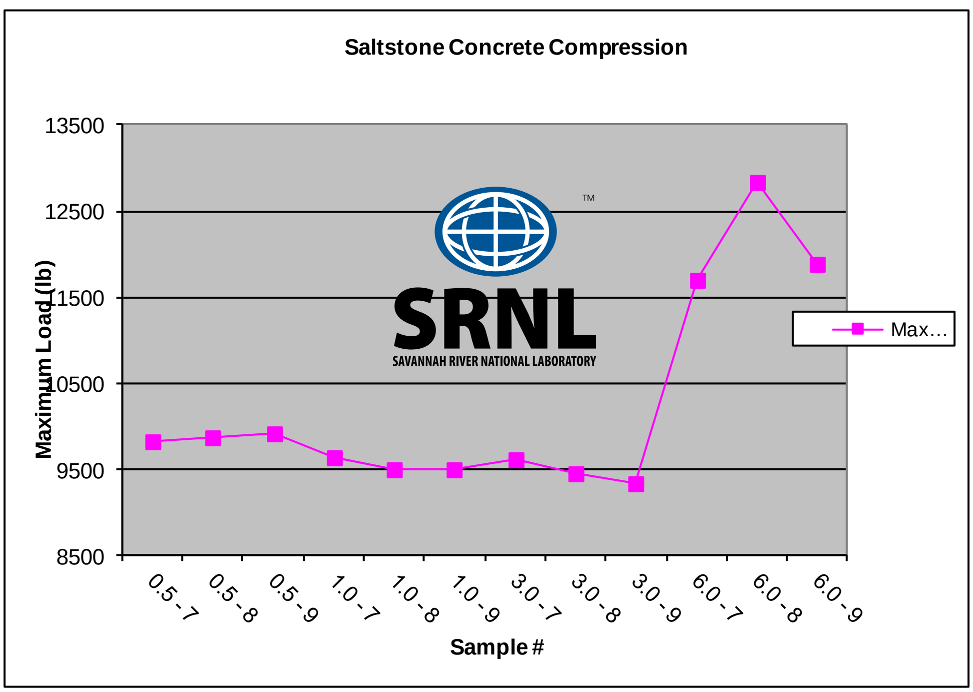


Figure 8. Maximum load/concrete compression.

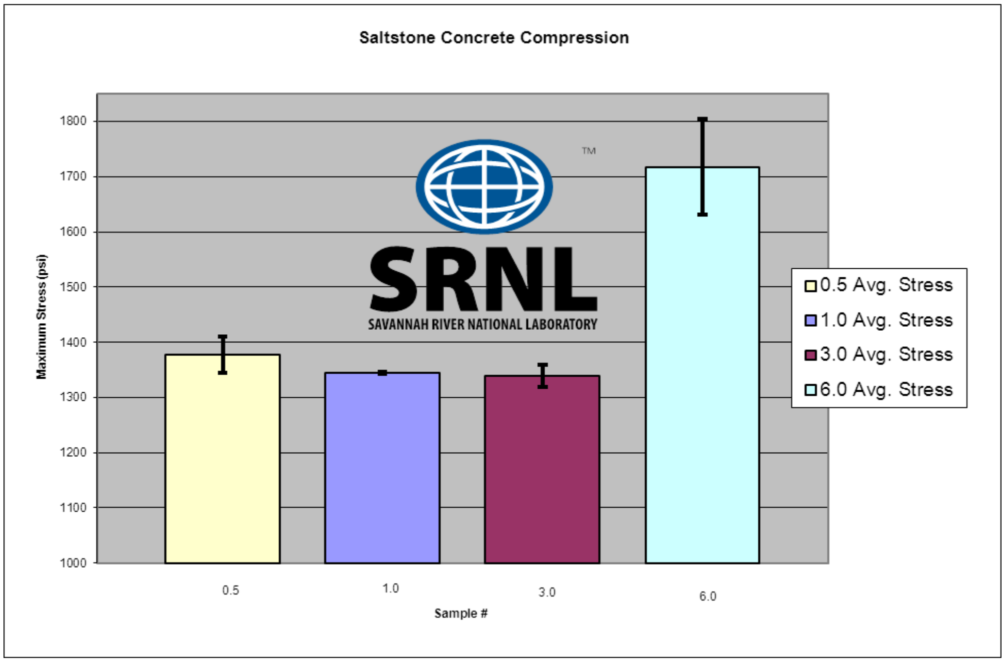


Figure 9. Average stress per sample/concrete compression.

These results clearly indicate that the layering process of the pour weaken the concrete sample. But the million dollar question is how much it will weaken the sample. With further examination of the results that were yielded, the 1 layer cylinder performed the best with an average stress level of 1717.33 lb/in^2; meanwhile, all of the other samples gave similar results that lingered around 1350 lb/in^2 until failure.

It has been proven that the layering/joint technique provided strong samples that almost mimicked the solid cylinder results. Considering how much saltstone grout will be poured in a single work day, the amount of grout that can be poured is estimated to be in the 3.0 – 6.0 inch range. The 3.0 – 6.0 inch cylinder samples seem to be very strong considering the number of joints that will be in the vault enclosure. With all of this testing, it has been concluded that the layering/joint technique is a major possibility on the day of the tank enclosure because of the shear size of the 100 feet long, 100 feet wide and 25 feet tall tanks that will be filled.

Moisture Content Analysis

Moisture content is a significant quality control measure at SRNL. Incorrect moisture content affects flow ability, chemical reactions, the ability of a product to be processed, and overall product performance. Determining actual moisture content and comparing it to specified moisture content is accomplished by using a moisture analyzer, also called a moisture balance.

Figure 10. Moisture analysis machine.

Moisture analyzers in the laboratory are an effective way to determine the percent solids that are left after the salt solution has been evaporated. This apparatus is also being used as a standard to ensure large oven dryers performing bulk drying on production lines are doing the job correctly.

Moisture analyzers are programmable benchtop analytical balances on which heaters are mounted to drive off moisture from products being tested. This is accomplished by periodically sampling bulk material and determining when bulk drying should be terminated.

How moisture analyzers work

Most moisture analyzers today operate on what is called the thermogravimetric principal. That is determining the loss of weight on drying (LOD). The loss represents the amount of moisture given off during the drying process while the change in weight is recorded by the analytical balance. Testing procedures are programmed into the balance and the change in weight is continually calculated as it performs the drying operation. Considering the small sample sizes, the analysis can be accomplished very quickly. Drying temperature is supplied by halogen heaters because it is faster than infrared drying.

Procedure of the analysis sequence

1. Establish the procedures for the products being tested and program the balance accordingly. Include each of these procedures in the operations manual.
2. Place the sample plate on the moisture balance sample plate holder then tare the balance.
3. Spread the recommended amount of product evenly on the sample plate and record the weight.
4. Close the cover of the moisture balance to start the sequence.
5. The unit's display panel continually updates the status of the process. The analysis automatically terminates when drying is complete and the dry weight is stable, or after a fixed time specified by the operator, or manually.

At the end of the moisture weighing all relevant data concerning initial mass, residual mass, test parameters and results can be printed out as shown below:

Figure 11. Moisture analysis receipt.

4. CONCLUSION

The Saltstone mixture was subjected to rigorous experiments including Concrete Compression in which the 1 layer cylinder performed the best with an average stress level of 1717.33 psi, meanwhile all of the other samples gave similar results that lingered around 1350 psi until failure. Results from the Leaching Tests also yielded pH levels of an average of 10 which meets EPA standards to be able to pour down regular septic tank drains. Maintaining a safe environment for the future generations is a major goal of the Department of Energy's Office of Environmental Management mission. The Saltstone grout mixture project is making significant progress in the processing and storage of low level radioactive waste at Savannah River site. The enclosure of the tank farms at SRNL by using the Saltstone approach is something that will be mimicked by other nuclear facilities because this breakthrough process not only encloses the vault itself, but absorbs some of the damaging chemicals that can potentially be transported offsite contaminating the environment.

Within the realm of optimizing this Saltstone grout mixture in the near future, the next step will be to actually set up small scale experiments other than the laboratory testing that has been taking place. These experiments will most likely go a long way in providing new data that cannot be replicated in a small setting such as a laboratory. It is believed that with the quality of research that has been carried out in the laboratory thus far, it can only translate to great things and new exemplary data for future reference in such related projects.

5. REFERENCES

Savannah River Remediation, http://srremediation.com/saltstone.html

ASTM C 39/C39M – 12 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C 204-00 Standard Test Method for Fineness of Hydraulic Cement by Air Permeability Apparatus.

ASTM C 1308 - 08 Standard Test Method for Accelerated Leach Test for Diffusive Releases from Solidified Waste

Thermo Scientific©, http://www.thermoscientific.com/ecomm/servlet/productsdetail?productId=11958175&groupType=PRODUCT&searchType=0&&storeId=11152

Concrete in Practice What, Why & How? http://www.nrmca.org/aboutconcrete/cips/35p.pdf

How to use a Moisture Analyzer http://www.tovatech.com/blog/2441/moisture-balance-2/how-to-use-a-moisture-analyzer

6. APPENDIX A: Area of Concentration

Figure 12: Saltstone Production Facility

Figure 13: Portion of the Saltstone Production Facility

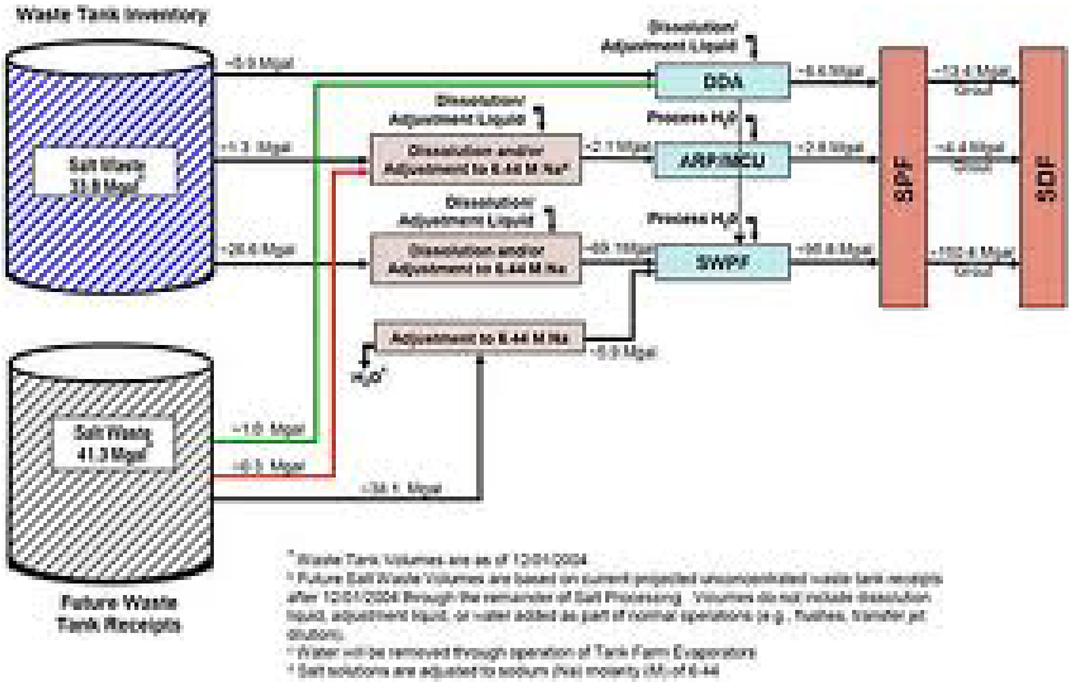


Figure 14: Saltstone Production Facility Layout

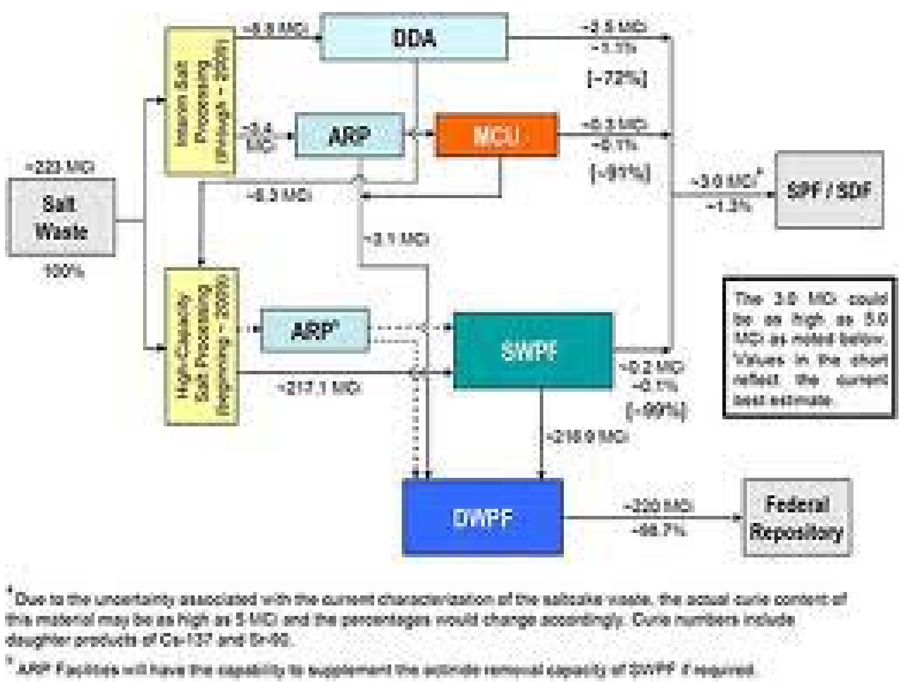


Figure 15: Saltstone Production Facility Process

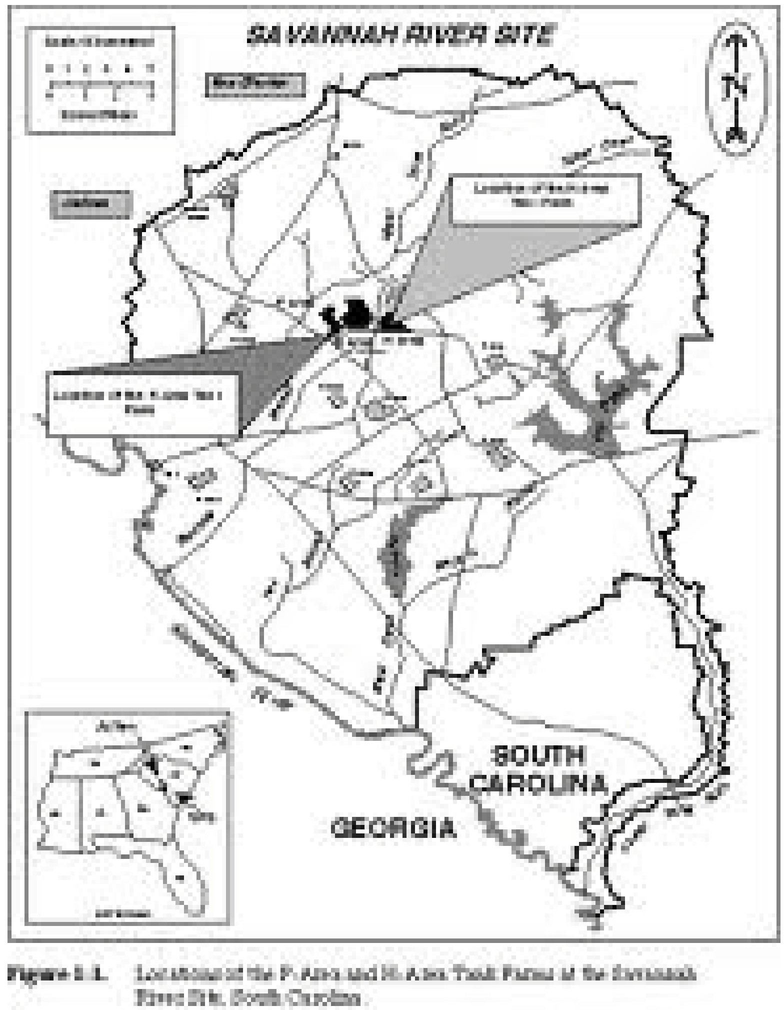


Figure 16: Savannah River Overview Map

Figure 17: Saltstone Production Facility Location of Old Reactors/Notable Areas

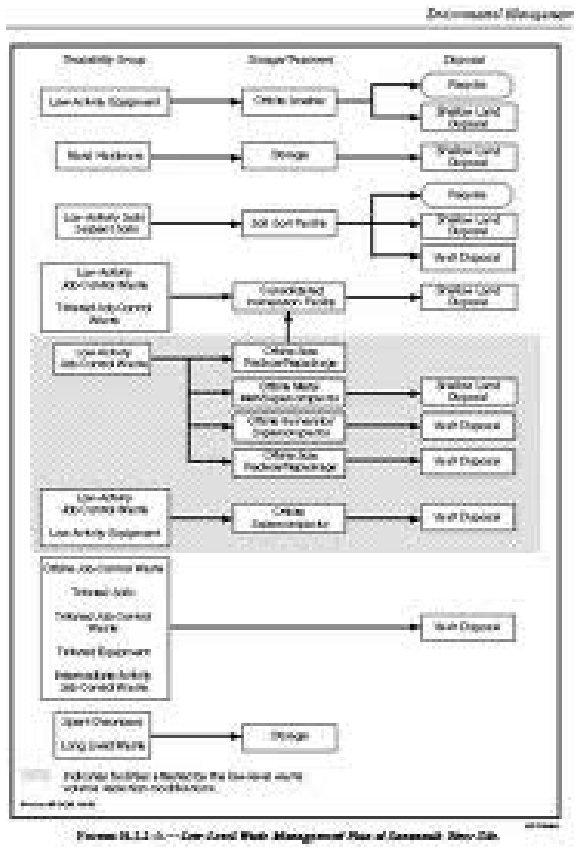


Figure 18: Low Level Waste Management at Savannah River Site