BJC/OR-279

C-Tank Transfers

Transuranic Sludge Removal From the C-1, C-2, and W-23 Waste Storage Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee

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DISCLAIMER

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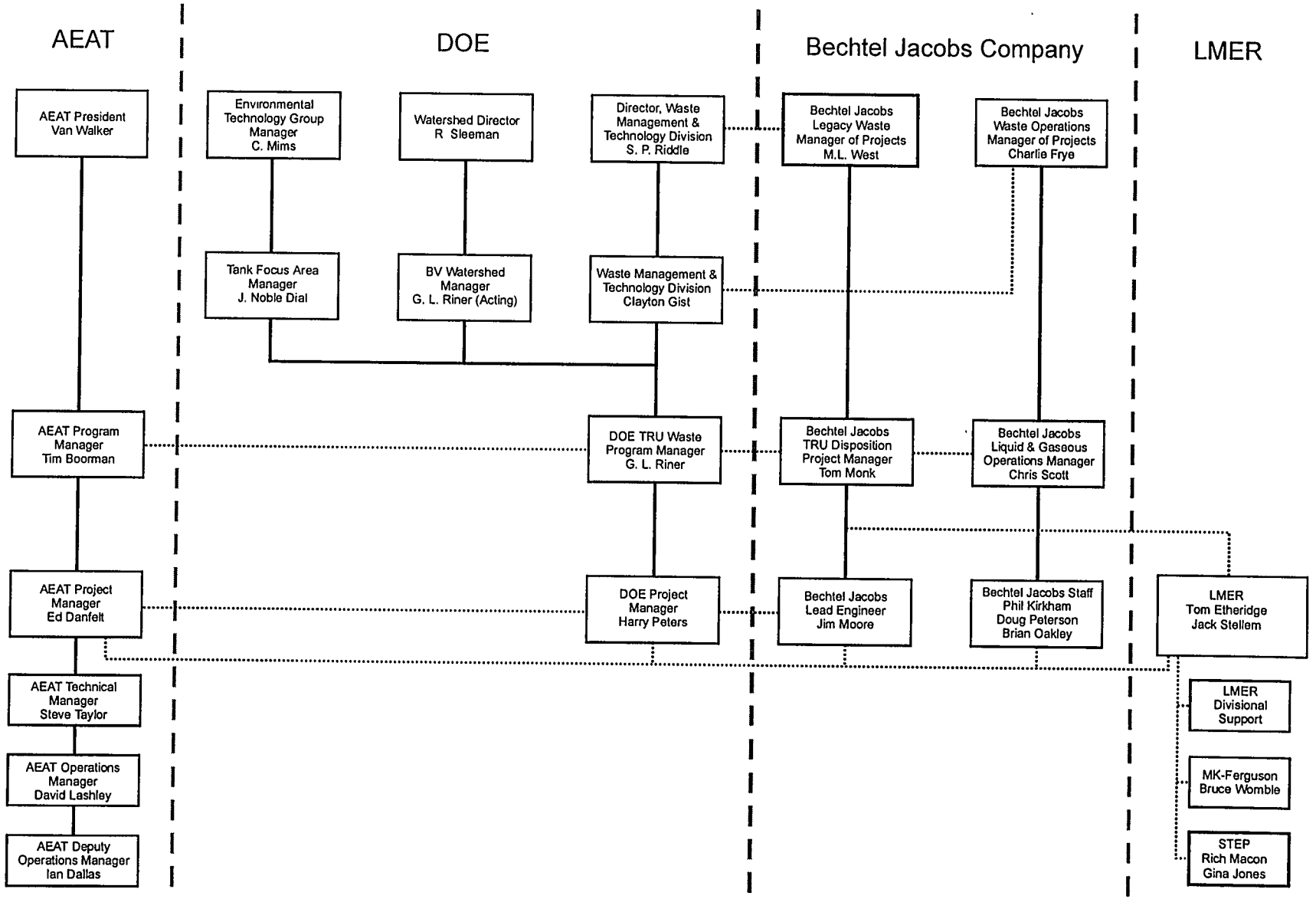
BVEST C-Tank Transfer Project Organization Chart



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ACRONYMS

AEAT	AEA Technology
BVEST	Bethel Valley Evaporator Service Tanks
DOE	U.S. Department of Energy
DOE-HQ	U.S. Department of Energy–Headquarters
DOE-ORO	U.S. Department of Energy–Oak Ridge Operations
HEPA	high-efficiency particulate air
ICP-MS	inductively coupled plasma-mass spectrometer
LLLW	liquid low-level (radioactive) waste
LMER	Lockheed Martin Energy Research Corp.
LMES	Lockheed Martin Energy Systems, Inc.
MVST	Melton Valley Storage Tanks
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyl
PVV	pump and valve vault
PWTP	Process Waste Treatment Plant
RCRA	Resource Conservation and Recovery Act
RH-TRU	remote-handled transuranic
STEP	Solutions to Environmental Problems, Inc.
TS	total solids
TSS	total suspended solids
TC	total carbon
TIC	total inorganic carbon
TIMS	Thermal Ionization Mass Spectrometry
TOC	total organic carbon
wt%	weight percent

EXECUTIVE SUMMARY

Two fluidic pulse jet mixing systems, designed and fabricated by AEA Technology, were used to successfully mobilize remote-handled transuranic (RH-TRU) sludge for retrieval from three 50,000-gal horizontal waste storage tanks (C-1, C-2, and W-23) at Oak Ridge National Laboratory (ORNL). The pulse jet system does not contain any moving parts that come in contact with the supernate-sludge slurry except level switches (which can be easily replaced, if necessary). One system was installed in the summer of 1997 and operated to mobilize sludge in tanks W-21, W-22, and W-23 during late 1997 and early 1998. Tank W-23 was not fully cleaned during this time because of its planned use during the upcoming C-Tank Transfers project. The W-Tank pulse jet system consisted of seven modular equipment skids and was specially designed to locate the system's six charge vessels inside the Building 2537 Pump and Valve Vault (PVV) and to use existing W-tank piping to mix the sludge and supernate. For the C-tank pulse jet system, the two charge vessels were designed to be installed inside each tank's two manhole extensions. Both systems used existing progressive cavity pumps located in PVV to transfer the slurry to the Melton Valley Storage Tanks (MVST).

Both systems were used to complete the transfers from the C-tanks to MVST. The C-tank system mixed the sludge and supernate in each C-tank, and the progressive cavity pumps located in PVV were used to transfer each C-tank's sludge/slurry to W-23. While in W-23 the C-tank slurry was kept mixed by operating the W-tank mixing system. When ready, the same progressive cavity pumps were used to transfer the slurry to MVST.

Tank C-2 was emptied first. The starting sludge volume in C-2 was approximately 8200 gal. A total of 8100 gal of sludge, or 99%, was transferred to tank W-23. After the charge vessels were moved from C-2 to C-1, approximately 3100 gal of sludge were transferred from C-1 to W-23. Since the initial volume in C-1 was 3250 gal, over 95% of the sludge was removed. During the earlier W-Tank sludge removal projects, all but 750 gal of the original 19,000 gal of sludge in Tank W-23 had been transferred to MVST. The final volume of sludge remaining in W-23 after the C-Tank Transfer project was complete was approximately 225 gal. Total sludge removal from W-23 was 18,775 gal or almost 99%. Water was not added to any of the tanks for sludge removal, but nitric acid was added to each tank to assist the slurry removal process during the last or last two transfers from each tank.

The pulse jet system operated well and experienced no major equipment malfunctions. The modular design and low-maintenance aspects of the system minimized radiation exposure during installation and operation of the system. The extent of sludge removal from the tanks was limited by the constraints of using the existing tank nozzles (on W-tanks) and access ports (on C-tanks) and by the physical characteristics of the sludge. Removing a greater percentage of sludge would require considerable additional time and expense and possibly other equipment such as a manual sluicer or a costly and elaborate robotic retrieval system. The results of this operation indicate that the pulse jet system should be considered for mixing and bulk retrieval of sludges in other vertical and horizontal waste tanks at ORNL and at other U.S. Department of Energy (DOE) sites.

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1. INTRODUCTION

The U.S. Department of Energy (DOE) is in the process of remediating underground storage tanks containing hazardous radioactive wastes at Oak Ridge National Laboratory (ORNL) and other DOE sites across the country. These tanks contain wastes generated from past and present development activities involving national defense initiatives, nuclear energy research, and radioisotope production. The wastes have separated into liquid and sludge layers after many years of storage. The remediation of these tanks involves removing and processing the wastes to stabilize the radioactive and hazardous components for disposal. The heavy layer of sludge in these tanks must be mobilized to remove it from the tanks. A preferred method involves mixing the sludge with existing tank liquids, rather than adding more liquids and thereby increasing the tank waste volume. Optimally, the sludges and liquids would be mixed to produce a uniform slurry of known composition that can be safely transferred by pipeline to another facility for additional processing.

AEAT has developed a fluidic pulse jet mixing system for tank waste that minimizes the use of moving parts and requires very little maintenance. For the ORNL horizontal tanks, two pulse jet systems were used to remove sludge from a total of five tanks. These systems required very little modification of the tank system. The pulse jet system has been used in nuclear applications in the United Kingdom for many years. These advantages led to the decision to deploy AEAT's fluidic pulse jet system for mixing and mobilizing the sludges stored in the Bethel Valley Evaporator Service Tanks (BVEST) at ORNL.

2. DESCRIPTION OF PULSE JET MIXING

Pulse jet mixing typically involves the use of large-diameter pulse tubes vertically mounted in the tank and immersed in the tank waste. A vacuum is applied to the pulse tube using a jet pump, with air as the motive fluid. Sludge and liquid fill the pulse tube (suction phase); when the tube is full, the jet pump is turned off, and the tube is vented (vent phase). Gravity causes the fluid in the tube to fall back into the tank and impart the mobilization and mixing action.

The AEAT pulse jet systems designed for the BVEST applications were constrained to fit existing tank configurations, and for the W-Tanks, to use existing in-tank nozzles. Because of these constraints, the systems were designed to include a drive phase in addition to the suction and vent phases. Figure 2-1 illustrates the three-phase operation of these systems. For both the W-Tank and C-Tank Systems each charge vessel had an associated jet pump pair. The jet pump was used to apply the necessary vacuum to pull the liquid/sludge mixture into the charge vessel. When the mixture reached a predetermined level in the charge vessel, the jet pump was switched from vacuum to pressure mode. Air pressure was then applied to the charge vessel to force the fluid back into the tank to create a mixing action. Before the charge vessel was completely emptied, the pressure was released and the charge vessel pressure was allowed to vent through the system off-gas. The pressure, frequency, and sequence of pulsing for the charge vessel, were adjusted to achieve optimum mixing.

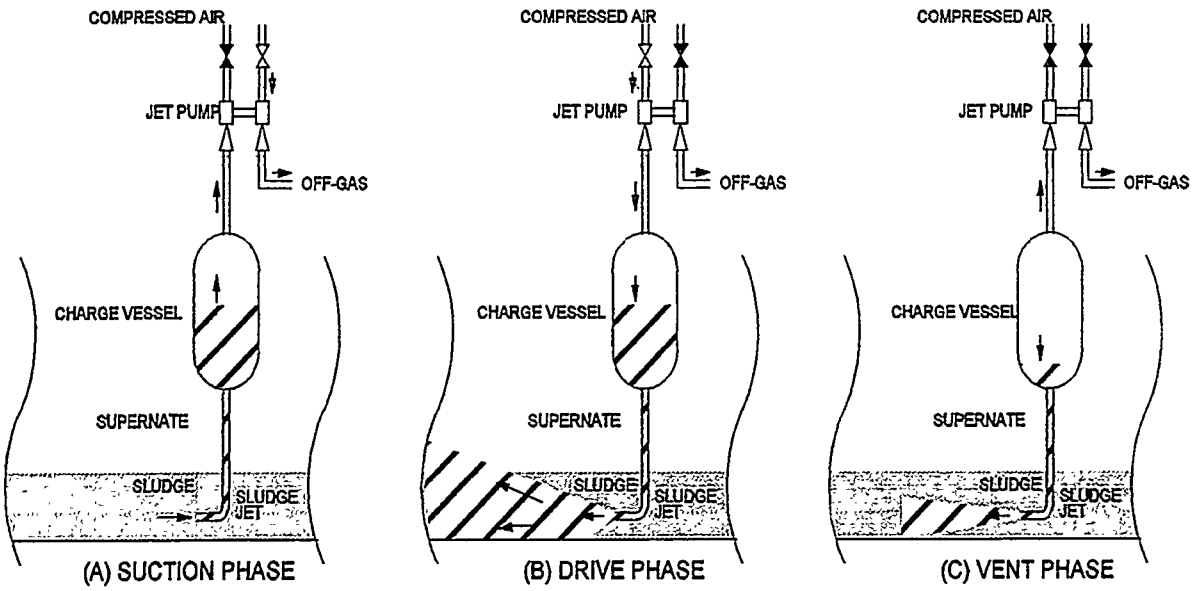


Fig. 2-1. Pulse Jet system operating principles.

3. DESCRIPTION OF THE BVEST SYSTEM

The BVEST are located in the center of the main ORNL complex. These tanks provide surge and storage capacity for processing liquid low-level waste (LLLW) collected from generators throughout the laboratory via an underground collection and transfer system. LLLW is processed by evaporation at the Evaporator Facility (Bldg. 2531) to reduce the volume for long-term storage. BVEST consists of five tanks: W-21, W-22, W-23, C-1, and C-2. Historically, tank W-22 has served as the feed tank for the evaporator, while the other tanks store the LLLW concentrate. Tanks W-21 and W-23 can also serve as alternate feed tanks for the evaporator if necessary. These tanks have a design volume of 50,000 gal, but each tank is operationally limited to a maximum capacity of 47,500 gal of liquid.

The W-21, W-22, and W-23 tanks are essentially identical in construction. Each tank is an all-welded vessel, fabricated of 0.5-in.-thick stainless steel, 12 ft in diam and approximately 61 ft 5 in. long. The tanks contain a large number of internal obstructions located along their centerlines (see Fig. 3-1). Each tank has three pairs of 3-in.-diam nozzles that extend from the top of the tank downward to where they elbow horizontally 8 in. above the bottom of the tank. These six 3-in. nozzles are connected by 3-in.-diam stainless steel pipelines that run back into the PVV. Prior to installing the AEAT pulse jet system, the pipelines ended in a series of blind, four-bolt flanges. The tanks operate at slight negative pressure at ambient temperature, but they are designed to withstand either full vacuum or 15 psig at 150°F. Access into the tanks is limited. Each tank has a single 19-in. manhole located 17 ft from the north end. Manhole extensions were added in 1997 to allow access into the tanks from the vault roof (see Fig. 3-2).

The C-1 and C-2 tanks are essentially identical in construction. They were originally designed to store high level waste but were never used for that purpose. Each tank is an all-welded vessel, fabricated of 0.5-in.-thick stainless steel, 12 ft in diam and approximately 61 ft 5 in. long. Although they have the same exterior dimensions as the W-tanks, they are quite different internally (see Fig. 3-3 for isometric view). In addition to the many vertical pipes and tubes running down the entire length of the tanks, along each tank's vertical centerline, there is a maze of horizontal cooling coils near the bottom of each tank. The tanks operate at a slightly negative pressure at ambient temperature, but have been designed to withstand either full vacuum or 30 psig at 200°F. Each C-tank has two 20-in.-ID manholes for access. The manholes are located on opposite ends of the tanks, approximately 5 ft from each end. These manhole accesses were added to the C-tanks in 1997 (see Fig. 3-4). Prior to this time the C-tanks had no access.

Figure 3-5 depicts the overall arrangement of these tanks. All tanks are horizontally mounted. Tanks W-21 and W-22 are located in a single, reinforced concrete underground vault. The W-21/W-22 tank vault is approximately 31 ft wide, 69 ft long, and 16 ft high, and the floor elevation is 780 ft above sea level. Tank W-23 is located in a separate vault, west of W-21 and W-22, at a floor elevation of 788.5 ft. The two vaults are separated by a PVV. Both C-tanks are located in a single vault which is approximately 29 ft wide, 65 ft long, and 16 ft high, and the floor elevation is 793.5 ft above sea level.

The tanks and vaults are designed for storage of radioactive liquids and provide double containment. The reinforced concrete walls of the W-tank vaults vary in thickness from 2 to 3 ft. The reinforced concrete walls of the C-tank vault varies in thickness from 14 in. to 2 ft. The concrete roof slabs are 3.5 ft thick over the W-21/W-22 vault, and 3 ft thick over the C-1/C-2 and W-23 vaults. The W-tank vault floors and walls are lined with 16-gauge stainless steel to a height of 7 ft 2 in. A drainage sump and sump pump are provided in all vaults for containment and transfer of liquids from tank leaks or other sources. All tanks and vaults are connected to HEPA filtered ventilation/off-gas systems.

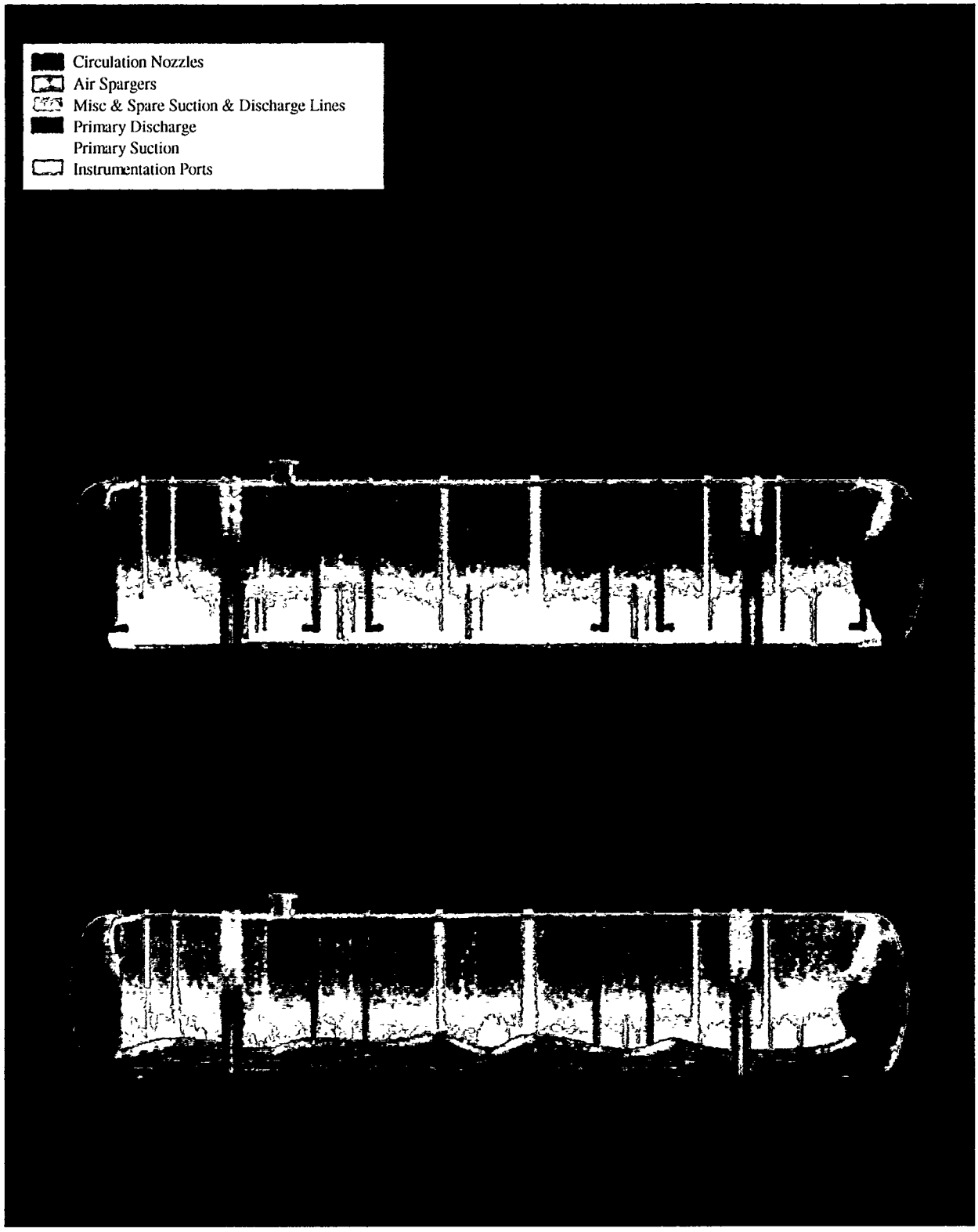


Fig. 3-1. Bethel Valley Evaporator Service Tanks are 50,000-gal, horizontal storage tanks with equipment placed along the length of the tanks' center lines.

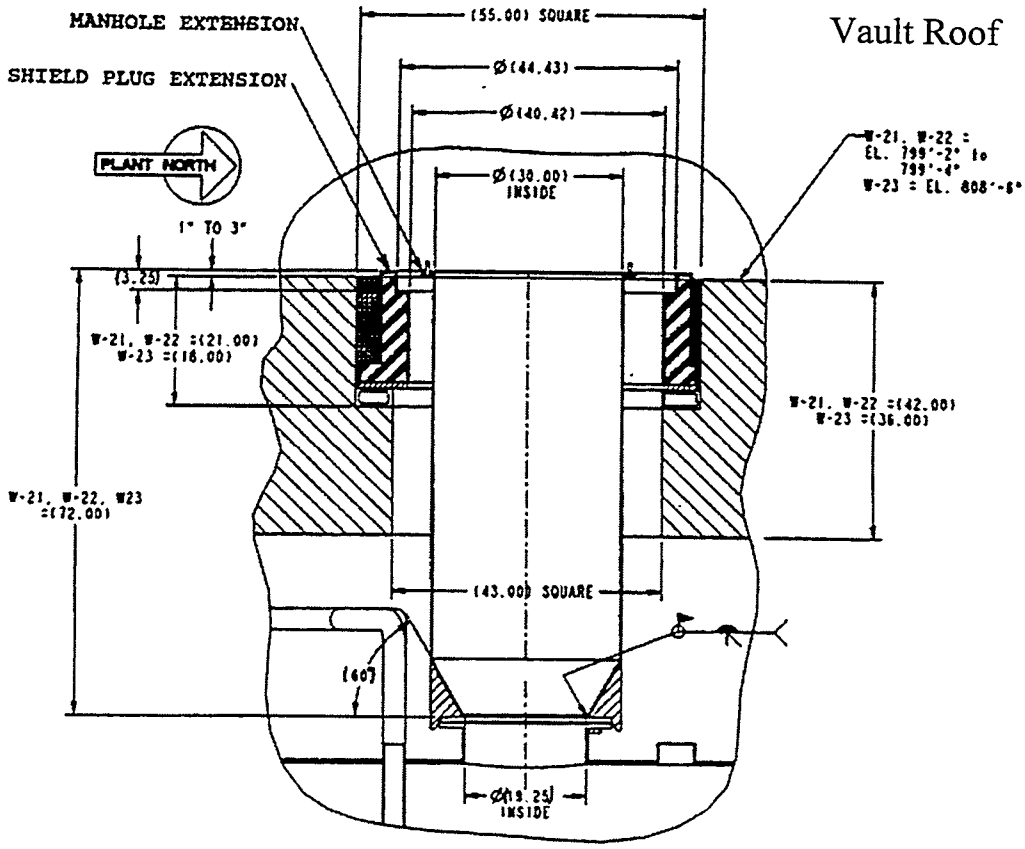


Fig. 3-2. Design schematic of "W" tanks' manhole extension.

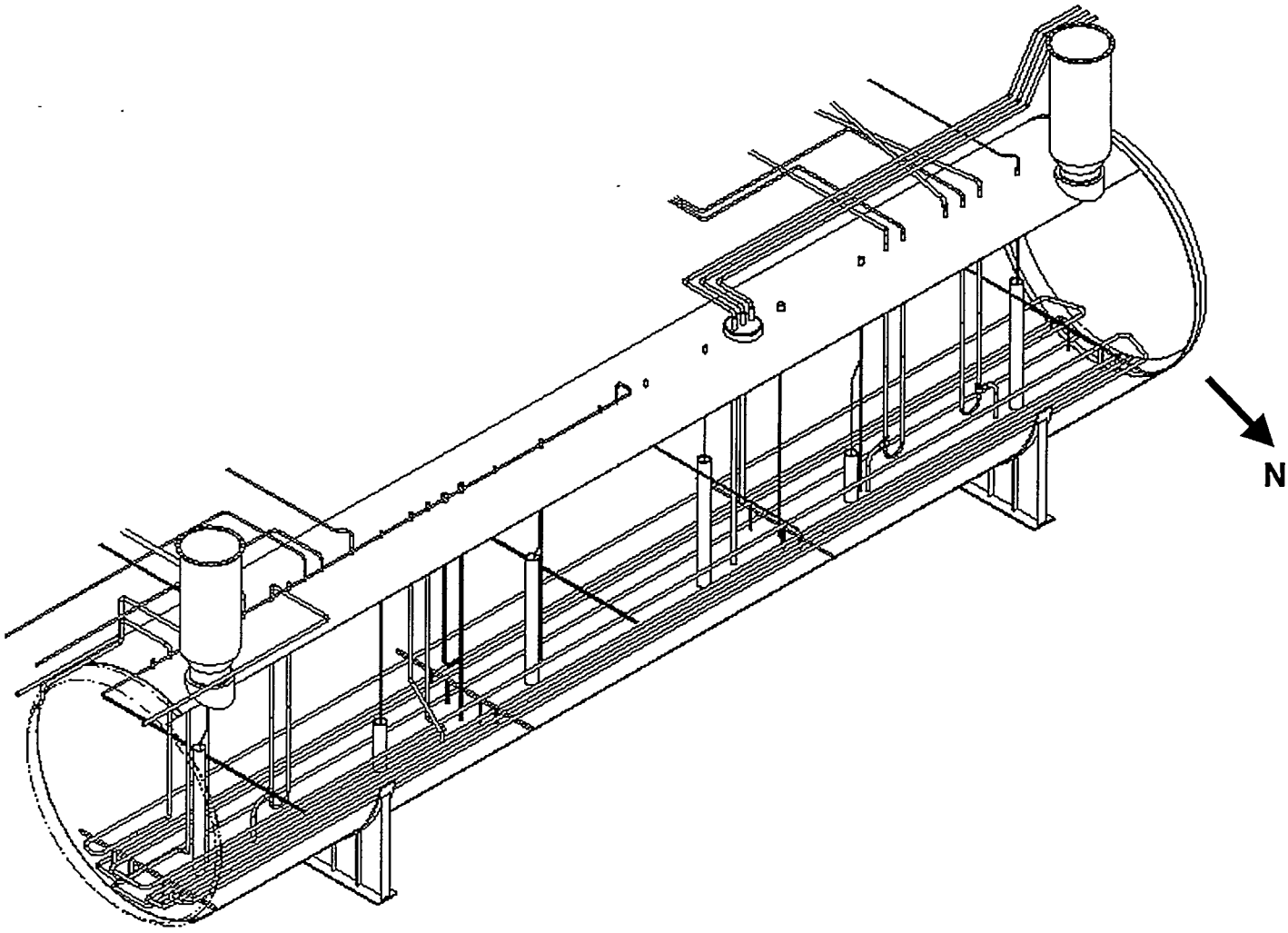
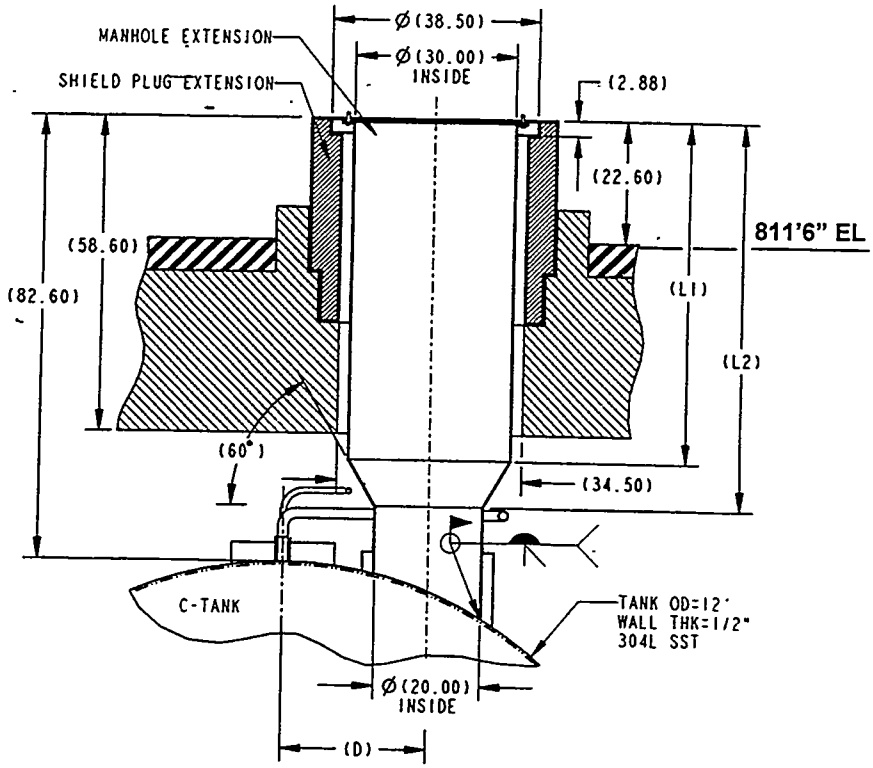


Fig. 3-3. C Tank drawing.



		"D"	"L1"	"L2"	UNIT
C-1 TANK	EAST	22.00	66.54	75.20	INCH
	WEST	22.00	66.54	75.20	INCH
C-2 TANK	EAST	27.00	63.54	72.20	INCH
	WEST	22.00	66.54	75.20	INCH

Figure 3-4. C-Tank manhole extension.

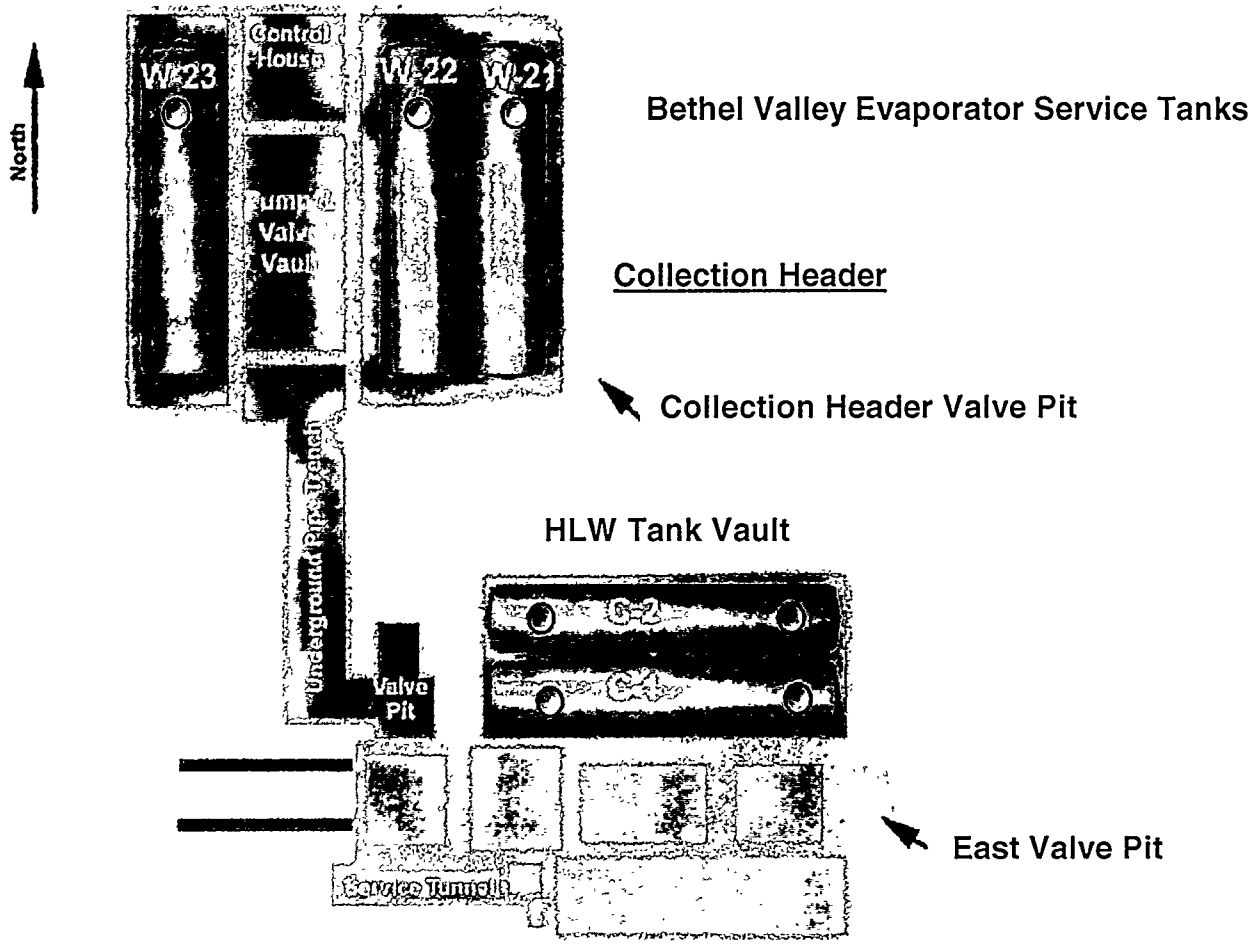


Figure 3-5. Layout of the Bethel Valley Evaporator Service Tanks at ORNL.

The PVV is an underground vault with internal dimensions of 25 ft long by 15 ft wide by 6 ft high. The vault walls and floor are 2- to 3-ft-thick, reinforced concrete. The ceiling is made of four interlocking 2-ft-thick concrete slabs plus one 4-in. thick steel cover plate. The PVV is designed to provide secondary containment of radioactive liquid. A 16-gauge stainless-steel base covers the floor and extends partway up the walls. A sump and sump pump are provided in the vault to permit the retrieval of any material that may have leaked. The PVV is ventilated through an existing centralized off-gas system.

The BVEST are connected by a double-contained stainless steel annular pipeline (with a 2-in. internal pipe) to MVST located approximately 1 mile away. Liquid may be transferred from BVEST to MVST by using either of two progressive-cavity pumps located in PVV. The pumps are mounted longitudinally in PVV approximately 2 ft 4 in. apart, and they are connected to tanks by piping located in PVV and tank vaults. The maximum working pressure for the pipeline is 300 psi, and the pumps routinely operate at approximately 240 psig at a flow of approximately 60 gal/min. The equivalent length of the pipeline (actual length plus equivalent lengths to account for bends, valves, and other fittings) is about 7100 ft.

4. BVEST SLUDGE CHARACTERISTICS

The BVEST are used to collect and store LLLW generated at ORNL. The liquid and solid phases have separated and formed distinct layers in the tanks. The volume of sludge was estimated to be 3250 gal in C-1 and 8200 gal in tank C-2; the starting total volume in each tank was 16,000 gal and 25,000 gal, respectively.

Tables 4-1 and 4-2 (Keller and Giaquinto 1998) provide supernate and sludge characterization data from sampling activities that took place in February and March 1999. The primary components of the sludge are metal nitrates, carbonates, and hydroxides. The major metal constituents include sodium, calcium, magnesium, potassium, and uranium. Smaller amounts of heavy metals are also present, such as chromium, cadmium, lead, mercury, and others that are regulated under the Resource Conservation and Recovery Act (RCRA). The principal radiological components of the sludge are fission products, such as ^{137}Cs and ^{90}Sr; activation products, such as ^{60}Co; and actinides, such as thorium, uranium, and plutonium. Other significant radiological components are three isotopes of Europium, (^{152}Eu, ^{154}Eu, ^{155}Eu) and ^{244}Cm. The sludge is classified as transuranic, due to the plutonium and americium content, and it is considered remote handled, due to the high gamma activity.

Table 4-1. Analytical data for sludge in C-1 tank

Characteristic (analysis)		C-1 East	C-1 West	C-1 Average
Physical properties and miscellaneous data				
pH		9.9	10.9	**10.4**
Water[a]	(%)	44.8	47.9	**46.4**
TS[b]	(mg/g)	552	521	**537**
TSS[c]	(mg/g)	315	296	**306**
Bulk density	(g/mL)	1.561	1.541	**1.551**
TC[d]	(mg/Kg)	25700	23700	**23500**
TIC[e]	(mg/Kg)	25100	21200	**24400**
TOC[f]	(mg/Kg)	600	< 1000	**1550**
PCB				
Aroclor-1254	(mg/Kg)	< 0.3	< 0.6	-
RCRA metals (±10%)				
Ag[g]	(mg/Kg)	15.4	16.5	**16**
As	(mg/Kg)	< 4.2	< 5.1	-
Ba	(mg/Kg)	83.2	57.2	**70.2**
Cd	(mg/Kg)	< 1.5	< 1.9	-
Cr	(mg/Kg)	119	102	**111**
Hg	(mg/Kg)	18.5	63.4	**41**
Ni	(mg/Kg)	63.3	45.4	**54.4**
Pb	(mg/Kg)	217	289	**253**
Se	(mg/Kg)	< 4.2	< 5.1	-
Tl	(mg/Kg)	< 4.2	< 5.1	-
Process metals (±10%)				
Al	(mg/Kg)	1360	1820	**1590**
B	(mg/Kg)	8	8	**8.2**
Be	(mg/Kg)	8	8	**7.9**
Ca	(mg/Kg)	81400	68800	**75100**
Co	(mg/Kg)	< 1.5	3	**3.3**
Cu	(mg/Kg)	46	50	**48**
Cs[h]	(mg/Kg)	< 1.5	< 1.9	-
Fe	(mg/Kg)	1600	1090	**1350**
K	(mg/Kg)	16600	20700	**18700**
Mg	(mg/Kg)	9450	10300	**9880**
Mn	(mg/Kg)	216	184	**200**
Na	(mg/Kg)	62200	61900	**62100**
P[i]	(mg/Kg)	1350	1530	**1440**
Sb	(mg/Kg)	219	199	**209**

Characteristic (analysis)		C-1 East	C-1 West	C-1 Average
Si [j]	(mg/Kg)	1710	1530	**1620**
Sr	(mg/Kg)	403	245	**324**
Th	(mg/Kg)	3990	5360	**4680**
U	(mg/Kg)	11800	17600	**14700**
V	(mg/Kg)	15	18	**16.5**
Zn	(mg/Kg)	761	564	**663**
Semiquantitative metals by ICP-MS (±30-50 %, * indicates data from water leach)				
Bi	(mg/Kg)	13	68	**41**
Ce	(mg/Kg)	5.8	5.7	**5.8**
Ga	(mg/Kg)	5.4	4.7	**5.1**
Gd	(mg/Kg)	4.0	4.8	**4.4**
Li	(mg/Kg)	2.2	3.3	**2.7**
Mo	(mg/Kg)	2.3	2.3	**2.3**
Sn	(mg/Kg)	9.0	8.5	**8.8**
Te	(mg/Kg)	6.7	14	**10**
Ti	(mg/Kg)	7.4	10	**8.7**
W	(mg/Kg)	2.1	< 1.9	-
Zr	(mg/Kg)	3.3	5.4	**4.4**
Anions by ion chromatography in water wash of sludge (±10%)				
Inorganic				
Bromide	(mg/Kg)	< 48	< 48	-
Chloride	(mg/Kg)	2810	3140	**2980**
Chromate	(mg/Kg)	< 5	< 4	-
Fluoride	(mg/Kg)	< 48	53.7	**53.7**
Nitrate	(mg/Kg)	195000	161000	**178000**
Nitrite	(mg/Kg)	1090	1860	**1475**
Phosphate	(mg/Kg)	< 10	< 9	-
Sulphate	(mg/Kg)	1230	1800	**1520**
Organic				
Acetate	(mg/Kg)	179	1820	**1000**
Citrate	(mg/Kg)	< 5	< 4	-
Formate	(mg/Kg)	87.6	99.4	**93.5**
Oxalate	(mg/Kg)	< 5	870	**870**
Phthalate	(mg/Kg)	< 5	< 4	-
Beta/gamma emitters (±10%)				
Gross beta	(Bq/g)	4100000	3600000	**3850000**
^{63}Ni	(Bq/g)	13000	4400	**8700**
^{60}Co	(Bq/g)	43000	21000	**32000**
$^{90}Sr/^{90}Y$	(Bq/g)	1200000	880000	**1000000**
^{99}Tc	(Bq/g)	< 140	507	**507**
^{129}I	(Bq/g)	-	-	-

Characteristic (analysis)		C-1 East	C-1 West	C-1 Average
^{134}Cs	(Bq/g)	7900	19000	**13500**
^{137}Cs	(Bq/g)	460000	700000	**580000**
^{152}Eu	(Bq/g)	540000	520000	**530000**
^{154}Eu	(Bq/g)	240000	150000	**195000**
^{155}Eu	(Bq/g)	39000	38000	**38500**
^{227}Ac	(Bq/g)	-	-	-
^{241}Pu	(Bq/g)	15000	15000	**15000**
Alpha emitters (±10%)				
Gross alpha	(Bq/g)	67000	84000	**75500**
^{232}Th	(Bq/g)	16	22	**19**
^{233}U	(Bq/g)	7800	28000	**17900**
^{234}U	(Bq/g)	170	420	**295**
^{235}U	(Bq/g)	2.1	4.3	**3.2**
^{238}U	(Bq/g)	146	217	**182**
^{237}Np	(Bq/g)	< 50	< 50	-
^{241}Am	(Bq/g)	4200	7500	**5850**
^{244}Cm	(Bq/g)	45000	35000	**40000**
^{250}Cf	(Bq/g)	< 50	< 50	-
^{252}Cf	(Bq/g)	< 50	< 50	-
Total Pu alpha[k]	(Bq/g)	8400	9300	**8850**
^{238}Pu	(Bq/g)	4400	5500	**4950**
$^{239}Pu/^{240}Pu$	(Bq/g)	3900	3700	**3800**
^{242}Pu	(Bq/g)	100	140	**120**
TRU activity Pu+Am (3700)	(Bq/g)	12600	16800	**14700**
Uranium isotopics by TIMS (±0.5%)				
^{233}U	(atom %)	0.197	0.468	
^{234}U	(atom %)	0.004	0.008	-
^{235}U	(atom %)	0.266	0.349	-
^{236}U	(atom %)	0.006	0.007	-
^{238}U	(atom %)	99.527	99.168	-
				-
$^{238}U/^{233}U$	(>200)	366	134	
$^{238}U/^{235}U$	(>110)	232	22	-
$^{238}U/^{235}U\ f_{35}$[l]	(>110)	190	103	-
				-

Characteristic (analysis)		C-1 East	C-1 West	C-1 Average
Uranium isotopics by ICP-MS (±2%)-				
^{233}U	(atom %)	0.1884	0.4596	-
^{234}U	(atom %)	0.0064	0.0105	-
^{235}U	(atom %)	0.2563	0.3453	-
^{236}U	(atom %)	0.0059	0.0056	-
^{238}U	(atom %)	99.5430	99.1790	-
$^{238}U/^{233}U$	(>200)	389	137	-
$^{238}U/^{235}U$	(>110)	248	27	-
$^{238}U/^{235}U\ f_{35}$ [l]	(>110)	198	105	-
Plutonium isotopics by ICP-MS (±2%)				
^{238}Pu	(atom %)	2.2252	1.9586	-
^{239}Pu	(atom %)	74.9464	83.1768	-
^{240}Pu	(atom %)	20.1524	13.2448	-
^{241}Pu	(atom %)	0.8350	0.6487	-
^{242}Pu	(atom %)	1.8410	0.9710	-
^{244}Pu	(atom %)	-	-	-
Pu activity[m]				
^{238}Pu	(Bq/g)	6800	7500	**7150**
^{239}Pu	(Bq/g)	830	1200	**1020**
^{240}Pu	(Bq/g)	820	680	**750**
^{241}Pu	(Bq/g)	15000	15000	**15000**
^{242}Pu	(Bq/g)	1	1	**1**
^{244}Pu	(Bq/g)	-	-	-
(^{239}Pu)	(ng/g)	360	500	**430**
$^{232}Th/^{239}Pu$		11065	10658	**10860**

[a] Free water content of sludge
[b] Total solids
[c] Total suspended solids
[d] Total carbon
[e] Total inorganic carbon
[f] Total organic carbon,
[g] nitric-hydrochloric acid prep.
[h] measured by ICP-MS
[i] nitric-hydrofluoric acid prep.
[j] measured by ion chromatography
[k] Pu activities based on alpha spectrometry
[l] f_{35} = fissile equivalent ^{235}U
[m] Pu activities based on Pu isotopic ratios by ICP-MS

Table 4-2. Analytical data for sludge in C-2 tank

Characteristic (analysis)		C-2 East	C-2 West	C-2 Average
Physical properties and miscellaneous data				
pH		12.5	12.1	**12.3**
Water[a]	(%)	53.2	51.8	**52.5**
TS[b]	(mg/g)	468	482	**475**
TSS[c]	(mg/g)	284	295	**290**
Bulk density	(g/mL)	1.479	1.501	**1.49**
TC[d]	(mg/Kg)	17800	30900	**24350**
TIC[e]	(mg/Kg)	14700	16800	**15750**
TOC[f]	(mg/Kg)	3100	14100	**8600**
PCB Aroclor-1254	(mg/Kg)	< 0.3	< 0.5	-
RCRA metals (±10%)				
Ag[g]	(mg/Kg)	19.4	23.9	**21.7**
As	(mg/Kg)	< 5.1	< 4.4	-
Ba	(mg/Kg)	65.1	98.3	**81.7**
Cd	(mg/Kg)	23.1	27.4	**25.3**
Cr	(mg/Kg)	128	229	**179**
Hg	(mg/Kg)	21.6	52.7	**37.2**
Ni	(mg/Kg)	62.8	114	**88.4**
Pb	(mg/Kg)	320	398	**359**
Se	(mg/Kg)	< 5.1	< 4.4	-
Tl	(mg/Kg)	< 5.1	< 4.4	-
Process metals (±10%)				
Al	(mg/Kg)	1330	2270	**1800**
B	(mg/Kg)	8	9	**8.7**
Be	(mg/Kg)	8	15	**11.5**
Ca	(mg/Kg)	62000	59300	**60700**
Co	(mg/Kg)	7	13	**10.2**
Cu	(mg/Kg)	67	79	**73.4**
Cs[h]	(mg/Kg)	< 1.8	< 1.6	-
Fe	(mg/Kg)	1520	3210	**2370**
K	(mg/Kg)	9670	9760	**9720**
Mg	(mg/Kg)	13000	9730	**11400**
Mn	(mg/Kg)	200	1360	**780**
Na	(mg/Kg)	58800	56000	**57400**

Characteristic (analysis)		C-2 East	C-2 West	C-2 Average
P[i]	(mg/Kg)	2570	3780	**3180**
Sb	(mg/Kg)	208	210	**209**
Si[j]	(mg/Kg)	1720	2300	**2010**
Sr	(mg/Kg)	210	341	**276**
Th	(mg/Kg)	3820	7490	**5660**
U	(mg/Kg)	18400	24300	**21400**
V	(mg/Kg)	18	25	**21.8**
Zn	(mg/Kg)	572	1230	**901**
Semi-quantitative metals by ICP-MS (±30-50 %, * indicates data from water leach)				
Bi	(mg/Kg)	18	23	**21**
Ce	(mg/Kg)	12	15	**14**
Ga	(mg/Kg)	5.2	8.2	**6.7**
Gd	(mg/Kg)	7.8	8.0	**7.9**
Li	(mg/Kg)	3.4	4.0	**3.7**
Mo	(mg/Kg)	3.5	3.3	**3.4**
Sn	(mg/Kg)	11	24	**18**
Te	(mg/Kg)	8.7	14	**11**
Ti	(mg/Kg)	11	23	**17**
W	(mg/Kg)	2.3	2.4	**2.4**
Zr	(mg/Kg)	4.1	8.2	**6.2**
Inorganic				
Bromide	(mg/Kg)	< 50	< 48	-
Chloride	(mg/Kg)	4800	4440	**4620**
Chromate	(mg/Kg)	< 5	< 5	-
Fluoride	(mg/Kg)	< 50	87.4	**87.4**
Nitrate	(mg/Kg)	134000	124000	**129000**
Nitrite	(mg/Kg)	3130	3140	**1730**
Phosphate	(mg/Kg)	15.8	< 10	**15.8**
Sulphate	(mg/Kg)	5540	5110	**5330**
Organic				
Acetate	(mg/Kg)	983	1330	**1160**
Citrate	(mg/Kg)	12.9	53.6	**33.3**
Formate	(mg/Kg)	170	178	**174**
Oxalate	(mg/Kg)	57.5	959	**508**
Phthalate	(mg/Kg)	10.4	25.4	**17.9**

Characteristic (analysis)		C-2 East	C-2 West	C-2 Average
Beta/gamma emitters (±10%)				
Gross beta	(Bq/g)	4800000	5800000	**5300000**
^{63}Ni	(Bq/g)	8000	21000	**15000**
^{60}Co	(Bq/g)	47000	64000	**55500**
$^{90}Sr/^{90}Y$	(Bq/g)	890000	1400000	**1145000**
^{99}Tc	(Bq/g)	< 170	< 150	-
^{129}I	(Bq/g)	-	-	-
^{134}Cs	(Bq/g)	35000	32000	**33500**
^{137}Cs	(Bq/g)	920000	860000	**890000**
^{152}Eu	(Bq/g)	1300000	1200000	**1250000**
^{154}Eu	(Bq/g)	380000	480000	**430000**
^{155}Eu	(Bq/g)	93000	98000	**95500**
^{227}Ac	(Bq/g)	-	-	-
^{241}Pu	(Bq/g)	26000	57000	-
Alpha emitters (±10%)				
Gross alpha	(Bq/g)	88000	160000	**124000**
^{232}Th	(Bq/g)	16	30	**23**
^{233}U	(Bq/g)	7300	14000	**10700**
^{234}U	(Bq/g)	250	280	**265**
^{235}U	(Bq/g)	4.1	6.4	**5.3**
^{238}U	(Bq/g)	230	300	**265**
^{237}Np	(Bq/g)	< 50	< 50	-
^{241}Am	(Bq/g)	12100	12000	**12100**
^{244}Cm	(Bq/g)	53000	110000	**81500**
^{250}Cf	(Bq/g)	< 50	< 50	-
^{252}Cf	(Bq/g)	< 50	< 50	-
Total Pu alpha[k]	(Bq/g)	14000	22000	**18000**
^{238}Pu	(Bq/g)	7900	14000	**11000**
$^{239}Pu/^{240}Pu$	(Bq/g)	5900	7700	**6800**
^{242}Pu	(Bq/g)	150	77	**113**
TRU activity Pu+Am (3700)	(Bq/g)	26100	34000	**30100**

Characteristic (analysis)		C-2 East	C-2 West	C-2 Average
Uranium isotopics by TIMS (±0.5%)				
^{233}U	(atom %)	0.101	0.175	-
^{234}U	(atom %)	0.003	0.005	-
^{235}U	(atom %)	0.305	0.380	-
^{236}U	(atom %)	0.010	0.006	-
^{238}U	(atom %)	99.580	99.434	-
$^{238}U/^{233}U$	(>200)	672	340	-
$^{238}U/^{235}U$	(>110)	265	174	-
$^{238}U/^{235}U\ f_{35}^{l}$	(>110)	229	164	-
Uranium isotopics by ICP-MS (±2%)				
^{233}U	(atom %)	0.1139	0.1682	-
^{234}U	(atom %)	0.0060	0.0050	-
^{235}U	(atom %)	0.3149	0.3764	-
^{236}U	(atom %)	0.0079	0.0048	-
^{238}U	(atom %)	99.5573	99.4456	-
$^{238}U/^{233}U$	(>200)	586	356	-
$^{238}U/^{235}U$	(>110)	248	179	-
$^{238}U/^{235}U\ f_{35}^{l}$	(>110)	216	167	-
Plutonium isotopics by TIMS (±1%)				
^{238}Pu	(atom %)	1.9350	1.0350	-
^{239}Pu	(atom %)	78.5289	77.2019	-
^{240}Pu	(atom %)	17.5362	19.2823	-
^{241}Pu	(atom %)	0.7408	0.6639	-
^{242}Pu	(atom %)	1.2590	1.8169	-
^{244}Pu	(atom %)	-	-	-
Pu activity[m]				
^{238}Pu	(Bq/g)	11000	14000	**12500**
^{239}Pu	(Bq/g)	1600	3900	**2750**
^{240}Pu	(Bq/g)	1300	3600	**2450**
^{241}Pu	(Bq/g)	25000	57000	**41500**
^{242}Pu	(Bq/g)	2	6	**4**
^{244}Pu	(Bq/g)	-	-	-
(^{239}Pu)	(ng/g)	710	1700	**1200**
$^{232}Th/^{239}Pu$		5382	4379	**4880**

[a] Free water content of sludge

[b] Total solids

[c] Total suspended solids

[d] Total carbon

[e] Total inorganic carbon

[f] Total organic carbon

[g] nitric-hydrochloric acid prep.

[h] measured by ICP-MS

[i] nitric-hydrofluoric acid prep.

[j] measured by ion chromatography

[k] Pu activities based on alpha spectrometry

[l] f_{35} = fissile equivalent ^{235}U

[m] Pu activities based on Pu isotopic ratios by ICP-MS.

5. COLD DEMONSTRATION TRIALS

Cold demonstration trials were carried out on the system proposed for C-Tank Sludge Mobilization, at AEAT's test facility at Risley in the United Kingdom. The test tank was the same diameter as a C-Tank, but half its length; therefore, all tests were carried out with a single charge vessel. Simulated cooling coils were installed within the tank to represent the obstructions found in the actual C-Tanks.

The main objectives of the tests were to determine the optimum design of sludge nozzles and operating parameters and to demonstrate that the system was effective in mixing and removing sludge-like material from the tanks.

Trials were carried out with a simulant consisting of a mixture of dicalite, china clay, and water which matched the (very fast) settling rate and viscosity of the sludge samples withdrawn from the C-Tanks.

The results of the trials are reported in Griffiths (1998). After six mixing/transfer operations, the initial volume of 2000 gal of sludge was reduced to an estimated ¼-in.-thick layer (~7 gal) on the bottom of the tank.

6. W-TANK SYSTEM DESCRIPTION

The initial use of the pulse jet system based on Power Fluidic™ principles was used to remove sludge/slurry from the three tanks W-21, W-22, and W-23 (as shown in Fig. 3-5) in 1997 and 1998. The original pulse jet systems were modified to make use of the existing nozzles (six per tank) in the W-Tanks. The nozzles are 3 in. diameter pipes installed from the top of the tank to about 8 in. from the tank bottom. The nozzles have a 90° elbow at the bottom and were installed for mixing purposes but were never used. These nozzles, unlike those in the C-Tanks, were fixed and could not be rotated. A cross section of the W-Tanks is shown in Figure 3-1. The original three dimensional model of the original pulse jet mixing system installation is shown in Figure 6-1. A complete and detailed description of the sludge/slurry removal from the W-Tanks can be found in Bechtel Jacobs Company (1998). W-23 Tank was then used to receive sludge/slurry from the C-Tanks for subsequent transfer to MVST for this C-Tank Transfer Project.

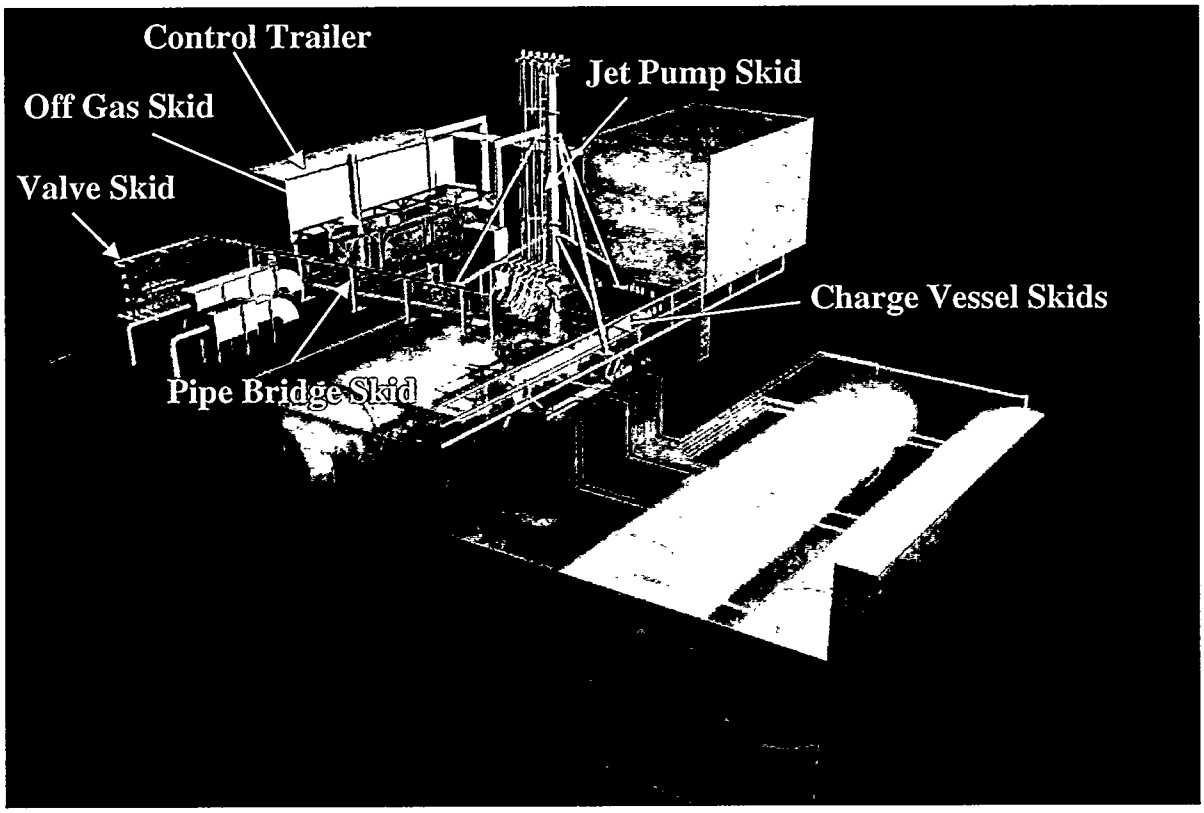


Fig. 6-1. Three-dimensional model of the fluidic pulse jet mixing system installed at the BVEST site.

7. C-TANK TRANSFERS MOBILIZATION EQUIPMENT

The C-Tank pulse jet system was based on Power Fluidic™ principles and was designed to remobilize the sludges contained within C-1 and C-2 by first drawing liquid out of the tank into the charge vessels, entraining a small amount of sludge and discharging it back in to the tank. Compressed air driven jet pumps were used to accomplish this. The process was repeated until the sludge/liquid mixture around the tank nozzle broke through into the overlaying supernate layer. Once this occurred, the mixing cycle continued until an acceptable suspended solids composition was reached, at which point the mobilized sludge/liquid was pumped out of the tanks.

In the C-Tank mobilization system, a charge vessel was inserted into each of the two manholes in the tank. The nozzle on the base of the charge vessel had two opposed jets so that the contents of the charge vessel were discharged simultaneously in opposite directions. Each charge vessel was designed so that it could be rotated about a vertical axis during operation, thus providing the ability to direct the sludge jet toward the settled sludge.

The charge vessels were designed such that the nozzles were positioned as close as possible to the bottom of the tank while avoiding the cooling coils near the bottom of the tank.

The charge vessels were first installed into and the mobilization system connected to Tank C-2 (i.e., the charge vessels were installed in the C-2 manholes) (see Fig. 7-1, 7-2, and 7-3). When mixing in C-2 was completed, the charge vessels were then moved to C-1 to mobilize the C-1 sludge (see Fig. 7-4).

The installed mixing equipment primarily consists of nine interconnected modules which are skid mounted for ease of installation and removal:

Module No	Name
1	East Charge Vessel assembly
2	West Charge Vessel assembly
3	East Charge Vessel Pipebridge
4	West Charge Vessel Pipebridge
5	Jet Pump Skid
6	Services Pipebridge
7	Valve Skid
8	Off-Gas Skid
9	Control Cabinet

The control cabinets for the C-Tank system were located in the existing trailer, Building 2508, sited to the west of BVEST tank W-23, outside the radiologically controlled area. Additionally, a dedicated air compressor and accumulator/receiver vessel was installed to provide the air supply required by the system. See Fig. 7-5 for a schematic view of the sludge mobilization equipment installed at Building 2531.

These modules and their interconnections with each other and with existing equipment and services are described in detail on the following pages.

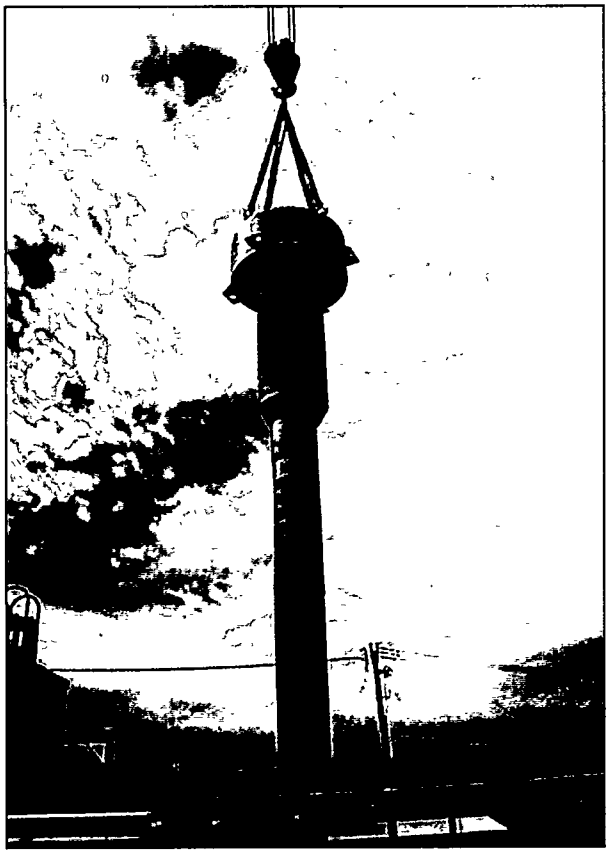


Fig. 7-1. Lifting the charge vessel for installation

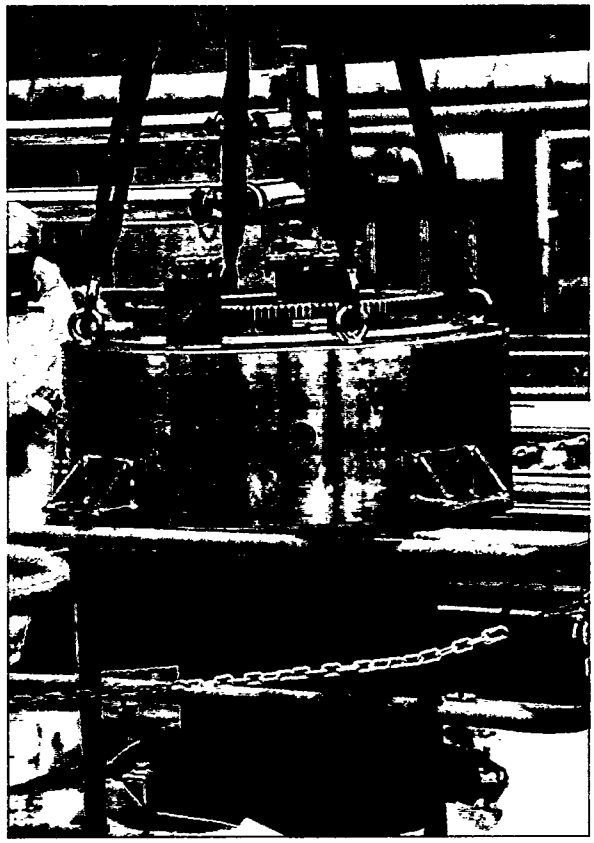


Fig. 7-2. Installing the charge vessel into the west manhole extension of Tank C-2.

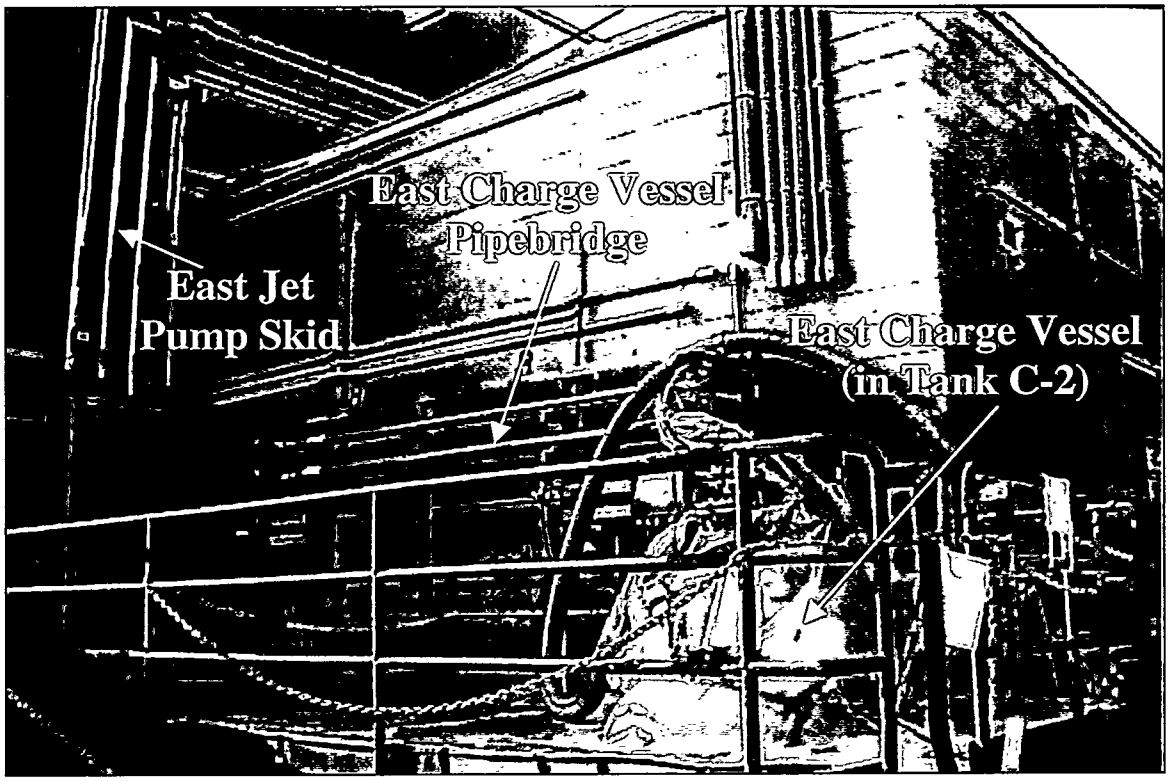


Fig. 7-3. East side of the C-Tanks Transfers project site after equipment installation.

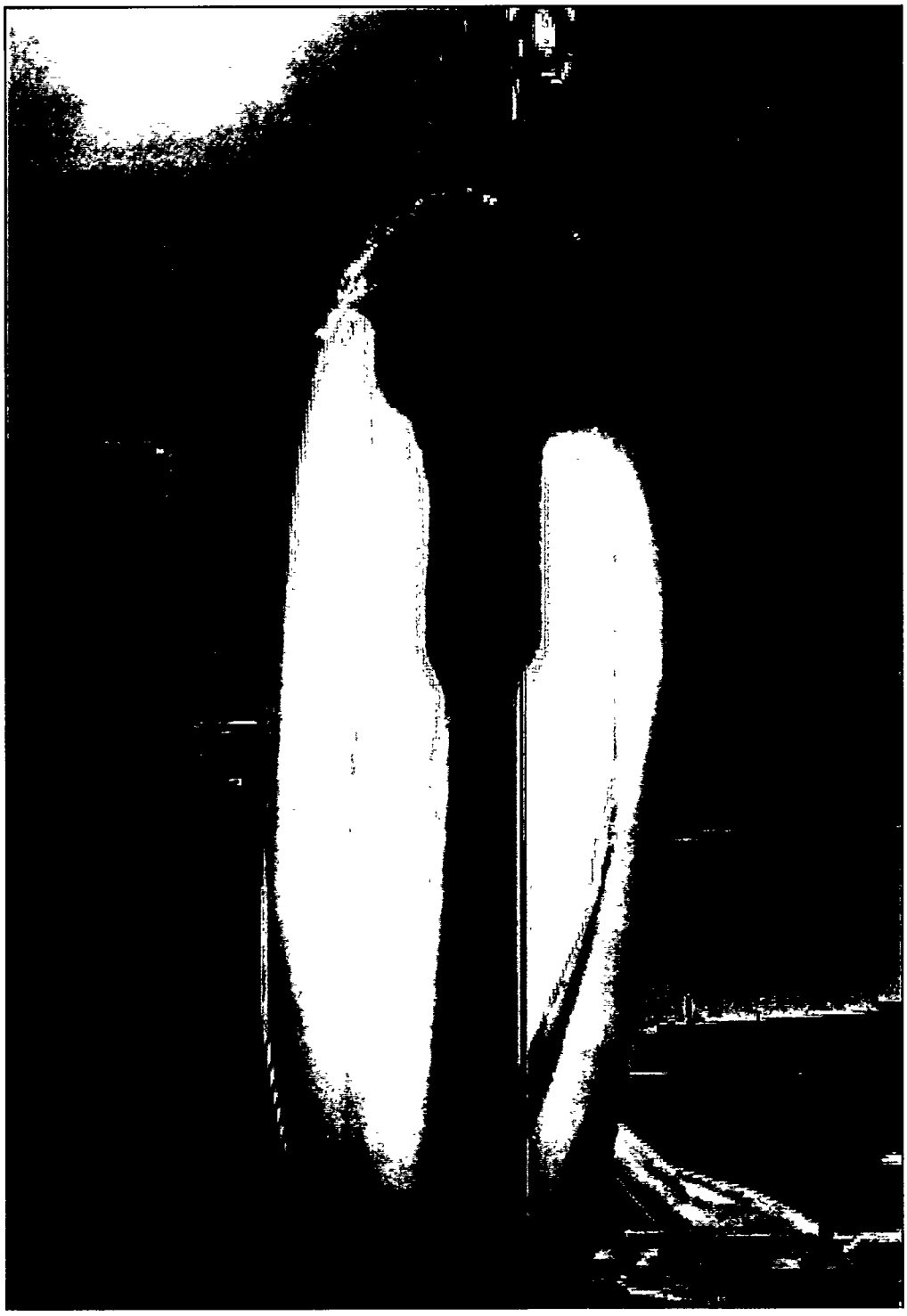


Fig. 7-4. Moving the west charge vessel from C-2 to C-1. Charge vessel is wrapped in plastic sleeve to control spread of contamination.

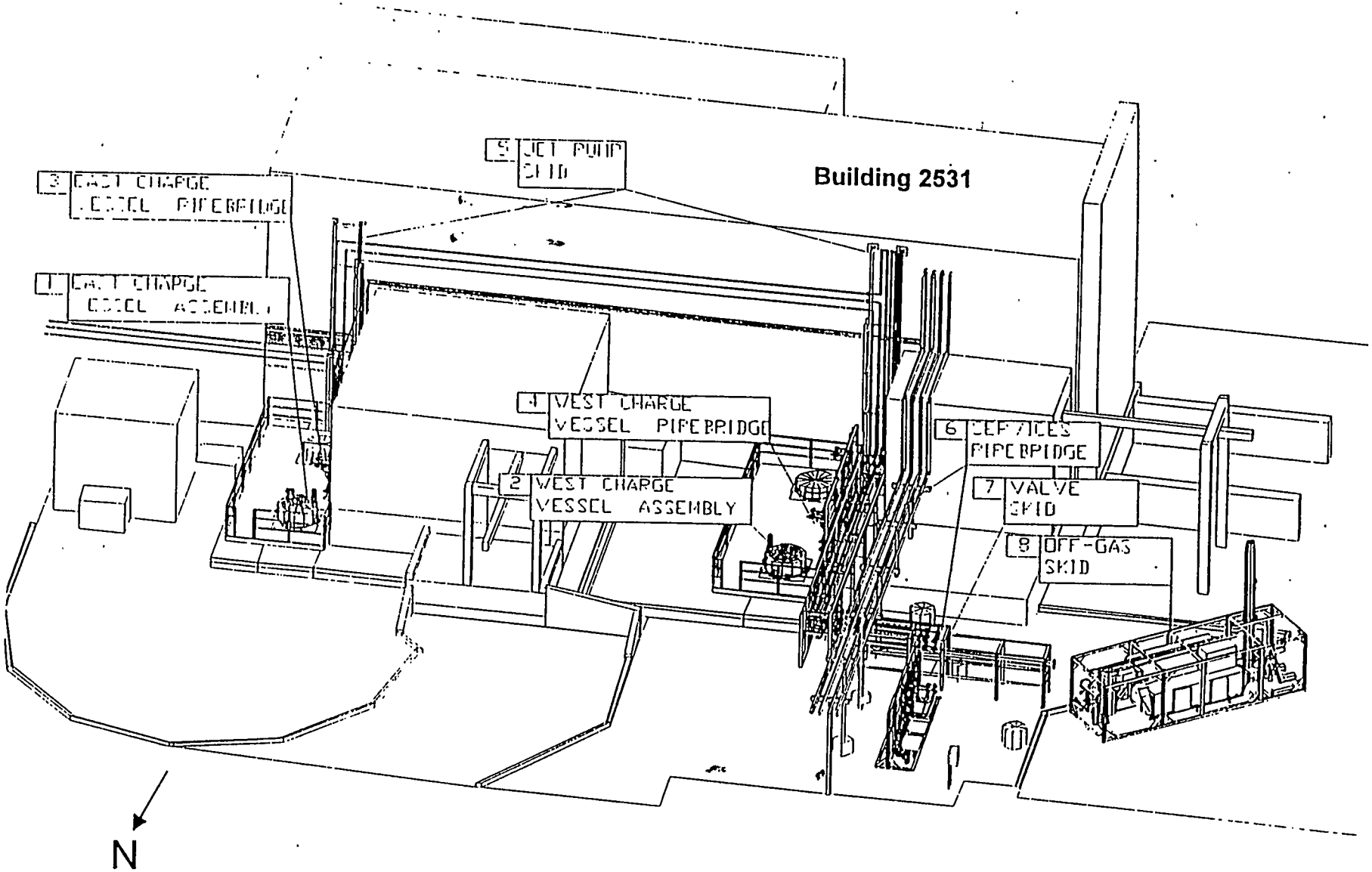


Fig. 7-5. Sludge mobilization equipment installed at B2531.

7.1 EAST AND WEST CHARGE VESSEL ASSEMBLIES

Each charge vessel assembly includes:

- the charge vessel (with sludge nozzle at the base)
- a rotating mechanism consisting of a bearing, gears, and motor
- the upper shielding/support assembly which houses the rotating mechanism

The east and west charge vessels(see Fig. 7-6) were of identical design except that the west charge vessel had the sludge nozzle in line with the vessel centerline whereas on the east charge vessel the sludge nozzle was offset from the vessel centerline.

The vessels were made of stainless steel up to 9/16-in. thick, were designed to withstand pressure loadings from full vacuum to 100 psig and were American Society of Mechanical Engineers U-stamped.

The sludge nozzle included a 1½-in. (38-mm) diameter "forward facing" jet and a 3/8-in. (10-mm) diameter "backward facing" jet. The larger jet was used to mobilize the majority of the sludge toward the center of the C-Tank, while the smaller jet cleared the sludge near the dished ends of the tank.

Each charge vessel had a 6-in. diameter pipe passing "diagonally" through the vessel, which enabled a camera to be inserted into the C-Tank through the charge vessel. The pipe was terminated on the top of the assembly in a 6-in. flange.

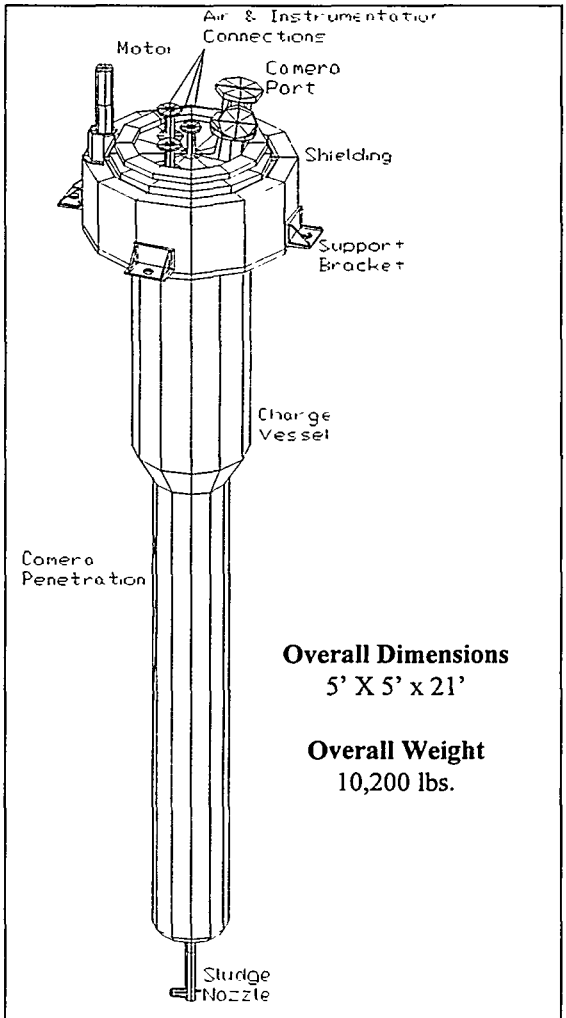


Fig. 7-6. Charge vessel assembly.

Each charge vessel had 1-in. wide rings polished on the external surface at 6-in. intervals to be used during operations to determine the depth of liquid in the tank via remote camera.

The charge vessel was suspended from the upper shielding/support assembly via a slewing ring type of bearing. The shielding assembly was supported from platforms on the vault roof via jacking studs which allowed for adjustment of the position of the full assembly during installation. A motor/gearbox that rotated the charge vessel was attached to the upper shielding, and operation of the motor was controlled via software from the control system as described below.

Each vessel had three connections on the top which penetrated through the shielding:

- A 1½-in. diameter air supply pipe through which the alternating pressure/vacuum was created in the vessel. This line was also used to introduce washwater to flush internal surfaces of the charge vessel.
- Two 2-in. diameter pipes into which level probes were inserted. The flanges from these pipes were also manifolded together and connected to a washwater line to clean the level probes.

The 1 ½-in. and 2-in. flanges on top of the charge vessel were connected to the corresponding pipebridges via stainless steel flexible pipework and quick-disconnect couplings.

7.2 EAST AND WEST VESSEL PIPEBRIDGES

The east and west vessel pipebridges (shown in Figs. 7-7 and 7-8) were comprised of compressed air pipes, water pipes, valves and electrical cables mounted on two frame works. These pipebridges were supported on the access platform grating.

The east charge vessel pipebridge was anchored to the wall of the sampling room and the west vessel pipebridge was anchored to the railings on the west side of the existing access platform.

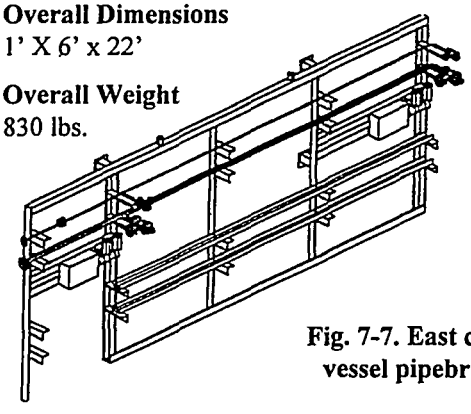


Fig. 7-7. East charge vessel pipebridge.

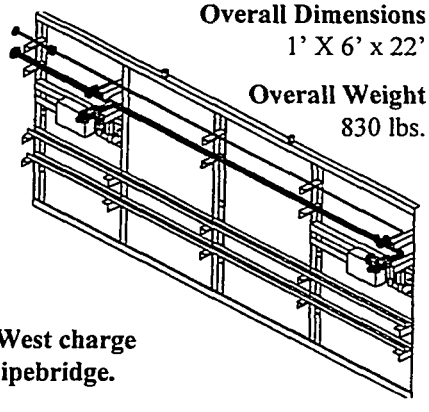


Fig. 7-8. West charge vessel pipebridge.

7.3 JET PUMP SKID

The air line pipework connecting the jet pumps to the charge vessels extended vertically upward approximately 34 ft above the top of the C-Tanks to provide barometric protection to the jet pumps. This made it physically impossible for sludge to reach the jet pumps during the suction phase of operation.

To achieve this the air pipes from the charge vessels were mounted on the jet pump skid, which extended vertically to the required elevation. The skid also carried the associated washwater pipework, jet pumps, valves, instrumentation and electrical cabling (see Figs. 7-3, 7-9, and 7-10).

The barometric protection piping was mounted on segment A of the skid, which was seismically qualified and rigidly fixed to the structural steelwork of Building 2531.

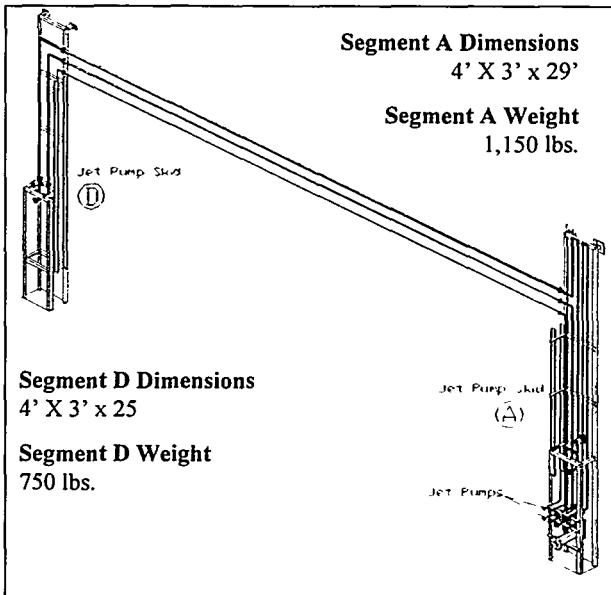


Fig. 7-9. Jet pump skid.

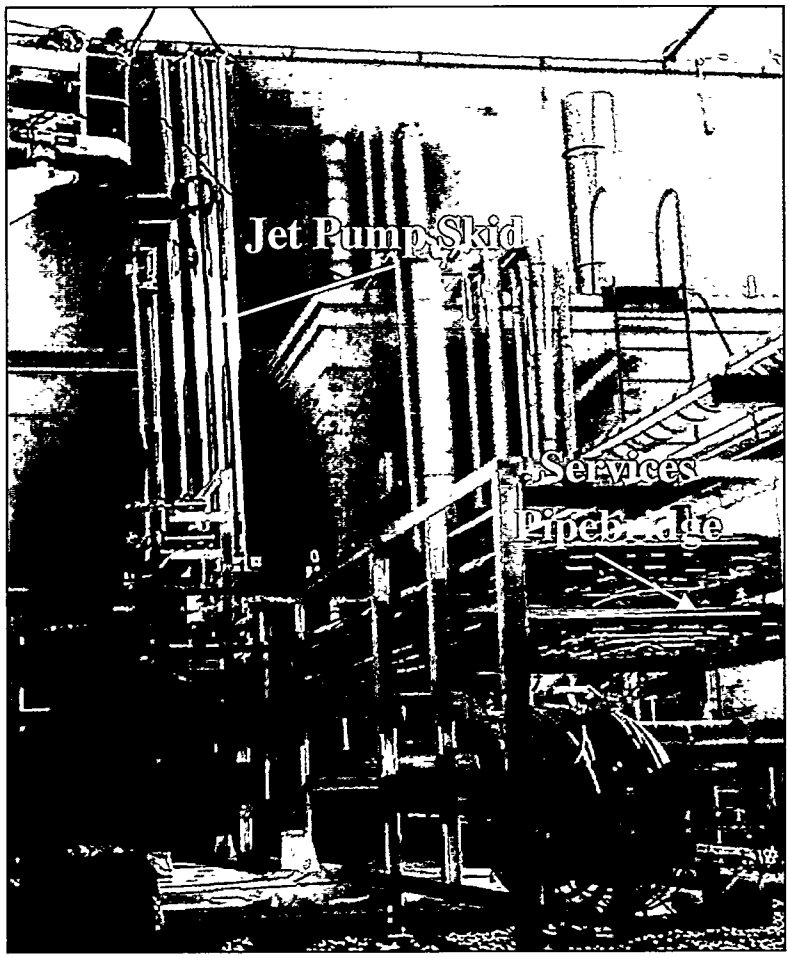


Fig. 7-10. Installing the jet pump skid on the west side of the C-Tanks Transfers Project.

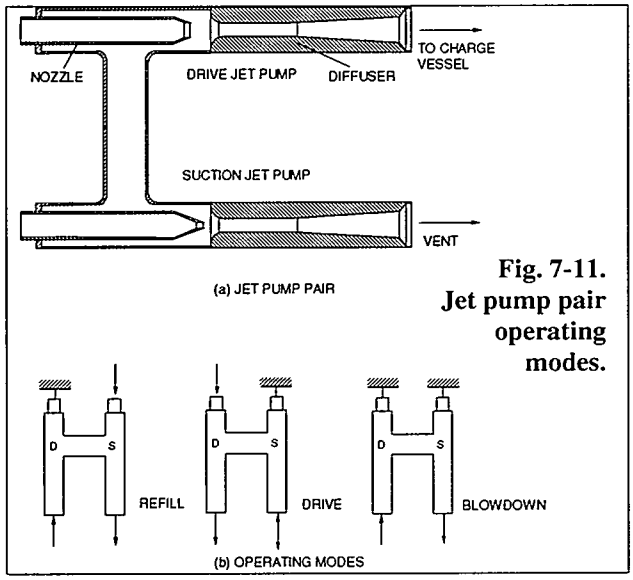


Fig. 7-11. Jet pump pair operating modes.

The jet pump skid contained two jet pump units, each connected to one of the charge vessels. Each pump unit comprised a coupled pair of jet pumps, including a drive jet pump and a suction jet pump (see Fig. 7-11). The diffuser end of each drive pump was routed to a charge vessel, and the diffuser end of each suction pump was routed to the off-gas system. The inlets to both sides of the pumps were connected to the compressed air supply via the services pipebridge and the valve skid.

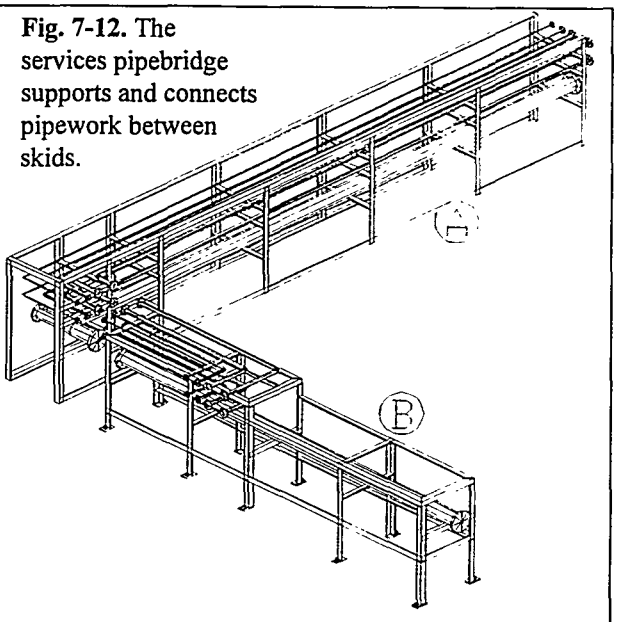
7.4 SERVICES PIPEBRIDGE

The services pipebridge was a rigid frame structure which supported the pipework and electrical cabling ran from the valve skid to the jet pump skid and the return off-gas line from the jet pump skid to the off-gas skid (see Figs. 7-10 and 7-12).

The skid was designed to ensure that all "clean" air and water lines were self-draining back to the valve skid, plus the jet pump vent pipe was self-draining back to the off-gas skid.

The skid was manufactured in two parts (segments A and B), and the process lines were connected together via stainless steel flexible pipes.

Fig. 7-12. The services pipebridge supports and connects pipework between skids.



Segment A Dimensions
2' X 5' x 31'

Segment B Dimensions
2' X 7' x 28'

Segment A Weight
2,650 lbs.

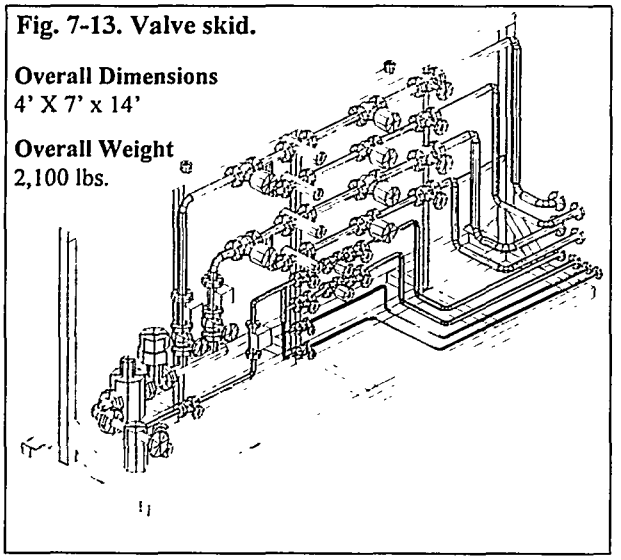
Segment B Weight
1,525 lbs.

7.5 VALVE SKID

Fig. 7-13. Valve skid.

Overall Dimensions
4' X 7' x 14'

Overall Weight
2,100 lbs.



The valve skid controlled the process air, instrument air, and water supply to the jet pumps and charge vessels, and was essentially comprised of valves and instrumentation with interconnecting pipework, mounted on a rigid support frame (see Figs. 7-13 and 7-14).

The valve skid was connected to the compressed air supply, which was generated by a dedicated compressor and air receiver/accumulator.

The valve skid was also fitted with preset pressure reducers.

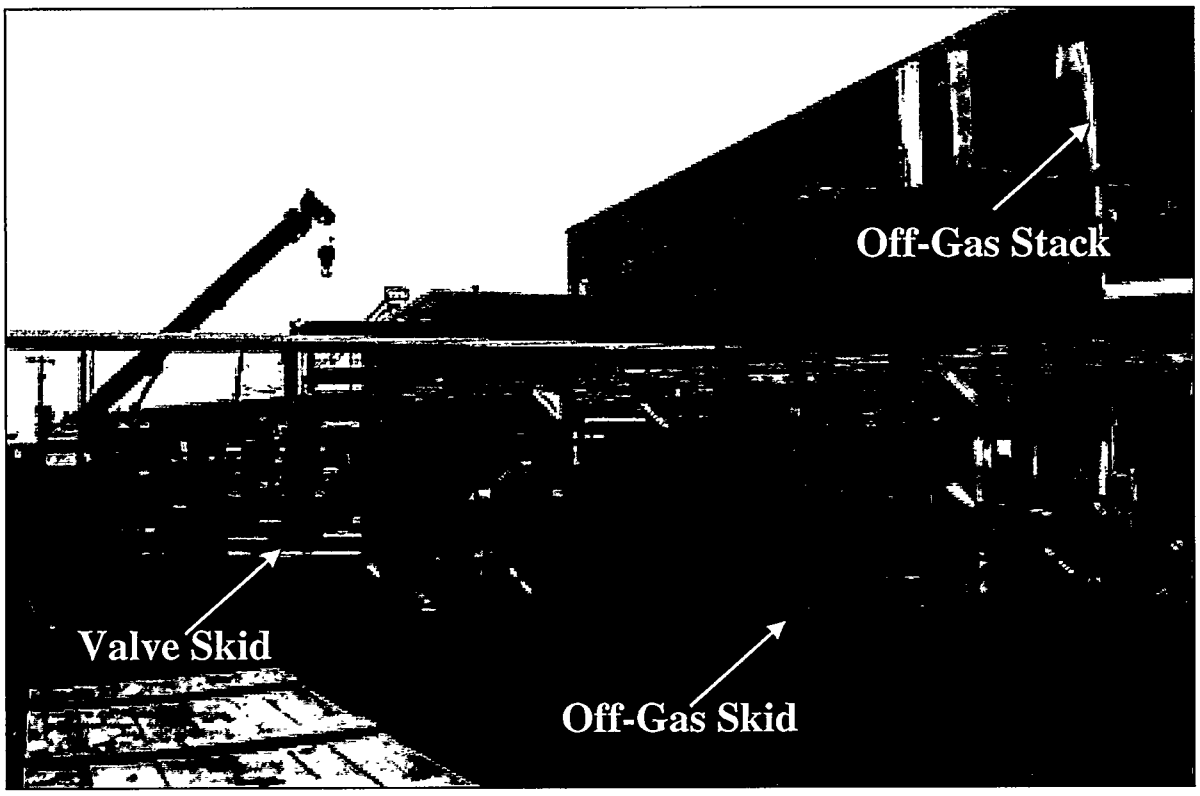


Fig. 7-14. Off-Gas Skid and Valve Skids, view southeast.

7.6 OFF-GAS SKID

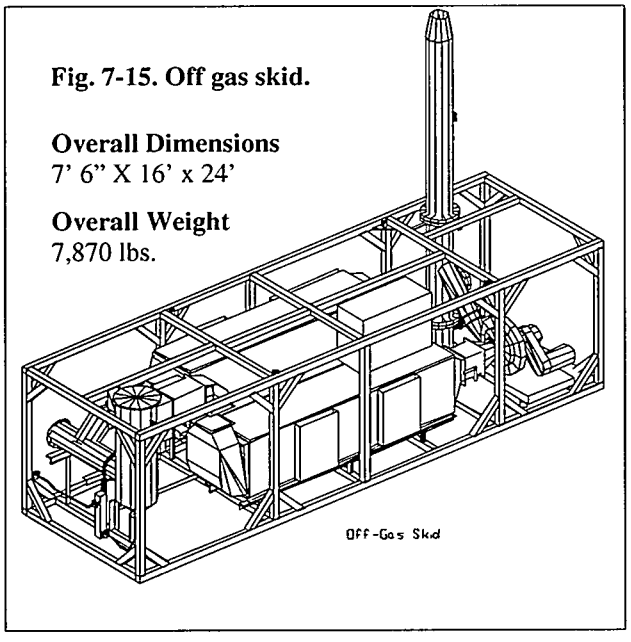


Fig. 7-15. Off gas skid.

Overall Dimensions
7' 6" X 16' x 24'

Overall Weight
7,870 lbs.

During the suction and vent phases of the pulse jet mixing system, gas was vented from the charge vessels via the jet pumps. Since this off-gas had been in contact with contaminated liquid/slurry in the charge vessels, a protective off-gas system was provided. The off-gas system (see Figs. 7-14 and 7-15) was designed for an intermittent exhaust off-gas flow rate from the jet pumps ranging from zero to 850 CFM (0-400 L/sec) during pump operation. This was sufficient capacity to support simultaneous operation of both charge vessels.

The off-gas first passed through a demister. Liquid collected in the demister was removed through a drain line. Immediately downstream of the demister were two stages of high-efficiency particulate air (HEPA) filtration to provide primary and secondary protection, with each stage having a 99.95% removal efficiency. The HEPA filters were of a bag-out design, and a belt-driven centrifugal fan provided the airflow through the system.

Filtered make-up air was added to the off-gas flow via a dedicated in-bleed system prior to the primary HEPA filter to create a more constant flow rate through the fan (approximately 1000 CFM). The off-gas was heated prior to the HEPA filtration by an electric heater to provide protection against a saturated airflow by reducing the relative humidity to less than 70%. Finally, to provide adequate dispersion of the filtered air, the discharge to atmosphere was via a 15-ft exhaust stack. Off-gas stack emissions were monitored by a continuous air monitor system that was installed by Lockheed Martin Energy Research Corp.

7.7 THE CONTROL SYSTEM

The control system had three basic functions:

- to allow the Operations Manager to control the operation of the system;
- to monitor pressures, liquid levels, and other instrumented parameters within the system (with visual displays and audible alarms where necessary); and
- to interlock safety systems on detection of faults.

The major operation controls were:

- startup/shutdown of the mobilization system;
- timings of the suction-drive-vent phases of the jet pump operation; and
- injection of flush water through the charge vessel system.

The system comprised both computer-based and conventional electrical and instrument control equipment to provide the necessary sequencing, monitoring, control and power for the valve, jet pump, charge vessel and off-gas ventilation plant (see Fig. 7-16).

Three ganged control cubicles housed the Prescon*, Trace Heating and Off-Gas skid control equipment. Sequence control and monitoring of process equipment on the valve and jet pump skids and charge vessel assemblies was performed from the Prescon computer.

*The Prescon (PRESsure CONtrol) system is the AEAT patented method of sensing liquid levels remotely and non-intrusively, and is used to control power.

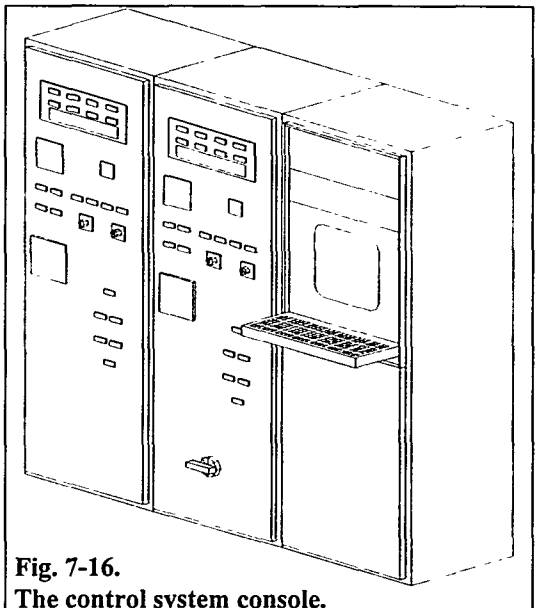


Fig. 7-16.
The control system console.

Overall Dimensions	Overall Weight
6' X 20' x 6'	1,000 lbs.

7.8 C-TANK OFF-GAS ENHANCEMENT

During the discharge cycle of the charge vessels the tank liquid/slurry level rose. This would tend to cause the internal tank pressure to increase. Facility safety documentation requires that the tanks internal pressure remain negative relative to atmosphere. A tank pressure switch was installed to shut down the AEAT System if the tank pressure rose above the minimum required negative pressure. To insure the maximum effective operation of the mixing system, shutdowns needed to be minimal. Due to concerns that there was not adequate capacity via the existing permanent off-gas system connection to the C-Tanks a temporary off-gas enhancement was provided. This included a 4-in. flexible stainless steel hose, control valve, and tank pressure transmitter. The hose and controller were attached to the east charge vessel via a tee-adapter in the 6-in. camera port and to a 2-in. off-gas line just east of the tank/vault site. The transmitter was calibrated and set to control the valve's open position.

8. PULSE JET OPERATION PLAN

The following was the Operations Plan for the mobilization of sludge in the C-Tanks.

Stage

1. AEAT Operations Manager advises on the required starting volume of supernate in the tank.

2. Bechtel Jacobs Company adjusts the supernate volume in the tank (as necessary).

3. AEAT operate the mobilization system as per the stages below.

   The performance objective during mobilization is to maximize the amount of sludge mobilized, up to the weight % limit prescribed by Bechtel Jacobs Company.

3.1 The AEAT Operations Manager executes the Initial Start-up sequence described in the Operating Manual prior to the first mixing cycle only.

3.2 The AEAT Operations Manager executes the Normal Start-up procedure as defined in the Operating Manual. The AEAT Operations Manager decides on the major control parameter input to the *MIXER* software, that is:

- Drive Pressure
- Suction Pressure
- Drive Time
- Nominal Suction Time
- Vent Time
- Mode of operation (Timed or Auto)
- Number of operational charge vessels (1 or 2)
- Phasing of charge vessels (in-phase, anti-phase, or independent)
- Charge vessel rotation angle

The AEAT Operations Manager bases the selection of parameter values on:

- Experience and data from the Cold Demo trials
- Slurry sample analysis supplied by Bechtel Jacobs Company
- Ongoing experience gained from C-Tank Mobilization
- Feedback and analysis of data displayed by the *MIXER* program (primarily suction time)
- Visual feedback from the in-tank cameras

3.3 During Normal Operations, all AEAT operators carry out the Normal Operations procedures as described in the Operating Manual.

At any time, the AEAT Operations Manager can decide to modify the *MIXER* parameters in order to optimize the system's operation to meet performance objectives. The AEAT Operations Manager will carry out an Operational Shutdown as described in the Operating Manual, modify the *MIXER* input parameter values, and perform a re-start following the Normal Start-up procedures.

Normal Operation will continue until:

1. An Interlock, Alarm, or Shutdown occurs. In this event, the AEAT Operator will follow the instructions in the Operating Manual. The AEAT Operations Manager will carry out and/or supervise the resolution of any fault, and perform or authorize a re-start following the Normal Start-up procedures.

or

2. Surveillance activities detailed in the Log Book identify a malfunction or fault leading to the AEAT Operator performing a system shutdown per the Log Book Instruction. The AEAT Operations Manager will carry out and/or supervise the resolution of any fault, and perform or authorize a re-start following the Normal Start-up procedures.

or

3. An Emergency Shutdown is performed. Resolution of any fault and authorization to re-start the system will be subject to the approved Project Interface Agreement between AEAT and Bechtel Jacobs Company LLC. When authorized to re-start, the AEAT Operations Manager will follow the Normal Start-up procedures.

or

4. A decision is made (per the Interface Agreement) to transfer the sludge. In this event proceed to Stage 4.

4. Bechtel Jacobs Company will transfer the sludge slurry from the C-Tank.

The AEAT Operations Manager will monitor the performance of the mixing system with the objective of keeping the system operating for as long as possible (i.e., until the sludge nozzle at the base of the Charge Vessel is uncovered) within the limits specified in the safety documentation. In particular, mixing shall not continue if greater than 2400 gals of sludge remain with less than 4800 gals of supernate.

9. SLUDGE MOBILIZATION OPERATIONS

9.1 SLUDGE TRANSFERS FROM C-2 TANK TO W-23 TANK TO MVST

The C-2 tank contents were mobilized and transferred to W-23 tank. The W-23 tank mixing system was operated to keep the C-2 sludge in suspension. The mobilized sludge was then transferred to MVST. All transfers continued until it was difficult to maintain pump suction. When loss of suction occurred, the transfer was stopped to prevent damage to the progressive-cavity pumps being used to make the transfers. To complete sludge removal from C-2, four mixing and transfer campaigns were used.

Slurry samples were pulled before most of the transfers. Weight percent (wt%) solids, density and pH data were determined using standard analytical procedures. C-2 slurries with a density adjusted suspended solids of up to 10.5 wt% were transferred to W-23. W-23 slurries with a density adjusted suspended solids of up to 5.0 wt% were transferred to MVST.

The distance between the C-Tanks and W-23 was short, less than 200 feet, compared to the over one mile distance between W-23 and MVST. Because of this, transfers from the C-Tanks to W-23 were allowed at higher suspended solids content than the W-23 to MVST transfers. The W-23 to MVST transfers were limited to no more than 5 wt% suspended solids.

The transfer data for the four slurry transfer campaigns, subsequently described, are shown in Table 9-1.

9.1.1 Campaign 1

The first campaign began on February 3, 1999. The starting volume of sludge in the tank was estimated at approximately 8200 gal. The total tank volume was set to 25,000 gal, the balance being supernate with a specific gravity of approximately 1.2. The AEAT mixing system was set to generate a depression of approximately -0.7 bar (20.7 in. Hg) by supplying the jet pump suction inlet of the east and west jet pumps with compressed air at 3.7 bar (54 psi). The drive pressure was set to 4 bar (58 psi) to discharge the slurry back into the tank from the charge vessel. Each charge vessel was set to apply suction for a maximum of 300 seconds and then to drive for a maximum of 20 seconds with the rotation angle of each charge vessel set to zero. The west charge vessel was used for the first set of mixing cycles. The sludge was drawn into the charge vessels in approximately 165 seconds. After stable operation was reached, the system was configured to allow mixing in the east charge vessel only. The sludge was drawn in to the east charge vessel in approximately 177 seconds. After stable operation the system was configured to run each charge vessel independently. After the system operated reliably, the charge vessel relationship was changed to anti-phase. The east charge vessel was selected to be the master and the west charge vessel the anti-phase slave. This relationship offsets the cycles of the slave 180° from the master, allowing the slave to drive halfway through the suction phase of the master. The system ran until February 5, 1999, when charge vessel rotation was added to the mixing steps. The east and west charge vessels were rotated one cycle at a time from 0° to -5° to 0°, then to +10°, then back to 0°, and then repeated. This configuration was then maintained until the first transfer to W-23.

The mobilized sludge from C-2 tank was transferred to W-23 tank on February 8, 1999. A total of 17,000 gal of slurry was pumped into W-23, approximately 4000 gal of which was sludge. This yielded a total volume of 35,600 gal in W-23. The slurry was kept mobilized by the W-23 tank mixing system and then transferred to MVST on February 9, 1999. A total of 33,600 gal of slurry was transferred to MVST, approximately 3600 gal of which was sludge. Approximately 4200 gal of sludge was left in C-2 and 1150 gal in W-23. Tank W-23 was then refilled with supernate to approximately 11,400 gal.

Table 9-1. C-2 Mixing Transfers

C-2 to W-23

	Date	Starting Volume	Starting Level	Transfer Volume	Final Level	Final Volume	Raw Suspended Solids	Density	Density Adjusted Suspended Solids	Weight of Sludge Xfer'd	Volume of Sludge Xfer'd	Estimated Sludge Remaing	Receiving Tank
		[gal]	[in]	[gal]	[in]	[gal]	[wt %]	[g/ml]	[wt %]	[lbs]	[gal]	[gal]	
												8,180	
1	2/8/99	25,000	72	17,000	~ 30	8,000	7.5%	1.225	**6.1%**	10,640	3,977	4,203	W-23
2	2/11/99	13,040		8,622	~ 20	4,418	13.3%	1.267	**10.5%**	9,570	2,767	1,436	W-23
3	2/16/99	5,300		4,800	~ 5	500	11.1%	1.231	**9.0%**	4,446	1,286	150	W-23
4	2/22/99	1,100		700	~ 4	400					60	90	W-23
											8,090		

[a] Acid Addition - ~ 400 gal spent nitric acid from PWTP was added to C-2 on 2/18/99

W-23 to MVST

	Date	Starting Volume	Starting Level	Transfer Volume	Final Level (Inch.)	Final Volume	Suspended Solids	Density	Density Adjusted Suspended Solids	Weight of Sludge Xfer'd	Volume of Sludge Xfer'd	Estimated Sludge Remaing	Receiving Tank
		[gal]	[in]	[gal]	[in]	[gal]	[wt %]	[g/ml]	[wt %]	[lbs]	[gal]	[gal]	
												4,727	
1	2/9/99	35,600		33,600		2,000	4.4%	1.233	**3.6%**	12,337	3,568	1,159	W-28, W-27
2	2/11/99	20,000		16,710		3,290	6.1%	1.225	**5.0%**	8,506	2,460	1,467	W-27
3	2/17/99	12,090		9,175		2,915					1,753	1,000	W-27, W-24
											7,780		

9.1.2 Campaign 2

The second campaign started immediately after the first C-2 slurry transfer to W-23 on February 8, 1999. C-2 was refilled with supernate to approximately 13,000 gal and mixing started. Both charge vessels were set to be independent and to rotate from 0° to 20°, 30°, 20°, 10°, 0°, -5°, and then back to 0°. Campaign 2 ended on February 11, 1999, when approximately 8600 gal of slurry was transferred to W-23, raising the total volume to 20,000 gal. (Approximately 10,000 gal of supernate from other ORNL tanks had been added to W-23 after the first W-23 to MVST transfer to ensure that the percent suspended solids limit would not be exceeded.) Approximately 2800 gal of sludge was suspended in the slurry. The slurry was immediately transferred from W-23 to MVST. The volume of the transferred material was a total of approximately 16,700 gal of slurry that included approximately 2500 gal of sludge. Approximately 1400 gal of sludge was left in C-2 (see Figs. 9-1 and 9-2) and 1500 gal in W-23 after the second campaign.

9.1.3 Campaign 3

Campaign 3 started on February 11, 1999. The C-2 tank volume was set to 5300 gal by adding supernate. The east charge vessel was set as master and the west charge vessel as anti-phase slave. Due to the low level in the tank, the charge vessels were set to 0° to concentrate the discharge jet in the center of the tank. The drive pressure was also increased to 5 bar (72 psi) to help move the slurry around the tank. On February 13, 1999, charge vessel rotation was once again introduced. Both east and west charge vessels were set to rotate from 0° to -10°, 0°, +15°, +30°, +90°, +120°, + 150°, +120°, +90°, +30°, +15° and back to 0°. Again an anti-phase relationship with the east charge vessel as master was set. During the transfer to W-23 on February 16, 1999, the rotation was changed to restrict the jets to near the center of the tank with angles set to 0°, -10°, 0° and +10°. The transfer to W-23 reduced the total volume in C-2 by 4800 gal, of which approximately 1,300 gal was sludge. This increased the volume of W-23 to approximately 12,000 gal, the contents of which were transferred to MVST on February 17, 1999. (Again, additional supernate had been added to W-23 prior to the C-2 transfer.) A total of 9200 gal of slurry was pumped to MVST including approximately 1750 gal of sludge. The volumes of sludge left at the end of the campaign were 150 gal in C-2, and 1,000 gal in W-23 (see Figs. 9-3, 9-4, and 9-5).

9.1.4 Campaign 4

The final C-2 mixing and transfer campaign started on February 17, 1999. Each charge vessel was set to independent operation. Both charge vessels were rotated in the following order: 0°, +15°, +50°, +30°, and back to the 0° position. Nitric acid was added to C-2 to dissolve more sludge, and the tank volume was increased to 1100 gal. The acid reacted with the sludge and created a dense foam. On the February 19, 1999, due to the low level in the tank, the suction inlet pressure was increased to 4 bar (58 psi) to speed refilling of the charge vessel. On February 21, 1999, the charge vessel rotation was stopped to allow the jets to concentrate on the center of the tank. The west charge vessel was set to +15° and the east charge vessel was set to 0°. The final C-2 transfer to W-23 was on February 22, 1999. Seven hundred gal of slurry was removed from the tank including 60 gal of sludge. This transfer left 90 gal of sludge in C-2 (see Figs. 9-6 and 9-7). A transfer out of W-23 was not performed due to the low volume in the tank.

9.1.5 Charge vessel relocation from C-2 to C-1

After the final C-2 transfers, the AEAT Mixing system was de-energized and preparations were made for the move of the charge vessels from C-2 to C-1. The west charge vessel was moved on February 22, 1999, and the east charge vessel was moved on February 23, 1999. Both charge vessels were re-commissioned and ready for operation on February 23, 1999.

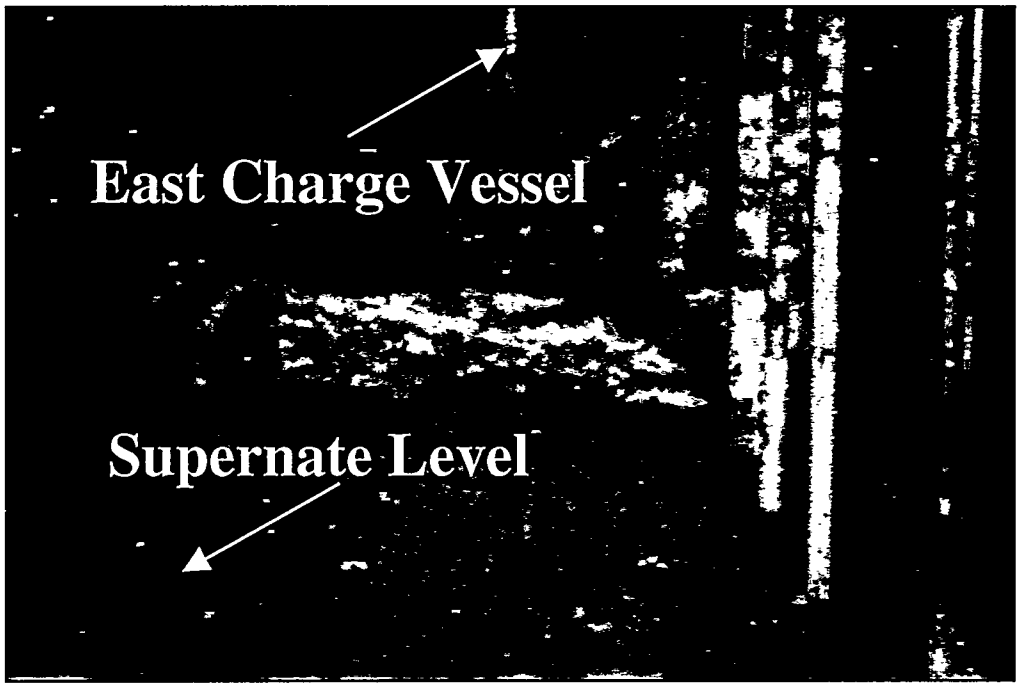


Fig. 9-1. Tank C-2 looking east after second transfer.

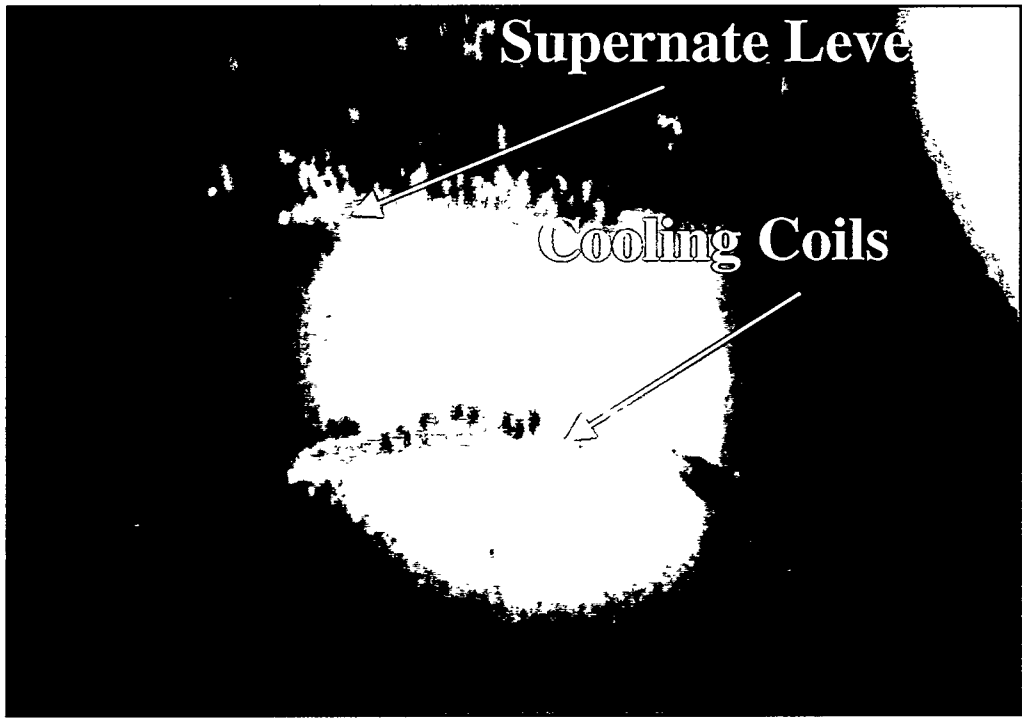


Fig. 9-2. Tank C-2 southwest corner after second transfer.

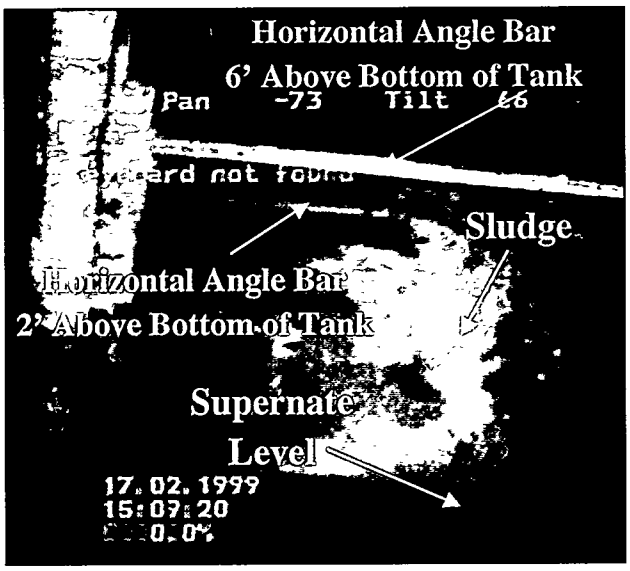


Fig. 9-3. Tank W-23 after third C-2 transfer, and after the subsequent transfer to MVST (looking south).

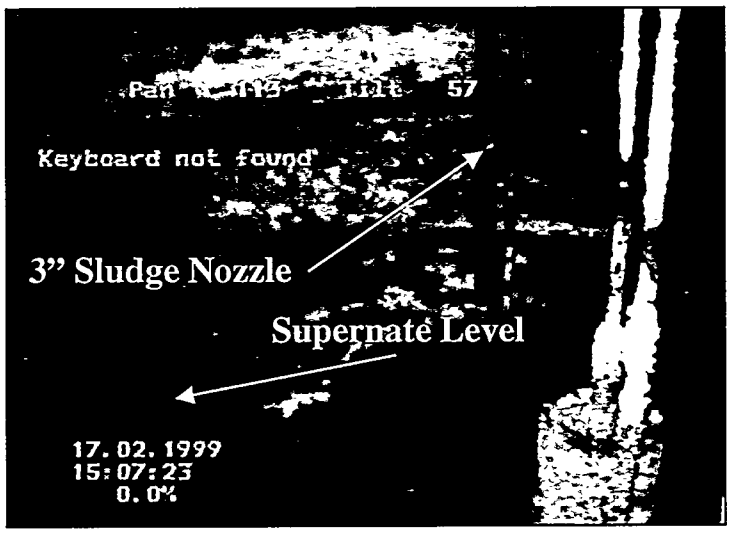


Fig. 9-4. Tank W-23 after third C-2 transfer, and after the subsequent transfer to MVST (looking north).

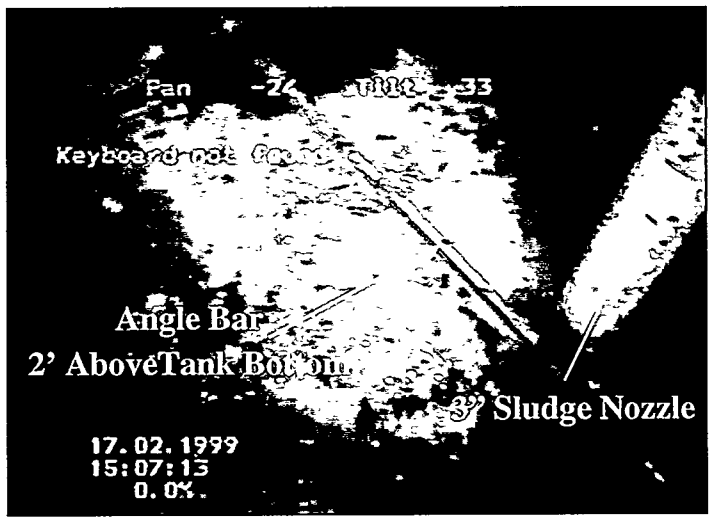


Fig. 9-5. Tank W-23 after third transfer from C-2 and subsequent transfer to MVST.

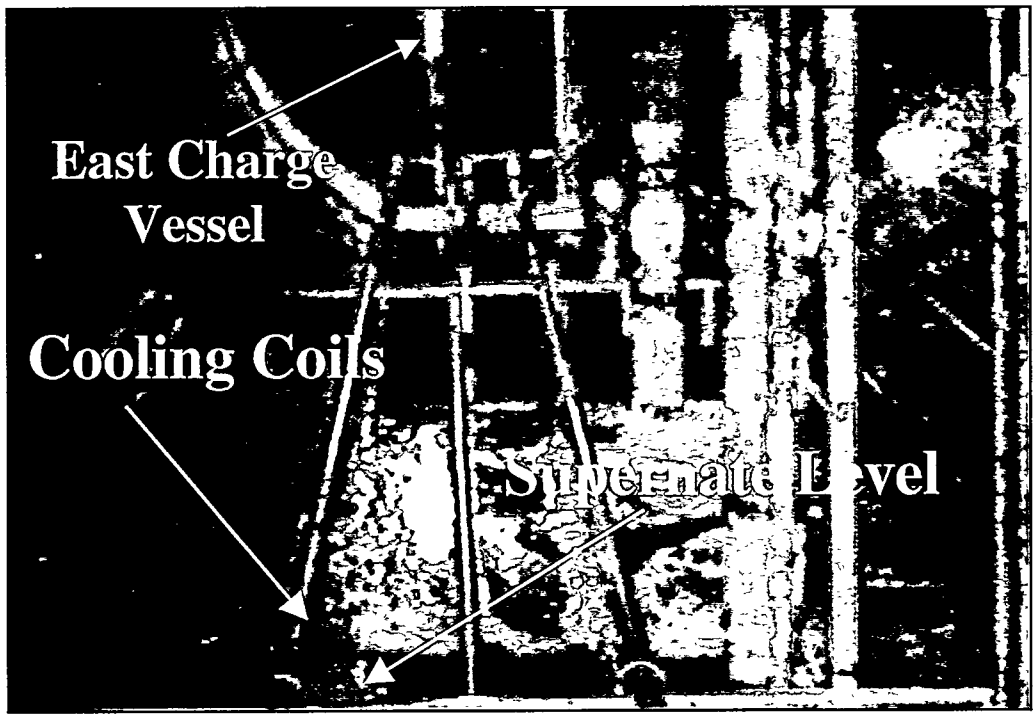


Fig. 9-6. Tank C-2 looking east after final transfer.

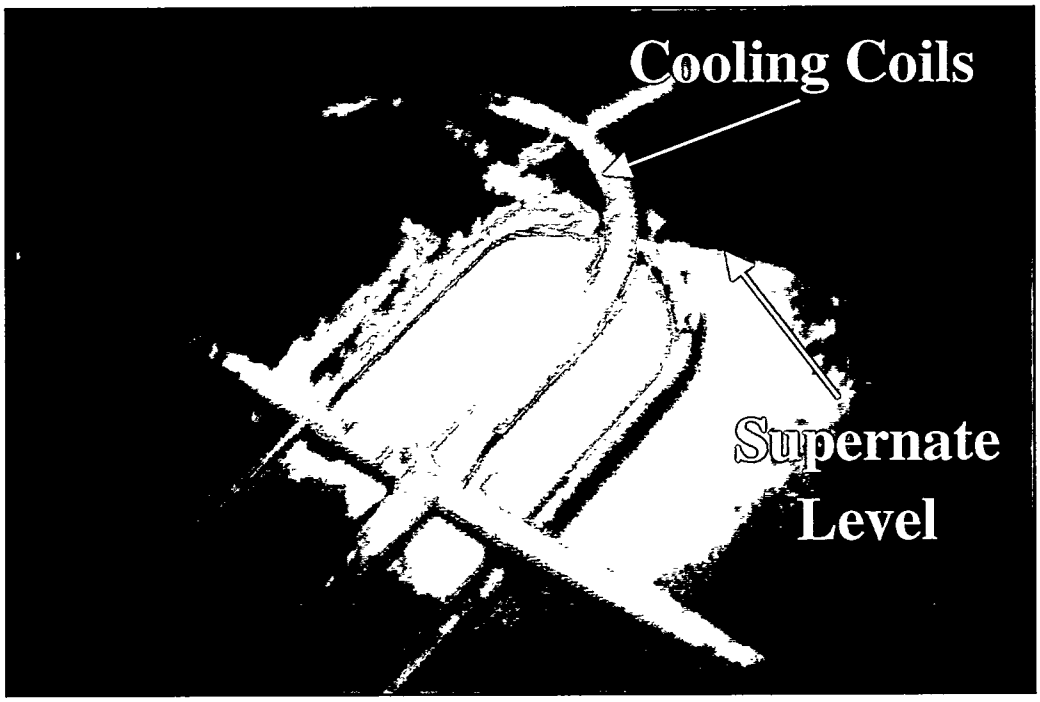


Fig. 9-7. Tank C-2 southwest corner after final transfer.

9.2 SLUDGE TRANSFERS FROM C-1 TANK TO W-23 TANK TO MVST

The contents of tank C-1 were mobilized and transferred to tank W-23 in the same manner as with tank C-2. The sludge added to W-23 was kept in suspension using the W-Tank mixing system, and the mobilized sludge was transferred to MVST. All transfers continued until it was difficult to maintain pump suction. When loss of suction occurred, the transfer was stopped to prevent damage to the progressive cavity pumps being used to make the transfers. The C-1 to W-23 to MVST mobilization and transfer also took four mixing campaigns.

Slurry samples were pulled before most of the transfers. Percent solids, density and pH data were determined. C-1 slurries with a density adjusted suspended solids of up to 2.9 wt%. were transferred to W-23. W-23 slurries with a density adjusted suspended solids of up to 4.1 wt%. were transferred to the MVST.

The transfer data for these four campaigns described subsequently are shown in Table 9-2.

9.2.1 Campaign 1

As with C-2, the charge vessels in C-1 were configured and operated independently to verify stable operation. On February 23, 1999, the west charge vessel was started with the nozzle rotation set to 0°. After the west charge vessel was operating satisfactorily, it was stopped and the east charge vessel was operated at 0°. The tank starting volume was 16,000 gal of which 3250 gal was sludge. Once both charge vessels were operating satisfactorily, the system was configured for anti-phase operation with the east charge vessel as master and the west charge vessel as the slave. Both charge vessels were set to 0° and the first transfer from C-1 was made February 25, 1999. A total of 13,500 gal of slurry was transferred from C-1 (see Fig. 9-8) to W-23, with the volume of W-23 increasing to 21,100 gal. (Between the last C-2 transfer and the first C-1 transfer, approximately 4000 gal of supernate from C-1 was transferred to W-23 to adjust the C-1 starting volume to the desired level.) This transfer included approximately 1900 gal of sludge and left 1300 gal for succeeding mixing campaigns. A transfer from W-23 to MVST followed, which involved 18,900 gal of slurry and approximately 1900 gal of sludge.

9.2.2 Campaign 2

Supernate was added to C-1 to increase the volume to 6100 gal prior to starting the second mixing campaign on February 25, 1999. Both charge vessels were configured to be independent and to rotate per the following pattern: 0°, -10°, 0°, +15°, +45°, +90°, +135°, +180°, +135°, +90°, +45°, +15°. The transfer to W-23 was made on March 1, 1999, with 5400 gal of slurry being transferred increasing the volume in W-23. Additional supernate had been added to W-23 after the first C-1 transfer to yield a total volume of 13,800 gal. Approximately 1000 gal of sludge was included in the transfer leaving 350 gal of sludge in C-1 for succeeding mixing campaigns (see Figs. 9-9 and 9-10). A total of 11,600 gal of slurry was transferred from W-23 to MVST on March 2, 1999, including approximately 1400 gal of sludge.

9.2.3 Campaign 3

Campaign 3 of C-1 mixing started on March 1, 1999 after the transfer to W-23. The starting volume of C-1 was adjusted to 2500 gal by adding nitric acid and supernate. The acid was allowed to stand in the tank overnight before the supernate was added. The acid reacted with the sludge and a thick foam was

Table 9-2. C-1 Mixing Transfers

C-1 to W-23

	Date	Starting Volume	Starting Level	Transfer Volume	Final Level	Final Volume	Raw Suspended Solids	Density	Density Adjusted Suspended Solids	Weight of Sludge Xfer'd	Volume of Sludge Xfer'd	Estimated Sludge Remaing	Receiving Tank
		[gal]	[in]	[gal]	[in]	[gal]	[wt %]	[g/ml]	[wt %]	[lbs]	[gal]	[gal]	
												3,250	
1	2/25/99	16,000		13,500		2,500	3.6%	1.23	**2.9%**	4,056	1,916 [a]	1,334	W-23
2 [b]	3/1/99	6,100		5,400		700	1.4%	1.29	**1.1%**	631	984 [a]	350	W-23
3 [c]	3/5/99	2,500		1,800		700					150	200	W-23
4	3/8/99	3,100		2,500		600					55	145	W-23
											3,105		

[a] Transfer volume adjusted to account for the Total Solids content of the slurry.
[b] Acid Addition - ~ 120 gal of 65 wt% nitric acid was added to C-1 on 3/2/99
[c] Acid Addition - ~ 400 gal of nitric acid from PWTP was added to C-1 on 3/5/99

W-23 to MVST

	Date	Starting Volume	Starting Level	Transfer Volume	Final Level (Inch.)	Final Volume	Suspended Solids	Density	Density Adjusted Suspended Solids	Weight of Sludge Xfer'd	Volume of Sludge Xfer'd	Estimate d Sludge Remaing	Receiving Tank
		[gal]	[in]	[gal]	[in]	[gal]	[wt %]	[g/ml]	[wt %]	[lbs]	[gal]	[gal]	
												1,060	
1	2/26/99	21,100		18,900		2,200	4.2%	1.22	**3.4%**	6,624	1,916	1,060	W-24
2	3/2/99	13,800		11,600		2,200	5.1%	1.23	**4.1%**	4,937	1,428	616	W-25
3	3/5/99	6,500		4,300		2,200					367	400	W-26
4 [a]	3/8/99	7,000		4,800		2,200					55	400	W-26
5	3/15/99	3,500		2,420	7.7	1,080					175	225	W-25
											3,940		

[a] Acid Addition - ~ 200 gal of 65 wt% nitric acid was added to W-23 on 3/8/99
Acid Addition - ~ 100 gal of 65 wt% nitric acid was added to W-23 on 3/11/99

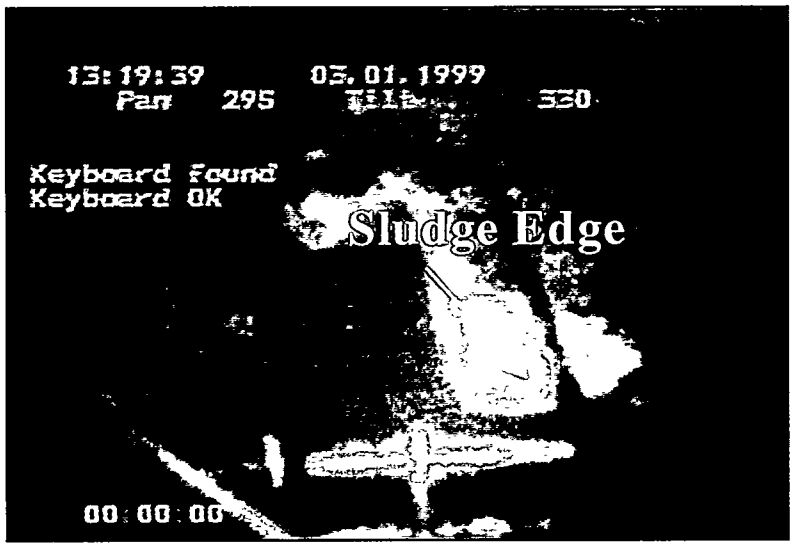


Fig. 9-8. Tank C-1 looking west (from east corner) after first transfer.

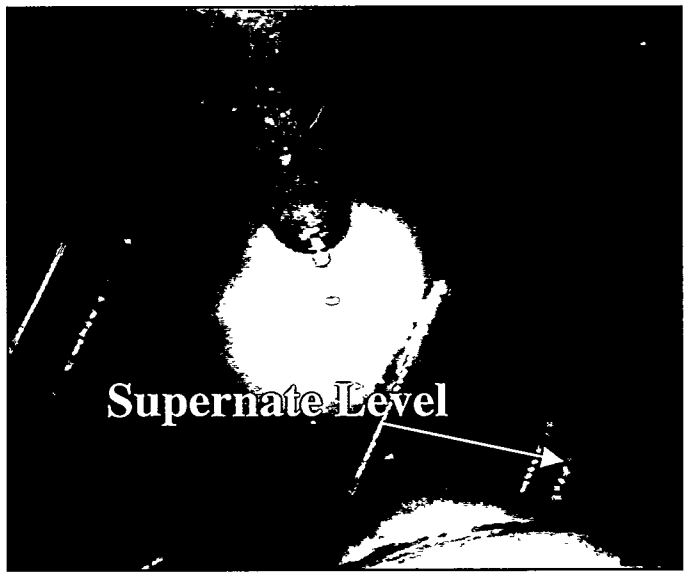


Fig. 9-9. Tank C-1 under west camera after second transfer.

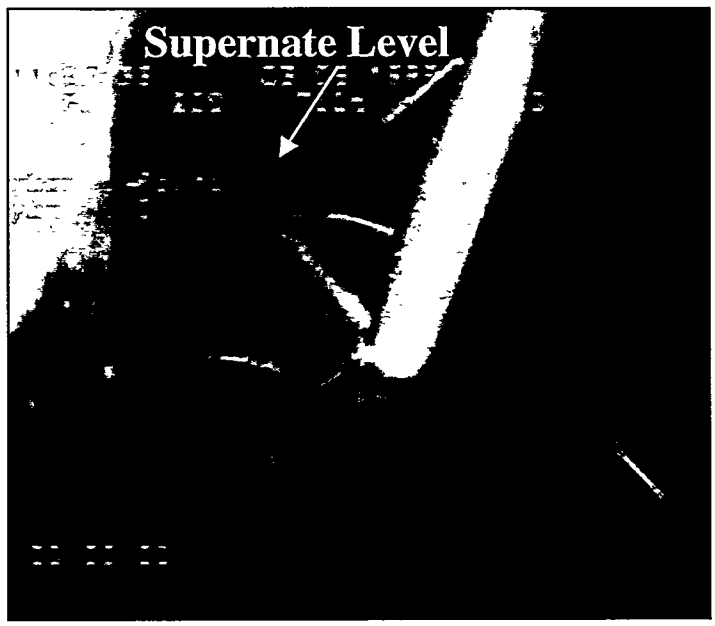


Fig. 9-10. Tank C-1 below east camera after second transfer.

generated. Due to the very low volume in C-1, each charge vessel was configured independently so as to fill the charge vessels alternately. The rotation was set to 0° to concentrate the discharge jet at the center of the tank. The transfer to W-23 took place on March 5, 1999, with 1800 gal of slurry being transferred to W-23 including 150 gal of suspended sludge. The volume of W-23 was increased to 6500 gal by the transfer. (Again, additional supernate had previously been added to ensure that the suspended solids limit of 5 wt% was not exceeded.) Approximately 200 gal of sludge was left in C-1 after the transfer (see Fig. 9-11). A total of 4300 gal of slurry was transferred from W-23 to MVST on March 5, 1999, including approximately 350 gal of sludge.

9.2.4 Campaign 4

Campaign 4 started on the March 5, 1999, with nitric acid and supernate being added to raise the volume of C-1 to 3100 gal. East and west charge vessels were both set to independent operation and the rotation was set as follows: 0°, +90°, +180°, +90° (to clear the ends of the tank). The fourth and final transfer from C-1 was made on March 8, 1999, with 2500 gal of slurry being pumped to W-23 including approximately 55 gal of sludge. The final volume of sludge remaining in C-1 was estimated at 145 gal (see Figs. 9-12, 9-13, and 9-14). The transfer from W-23 to MVST started at 7000 gal on March 8, 1999, and removed 4800 gal of slurry leaving 400 gal of sludge in the tank (see Figs. 9-16, 9-17 and 9-18).

9.2.5 Campaign 5 (W-23 to MVST only)

One additional W-23 mixing and transfer campaign was executed. Two batches of acid were added. The first batch, added on March 8, 1999, was approximately 200 gals of 65 wt% nitric acid. The second batch, of approximately 100 gals of 65 wt% nitric acid, was added on March 11. AEAT mixing system was operated to move the acid around the tank to increase the sludge-acid interaction. A first batch of acid reacted in the tank generating a layer of foam (see Fig. 9-15). The AEAT mixing system continued to mix the tank contents until March 15, 1999 when the contents of W-23 were transferred to MVST. Approximately 2400 gal of slurry were transferred leaving 1080 gal in the tank. An estimated 175 gals of sludge were transferred leaving a final sludge volume in W-23 of 225 gal (see Fig. 9-16, 9-17 and 9-18).

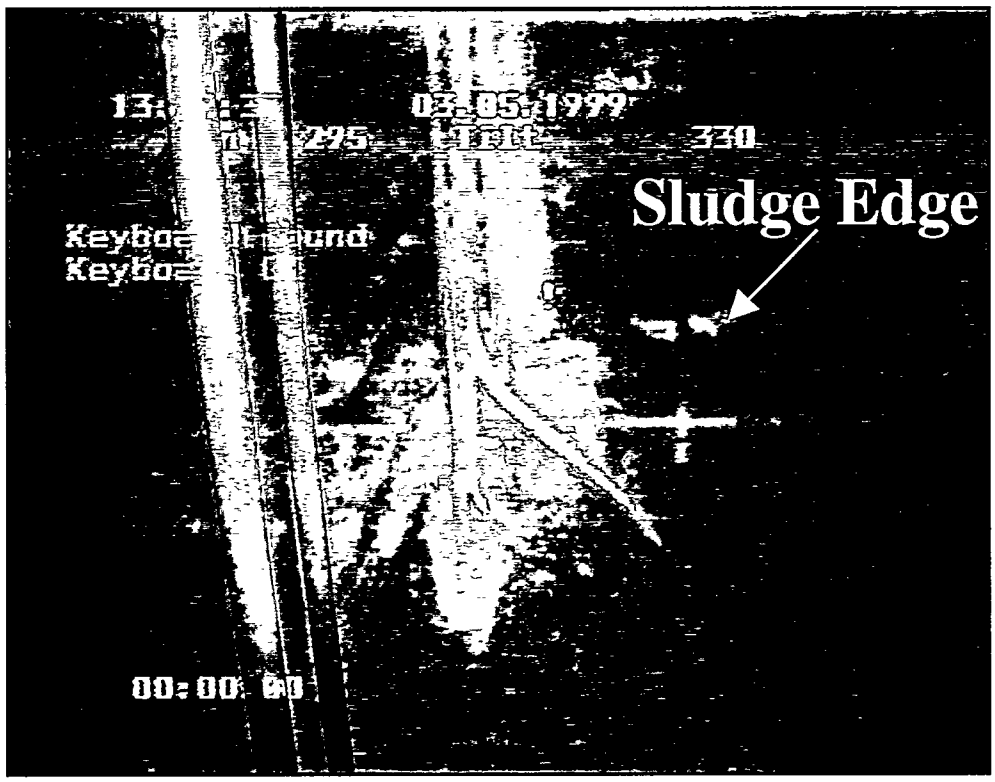


Fig. 9-11. Tank C-1 looking west (from east corner) after third transfer.

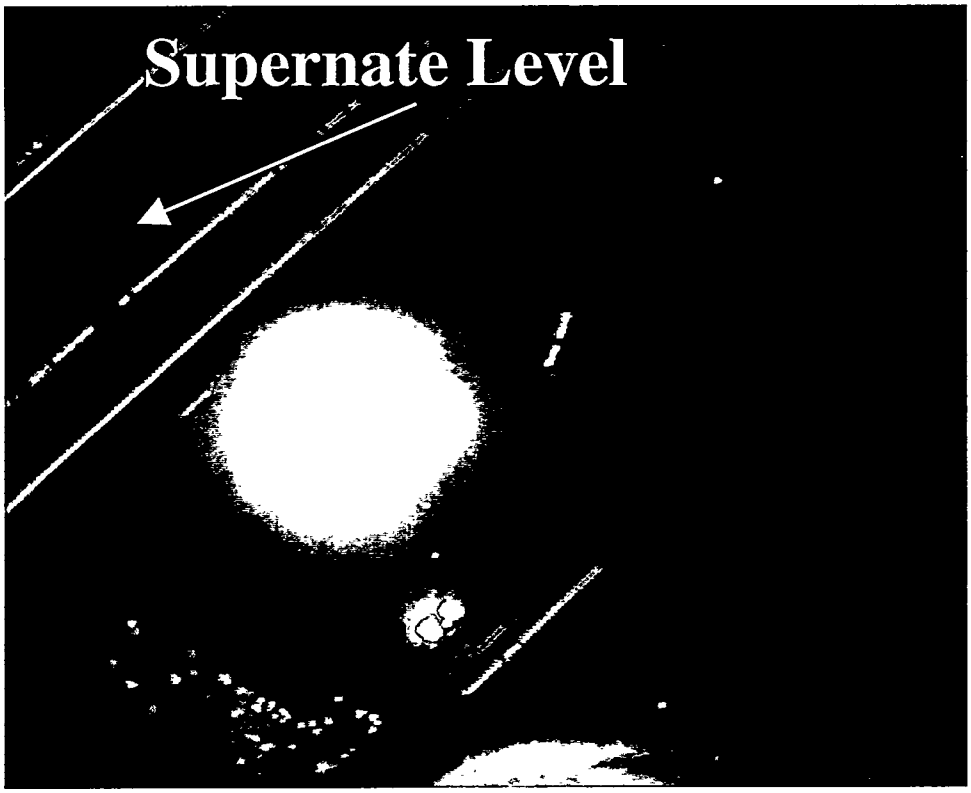


Fig. 9-12. Tank C-1 under west camera after final transfer.

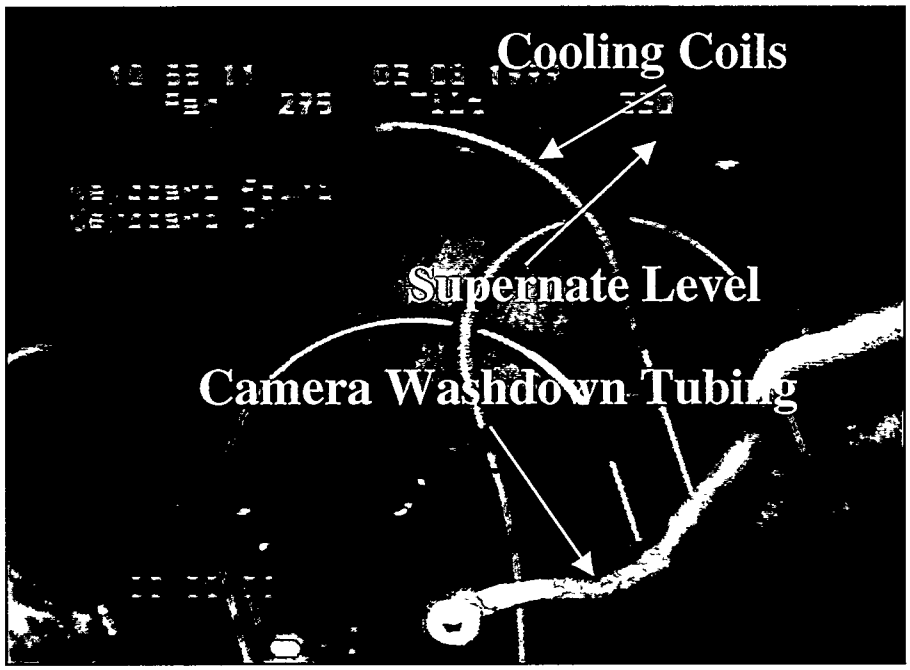


Fig. 9-13. Tank C-1 below east camera after final transfer.

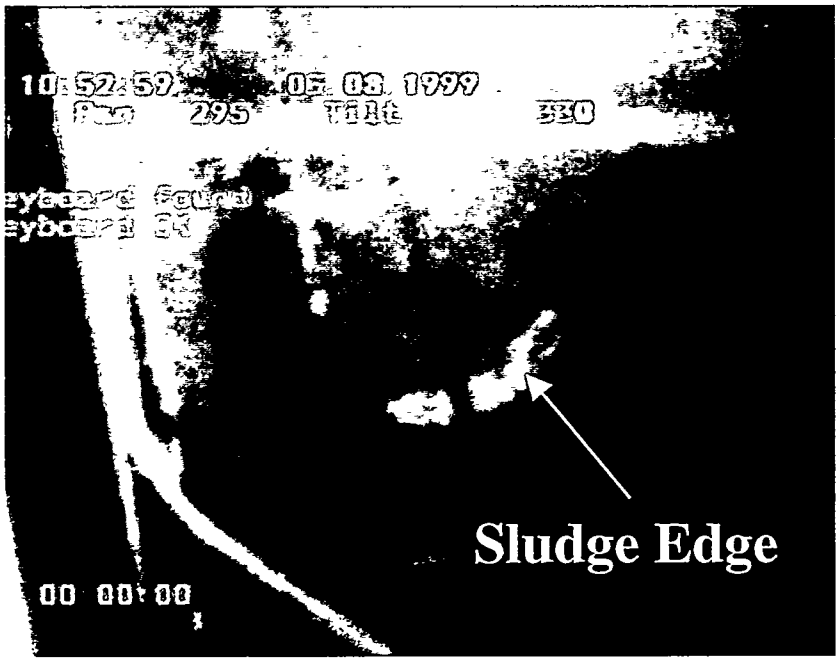


Fig. 9-14. Tank C-1 looking west after final transfer, showing receding sludge bank.

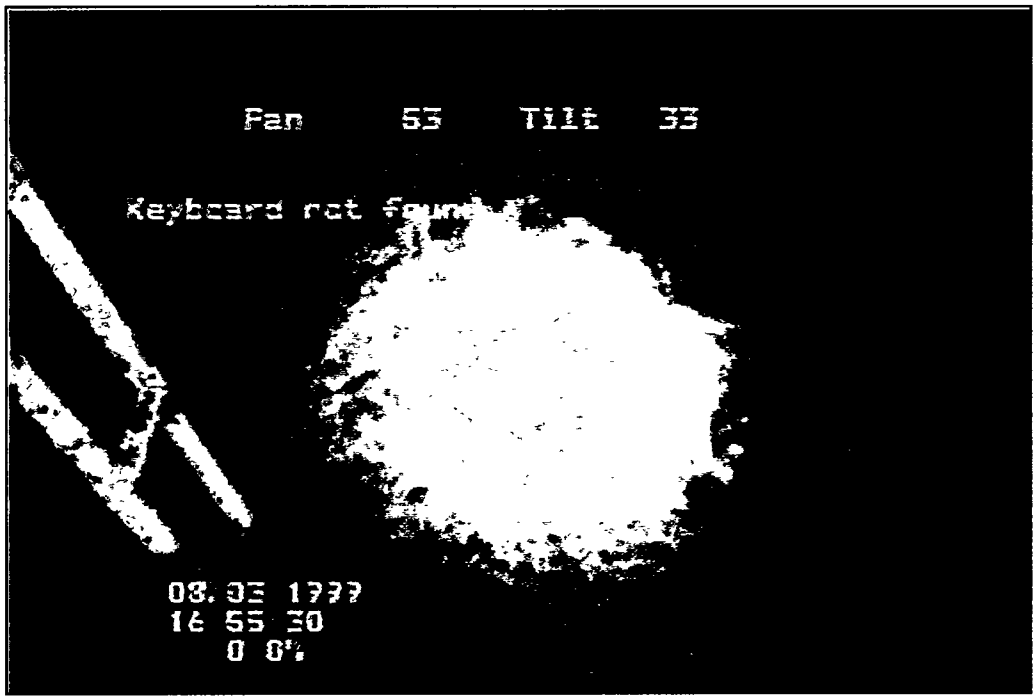


Fig. 9-15. Tank W-23 after acid addition.

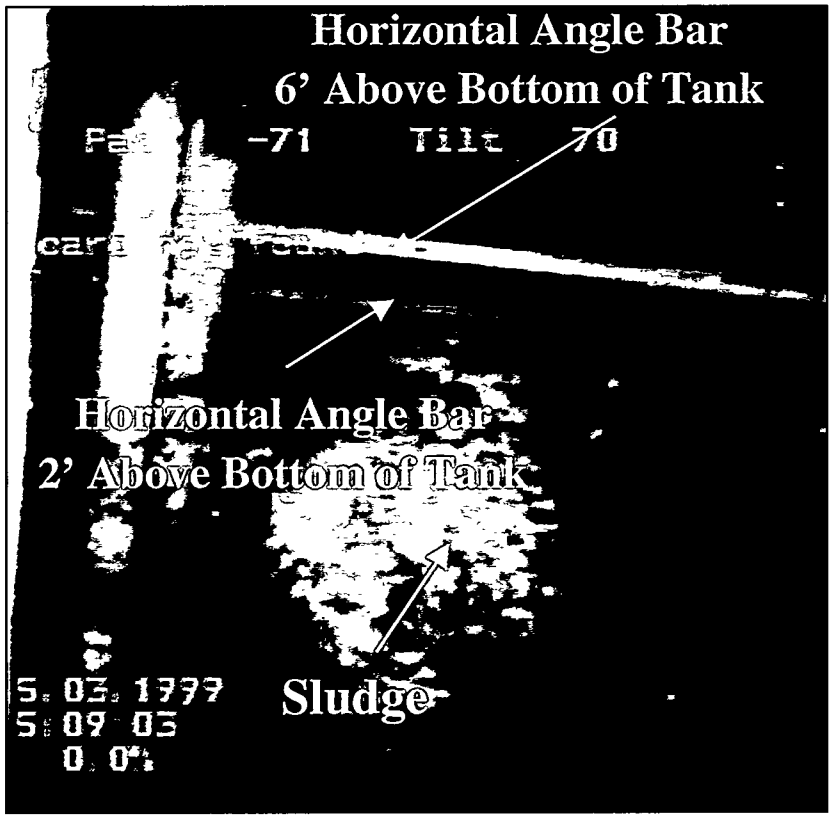


Fig. 9-16. Tank W-23 after all C-1 transfers,
and after the fifth and final transfer to MVST (looking south).

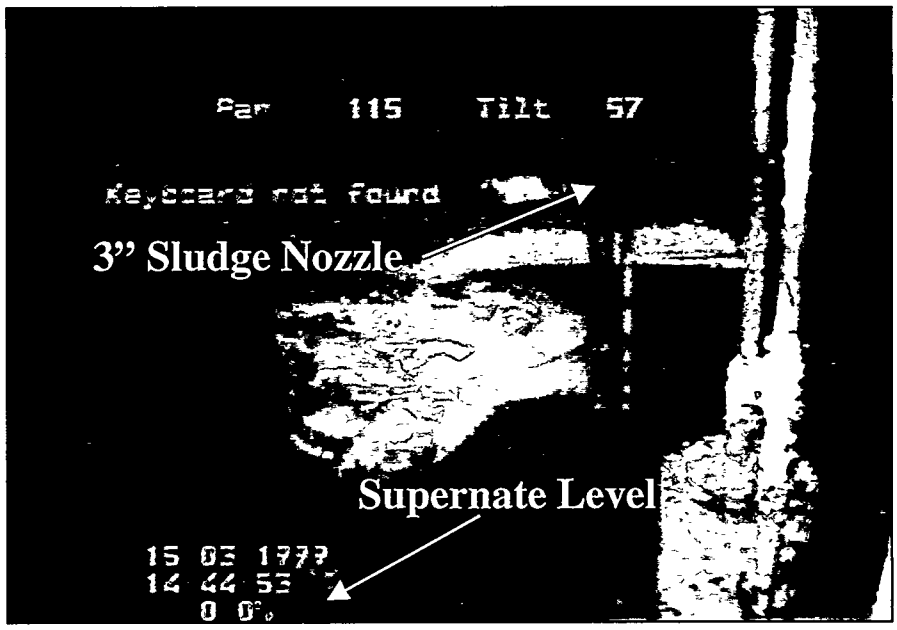


Fig. 9-17. Tank W-23 after final transfer from C-1 and Fifth and final transfer to MVST (looking north).

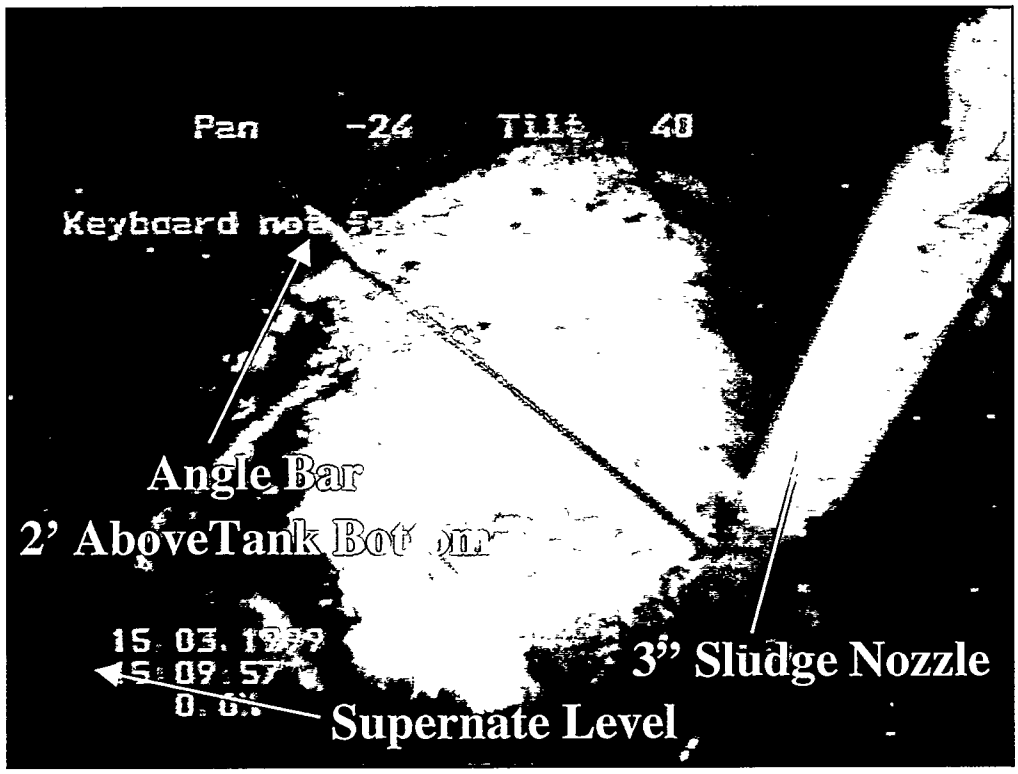


Fig. 9-18. Tank W-23 after final transfer from C-1 and fifth and final transfer to MVST.

10. SAMPLE ANALYSIS

Samples of the waste slurries were taken periodically from tanks C-1, C-2 and W-23 during the pulse jet system operation to determine the pH, density, and suspended solids content in the liquid/sludge mixture. This information was used to estimate the amount of sludge mobilized into the supernate for the particular campaign. In addition, samples were taken from each tank to reconfirm criticality safety [previous sampling and analysis (Keller and Giaquinto 1998) had established this] determined the major radioisotopic constituents. Tables A-1 through A-4 in Appendix A provide the results of the sample analysis.

11. PROJECT COST SUMMARY

Table 10-1 provides a general breakdown of the cost for this project. The table reflects the total costs for design, installation, startup, and operations for all three tanks.

Table 10-1. Pulse jet deployment costs

Organization	Activities	Cost ($K)
AEA Technology	- Design, fabrication, and delivery of pulse jet system - Installation management - Operation of pulse jet system	~$3000
Bechtel Jacobs Company LLC	- Project management - Project financial control - Field engineering support - Prepare Final Report - Design of BVEST installation interfaces - Safety analysis - Engineering support - Field operations support - Technical support and documentation - Installation of pulse jet system[a] - Radiation Protection support - Photography and Video support[a]	$1065
Total		~$4050

[a] Approximately 85% of the Bechtel Jacobs Company LLC managed work was performed by Tetra Tech and Lockheed Martin Energy Research and their subcontractors M.K. Ferguson and Step.

12. SUMMARY AND CONCLUSIONS

The AEAT fluidic pulse jet mixing system was used, along with existing BVEST pumps and nozzles to successfully remove sludge from three 50,000-gal, horizontal storage tanks, C-1, C-2 and W-23. The mixing system used modular equipment to mix the settled tank sludge with existing tank supernate liquids. The pulse jet system was designed, fabricated, installed, tested, and operated for sludge retrieval over a 12-month period.

For tank C-1, approximately 20,000 gal of liquid were used to transfer 3100 gal of sludge. Of the liquid used essentially all was either existing or recycled tank supernate. Two acid additions were used to increase the amount of sludge removed. Lab tests on slurry samples taken from the tank prior to acid addition indicated that acid addition should be very successful. However, the acid addition did not significantly increase the sludge removal efficiency. Waste retrieval operations for tank C-1 occurred over a period of 12 days, with essentially no down time. Greater than 95% of the sludge was removed leaving an estimated final sludge volume of 145 gal.

For tank C-2, approximately 23,000 gal of liquid were used to mix and transfer approximately 8,090 gal of sludge. Essentially all of liquid used was existing or recycled tank supernate. One acid addition was used to increase the amount of sludge removed. Lab tests on slurry samples taken from the tank prior to acid addition indicated that acid addition should be very successful. However, the acid addition did not significantly increase the sludge removal efficiency. The pulse jet system was operated over a period of 15 days, with essentially no down time. Approximately 99% of the sludge was retrieved from tank C-2 leaving an estimated final sludge volume of 90 gal.

For tank W-23, approximately 11,700 gal of sludge were mixed and transferred with approximately 90,000 gal of liquid. When the C-tank Transfers project started W-23 contained approximately 750 gal of sludge. The additional sludge came from the C-1 and C-2 Tanks. Essentially all of the liquid used was existing or recycled tank supernate. Two acid additions were used to increase the amount of sludge removed. Lab tests on slurry samples taken from the tank prior to acid addition indicated that acid addition should be very successful. As in the C-Tanks, the acid addition did not significantly increase the sludge removal efficiency. The pulse jet system was operated for 34 days, with essentially no down time. The original sludge volume in W-23 before the previous W-Tank Transfer sludge removal project was 19,000 gal. Including the sludge removed by both projects, approximately 99% of the sludge was removed and transferred to MVST. The estimated final sludge in W-23 was 225 gal.

The maximum concentration of density adjusted suspended solids, as indicated by analyzed samples, obtained during the mixing campaigns was 10.5 wt.%. The distance between the C-Tanks and W-23 was short, less than 200 feet, compared to the over one mile distance between W-23 and the MVST. Because of this transfers from the C-Tanks to W-23 were allowed at higher suspended solids content than the W-23 to MVST transfers. The W-23 to MVST transfers were limited to no more than 5% suspended solids.

The modular design of the system allowed for quick installation and minimized personnel exposure for work being performed in high-radiation areas. The system operated well and experienced no major equipment malfunctions or unplanned maintenance outages.

These results indicate that the pulse jet system should be seriously considered for mixing and bulk retrieval of sludges in other vertical and horizontal tanks at ORNL and at other DOE sites such as Idaho and Savannah River.

13. REFERENCES

Griffiths, P.G. 1998. *C-Tanks Cold Demo Mobilization Trials*, 20/1129/R2-A, Oak Ridge, TN.

Bechtel Jacobs Company LLC 1998. *Deployment of a Fluidic Pulse Jet Mixing System for Horizontal Waste Storage Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee,* BJC/OR-82.

Keller, J.M. and J.M. Giaquinto 1998. *Characterization of the C-1 and C-2 Waste Tanks Located in the BVEST System at ORNL,* ORNL/TN-13546.

APPENDIX A

C-TANK SAMPLES CHARACTERIZATION

Table A-1. Results of analyses of Tank C-2 samples pulled

February 8, 1999

Analysis		C-2 S	C-2 M	C-2 Avg.
Sample number		**990208-011**	**1990208-012**	
Physical properties				
pH		13.32	13.28	13.30
Density	(g/mL)	1.23	1.23	1.23
Total solids (TS)	(mg/L)	386000	386000	386000
Suspended solids (TSS)	(mg/L)	75000	69400	72200
Total uranium				
U	(µg/mL)	6.36E+03	6.33E+03	6.345
Uranium isotopics				
U-233	(atom %)	0.0924	0.0928	0.0926
U-234	(atom %)	0.0040	0.0040	0.0040
U-235	(atom %)	0.3642	0.3600	0.3621
U-236	(atom %)	0.0077	0.0076	0.00765
U-238	(atom %)	99.5384	99.5356	99.537
Beta/gamma emitters				
Gross beta	(Bq/mL)	2.4E+6	2.3E+6	2.35E+6
^{60}Co	(Bq/mL)	1.1E+4	1.0E+4	1.05E+4
^{134}Cs	(Bq/mL)	1.8E+4	1.6E+4	1.7E+4
^{137}Cs	(Bq/mL)	1.0E+6	9.5E+5	9.75E+5
^{152}Eu	(Bq/mL)	4.0E+5	3.9E+5	3.95E+5
^{154}Eu	(Bq/mL)	1.2E+5	1.1E+5	1.15E+5
^{155}Eu	(Bq/mL)	3.4E+4	2.4E+4	2.9E+4
Alpha emitters				
Gross alpha	(Bq/mL)	2.7E+4	1.4E+4	2.05E+4
Pu (total)	(Bq/mL)	2.3E+3	5.6E+2	1.43E+3
Pu-238	(Bq/mL)	1.2E+3	3.1E+2	7.55E+2
Pu-239/240	(Bq/mL)	1.1E+3	2.5E+2	6.75E+2
Th	(µg/mL)	8.59E+02	5.61E+02	7.1E+02
Percent activity per peak energies				
4.20 Mev U238	%	0.5	0.4	0.45
4.80 Mev U233/U234	%	7.3	8.0	7.65
5.15 Mev Pu239/Pu240	%	5.1	3.3	4.2
5.50 Mev Pu238/Am241	%	23.8	20.9	22.35
5.80 Mev Cm244	%	63.2	67.3	65.25

Table A-2. Results of analyses of Tank C-2 samples pulled February 11, 1999

Analysis		C-2 W-1	C-2 W-2	C-2 Avg.
Sample number		**990211-015**	**990211-016**	
Physical properties				
pH		12.62	12.66	12.64
Density	(g/mL)	1.24	1.27	1.255
Total solids (TS)	(mg/L)	428000	440000	434000
Suspended solids (TSS)	(mg/L)	128000	133000	130500
Gross alpha	(Bq/mL)	7.0E+4	6.2E+4	6.6E+4
Beta/gamma emitters				
Gross beta	(Bq/mL)	3.3E+6	3.3E+6	3.3E+6
^{60}Co	(Bq/mL)	1.8E+4	1.7E+4	1.75E+4
^{134}Cs	(Bq/mL)	1.5E+4	1.4E+4	1.45E+4
^{137}Cs	(Bq/mL)	8.9E+5	8.8E+5	8.85E+5
^{152}Eu	(Bq/mL)	6.3E+5	6.6E+5	6.45E+5
^{154}Eu	(Bq/mL)	1.8E+5	1.9E+5	1.85E+5
^{155}Eu	(Bq/mL)	5.4E+4	3.8E+4	4.6E+4
Percent activity per peak energies				
4.20 Mev U238	%	0.2	0.3	0.25
4.80 Mev U233/U234	%	4.4	5.3	4.85
5.15 Mev Pu239/Pu240	%	3.1	2.4	2.75
5.50 Mev Pu238/Am241	%	26.7	28.4	27.55
5.80 Mev Cm244	%	65.6	63.6	64.6

Table A-3. Results of analyses of Tank W-23 samples pulled

February 9, 1999

Analysis		W-23-1	W-23-2	W-23-3	W-23 Avg.
Sample number		**990209-013**	**990209-014**	**990209-015**	
Physical properties					
pH		12.97	12.93	12.89	12.93
Density	(g/mL)	1.23	1.23	1.23	1.23
Total solids (TS)	(mg/L)	389000	389000	390000	38933.33
Suspended solids (TSS)	(mg/L)	44100	44800	44200	44366.66
Gross alpha	(Bq/mL)	1.3E+4	1.2E+4	1.7E+4	1.4E+4
Beta/gamma emitters					
Gross beta	(Bq/mL)	2.0E+6	2.0E+6	2.0E+6	2.0E+6
^{60}Co	(Bq/mL)	7.6E+3	6.4E+3	7.6E+3	7.2E+3
^{134}Cs	(Bq/mL)	1.8E+4	1.9E+4	1.9E+4	1.866E+4
^{137}Cs	(Bq/mL)	1.0E+6	1.0E+6	1.0E+6	1.0E+6
^{152}Eu	(Bq/mL)	2.2E+5	2.2E+5	2.1E+5	2.16E+5
^{154}Eu	(Bq/mL)	6.4E+4	6.2E+4	6.7E+4	6.43E+4
^{155}Eu	(Bq/mL)	2.7E+4	1.7E+4	1.3E+4	1.9E+4
Percent activity per peak energies					
4.20 Mev U238	%	0.3	0.4	0.3	0.33
4.80 Mev U233/U234	%	6.4	6.3	6.1	6.26
5.15 Mev Pu239/Pu240	%	2.1	2.4	2.2	2.23
5.50 Mev Pu238/Am241	%	20.0	20.1	20.7	20.26
5.80 Mev Cm244	%	71.3	70.8	70.6	70.9

Table A-4. Results of analyses of Tank C-1 samples

February 25, 1999

Analysis		C-1-1	C-2-2	Avg.
Sample number		**990225-013**	**990225-014**	
Physical properties				
pH		9.84	9.86	9.85
Density	(g/mL)	1.23	1.23	1.23
Total solids (TS)	(mg/L)	383000	398000	390500
Suspended solids (TSS)	(mg/L)	23000	48500	35750
Total uranium				
U	(µg/mL)	1.52E+03	3.50E+03	2.51E+03
Uranium isotopics				
U-233	(atom %)	0.1660	0.1604	0.1632
U-234	(atom %)	0.0040	0.0045	0.0043
U-235	(atom %)	0.3373	0.3366	0.3370
U-236	(atom %)	0.0053	0.0058	0.0056
U-238	(atom %)	99.4874	99.4927	99.4901
Total Activity	(Bq/mL)	1.2E+6	1.6E+6	1.4E+6
Beta/gamma emitters				
^{60}Co	(Bq/mL)	4.5E+3	7.3E+3	5.9E+3
^{134}Cs	(Bq/mL)	7.4E+3	6.2E+3	6.8E+3
^{137}Cs	(Bq/mL)	7.2E+5	7.5E+5	7.4E+5
^{152}Eu	(Bq/mL)	5.5E+4	1.1E+5	8.2E+4
^{154}Eu	(Bq/mL)	2.1E+4	4.7E+4	3.4E+4
^{155}Eu	(Bq/mL)	3.8E+3	9.8E+3	6.8E+3
Alpha emitters				
Gross alpha	(Bq/mL)	9.0E+3	1.6E+4	1.3E+4
Pu (total)	(Bq/mL)	2.3E+3		
Pu-238	(Bq/mL)	1.2E+3		
Pu-239/240	(Bq/mL)	1.1E+3		
Percent activity per peak energies				
4.80 Mev U233/U234	%	10.4	11.6	11.0
5.15 Mev Pu239/Pu240	%	4.0	4.3	4.2
5.50 Mev Pu238/Am241	%	17.4	12.1	14.8
5.80 Mev Cm244	%	68.27	72.1	70.2
Process metals				
Ag	(µg/mL)	<3.50E-02	<3.50E-02	<3.50E-02
Al	(µg/mL)	1.49E+02	3.38E+02	2.44E+02
Ba	(µg/mL)	7.28E+00	1.47E+01	1.10E+01
Be	(µg/mL)	<5.00E-02	4.25E-01	2.38E-01

Analysis		C-1-1	C-2-2	Avg.
Sample number		990225-013	990225-014	
Process metals (continued)				
Ca	(µg/mL)	7.02E+03	1.36E+04	1.03E+04
Cd	(µg/mL)	1.58E+00	2.92E+00	2.25E+00
Co	(µg/mL)	<3.80E-01	1.09E+00	7.35E-01
Cr	(µg/mL)	1.23E+01	2.44E+01	1.84E+01
Cu	(µg/mL)	2.91E+00	6.19E+00	4.55E+00
Fe	(µg/mL)	1.51E+02	3.32E+02	2.42E+02
K	(µg/mL)	2.66E+04	2.74E+04	2.70E+04
Mg	(µg/mL)	1.37E+03	2.50E+03	1.94E+03
Mn	(µg/mL)	3.63E+01	8.05E+01	5.84E+01
Na	(µg/mL)	7.70E+04	8.00E+04	7.85E+04
Ni	(µg/mL)	7.37E+00	1.30E+01	1.02E+01
Sb	(µg/mL)	<1.34E+00	<1.34E+00	<1.34E+00
Th	(µg/mL)	4.26E+02	8.85E+02	6.56E+02
V	(µg/mL)	<6.50E-02	<6.50E-02	<6.50E-02
Zn	(µg/mL)	6.43E+01	1.42E+02	1.03E+02