ORNL/TM-13646

OAK RIDGE NATIONAL LABORATORY

LOCKHEED MARTIN

Performance Assessment for Operation of the Modified Light-Duty Utility Arm and Confined Sluicing End Effector in Oak Ridge National Laboratory Tank W-3

Gunite and Associated Tanks Project

J. A. Blank, B. L. Burks, and W. H. Glover
The Providence Group
Knoxville, Tennessee

R. L. Glassell, J. D. Randolph, and P. D. Lloyd
Oak Ridge National Laboratory
Oak Ridge, Tennessee

V. Rule
XL Associates
Oak Ridge, Tennessee

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
managed by
Lockheed Martin Energy Research Corporation
for the
U.S. Department of Energy
under contract DE-AC05-96OR22464

MANAGED AND OPERATED BY
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL-27 (3-96)

ORNL/TM 13646

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R. L. Glassell
J. D. Randolph
P. D. Lloyd
Oak Ridge National Laboratory
Oak Ridge, TN

V. Rule
XL Associates, Inc.
Oak Ridge, TN

Published Date—September 1998

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1 INTRODUCTION

The U.S. Department of Energy (DOE) Office of Science and Technology (OST) in cooperation with the Oak Ridge Environmental Management (EM) Program has developed and demonstrated the first full-scale remotely operated system for cleaning radioactive liquid and sludge waste from large underground waste storage tanks. Almost all sludge waste removal from such tanks has previously been accomplished using water sluicing techniques that are most effective for removing bulk waste but that are ineffective for the final cleaning required to close a tank. The remotely operated waste retrieval system developed and demonstrated at Oak Ridge National Laboratory (ORNL) is designed to accomplish both bulk and final cleaning for waste forms that include liquids, thick sludges, and concrete.

The system was developed for use at the ORNL Gunite and Associated Tanks (GAATs) in a remediation campaign that started in June 1997. Liquid and sludge waste is being removed and transferred to the ORNL Melton Valley Storage Tanks (MVSTs). This waste, along with similar waste from other ORNL tanks, will then be treated, packaged, and shipped to the Waste Isolation Pilot Plant as part of a DOE privatization initiative.

There are several major subsystems that comprise the waste retrieval system: the Modified Light-Duty Utility Arm (MLDUA), Houdini remotely operated vehicle, waste dislodging and conveyance (WD&C), cameras and lights, controls, and the balance of plant (BOP). An overview description of the complete system can be found in ref. 1. System development started in May 1994 and culminated in December 1996 when all the major hardware systems were integrated for testing at the ORNL Tanks Technology Cold Test Facility. An open house was conducted during the week of December 9, 1996, at which the remotely operated tank waste retrieval system was demonstrated to more than 230 people from across the DOE complex. Cold testing and operator training continued until mid May when relocation to the ORNL North Tank Farm started. This report provides an assessment of the performance of the MLDUA and WD&C systems during operations in Tank W-3. These operations were completed on September 19, 1997, when the MLDUA and WD&C systems were stowed in preparation for the move to Tank W-4. During all of the Tank W-3 operations, the MLDUA system was located at the center riser of the 25-ft-diam tank. The WD&C hose management arm was located in the east riser of W-3 and discharged waste slurry into the west riser of Tank W-4.

2 PERFORMANCE ASSESSMENT FOR THE MODIFIED LIGHT-DUTY UTILITY ARM

The MLDUA was operated for a variety of tasks, including:

- teleoperated deployment to determine the correct joint motion sequence for automated deployment,
- automated deployment,
- deployment of a characterization end effector for radiation and video surveys,
- wall inspection using the gripper camera,
- grasping of the confined sluicing end effector (CSEE) to facilitate deployments and retractions of the hose management arm,
- positioning of the CSEE for sludge removal,
- positioning of the CSEE for wall scarifying,
- deployment of a sludge depth gauge,
- deployment of a feeler gauge for determining the variance of the wall surface along both a vertical and radial path,
- deployment of tools for obtaining wall scrapings,
- deployment of the CSEE cradle so that the CSEE could remain in the tank but be out of the sludge on the tank floor, and
- grasping and positioning pipe debris for removal.

The MLDUA was first deployed into Tank W-3 on June 26, 1997. This first deployment was primarily a part of system checkout but also served as an opportunity to perform some closeup wall inspections and to determine joint motions for automated deployments. Because of the repeatability and accuracy with which the MLDUA can be positioned, it was the system of choice for deployment of the characterization end effector (CEE). The CEE was deployed a total of three times: twice initially to obtain baseline surveys of the tank walls before cleaning and a third time to complete a survey of the walls following scarifying at 7000 psi with the CSEE. A total of 12 points were surveyed during each campaign. An average reduction in radioactivity of ~20% was measured, which shows that the wall scarifying was somewhat effective but that the majority of the wall contamination remains. Analysis of wall core samples showed that more than 90% of the remaining contamination is contained within the inner 0.125 in. of wall surface.

The MLDUA has both a primary contamination prevention boot and a secondary boot. The primary boot was replaced once during operations and was partially replaced on two other occasions. The usual reason for replacing all or part of the primary boot was because of tears in the boot. The secondary boot was replaced four times. Because of tears and when (1) the boot had become sufficiently contaminated to threaten contamination of the primary boot and risk internal contamination of the MLDUA or (2) when oil leaks had sufficiently dirtied the boot to warrant replacement. A small boot was used on the gripper end effector (GEE), which was also replaced four times.

Two major oil leaks occurred during operations. A total of ~7 gal of fluid was added to the MLDUA reservoir. It is estimated that <1L of oil was actually leaked to the tank. The rest of the leaked oil was captured inside the robot arm and the secondary boot.

There were four significant component failures that resulted in lost availability of the system. The temperature sensor in the hydraulic oil reservoir failed during the first two weeks of operations. Since replacement of this sensor would require draining the reservoir, an alternative was derived for obtaining the necessary temperature feedback. A thermometer was placed outside the reservoir for visual feedback, and a mock feedback signal of the appropriate voltage was provided to the computer to satisfy interlock requirements. This allowed operations to go forward until a more permanent solution was implemented. A temperature sensor that fits into the top of the reservoir has now been installed, avoiding the need to drain the reservoir. The total time lost to diagnose this sensor failure and implement a solution was two days.

A more serious failure occurred when an O-ring seal failed in the wrist pitch joint. To access the wrist pitch hydraulics, the tank riser interface and containment (TRIC) structure was removed from the riser and set aside. This provided sufficient clearance between the bottom of the vertical positioning mast (VPM) and the support platform so that the MLDUA lower joints could be deployed and supported on the platform. The arm covers were removed, and the O-ring problem was discovered. This failure happened twice on the same hydraulic fitting. The first time this failure occurred, eight days were spent preparing for and completing the repair and returning the MLDUA to service. The repair for the first incident involved simply replacing the damaged O-ring with a new one of identical dimensions. Within two days after returning to service, the same wrist pitch drift symptom was observed. An investigation was conducted and it was determined that the design of the O-ring seating surface was inadequate for a reliable long-term seal. The hydraulic fitting was modified to provide a better seal surface, and a larger O-ring was inserted to ensure an adequate seal. This repair took about five days. The major reason for reduced down time was experience gained the first time in contamination control measures. Note that after the second leak was discovered, the MLDUA continued in-tank operations until a convenient time for scheduling the maintenance. The wrist pitch drift was at a sufficiently low rate for servo-controlled operations to continue to track and command the joint position.

The only other significant component failure occurred when the cable attached to the VPM encoder came off the guide pulley outside of the umbilical cable bundle. This was caused by interference with a camera cable that was attached to the umbilical. The camera cable was repositioned and the encoder cable repaired. This repair required use of a bucket lift to access the top of the VPM housing while in the vertical position. About two days were required for this repair.

Table 1 contains revealing statistics about MLDUA operations that were logged.

Table 1. Statistics logged for MLDUA operations

Event	Occurrences
Total number of computer power startups	87
Total number of hydraulic pressure pump startups	133
Total number of times the VPM housing was raised	5
Total number of times the VPM housing gate valve was opened	1
Total number of times the VPM was deployed (off limit switches)	6
Total number of times the GEE was attached to the MLDUA	3
Total number of times the MLDUA was deployed into the tank	20
Total number of times the CSEE was grasped for sludge and supernatant removal	18
Total number of times the GEE grasped the CEE for surveys	3
Total number of times the CSEE was grasped for wall scarifying	17
Total number of times the decontamination spray ring (DSR) was turned on	21
Total number of times the secondary boot was attached to the MLDUA	18

Time-significant events	
Event	**Duration (h)**
Computer was powered	545.98
Hydraulic pump was powered	238.05
MLDUA was inside the tank	686.03
GEE grasped the CSEE for sluicing	68.78
GEE grasped the CEE[1]	31.90
GEE grasped the CSEE for wall scarifying	76.42
DSR was spraying water for MLDUA decontamination	1.15

[1] On some occasions, the MLDUA remained overnight in a shut down mode that left the lower arm inside the tank but with all joints aligned in a vertical position.

In summary, the MLDUA performed as designed for deployment of various tools for in-tank operations. In particular, MLDUA is well designed for performing tasks requiring repeatability or accuracy in positioning tools. The dynamic effects of the CSEE during both sluicing and wall scarifying were not sufficient to hinder MLDUA operations. However, the dynamics of the DSR impinging on the MLDUA mast did cause sufficient problems so that the decontamination had to be conducted at pressures of ~500 psi, well below the 2100-psi maximum available from the DSR. Although the system was unavailable for a total of 16 days during the 17 weeks of operations in Tank W-3, the operating crew was usually able to reschedule in-tank tasks so that the Houdini system could carry on in place of the MLDUA or so that other beneficial operations could be scheduled. Incidentally, the Houdini system suffered a comparable amount of down time, and the WD&C system was unavailable about half as much as the MLDUA. The nature of the component failures is such that the down time during future deployments is anticipated to be less than during this initial field operation.

3 PERFORMANCE ASSESSMENT FOR THE WASTE DISLODING AND CONVEYANCE SYSTEM AND BALANCE OF PLANT SYSTEM

The WD&C is composed of a 4 degree-of-freedom hose management arm (HMA), confinement box (CB) and storage tube. The HMA is designed to provide access to all points within a 15-m (50-ft-diam) or smaller tank. The HMA is constructed in such a fashion that the arm links and mast contain pipe components, including the jet pump, for conveyance of retrieved waste. The CB contains a mast elevate table used to provide elevation and mast rotate capability to the HMA. The CB also houses necessary hoses and cables for operating the HMA and waste retrieval end effectors such as the CSEE. The CB is also equipped with glove port access for operational needs and limited maintenance. The storage tube (ST) contains the HMA hoist and storage housing. The hoist is used to deploy and retract the HMA.

The WD&C system experienced several operational problems during operations in Tank W-3. The most severe problem was the failure of the rupture disk mounted in the HMA mast. The rupture disk failed twice within a one week period. The first failure was caused by a process problem, described subsequently, and the second failure was caused by an installation error. After the second failure, the rupture disk was relocated to the flow control equipment (FCE) box located at the platform level. This provides easy access in the event of additional failures. After relocation of the rupture disk and selection of a different rupture disk no, additional failures were experienced. While the rupture disk was being relocated, other in-tank operations were under way. The previous rupture disk was located and installed in a way that resulted in high stresses during backflush operations.

The balance of plant (BOP) system is composed of a process water supply (PW) system (designated L-04) and three high-pressure water pumps. The high-pressure pumps supply the DSR system (designated L-01), CSEE cutting jet supply (L-02), and jet pump supply (L-03). The BOP system also consists of the FCE, which houses the Coriolios flow meter, the Isolok sampler, and the flush system. Also included as a part of the BOP system are the air compressor and the tank ventilation system, and the tank level sensing system.

The PW system supplies water to the high-pressure water pumps and the flush system. The DSR pump operates at up to 2.1 ksi@114 Lpm (30 gpm). The CSEE and jet pump supply pumps operate at up to 7 ksi@39.7 Lpm (10.5 gpm). The air compressor supplies air to the MLDUA, Houdini vehicle system, pumps, and pressure control valves. The Isolok sampler is a proportional sampler designed to capture samples of liquid and slurry solutions. The Coriolis flow meter (Micro-Motion) is designed to provide flow measurements, density measurements, total flow, and mass inventory.

The WD&C system log shown in Table 2 indicates that the pumps were operated for the following total times:

Table 2. High-pressure pump operating time

Pump	Hours
DSR, L-01	19.40
CSEE, L-02	64.28[2]
Jet pump, L-03	34.33
PW pump, L-04	112.06

Data indicate that a total of two samples were collected via the Isolok sampler and were submitted for analysis. The only problem noted for the sampler was a slight, slow leakage at the mating of one of the bottles to the sampler. The sampler was cleaned, and a tight seal was obtained on the next bottle.

The Coriolis flow meter provided real-time data to the operators. However, the data are questionable because the flow meter experienced saturation of signal at some phases of operation and performed erratically when air entertainment occurred.

The air compressor performed well. The unit experienced a failure of a solenoid valve on the drier that was then replaced.

The HMA and most of the BOP systems are remotely operable and have been connected to the Operations Control Trailer's WD&C and BOP graphical user interface station. These control systems were the primary operations systems, and no manual (i.e., field) operations were performed. Only a few software problems were experienced, and these were corrected with minimal effort. The control engineer provided a couple of enhancements to the system during the operations period. The air compressor and tank ventilation systems are stand-alone systems. The tank ventilation system performed well. The tank level sensing system performed well but required some calibration during the operating period.

The HMA was deployed and retracted a total of 12 times for 25 separate campaigns during the Tank W-3 operation. The WD&C system was used to perform a variety of operations:

- wall scarifying,
- supernatant retrieval,
- sludge retrieval, and
- scale retrieval.

The WD&C system was initially deployed into Tank W-3 on June 30, 1997, for the initial checkout of the system. Upon completion of the initial checkouts, the unit was made available for operations. Table 3 presents data gleaned from the data logging profile generated during the Tank W-3 retrieval effort. Note that the data have not been thoroughly analyzed and that discrepancies are apparent. After further analysis, a revision to this report will be issued or a second report will be written and distributed.

[2] L-02 was used for a short time in place of L-03 to supply the jet pump motive water.

Table 3. GAAT W-3 Summary Data

DATE	flush water	CSEE	decontamination	jet pump	FQIT-204	FIT-204		TOTAL WATER ADDED	RATIO water transferred to water added	MATERIAL REMOVED material transferred - water added	W-3 CHANGE IN LEVEL	W-3 CHANGE IN VOLUME	W-4 CHANGE IN LEVEL	W-4 CHANGE IN VOLUME	RATIO water transferred to water added using tank levels	MATERIAL REMOVED material transferred - water added using tank levels
	gal	gal	gal	gal	gal	lo gpm	hi gpm	gal		gal	ft	gal	ft	gal		
7/7/97	0	3	0	0				3								
7/9/97				0	0			0		0	0	0	0	0		
7/11/97	39.3	not op	47.6	487.1	4294.2			574			-1.04		1.38	5067.36		
7/16/97	96.7	not op	0	306.9	2905.3	75	76	403.6			-0.697		0.772	2834.76		
7/16/97	51.2	not op	0					51.2			-0.287		0.162	594.86		
7/17/97	94.2	not op	36.8	151.8	648	30	113	282.8								
7/24/97	0	0	0	0	0			0								
7/25/97	0	0	0	0	0			0								
7/30/97	367.4	3	0	1625.4	7860.6			1995.8	3.94	5864.8	-0.855	-3139.56	1.16	4259.52	1.57	2263.72
7/31/97	58	252	0	1003	6386			1313	4.86	5073	-1.02	-3745	0.519	1906	2.85	593
8/1/97	229	181.2	0	693.6	5763.7			1103.8	5.22	4659.9	-0.325	-1193.4	0.292	1072.2	1.08	-31.6
8/4/97	220.1	495.5	17.7	1667.6	12242.8			2400.9	5.10	9841.9	-0.511	-1876.4	0.68	2497	0.78	96.1
8/5/97	61.3	281.3	67.6	1138.9	6658.6			1549.1	4.30	5109.5	-0.141	-518	0.476	1748	0.33	198.9
8/6/97	108.7	380	0	1834.5	9272.3			2323.2	3.99	6949.1	-0.229	-840.9	0.618	2269.3	0.36	-53.9
8/7/97	239.9	431.5	0	1064.6	8295.2			1736	4.78	6559.2	-0.167	-613.2	0.674	2474.9	0.35	738.9
8/13/97	123	372.9	160.2	1156.4	7685.3			1812.5	4.24	5872.8	-0.131	-481	0.685	2515	0.27	702.5
8/18/97	119.3	519.8	209.9	2266.2	12083.7			3115.2	3.88	8968.5	-0.386	-1417.4	1.291	4740.6	0.45	1625.4
8/20/97	0	121.2	90.2	0	0			211.4	0.00	-211.4	0		0		0.00	-211.4
		3041.4														
8/21/97	121.1	774.4	130.5	893.3	3715.8			1919.3	1.94	1796.5	-0.055	-202	0.638	2342.7	0.11	423.4
8/22/97	55.3	1203.8	0	322.2	2686.3			1581.3	1.70	1105	-0.012	-44.1	0.472	1733.2	0.03	151.9
8/26/97	0	0	0	0	0			0	#DIV/0!	0	0		0		#DIV/0!	0
8/27/97	53.3	1124.7	0	221.2	2022.8			1399.2	1.45	623.6	-0.04	-146.88	-0.778	-2856.82	0.10	-4256.02
8/28/97	40.8	2016	0	453	3730.8			2509.8	1.49	1221	-0.06	-220	0.806	2960	0.09	450.2
9/4/97	38.9	2181.3	55	308.9	2222.1			2584.1	0.86	-362	0.362	1329	0.379	1392	-0.51	-1192.1
9/4/97	75.3	0	0	194.6	1693.2			269.9	6.27	1423.3	-0.16	-588	0.195	716	2.18	446.1
9/5/97	60.5	1939.2	0	559.8	5741.5			2559.5	2.24	3182	-0.37	-1359	1.152	4230	0.53	1670.5
9/6/97	0	776.1	0	0	0			776.1	0.00	-776.1	0.096	352.32	-4.962	-18220	-0.45	-18996.1
9/8/97	0	401.5	0	0	0			401.5	0.00	-401.5	0.002	7	-0.002	-7	-0.02	-408.5
9/9/97	46.5	1402.3	124.2	992.9	4889.3			2567.9	1.90	2321.4	-0.452	-1660	0.923	3389	0.65	821.1
9/10/97	0	1427.6	0	0	0			1427.6	0.00	-1427.6					0.00	-1427.6
9/10/97	0	134.5	174.7	585.8	3800			895	4.25	2905	-0.5	-1836	0.71	2622	2.05	1727
9/12/97	0	44.4	0	0	0			44.4	0.00	-44.4					0.00	-44.4
9/13/97	269.6	0	28.2	1366.1	10292.8			1663.9	6.19	8628.9	-0.056	-206	-1.717	-6305	0.12	-7968.9
9/13/97	0	50.9	0	167.7	1515.77			218.6	6.93	1297.17	0.01	37	-0.157	-577	-0.17	-795.6
9/15/97	240.6	0	96.3	1486.2	14669.1			1823.1	8.05	12846	0.043	158	0.472	1733	-0.09	-90.1
9/18/97	40.7	0	0	449.7	2705.1			490.4	5.52	2214.7	0.017	62	0.173	635	-0.13	144.6
	2852.7	13476.7	1238.9	21397.4	143780.3			40692.5				(18,141.52)		25,766.61		

3.1 WALL SCARIFYING

The first activity performed was wall scarifying, with the MLDUA maneuvering the CSEE about the tank. A total of 15 wall-scarifying campaigns were performed. Each campaign translates into a single-day activity but not necessarily a full-day activity. The initial effort was performed on July 1, 1997, to determine the required operating water pressure for scarifying and to determine the MLDUA parameters (traverse rate, standoff distance, etc.) for obtaining the best performance. Approximately four areas [~1.2 by 1.8 m (~4 by 6 ft)] at different quadrants of the tank were scarified during testing.

Initial results revealed that the operating pressure should be maximized to 120 to 140 kPa (6 to 7 ksi), the traverse rate slowed to 6.4 to 12.7 mm (0.25 to 0.5 in.)/s, the standoff distance increased up to 0.46 m (18 in.) for safety and large area coverage, and robotic control used rather than teleoperations. As a best guess effort, the dried sludge layer on the inner wall liner appeared to be ≤1.6 mm (≤0.0625 in.) thick.

After removal of most of the sludge, the tank walls were scarified. Most of the walls were cleaned to the concrete surface using a standoff distance of about 25.4 cm (10 in.), however, there are a few small areas that could not be scarified. These areas were behind the WD&C mast and behind overview cameras. Note that although it is not clear whether any concrete material was removed in this operation, much scale material was removed.

Before scarification, the CEE was used to determine a baseline of the radiation levels. Once the scarification effort was complete, the CEE was redeployed and additional measurements were taken. Generally, the results showed a 20% reduction in radiation levels after scarifying. Isotopic migration within the inner liner concrete structure accounts for the remainder of the radiation measurements.

Wall coring was performed with samples taken at different elevations and at core depths of 5 to 8 cm (~2 to 3 in.). The Gunite™ tank walls are constructed of a 15-cm (6-in.) outer wall, 1.27-cm_{MAX} (0.5-$in._{MAX}$) asphalt layer, and an ~5-cm (~2-in.) inner Gunite™ layer. Results revealed the Gunite™ inner tank liner to be 3.81 to 4.45 cm (1.5 to 1.75 in.) deep and the asphalt underlayer (sealant) to have a depth of ~1.27 cm_{MAX} (~0.5 $in._{MAX}$). The core also penetrated the main wall by ~1.27 cm_{MAX} (~0.5 $in._{MAX}$). The purpose of the coring exercise was to determine the depth of isotopic migration and the type of isotope(s) bonded with the Gunite™. Data received to date indicate that the isotopic migration did not exceed 5 mm (0.2 in.).

3.2 SUPERNATANT RETRIEVAL

The next exercise after the initial wall scarifying effort was to remove the remainder of the supernatant. Tank W-3 was pumped down by the ORNL Waste Management Organization, leaving an ~12-in. depth of supernatant over the sludge. Retrieval of the supernatant was performed in two events, with retrieval rates of 265 to 379 Lpm_{TOTAL} (70 to 100 gpm_{TOTAL}). The jet pump pressure was limited to avoid transfer rates of more than 100 gpm. The motive water rate for the high-pressure water jet pump was 36 to 39.8 Lpm (9.5 to 10.5 gpm). A total of about 7200 gal of supernatant were transferred.

3.3 SLUDGE RETRIEVAL

Once the supernatant was removed, the sludge layer was clearly visible. One important note of interest is that the original sludge depth measurements provided to the operations team were inaccurate. Although the original information indicated that the total sludge depth was 15.24 to 20.32 cm (6 to 8 in.), it was obviously deeper. An in-tank measurement made using the MLDUA and a ruler revealed the true depth of the sludge to be ~61 cm (24 in.). Preoperations planning included a mining strategy with plans to plane the waste surface to permit a layered retrieval effort. However, it was soon realized that the sludge was very mobile when sluiced, as dewatering resulted in "mud slides." Therefore, a mining strategy was developed "on the fly". The best method was to mine an area of ~1.8 by 1.8 m (6 by 6 ft) and down to the floor surface. Once this area was mined, the Houdini vehicle system was used to manipulate the CSEE for additional sludge retrieval.

The sludge was then mined near a "bank" or "wall" of sludge, with the CSEE at the tank floor surface. As the material at the surface was being retrieved, areas of the sludge wall would slide to the floor's surface, breaking up and mixing with the cutting jet water in the process. The CSEE cutting jets were also used to slurry this material and dislodge additional "walls" of material. Additionally, a coordinated effort using the MLDUA to position the CSEE in a predetermined point and using the ROV to plow sludge to the CSEE resulted in successful retrieval.

Retrieval rates vary, and complete analysis of the collected data is in progress. Once this effort is completed, a revision to this report can be issued. Variations in retrieval rates for sludge is caused by the particular operation being performed. For example, when retrieving large sludge volumes, it is typically easier to obtain high rates; but when retrieving small volumes, the system also entrains air, resulting in poor retrieval rates. Attempts to transfer high solids-content sludges resulted in more frequent plugging and, hence, backflushing. A less aggressive approach, holding the jet pump farther away from the sludge surface, allowed a better mixed slurry to develop that was more easily transferred with fewer plugs. We found it more efficient to use the less aggressive approach. A screen integrator is attached to the CSEE inlet for rejection of objects larger than 1.27 cm (0.5 in.). In the early phase of sludge retrieval, the screen became plugged by either debris or sludge or both. Backflushing easily cleared the majority of the material from the screen.

3.4 SCALE RETRIEVAL

At the conclusion of supernatant and sludge retrieval exercises, a full effort was given to wall cleaning. This resulted in an ~2.54-cm (1-in.) depth of gritty, hardened material on the tank's floor. An effort was made to retrieve all of this material with the CSEE. It is possible that 50 to 70% of this material was retrieved with this unit. However, the CSEE was not capable of retrieving the remainder. Another end effector was designed and fabricated for attachment to the WD&C HMA. This end effector, shaped like a carpet cleaner nozzle, was used to retrieve an additional 10 to 20% of material.

3.5 DECONTAMINATION SYSTEM

The BOP system provides a decontamination system and a flushing system. The decontamination system was used to clean the operating equipment (MLDUA, WD&C HMA, Houdini, etc.) as it was retracted from the tank. A total of 32 decontamination events were performed. The data in Table 3 indicate that a total of 4689.2 L (1238.9 gal) of water were added to Tank W-3 and then retrieved to Tank W-4.

A small off-the-shelf unit was also used on a limited basis for localized decontamination through the glove ports. The maximum flow rate for this equipment is 4.16 Lpm (1.1 gpm). No log was kept on the addition of water to the waste stream via this unit.

The flushing system provided the ability to dislodge a blocked line during phases of operations and to clean the process line at the end of each sluicing operation. This system proved invaluable and was used as necessary to dislodge material from a clogging event. The flow volume delivered to the flush line is ~75 Lpm (20 gpm) at a pressure of~1.2 kPa (60 psi). The system is arranged to provide either back or forward flush. The operation to clean the process line at the end of each sluicing operation was easily performed, and minimal water was added to the tank waste stream while providing a complete flush.

In summary, the WD&C and BOP systems performed well. A few failures and maintenance events occurred during this operation, but only the two rupture disk failures significantly affected operations.

The mining strategy for sluicing will probably be on a tank-by-tank basis as new discoveries about each waste form are made after tank entry. A general guide has been developed from the Tank W-3 effort and can be used as a first effort to be changed as necessary.

Operations may be improved after a thorough review process with the GAAT team members. For example, an effort can be made to minimize water addition to the waste stream by evaluating each phase of sluicing, the decontamination effort to be performed, and other means for dislodgment of a clogged line. Another example is from the process effort. When a process line blockage occurred during sluicing of sludge, the operator first attempted to clear the blockage by dead-heading the jet pump before performing any backflushing. This worked most of the time and added water to the tank only at a rate of 39.7 Lpm (10.5 gpm) versus the flush system rate of ~75 Lpm (~20 gpm).

4 SUMMARY

A total of about 7200 gal of supernatant and 5500 gal of sludge were removed from Tank W-3. Figure 1 illustrates the cleaning efficiency for retrieval operations in Tank W-3. Most of the time spent during operations was in setup, system checkout, maintenance, repairs, and other associated tasks. The actual operating time during waste removal was very short. The time required to transfer the supernatant was ~7.4 hours for an average rate of 973 gal hour, equivalent to 0.14 Ci/hour. The 5200 gal of bulk sludge (does not include 300 gal in the last inch of material) were removed in ~19 hours of operation for an average rate of 274 gal/hour, equivalent to 16.2 Ci/hour. The equivalent of about 88 gal of scale was removed from the tank walls, containing an estimated 5.2 Ci. The ~41,800 gal of total water added to the waste stream included 17,000 gal for the CSEE, 20,910 gal for the jet pump, 2650 gal during flush operations, and 1240 gal for decontamination. The amount of flush and decontamination water is small compared with the total. However, scarifying operations generated about one-third of the total water used, and sluicing operations generated about two-thirds of the total water used. During Tank W-4 operations, some improvements are expected. In particular, the total number of deployments of the HMA and MLDUA required for sluicing and scarifying campaigns will be reduced by the use of longer shift schedules.

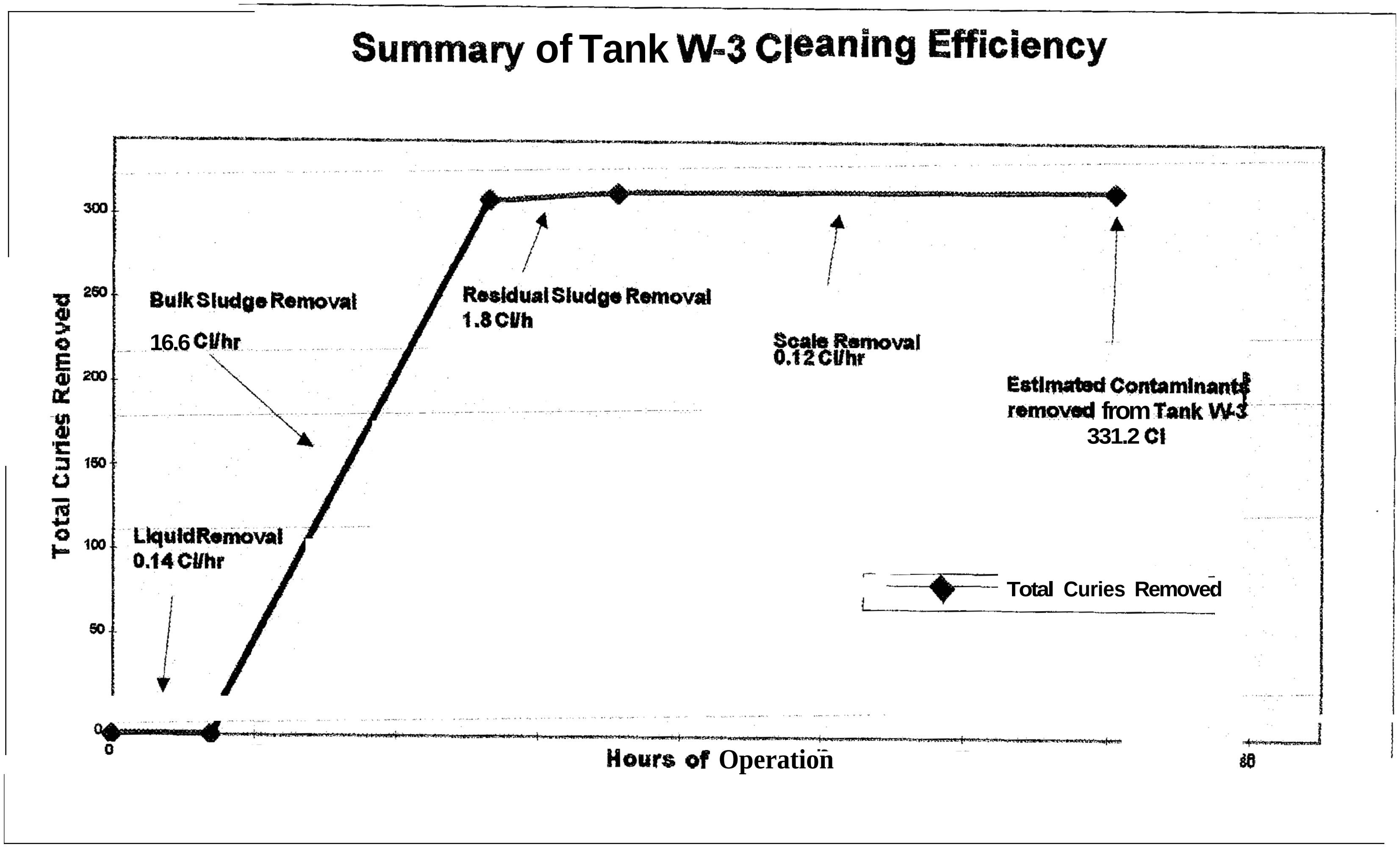

Fig. 1. Summary of tank W-3 cleaning efficiency.

5 ACKNOWLEDGMENTS

The authors acknowledge the diligent efforts of the team members from the Gunite™ and Associated Tanks Treatability Study Project and the many collaborators who have shared responsibility for system development. We appreciate the opportunity to give visibility in print to the fruits of your labors.

6 REFERENCE

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7 ABBREVIATIONS

BOP	balance of plant
CB	confinement box
CEE	characterization end effector
CSEE	confined sluicing end effector
DOE	Department of Energy
EM	Environmental Management
FCE	flow control equipment
GAAT	Gunite and Associated Tanks
GEE	gripper end effector
HMA	hose management arm
MLDUA	modified light-duty utility arm
MVST	Melton Valley Storage Tanks
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology
PW	process water
ST	storage tube
TRIC	tank riser interface and containment
VPM	vertical positioning mast
WD&C	waste dislodging and conveyance

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