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Field Performance of the Waste Retrieval End Effectors in the Oak Ridge Gunite Tanks

O. D. Mullen

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Summary

Waterjet-based tank waste retrieval end effectors have been developed by Retrieval Process Development and Enhancements through several generations of test articles targeted at deployment in Hanford underground storage tanks with a large robotic arm. The basic technology has demonstrated effectiveness for retrieval of simulants bounding a wide range of waste properties and compatibility with foreseen deployment systems. The Oak Ridge National Laboratory (ORNL) selected the waterjet scarifying end effector, the jet pump conveyance system, and the Modified Light Duty Utility Arm and Houdini Remotely Operated Vehicle deployment and manipulator systems for evaluation in the Gunite and Associated Tanks Treatability Study (GAAT-TS). The Retrieval Process Development and Enhancements (RPD&E) team was tasked with developing a version of the retrieval end effector tailored to the Oak Ridge tanks, waste, and deployment platforms.

The conceptual design was done by the University of Missouri-Rolla in FY 1995-96. The university researchers conducted separate effects tests of the component concepts, scaled the basic design features, and constructed a full-scale test article incorporating their findings in early FY 1996. The test article was extensively evaluated in the Hanford Hydraulic Testbed and the design features were further refined. Detail design of the prototype item was started at Waterjet Technology, Inc. before the development testing was finished, and two of the three main subassemblies were substantially complete before final design of the waterjet manifold was determined from the Hanford hydraulic testbed (HTB) testing. The manifold on the first prototype was optimized for sludge retrieval; assembled with that manifold, the end effector is termed the Sludge Retrieval End Effector (SREE). A different manifold was designed for high-pressure scarification of the gunite surfaces; assembled with that manifold, the end effector is termed the Gunite Scarifying End Effector (GSEE). The manifolds are interchangeable, as are the other modular subassemblies and most of the parts.

Two finished prototypes, one in each configuration, were delivered to Oak Ridge. They have undergone extensive operational testing in the Oak Ridge National Laboratory Tanks Technology Cold Test Facility and performed well. The SREE has been deployed in the North Tank Farm Tank W-3, and has successfully retrieved nearly the entire contents of the tank (sludge, supernate, and dried sludge crusted on the walls). At the time of this report, ORNL was core sampling the tank surfaces to inform a decision whether or not to remove some of the tank liner with the GSEE prior to scavenging the remaining dregs of waste.

Acknowledgments

RPD&E team scientists and engineers from the Pacific Northwest National Laboratory (PNNL), Waterjet Technology Incorporated (WTI), and University of Missouri at Rolla (UM-R) contributed to the development, design, and testing of the retrieval end effectors. ORNL GAAT-TS, the end user, ably represented by John Randolph, provided additional assistance during the process. Individuals deserving of particular mention include Drs. David Summers and Gregor Galecki (UM-R) for conceptual design; Dan Alberts, Joe Allen, and Robert Niblock (WTI) for engineering and production of the prototypes; Brian Hatchell and Leonard Shotwell (PNNL) and Jeff Pintler (SGN Urisys Services Corporation) for HTB testing; Jon Smalley (PNNL) for vibration analysis; and Mike Rinker (PNNL) for absolutely dogged program management.

Terms and Acronyms

BOP	Balance of plant—the other systems in the tank farm related to or interfacing with the system(s) discussed
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMS	cable management system—that portion of the WD&C deployment system which handles and manipulates the conduit, hoses, cables, etc.
CSEE	confined sluicing end effector—the name for the test-article stage of the development of the ORNL waste retrieval end effectors
DOE	Department of Energy
EE	end effector—a tool deployed by a robotic or teleoperated manipulator
F-M	force-moment sensor—a multi-axis load cell, placed in the load path of a structure or mechanism, to detect forces and moments transmitted through it
GAAT	gunite and associated tanks—refers to the underground waste storage tanks in the north and south tank farms at ORNL
GAAT TS	Gunite and Associated Tanks Treatability Study—a project started in FY 1994 to support a record of decision on remediation of waste at ORNL
GEE	gripper end effector—a special end effector which enables the MLDUA to engage with the WREE inside the tank. The GEE is within the LDUA workscope and is not part of the WD&C system.
GSEE	gunite scarifying end effector—the version of the ORNL waste retrieval end effector specialized for removing contaminated gunite from the tank surfaces
HMS	hose management system—an articulated pipe and hose arm deployed from a vertical mast inserted into a tank riser. The arm is the conveyance system inlet line—a jet pump at the bottom of the mast pumps the waste to the flow control box at the surface. Water, power, and control conduits to the end effectors are routed down the mast and out the arm.
HPS	high pressure half-scale scarifier

HTB	Hanford hydraulic testbed—a cold testing facility for waterjet equipment. It includes a gantry manipulator, a medium-pressure pump, simulant preparation facilities, and a data acquisition and control system.
ITH	in-tank hardware—the tank being processed may contain various items of scrap metal, tools, or other articles that were tossed into it as radioactive "scrap." All such scrap and structures are considered to be ITH.
MAWP	maximum allowable working pressure
MLDUA	modified light duty utility arm—a light duty utility arm in production with special modifications to comply with ORNL applications (e.g., increased load capacity, etc.)
ORNL	Oak Ridge National Laboratory—the Federal Government facility at Oak Ridge, Tennessee, where the WD&C system will be deployed
SREE	sludge retrieval end effector—the version of the ORNL waste retrieval end effectors specialized for retrieval of sludge waste forms
ROV	remotely operated vehicle
TIP	tool interface plate—the TIP is a two-part component of the MLDUA used to allow the GEE to be manually attached to the end of the MLDUA arm in a standardized manner. The arm TIP half remains attached to the MLDUA arm. The end effector TIP half remains attached to the GEE. The TIP is not part of the WD&C.
TMADS	tether management and deployment system—the apparatus mounted on the tank platform atop a riser to deploy the Houdini ROV
TRIC	tank riser interface and confinement system—a service and confinement enclosure mounted on the platform atop a riser. The MLDUA is installed above the TRIC and is deployed into the riser through it.
TT-CTF	Tanks Technology Cold Test Facility—the ORNL tank mock-up
UM-R	University of Missouri-Rolla
UST-ID	Underground Storage Tanks - Integrated Demonstration—a DOE EM-50 program for development of tank waste retrieval technologies
Waste	In this document the term "waste" refers only to those chemical compounds stored in the tank, which were the result of past processing of various chemical and nuclear materials, and does not include various ITH found within the tank.

WD&C	waste dislodging and conveyance—the overall system of equipment (excluding the MLDUA or crawler and the GEE) used directly to dislodge and convey waste from inside the underground storage tanks to the interface with the BOP
WREE	waste retrieval end effector—that portion of the WD&C system used to dislodge waste from the tank and transfer it to the Waste Conveyance System
WTI	Waterjet Technology, Inc.—the subcontractor to PNNL which designed and manufactured the waste retrieval end effectors

Contents

Figures

1.0 Introduction

1.1 Scope of Report

This report is follow-up to "Engineering Development of Waste Retrieval End Effectors for the Oak Ridge Gunite Tanks," (Mullen 1997). The subject of this report is confined to the Waste Retrieval End Effectors and their relation to other GAAT-TS retrieval system elements and to the waste and tank characteristics. Manipulation of the WREEs; procedures for and performance at the functions of dislodging sludge and tank surface scarifying; waste conveyance system issues; and durability, maintenance, and decontamination will be discussed. This report was prepared to meet a milestone date and represents the best summary of the field performance collected to date. The GAAT-TS will be performing more extensive review of the data.

Issues outside the scope of this report include performance of the manipulators and the conveyance and hose-management system except as germane to the discussion of the WREE. The Oak Ridge National Laboratory GAAT-TS will be reporting extensively on these and other subjects in due course.

2.0 Observations

2.1 Waste and Tank Characteristics

The waste found in Tank W-3 was much deeper than expected. Tank characterization work (Martin Marietta 1995) done in 1994 indicated that the sludge depth would be in the range of 0.27-0.37 ft (83-113 mm). The actual waste depth discovered after pumping off the supernate was an estimated 2 ft (610 mm). The sludge waste had a bulk specific gravity of approximately 1.4. The waste was stratified in irregular layers. Some layers appeared to be fairly solid or elastic, like damp chalk or gypsum, while others were more viscous.

Some of the sludge waste liquifies as soon as it is disturbed and flows readily, undermining overburden for 10 cm or so, while some remains quite "sticky" or "chunky" and floats around in "sludgebergs" which can, in cases, be sturdy enough to clog the conveyance inlet.

There was some black sediment, buried in or between some of the layers, which floated on the slurry surface once released. It turned out to be tri-butyl phosphate and some 10 distinct light hydrocarbons[a] in concentrations of 1500 ppm and 100 ppm, respectively, in a grab sample taken from a black deposit. Those concentrations were not representative of the tank waste in general. Figure 1 shows typical waste consistencies, including some stratified material at left, some sludgebergs, some well-slurried material, and some of the floating black organic material.

Some qualitative information can be obtained by reviewing the videotapes of the CSEE operation within ORNL Tank W-3.[b] For example, when the CSEE jets are used to blast away at the exposed sludge bank, large pieces of sludge tend to break away and slide into the slurry. This behavior implies that the sludge is not very strong at the depth at which the blocks break away from the rest of the sludge bank. In addition, it appears that the parts that remain as chunks tend to be those that are initially near the surface. The surface of the waste was probably allowed to dry out some time in the past (or just during the present waste retrieval campaign); and since it dried from the top down, the sludge near the top became a bit stronger than the that underneath.

The large pieces of sludge that break free from the sludge bank appear to have some elastic characteristics that are reminiscent of sludge simulants prepared from bentonite clay. This sort of behavior is common when sludge obtains its mechanical strength from the colloidal interactions between very small particles. An extended gel network is formed that responds elastically to small applied strains. This is in contrast to other types of sludge that obtain most of their strength from interpartice friction. These frictional sludges are often observed only at relatively high solids fractions. The ORNL Tank W-3 sludge does not appear to fall into this category judging both by its low measured density and elastic appearance.

(a) E-mail from Sara H. Harmon to Dirk Van Hoesen, August 7, 1997.
(b) Personal communication with Mike Powell, PNNL, September 26, 1997.

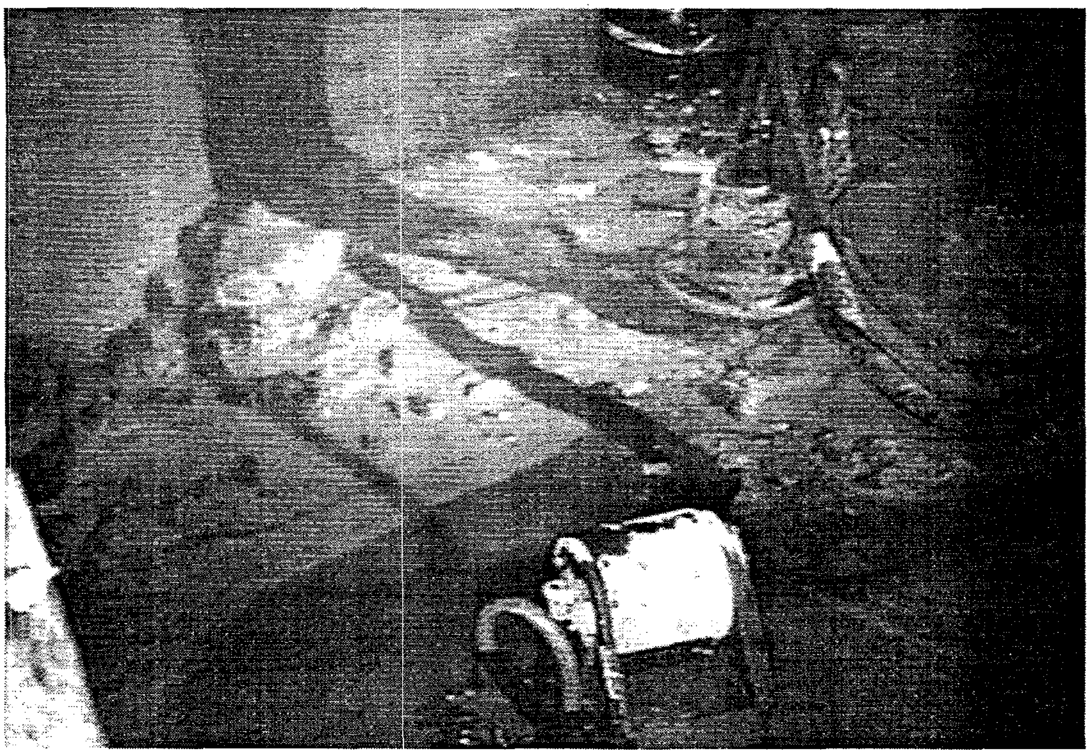

Figure 1. SREE Deployed on the MLDUA. Pumping slurry out of W-3. Note the stream of black organic material floating on the surface. The white object in foreground is the elbow joint of the Houdini arm.

Accurate estimates of the sludge strength properties cannot be made based on the videotape, but it is possible to develop a *rough* estimate by comparing the observed W-3 sludge behavior to that observed from sludge simulants. The large pieces of sludge appear similar in strength to a bentonite/water slurry in the 15 to 20 wt% solids range. The shear strength of such a mixture is between about 100 and 1500 Pa. It is worth noting that when the ORNL gunite tanks were last sluiced, a bentonite slurry was used as the sluice fluid to help maintain the waste solids in suspension. It is possible that much of the apparent elastic behavior of the W-3 sludge is due to the presence of residual bentonite.

The waste slurry pumped into tank W-4 seemed to remain in suspension. Data from bottle samples taken at various depths has not yet been reported. No clarified layer developed at the top of the slurry between shifts of retrieval work. The black organic material tends to coalesce into small globs rather than remain dispersed on the surface.

2.2 Manipulation

The developmental testing had all been performed manipulating the end effectors with the HTB gantry, which, while ideal for planned-path steady motions, is anything but a dexterous tool for freehand teleoperation. The MLDUA is fairly dexterous in terms of range of motion and degrees of freedom, but not well-suited for freehand teleoperation due to highly abstracted controls. The Houdini arm utilizes a proportional controller with a hand-manipulated arm model serving as the input device, giving an operator very intuitive teleoperational control. This allows, in practice, for greater dexterity and faster operation but sacrifices a degree of precision and repeatability of motions.

The initial pit (see below—quotation from John Randolph) was excavated using the WREE on the MLDUA (Figure 2), since the sludge was too deep for the Houdini to operate effectively. Once sufficient

Figure 2. Mining in the Original Pit with the SREE on the MLDUA

working space had been cleared for the Houdini, it was deployed through the shallow remaining layer of soft sludge/slurry onto the tank floor where it could then operate without burying the umbilical termination (not well sealed) or the chassis-mounted camera.

Dynamic forces produced by end effector and conveyance system operation caused no difficulties for manipulators. The forces produced are moderate and the conveyance hose, cables, and high-pressure hose provide both some bracing and damping to the system. The Schilling arm on the Houdini ROV is stiff enough to handle considerable forces without significant deflection, but has no convenient reference frame for precise location of the end effector. Therefore, the only practical means of determining the position of the end effector relative to a surface is to actually touch the surface, detecting contact by either the noise made on contact or visual detection of the change in rotational velocity of the end effector manifold. The MLDUA is capable of very accurate positioning, but was out of service or being set up or used for other tasks for much of the time, so the bulk of the retrieval work was done with the ROV. Of course, the exact profile of the tank floor beneath the sludge was unknown, so maintaining a constant small standoff distance would be difficult even with the MLDUA. The main bearings in the WREE were designed for this kind of service, and effectively isolate the contact forces from the rest of the machinery.

2.3 Dislodging of Sludge

The operational concept for the SREE was for it to be moved roughly parallel to the waste surface, with the inlet shroud and the conical jet pattern extending several inches into the waste, slurrying and removing a kerf or channel from the body of the waste. In development testing, the end effector was always moved in this manner and the parameters were adjusted to optimize performance. Low jet pressure (250 psi) and slow rotation (60-120 rpm) were found to work best in the simulations.

In W-3, the operators established a preference for holding the SREE well away (1-2 ft) from the surface and operating the SREE at 1,000-4,000 psi (7-28 Mpa) and 200 rpm to slurry the waste, then lowering the SREE into the slurry (with the jets and rotation still on) to pump it out with the conveyance jet pump (see Figure 3).

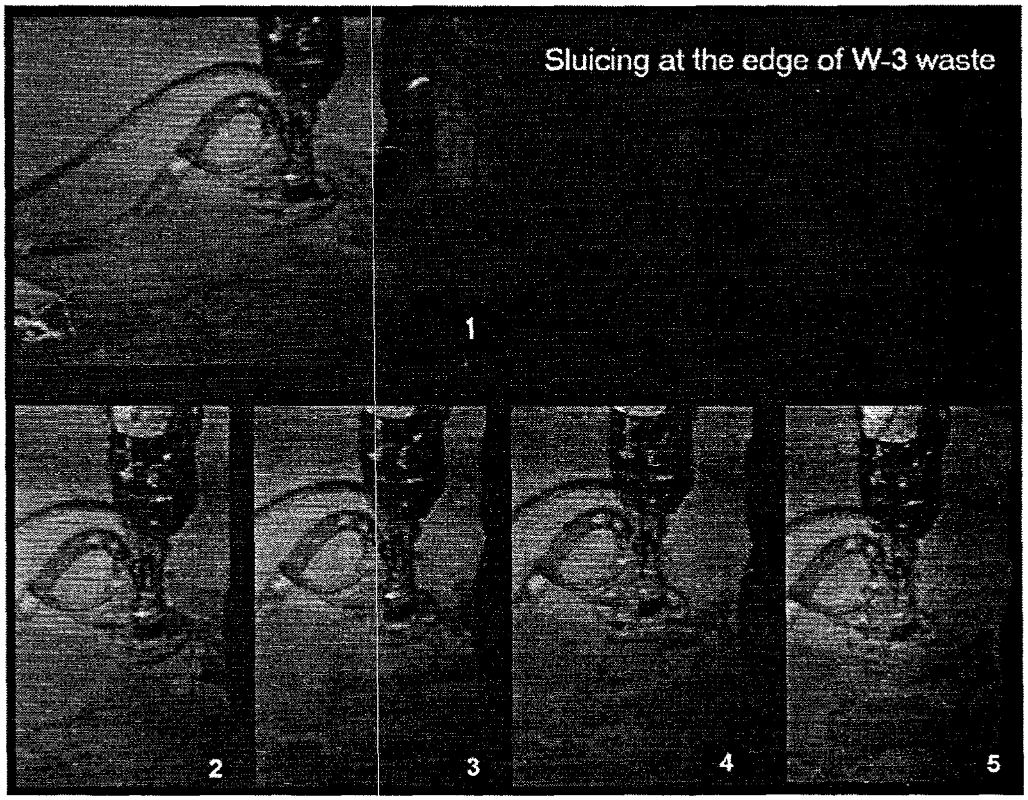

Figure 3. Sluicing Sequence. Shows the texture of the waste and response to 3000 psi jets.

As described by John Randolph[c] "Mining Strategy—Our best ideas flew out the door when we encountered a wet sludge, 2 ft high (versus 6-8 in. as reported). We could not mine as you might with a dry/drier material. We soon realized that the wet material is best mined by 'digging a hole' as close to the floor as possible and then clearing an area (6' x 6', basically) and then mining near the floor and close (to) the bank of sludge (2' or so stand-off). As mining is being performed, the sludge will generate 'mud slides' toward the CSEE. We then will slurry that material, as needed, and continue sluicing. At times the operator will generate a slide by aiming the cutting jets (low pressure) at the bank."

2.4 Scarifying and Wall Cleaning

2.4.1 Performance

The SREE was tested for scarifying the gunite tank walls in several areas at jet pressures of up to ~7000 psi (48 Mpa). Detailed inspection of the resulting surface is not possible with the vision systems available in W-3; however, the scarified surface was quite clean and it appears that some paste and aggregate was removed leaving the surface slightly roughened. Initial scanning of the scarified areas, using the gamma/beta detector on the Characterization End Effector, showed no reduction in activity. Core samples are being taken during the week of August 25, 1997, and will be sectioned and tested to determine the depth of radiological contamination. If warranted, the high-pressure GSEE will be deployed to remove gunite from the tank surfaces.

It was found that the dried sludge on the surface could be washed off by 1,000-3,000 psig (7-21 Mpa) jets from a standoff distance of 12-24 in. (30-60 cm) from the inlet shroud, at which range the jet power was diffused but the area swept was much wider than the nominal working area at the inlet shroud end due to the diverging jet pattern (Figure 4). Jet impact pressure is inversely proportional to standoff distance at standoff distances greater than the convergence range for the three jets, so the operator can increase power by simply moving the SREE closer to the convergence range without changing pressure (a relatively time-consuming procedure). Scarifying with the SREE was performed from a minimal standoff distance using the MLDUA to sweep the surface in a methodical "lawnmower" path of overlapping passes. From J. D. Randolph:[d]

"Traverse rate is 0.25 in/sec
Standoff distance is 1 to 2 inches (hard to tell)
Path width is approximately 4 inches
Path overlap is approximately 2 inches
As a first effort this looks good. We will improve on this as we gain better understanding of the operation."

(c) E-mail from J. D. Randolph to author August 21, 1997

(d) E-mail from J. D. Randolph to author September 4, 1997, 7:25 a.m.

Figure 4. Sluicing the Tank Knuckle Area

Some core samples have been taken from the W-3 tank walls to evaluate the extent to which radioisotopes have migrated into the gunite. From J. D. Randolph[a]

"Isotopic Migration.
We have some data in on core samples. Brief(ly):

Core Depth - 2 to 3 inches
Inner Liner Depth - 1 1/2 to 1 3/4 inches
Asphalt Sealant after Inner Liner
Tank Wall (~1/2 inch core depth) - No signs of isotopic migration, which would make sense to me because of the asphalt layer.
Isotopic Migration appears to be <0.2 inch at any point around the tank."

2.4.2 Visibility

Severe misting and occlusion of visibility occur while scarifying with the SREE, since the conveyance system doesn't move enough air to capture ejecta and spray from the jets scattered by the irregular concrete surface, and there is no shroud to confine the spray to the immediate area. The scarifier version (GSEE) is expected to produce even more spray, operating at higher pressure. It has no conveyance system connection; however, it would be a trivial change to replace the cover plate on the GSEE with the conveyance connector from the SREE and operate the GSEE with the conveyance system. This alone is unlikely to have much effect on the misting, and would require coordination of the manipulator, the Tether Handling System (with the high-pressure supply), and the WD&C arm. The volumetric flow rate through the conveyance system (limited by the conduit resistance and attainable pressure differential) divided by the effective inlet area of the GSEE simply doesn't produce sufficient velocity to capture anything but slow, small particles and droplets. Adding a rubber skirt and a shield to cover the holes in the top of the GSEE outer shroud may suffice to confine the spray, with or without the conveyance system, to the extent that adequate visibility for operator control will be preserved in the tank.

Due to the fact that waterjet energy dissipates rapidly with jet length, any aggressive high-pressure scarifying will probably have to be performed using robotic control to keep standoff distance to a minimum. This should be done after a careful surface mapping campaign to validate the planned paths. This will reduce the need for good visual surveillance as far as manipulation is concerned. Monitoring the depth of material removal from the tank structure in real time may require that the misting be reduced, however. Operating the conveyance system while scarifying will consume quite a lot of water, so the intent is to scarify first, then retrieve the sandy debris systematically from the tank floor using a simple inlet nozzle on the conveyance system.

2.5 Conveyance

Plugging of the inlet screen was the single greatest impediment to productivity. Strategies for reducing inlet plugging became important and influenced overall mining strategy.

A number of debris items were discovered in the waste, mostly buried in the sludge where they could not be detected until they blocked the inlet and reduced or stopped conveyance line flow. A video monitor displaying the discharge from the conveyance system in W-4 made detection of impeded flow pretty easy, and the mass flowmeter in the discharge line also was useful when pumping with minimal air in the flow. Tape remnants (duct tape and strapping tape), gloves, wire, pipe and tools (some on wire tethers), and gunite chunks were found. Tape and gloves tended to hang up on the inlet screen and block flow quickly. Backflushing was often effective for recovering from such incidents, but some of the strapping tape was decayed such that the fibers tended to wrap onto the screen and become very resistant to flushing off. Wire and duct tape could usually be seen while operating and could be picked off with the Houdini gripper (if available). One piece of wire is known to have passed the screen and transited the entire conveyance system, fortunately without wrapping onto the manifold. Two screen designs have been tested (Figures 5 and 6). The petal design was used in Tank W-3.

Some fraction of the waste sludge was sufficiently cohesive and sticky that lumps could get past the conical path of the rotating jet array intact and lodge on the screen. The lumps were solid and strong enough to resist disaggregation by the waste stream or, once the inlet was blocked, by the vacuum of the conveyance system (estimated at up to 10 psia [70 kPa]). In some cases, the SREE may have been fed into the sludge faster than the jets could slurry the lumps at the given manifold rotation speed, or the lumps were carried quickly through the jets by flowing slurry. Lumps submerged in the flowing slurry would be protected to some degree from the jets, as the jets attenuate rapidly in liquid. It was found that holding the SREE stationary with the screen retainer bolt just touching or slightly off the tank floor, the jets on and the manifold rotating while evacuating the slurry would prevent most lumps and debris from getting to the screen. The lumps would be blocked at the narrow gap between the inlet shroud edge and

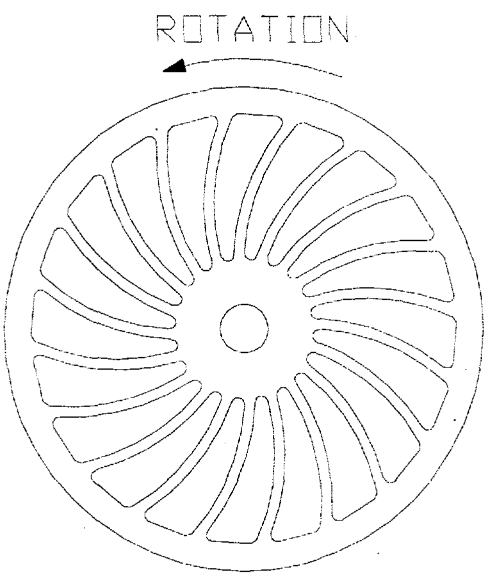

Figure 5. Petal Style Inlet Screen

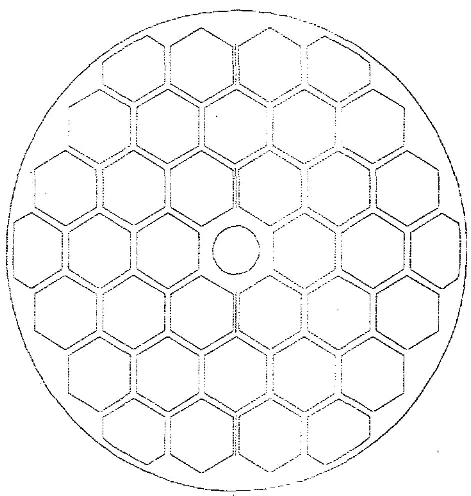

Figure 6. Hex Cell Style Inlet Screen

the floor and either broken down mechanically by the shear between the rotating inlet and the floor or by the jets. This technique improved productivity when there was a confined bed of fluid slurry to work with.

Holding the SREE stationary also reduces the amount of debris encountered and thereby reduces downtime and backflushing. When the slurry level is reduced sufficiently to expose debris on the tank floor, the SREE can be safely maneuvered to avoid known hazards, and debris can be removed using the Houdini gripper to clear areas for final slurry retrieval.

2.6 Maintenance and Decontamination

The only component that has required replacement due to wear during the cold testing and W-3 retrieval campaign is the high-pressure water swivel. The vendor estimated a service life for the swivel of about 80 hours, but had no statistical support for that estimate. The actual service life for the one swivel tested in the TTCTF and W-3 was about 200 hours, including some operation at low water pressure or essentially dry. The swivel is intended to operate wetted to provide cooling for the plastic internal face seal.

The swivel is rebuildable and easily replaced. Failure was progressive, evidenced by squealing noise and water leakage at the vent. ORNL will evaluate the costs and ALARA considerations to determine whether it is better to perform preventive replacements or rebuilds of the swivel or run it to failure, and whether it is worthwhile to rebuild the worn seals or simply replace the entire assembly.

The double-lip seal between the manifold and the bearing carrier wore in more than was expected during cold testing. It did not seem to be causing any problem with the operation or performance of the equipment during the W-3 retrieval. An improved design is being considered if examination of the part reveals that the expense is justifiable.

The snapring securing the inlet screen to the inlet shroud was found to be tricky to remove and replace, and consequently was left off. The screen is also held on by the central bolt.

Decontamination of the SREE was performed in the Hose Management Arm (HMA) riser Decontamination Spray Ring (DSR) and in the HMA confinement box on the bridge, using a hand-held spray gun to reach cavities sheltered from the DSR wash. No particular difficulties with decontamination of the SREE have been reported to date.

2.7 General Operation

The inlet screen was lost once when the SREE manifold was rotated in reverse, close to the tank floor, with the screen retainer ring removed. The screen retaining bolt was loosened by impacts with the floor and unscrewed. Both parts were recovered and replaced.

2.8 Performance

Based on preliminary figures from GAAT-TS, the overall dilution ratio for the W-3 retrieval campaign, determined by W-3 tank level measurements, was a little over 2 parts process water added per 1 part waste retrieved (including supernate). The figures available as of September 24, 1997 were:

Water consumed by the jet pump	14,063 gal (from flowmeter on the power pump)
Backflush water	1,766 gal (from process water flowmeter)
Decon spray ring & wand	761 gal (from flowmeter)
SREE jet water	5,658 gal (from flowmeter on the power pump)
Total water consumed	(a) 22,248 gal
Total discharge to W-4	(b) 91652 gal (from Coriolis flowmeter in discharge line)
Net waste transfer	69,404 gal
Waste removed from W-3	(c) 21,492 gal (based on W-3 tank level instrumentation readings)
Waste removed from W-3	11,014 gal (41,694 L) (based on mechanical probe measurement of W-3 level)

Waste and water discharged into W-4 36,056 gal (based on W-4 tank level readings)

Waste and water discharged into W-4 43,740 gal (sum of {a} + {c})

Obviously, there is considerable uncertainty at this point about the actual performance. The water consumption numbers are probably good +/- 100 gallons. The Coriolis flowmeter total is regarded as highly unreliable. At worst, the dilution ratio achieved for the campaign is about 2 parts water to 1 part waste.

The high efficiency of the bulk sludge retrieval, where the conveyance system was able to operate with flooded suction and two-phase flow, was offset by the low efficiency/high dilution realized when the inlet is not immersed and significant amounts of air are entrained. With the experience of W-3 to inform the operations in future campaigns, it is expected that better dilution ratios may be achieved.

3.0 Conclusions

3.1 Summary Assessment

The SREE proved to be a useful tool for retrieval of a limited variety of waste forms, and to be compatible with two significantly differing deployment platforms. As one of two retrieval end effectors developed to the current level (the high-pressure lightweight scarifier being the other), and the first such device to be deployed in actual waste, it represents an important first step from which a great deal may be learned. Some features could benefit from more development and testing—some were not developed much beyond the conceptual design. Further critique of the equipment is expected from GAAT-TS when field testing is completed and the results analyzed.

3.2 Lessons Learned

3.2.1 Design

The double-lip seal (Figure 7) between the solid ring on the manifold and the main chassis proved to be only adequate. The o-rings and part geometry intended to provide elastic preload and compliance to

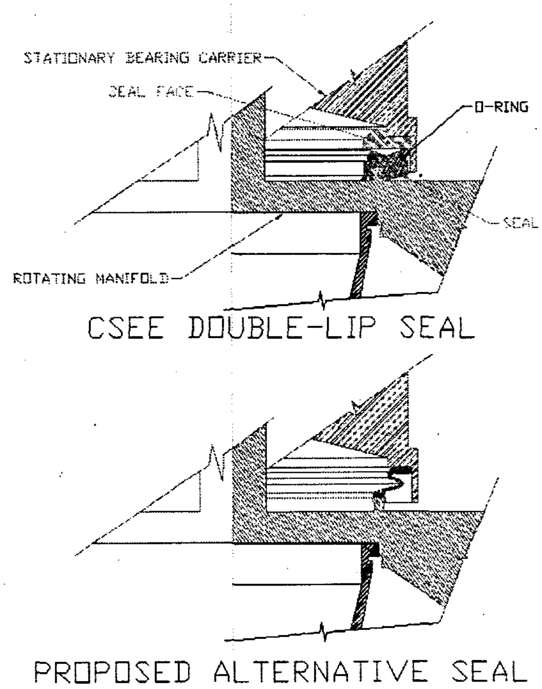

Figure 7. Replacement Seal Design

accommodate wear were too stiff, resulting in unnecessarily high frictional drag, and rapid initial wear. The o-rings were removed to alleviate the friction problem. The UHMW polyethylene seal material is not very elastic, so without the o-rings to provide preload, the seal lips take a set and maintain little pressure on the seal face. Once the initial wear-in was complete, the seal caused no further problems. It does trap some waste in the central cavity and in the crevices.

An alternative design is under consideration. It uses the manifold seal mounting boss as the wearing face and incorporates geometry designed to allow lots of compliance so it can maintain light sealing pressure on the contact surfaces even after the deep face has eroded. The plastic seal face is deep and thick to provide long wear life. The seal is one piece, machined from graphite-filled Meldin, which should tolerate the tank waste and radiation reasonably well. The new seal geometry is such that a strong vacuum inside the end effector will open the seal and allow leakage, which, if the seal area is open to the air, will help maintain the conveyance flow.

The conveyance inlet screen is easily plugged and sometimes difficult to clear. Backflushing with low-pressure process water may not be the most efficient method of clearing it since the expansion of the flow passage at the end effector makes it impossible to maintain much pressure or velocity against some of the troublesome areas. Each time the system is backflushed the water volume used is significant – on the order of 40 gal (151 L).

To be evaluated in the next design iteration is the idea of incorporating a high-pressure jet inside the main chassis, which would play directly on the inlet area. The cleaning jet might be a narrow fan to cover most of one side of the inlet/manifold interior, sweeping the entire interior as it rotates. The clearing nozzle could be fed independently from a pump at the surface operating at whatever pressure is found effective. This approach would require a second high-pressure line to the end effector.

3.2.2 Operational

The planned operating mode of incrementally milling away the waste was not deemed the most productive or practical by the operators. Given the manipulator dexterity required to work freehand, operators will prefer to do so, and in some cases that may be the most productive mode. Sluicing from a short distance allows the operators to control the intensity of the sluicing action and the size of the area and incurs no risk of conveyance line plugging or striking obstacles. It does result in a lot of scattered fluid and splattered waste; however, the free fluid level can be controlled by intermittent pumping.

Operation in the planned mode, using 250-500 psi (1.7-3.4 Mpa) cutting jets, 90-120 rpm rotation and 1-2 in/sec (25-50 mm/sec) traverse speed, was not extensively tested due to problems with the MLDUA. Most of the retrieval work was conducted using the Houdini ROV, which better supported the freehand technique using higher pressures and greater standoff.

Careful coordination of activities with more emphasis placed on conservation of water could materially reduce the dilution ratio achieved in the W-3 campaign. For example, the jet pump was usually left on while the SREE was in use, even when the operator was sluicing from some distance, in which case 10 gpm (38 L/min) was being consumed to little purpose. It may be that more active control of the cutting jet pressure—reducing it during the slurry-pumping phase of the retrieval—would reduce consumption without compromising effectiveness. The rotating jets are helpful in cutting up lumps which would otherwise tend to block the inlet screen, but jet pressure and flow beyond the minimum required to break up the lumps disrupts the conveyance (the momentum of the jets must be countered by the conveyance pump).

One procedure devised by the operators—inverting the SREE and holding it over the ROV while backflushing—proved to be an excellent way to conserve water. The operators could see the inlet screen clearly so excessive flushing wasn't necessary, and the spent flush water also rinsed off the body of the SREE and the ROV. Backflushing is not a very efficient means of cleaning the inlet screen, however. See Section 3.2.1 "Design" for discussion of alternatives.

3.2.3 Recommendations

If similar wastes are found in W-4 after pumping off the slurry from W-3, we recommend testing:

1. The "milling" approach to sludge removal, using low-pressure jets, low rotation and moderate traverse speeds, taking a cut 2-3 in. (25-75 mm) deep. This will require that the MLDUA be operational.

2. Use the GSEE or SREE at low pressure, say 1,000-3,000 psi (7-20 Mpa) to slurry the sludge, manipulating it with the ROV, while pumping the slurry off with a dedicated immersed suction inlet on the conveyance line manipulated with the MLDUA. The conveyance inlet should have a large screen area to allow longer periods of operation between cleanings. Use the WREE to flush the screen instead of backflushing if any blockage occurs due to waste lumps.

3. Add a "holster" to the Houdini ROV for temporary parking of the WREE when the ROV arm is needed for brief tasks. Add a stationary scraper and a wire brush on the ROV for clearing the screen. The WREE could be simply held with the rotating inlet against the cleaning fixture.

Because of the requirements of cross-site slurry transfer at ORNL, excessive dilution is not a real concern. The interest in dilution and water usage is prompted by other potential users of these technologies, i.e., Hanford, where there is more concern about standing water in the tanks during retrieval operations. To support the development of retrieval technologies for the entire DOE complex, and return better value for the development funding spent to date, we think it would be worthwhile to spend some effort at W-4 on optimizing the dilution.

4.0 References

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