

St. 37-70

FEB 9 1998

ENGINEERING DATA TRANSMITTAL

Page 1 of 1
1. EDT 622831

2. To: (Receiving Organization) Distribution	3. From: (Originating Organization) Retrieval Engineering	4. Related EDT No.: N/A
5. Proj./Prog./Dept./Div.: Waste Management	6. Design Authority/ Design Agent/Cog. Engr.: EJ Berglin	7. Purchase Order No.: N/A
8. Originator Remarks: This document is being processed for release.		9. Equip./Component No.: N/A
		10. System/Bldg./Facility: N/A
11. Receiver Remarks: 11A. Design Baseline Document? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No		12. Major Assm. Dwg. No.: N/A
		13. Permit/Permit Application No.: N/A
		14. Required Response Date: N/A

15. DATA TRANSMITTED								
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Approval Designator	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	HNF-SD-HTI-RPT-001		0	Hanford Tanks Initiative Fiscal Year 1997 Retrieval Technology Demonstrations	NA	2		

16. KEY

Approval Designator (F)	Reason for Transmittal (G)	Disposition (H) & (I)
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION
(See Approval Designator for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN
		Design Authority				1	1	B. K. Hatchell	<i>B. K. Hatchell</i>	K5-22	2/2/98
		Design Agent				1	1	J. A. Young	<i>J. A. Young</i>	K5-22	2/1/98
I	I	Cog. Eng. E. J. Berglin	<i>E. J. Berglin</i>	2/5/98							
I	I	Cog. Mgr. L. B. ...	<i>L. B. ...</i>	2/2/98							
		QA									
		Safety									
		Env.									

18. <i>ok telecon</i> E. J. Berglin <i>E. J. Berglin</i> Signature of EDT Originator Date 2/1/98	19. _____ Authorized Representative Date for Receiving Organization	20. <i>J. A. Young</i> J. A. Young <i>J. A. Young</i> Design Authority/Cognizant Manager Date 2/4/98	21. DOE APPROVAL (if required) Ctrl. No. <input type="checkbox"/> Approved <input type="checkbox"/> Approved w/comments <input type="checkbox"/> Disapproved w/comments
--	--	--	---

**Hanford Tanks Initiative
Fiscal Year 1997
Retrieval Technology Demonstrations**

E.J. Berglin
SGN Eurisys Services Corporation, Richland, WA 99352

B.K. Hatchell
J.A. Yount
Pacific Northwest National Laboratory, Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-96RL13200

EDT/ECN: EDT-622831 UC: 2030
Org Code: 73500 Charge Code: D25AA
B&R Code: EW3130010 Total Pages: 106

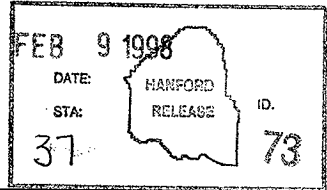
Key Words: HTI, Hanford Tanks Initiative, ACTR, Acquire Commercial Technology for Retrieval, FY 1997, IT, integrated testing, ARTD, Alternate Retrieval Technology Demonstrations, single-shell tanks, SST, underground, radioactive, hazardous, sluicing, sluicer, high pressure, medium pressure, water-jets; crawlers, wheels, self-propelled vehicles, manipulator, robotic arm, tank waste simulants, LATA, Los Alamos Technical Associates, ARD Environmental, Magnox Electric, ESG, Environmental Specialties Group, Delphinus Engineering, EagleTech, GreyPiggrim, dried sludge, soft sludge, handpan, saltcake, jet educator, air conveyance, displacement pump, cable, hydraulic, link, manipulator, umbilical management, waste conditioning, scavenging.

Abstract: This report summarizes the Hanford Tanks Initiative (HTI) retrieval testing/demonstrations completed in Fiscal Year 1997. The goal of this testing was to address issues to minimize the risk, uncertainties, and ultimately the cost of removing waste from Hanford underground storage tanks. Contracts with seven commercial vendors were placed to demonstrate a variety of retrieval technologies using waste simulants. The demonstrations were conducted into two series: the first series, three integrated tests (IT) which were followed by a more comprehensive second series, four Alternative Technology Retrieval Demonstrations (ARTD). The technologies tested were separated into three tracks based on how tools were deployed in a tank; these included an advanced sluicer, two different vehicles, and three unique arms each deploying a wide range of dislodging tools and conveyance systems. Seven individual vendor test reports resulted from these demonstrations and are summarized in this report. This report analyzes tank waste retrieval issues, describes what has been learned, and issues that need further resolution. The major issues discussed are tank access, deployment, mining strategy, waste retrieval, liquid/water scavenging and usage, maneuverability, positioning, static and dynamic performance, remote operations, reliability, availability, maintainability, tank safety, and cost. This work supports the next series of work for HTI, the C-106 Waste Retrieval Demonstration.

TRADEMARK DISCLAIMER. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

Printed in the United States of America. To obtain copies of this document, contact: Document Control Services, P.O. Box 950, Mailstop H6-08, Richland WA 99352, Phone (509) 372-2420; Fax (509) 376-4989.

Y.L. Berkland 2/5/98
Release Approval Date



Approved for Public Release

Hanford Tanks Initiative
Fiscal Year 1997
Retrieval Technology Demonstrations

HNF-SD-HTI-RPT-001
Revision 0

October 7, 1997

E.J. Berglin
B.K. Hatchell
J.A. Yount

This page intentionally left blank.

EXECUTIVE SUMMARY

The Hanford Tanks Initiative was established in 1996 to address a range of retrieval and closure issues associated with radioactive and hazardous waste stored in Hanford's single shell tanks (SSTs). One of HTI's retrieval goals is to "Successfully demonstrate technology(s) that provide expanded capabilities beyond past practice sluicing and are extensible to retrieve waste from other SSTs." Specifically, HTI is to address "Alternative technologies to past practice sluicing" ... that can ... "successfully remove the hard heel from a sluiced tank or to remove waste from a leaking SST" (HTI Mission Analysis).

During fiscal year 1997, the project contracted with seven commercial vendor teams to demonstrate retrieval technologies using waste simulants. These tests were conducted in two series: three integrated tests (IT) were completed in January 1997, and four more comprehensive Alternative Technology Retrieval Demonstrations (ARTD) were completed in July 1997. The goal of this testing was to address issues to minimize the risk, uncertainties, and ultimately the overall cost of removing waste from the SSTs.

Retrieval technologies can be separated into three "tracks" based on how the tools would be deployed in the tank: globally (e.g., sluicing) or using vehicles or robotic manipulators. Accordingly, the HTI tests included an advanced sluicer (Track 1: global systems), two different vehicles (Track 2: vehicle based systems), and three unique manipulators (Track 3: arm-based systems), each deploying a wide range of dislodging tools and conveyance systems. Each industry team produced a system description as envisioned for actual retrieval and a list of issues that could prevent using the described system; defined the tests to resolve the issues; performed the test; and reported the results, lessons learned, and state of issue resolution. These test reports are cited in this document, listed in the reference section, and summarized in the appendices.

This report analyzes the retrieval testing issues and describes what has been learned and issues that need further resolution. As such, it can serve as a guide to additional testing that must be performed before the systems are used in-tank. The major issues discussed are tank access, deployment, mining strategy, waste retrieval, liquid scavenging (liquid usage), maneuverability, positioning, static and dynamic performance, remote operations, reliability, availability, maintenance, tank safety, and cost. These demonstrations have helped commercial vendors understand some of the challenges associated with tank waste retrieval, given insight into some of the innovative ways the commercial sector can apply proven technologies to meet tank remediation needs at DOE sites and, as a result, have the potential to reduce both the risk and cost of radioactive tank waste remediation across the entire DOE complex.

Based on the results of this work, issues have been defined sufficiently to proceed with the final retrieval step of the HTI: the C-106 Waste Retrieval Demonstration, which will remove residual sludge and hardpan waste remaining in the heel of the tank after sluicing operations have been completed.

This page intentionally left blank.

CONTENTS

1.0 INTRODUCTION 1-1

 1.1 Single-Shell Tank Background and Description 1-1

 1.2 Hanford Tanks Initiative Project History and Activities 1-2

2.0 TEST AND ACTIVITIES SUMMARY 2-1

 2.1 Testing Strategy 2-1

 2.2 Integrated Testing 2-3

 2.2.1 Global System (Track 1) 2-3

 2.2.2 Vehicle-Based Local System (Track 2) 2-4

 2.2.3 Arm-Based Local System (Track 3) 2-4

 2.2.4 Testing Summary 2-4

 2.3 Alternative Retrieval Technology Demonstrations 2-5

 2.3.1 Global System (Track 1) 2-6

 2.3.2 Vehicle-Based Local Systems (Track 2) 2-6

 2.3.3 Arm-Based Local Systems (Track 3) 2-6

 2.3.4 Testing Summary 2-7

3.0 ISSUE RESOLUTION 3-1

 3.1 Tank Access 3-1

 3.2 Deployment 3-1

 3.3 Mining Strategy 3-2

 3.4 Waste Retrieval 3-3

 3.5 Water Scavenging 3-8

 3.6 Maneuverability 3-10

 3.7 Positioning 3-12

 3.8 Static and Dynamic Performance 3-16

 3.9 Remote Operation 3-17

 3.10 Reliability, Availability, Maintainability 3-18

 3.11 Decontamination 3-19

 3.12 Tank Safety 3-20

 3.13 Costs 3-21

4.0 OPEN ISSUES REMAINING 4-1

 4.1 Tank Access 4-1

 4.2 Deployment 4-1

 4.3 Mining Strategy 4-1

 4.4 Waste Retrieval 4-1

 4.5 Water Scavenging (water usage) 4-2

 4.6 Maneuverability 4-2

 4.7 Positioning 4-2

 4.8 Static and Dynamic Performance 4-2

4.9 Remote Operation 4-3
 4.10 Reliability, Availability, Maintainability and Decontamination 4-3
 4.11 Tank Safety 4-3
 4.12 Cost 4-3
 4.13 Summary 4-3

5.0 CONCLUSIONS AND RELATIONSHIP TO HTI FUTURE WORK 5-1

6.0 REFERENCES 6-1

APPENDICES

A LATA SLUICER RETRIEVAL SYSTEM (TRACK 1)
 - INTEGRATED TESTING A-1

B ARD VEHICLE-BASED RETRIEVAL SYSTEM (TRACK 2)
 - INTEGRATED TESTING B-1

C MAGNOX ARM-BASED RETRIEVAL SYSTEM (TRACK 3)
 - INTEGRATED TESTING C-1

D ARD VEHICLE-BASED RETRIEVAL SYSTEM (TRACK 2)
 - ALTERNATE TECHNOLOGY RETRIEVAL DEMONSTRATIONS D-1

E ESG VEHICLE-BASED RETRIEVAL SYSTEM - ALTERNATE TECHNOLOGY
 RETRIEVAL DEMONSTRATIONS E-1

F DELPHINUS ARM-BASED RETRIEVAL SYSTEM (TRACK 3)
 - ALTERNATE RETRIEVAL TECHNOLOGY DEMONSTRATIONS F-1

G GREYPILGRIM ARM-BASED RETRIEVAL SYSTEM G-1

H WASTE SIMULANT INFORMATION H-1

I INFORMATION SOURCES I-1

LIST OF FIGURES

Figure 1-1. Single-Shell Tank Typical Cross-Section with Hard Waste Heel. 1-2
 Figure 1-2. Hanford Tanks Initiative Activity Schedule. 1-3

LIST OF TABLES

Table 2-1. Summary of Integrated Testing. 2-4
 Table 2-2. Summary of Alternative Retrieval Technology Demonstrations. 2-7
 Table 3-1. Tank Access Summary by Track. 3-1
 Table 3-2. Deployment Summary by Track. 3-2
 Table 3-3. Mining Strategy Summary by Track. 3-3
 Table 3-4. Summary of Retrieval Rates and Test Parameters. 3-5
 Table 3-5. Retrieval Rates by Dislodging Device. 3-6
 Table 3-6. Retrieval Performance by Waste Simulant Type. 3-7
 Table 3-7. Water Scavenging Summary by Track. 3-9
 Table 3-8. Maneuverability Summary by Track. 3-11
 Table 3-9. Positioning Summary by Track. 3-12
 Table 3-10. Positioning Test Summary for Arm-Based Systems (Track 3). 3-13
 Table 3-11. Static and Dynamic Performance Summary by Track. 3-17
 Table 3-12. Remote Operation Summary by Track. 3-17
 Table 3-13. RAM and Decontamination Issues by Track. 3-18
 Table 3-14. Tank Safety Summary by Track. 3-20
 Table 4-1. Open Issues Remaining after HTI FY98 Testing and Issues to be
 Addressed by C-106 Retrieval Demonstration. 4-4

CONVERSION FACTORS		
TO CONVERT	MULTIPLY BY	TO OBTAIN
cubic feet	0.02832	cubic meters
feet	0.3048	meters
gallons	0.1137	cubic feet
gallons per minute	0.003785	cubic meters
inches	2.54	centimeters
pounds	0.4536	kilograms
pounds per cubic feet	0.001602	grams per cubic centimeter
pounds per inch	178.6	grams per centimeter
pounds per square inch	703.1	kilograms per square meter

TERMS

ACTR	Acquire Commercial Technology for Retrieval
ARD	ARD Environmental, Inc.
ARTD	Alternative Retrieval Technology Demonstrations
DCCV	Decontamination Containment Capture Vessel
DOE	U.S. Department of Energy
DST	double-shell tank
FY	fiscal year
gpm	gallons per minute
HTI	Hanford Tanks Initiative
kPa	kilopascals
LAASS	LATA/ARD Advanced Sluicing System
LATA	Los Alamos Technical Associates, Inc
L.L.C.	Limited Liability Company
LWS	Light Weight Scarifier
NIST	National Institute of Science and Technology
NLB	National Liquid Blasting
PNNL	Pacific Northwest National Laboratory
RFP	Request for Proposal
SAIC	Science Applications International Corp.
SST	single-shell tank
TFA	Tank Focus Area
TWRS	Tank Waste Remediation System
WTI	Waterjet Technologies, Incorporated

DEFINITIONS

access* - a way of getting inside a tank; usually through a riser.

arm - a mechanical device, similar in mechanical function to a human arm with multiple joints, that is used to deploy or position a tool or end effector from a single location. Control of these devices can range from manual to fully automated.

availability* - the quality or state of equipment being available to perform operations.

boot - an enclosing or protective casing or sheath, usually of flexible material like rubber, to minimize direct contamination of equipment. The boot is usually considered an expendable item and may be replaced during a retrieval campaign.

cable manipulator - a manipulator that is motivated by cable actuators; the GreyPilgrim EMMA arm is a cable manipulator.

composition - a number given to separate various Hanford waste simulants of the same type; see Appendix H for more details.

confined sluicer - a dislodging device that uses water, like a sluicer, but is encased in a shroud to confine the water spray and generally has water scavenging capabilities that are in, or attached to, the shroud to remove the water locally. The sluicer described herein is not technically a sluicer, but consists of multiple high-pressure water jets. Water could be replaced with other liquids such as supernatant liquid.

convey - the process of moving the waste out of a tank, generally with pumps, but also with mechanical devices.

congested tank - a waste tank that has many internal obstacles (such as vertical pipes, equipment such as pumps, etc.) that can impede access to waste in a tank.

cost* - refers to any costs associated with the complete retrieval system operation from start to finish.

crawler - (see vehicle). Sometimes can signify a specific type of vehicle that uses tracks for motivation.

debris - remains in waste tanks other than waste (examples include steel tapes, tools, old discarded equipment pieces, etc.)

decontamination* - the process of removing contamination; usually radioactive.

Delphinus - abbreviation for company Delphinus Engineering Inc.

deploy, deployment* - the process of placing equipment in or on a tank to facilitate tank waste retrieval. Tank waste deployment platforms include vehicles, crawlers, arms, and manipulators.

dislodge - the process of breaking up waste in a tank. Tank waste dislodging devices can include low-pressure water jets (such as sluicers), high-pressure water jets, and mechanical tools (such as shovels).

dried sludge - (see hardpan)

dynamic performance* - the performance of equipment when it is moving; vibration, for example.

EagleTech - a company.

eductor - a device similar to an ejector that mixes two fluids together. Eductors in this testing used a liquid jet to create a suction that allowed a three-phase flow of gas, liquids, and solids to be removed.

EMMA™ - name for GreyPilgrim cable manipulator.

end effector - a term classically used in robotics to describe the tool attached to the end of a robotic arm to increase functionality, such as a gripper or drill. Used in this report to signify the tools added to a deployment device, vehicle or arm, to increase functionality, such as a confined sluicer, a mechanical tool like an auger, a gripper, or a sampler.

ESG - abbreviation for company Environmental Specialties Group L.L.C.

fiscal year - DOE budget year starting October 1 of the previous calendar year and ending September 30.

flowrate - a rate of flow (i.e., gpm)

global - a waste retrieval process that functions generally from a single location (examples include sluicers and transfer pumps).

GreyPilgrim - abbreviation for company GreyPilgrim L.L.C.

Hanford - A DOE site located in Richland, Washington, that has underground storage tanks filled with radioactive and hazardous waste materials.

hardpan - A Hanford tank waste material that is like clay; sometimes referred to as dried sludge.

local, localized - a process that needs to be close to the waste to function effectively; generally the process is mobile (examples include confined sluicers, scarifiers).

Magnox - abbreviation for company Magnox Electric P.L.C.

maintainability* - to keep equipment in a workable state.

manipulator - (see arm).

maneuverability* - the ability of equipment to maneuver in a tank during waste retrieval processing.

mobilize - the process of moving the waste in a tank to facilitate its removal from the tank; keeping the waste mixed as a homogeneous material.

mining strategy* - the overall process sequence to remove waste from a tank.

P.L.C. - British acronym similar to the United States term L.L.C.

positioning* - the ability of equipment to move to a specific location within a tank during waste retrieval operations.

quantitative data - data for which a specific measurement of quantity or amount is given.

recipe - a name or number given to distinguish the various Hanford waste simulants, which all have different formulations; see Appendix H for more details.

recirculate - to move material (such as water) in a continuous process loop. A typical tank waste retrieval recirculation process is a sluicer, which can use the same liquid (such as water, supernatant liquid, waste slurry) from the tank over and over to dislodge waste material using a "water" jet.

reliability* - the quality or state of equipment operating in a dependable manner.

remediation - the act or process of correcting a problem; for tank waste remediation this would be the process of getting the waste into a safe condition.

remote operations* - the ability of equipment to be operated from a distant or remote location.

residuals - material that remains after removing the bulk of the material; for tank waste retrieval, this is the small amount of waste or water still in the tank that may be in crevices, low spots, or hard-to-reach places.

robotic - a mechanism guided by automatic controls.

safety* - the quality or state of equipment being safe to operate.

saltcake - a Hanford tank waste material that has a grainy consistency; it resembles a bonded clump of salt crystals.

saltwell pump - a Hanford waste tank pump used to remove water from the saltcake in a tank.

scarifier - a device that breaks up or loosens the surface of a waste field. Scarifiers used in this testing all used high-pressure water spray nozzles with pressures ranging from 400 to over 20,000 psi.

simulant - (see waste simulant)

sludge - a Hanford tank waste material that resembles a muddy or slushy deposit.

sluicer - a device that uses water or other liquid flow to wash waste material and dislodge it. At Hanford, the sluicer is typically a low-pressure (under 200 psi) water jet from a nozzle that resembles a fire hose. Earlier Hanford sluicers are now referred to as "past practice sluicers."

sluicing - the process of using a sluicer to dislodge waste material by washing. Earlier Hanford sluicing processes are now referred to as "past practice sluicing."

static performance* - the performance of equipment when it is not moving; deflection, for example.

supernatant - the clear liquid (mostly water) overlying material deposited by waste slurries settling in tanks.

supernate - (see supernatant)

teleoperated - (see tele-operation)

tele-operation - Remote operation of a device by a human using a combination of video feedback and controls.

telepresence - Sensing technology that provides a human operator with sufficient information about a remote device and its environment to enable the operator to feel physically present at the remote site.

Track - in this report, a method of deployment (see Section 2.1, last paragraph).

TracPump™ - ESG retrieval pump used in testing.

transfer pump - a Hanford waste tank pump used to transfer water or supernatant liquid by pumping.

umbilical - a tethering and/or supply line. Used on both arm and vehicle deployment systems to provide various functions (motivation power, control, deployment, dislodging supply water, and return waste conveyance lines) depending on configuration.

uncongested tank - a waste tank that has few or no internal obstacles that impede access to waste in a tank.

vehicle - a mechanical device used to deploy or position an end effector using local motivation (i.e., wheels, tracks, props, etc.).

waste - material deposited in Hanford underground storage tanks, generally left over from chemical processing, that is no longer useful. This material can be in various forms (liquid, sludge, or hard solid) and is generally hazardous and radioactive.

waste simulant - a material that simulates various Hanford tank waste properties but is non-hazardous. These materials were developed to reduce the cost of testing tank waste retrieval systems and are grouped by three waste types: sludge, hardpan, and saltcake.

waste retrieval* - the process of removing waste from a Hanford tank.

waterjet - water that flows through a nozzle or nozzles forming a jet or spray pattern.

water scavenging* - the process of removing water or liquids in a tank during waste retrieval processing.

wet sludge - A Hanford tank waste sludge (see sludge).

* More details as a specific issue for HTI can be found in Section 2.4, Issue Definition, of this report.

1.0 INTRODUCTION

The Hanford Tanks Initiative (HTI) project activities described in this report demonstrate a range of retrieval technologies and solutions for removing waste from the underground single-shell tanks (SST) at the Hanford Site. This report covers two testing/demonstration programs completed during fiscal year (FY) 1997 (October 1996 to September 1997):

Integrated Testing - A testing program started under the Acquire Commercial Technology for Retrieval (ACTR) project and later integrated with the retrieval portion of the HTI project. Initial waste retrieval issues were addressed in limited tests.

Alternative Retrieval Technology Demonstrations - This first phase of retrieval testing under the HTI project builds on the Integrated Testing work. These tests were more comprehensive and addressed a broader range of retrieval issues.

A brief background of the Hanford Site SSTs follows to explain the location of the tanks, the waste characteristics, and the basis for waste retrieval. "The Hanford Tanks Initiative Project History and Activities" provides background on the initiative and describes what has been accomplished, what is planned for the future, and how the HTI relates to the ACTR project.

1.1 Single-Shell Tank Background and Description

The SSTs were built on the Hanford Site in southeastern Washington State to store radioactively and chemically hazardous wastes generated during the production of defense-related materials at Hanford. Between 1943 and 1964, 133 SSTs, 75-ft in diameter, 30 to 54 ft tall, and with nominal capacities of 500,000, 750,000, and 1,000,000 gallons, were built to store radioactive wastes at Hanford. They are located in 12 tank farms of 4 to 18 tanks each in the 200 West and 200 East Areas of the Site. No wastes have been added to these tanks since November 1980; however, water is added to Tank 241-C-106 (commonly referred to as C-106) for evaporative cooling purposes. Some of these SSTs are suspected of having breaches that could allow radioactive material to leak into the surrounding ground; therefore, pumpable interstitial liquid and supernatant wastes are continually being removed and transferred to newer double-shell tanks (DSTs), which are more environmentally safe.

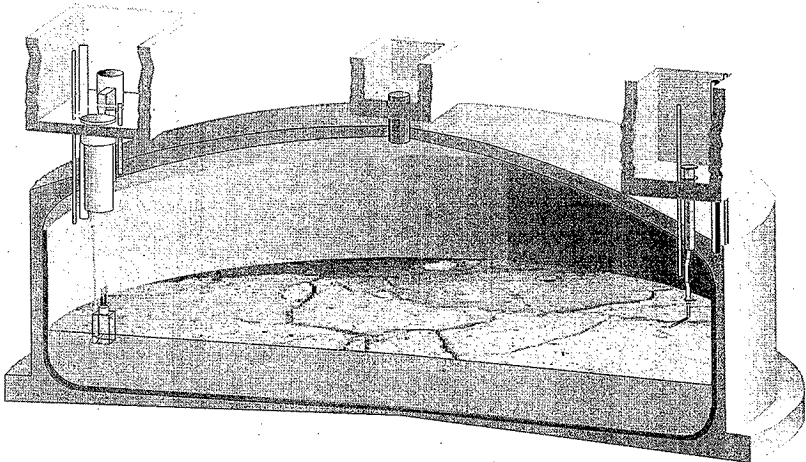
The DSTs were constructed between 1968 and 1986. They perform a function similar to the SSTs but have an additional liner (i.e., shell) to allow enhanced leak detection and prevent waste leakage into the ground. They can thus store waste with higher levels of radioactivity. The SSTs have been used beyond their intended design life, and the current activities at the tank farms involve tank waste remediation and closure. Day-to-day operation of the tank farms is managed by Tank Waste Remediation System (TWRS) within the Project Hanford Management Contract.

Six to eight feet of earth cover each tank at the centerline of the dome. A typical SST configuration is shown in Figure 1-1. While the design varied over the 30-year construction schedule, the SSTs are constructed of reinforced concrete with 6-inch concrete floors, 13- to 24-inch concrete walls, and 13- to 15-inch concrete domes. The tank floor and walls are lined with 1/4- to 3/8-inch plate steel; the concrete dome is unlined. Access to the tanks is provided by risers penetrating the domes of the tanks and extending above grade; they vary in size from 4 to 42 inches in diameter, with the 4 and 12-inches size being most common.

1.2 Hanford Tanks Initiative Project History and Activities

The HTI began in October 1996 as a four-year project to demonstrate the retrieval, characterization, and evaluation of the closure readiness of SSTs at the Hanford Site. The scope of the HTI project is to demonstrate alternative retrieval technologies; retrieve hard heel wastes from Tank C-106 and assess compliance with retrieval performance evaluation criteria; develop retrieval performance evaluation criteria supporting readiness to close SSTs; and characterize residual waste to assess compliance with retrieval performance criteria in Tank AX-104.

The alternative retrieval demonstration portion of the HTI, tested and demonstrated various commercial retrieval technologies to identify and evaluate technologies other than sluicing that could be used to retrieve waste from the SSTs. The demonstrations also support the final activity of retrieving the hard heel waste from C-106, an SST that contains high-level radioactive waste, starting in FY 1998.



2-1. Single-Shell Tank Typical Cross-Section with Hard Waste Heel.

The schedule in Figure 1-2 shows the history and future planning of HTI retrieval related activities; current testing as part of this report is marked in bold.

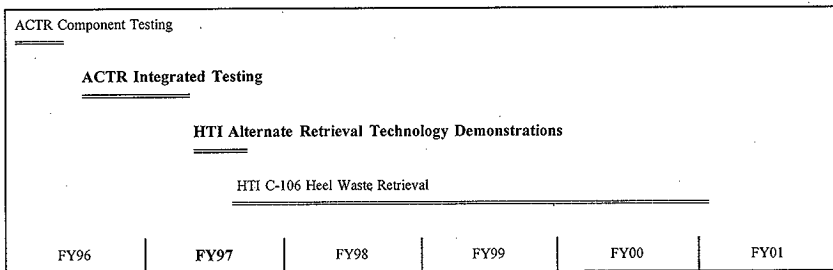


FIGURE 1-2. Hanford Tanks Initiative Retrieval Activity Schedule

This report summarizes the tests conducted on non-radioactive simulated wastes during FY97; It includes work performed under both the ACTR program and the HTI Alternative Retrieval Technology Demonstrations (ARTD) that followed.

A predecessor to the HTI, ACTR began in 1995 to seek and evaluate commercial technologies that could be used for radioactive waste retrieval, including the retrieval of stubborn wastes from leaking SSTs on the Hanford Site. ACTR Component Testing, completed in FY 1996 (Berglin et al. 1996), supported the initial investigation of commercial retrieval solutions. ACTR Integrated Testing (completed in January 1997 and reported in this document) was the first step in providing partial system demonstration retrieval methods of innovative industry solutions.

The remaining step for HTI is to perform the C-106 Waste Retrieval Demonstration to remove the heel of waste that remains in Tank C-106 after sluicing. HTI released a request for proposal on August 6, 1997, for a performance-based service contract. Proposals were received from industry on October 9, 1997, and vendor selection is scheduled to be completed by February 1998.

Section 2 provides the background and general information for the FY 1997 waste retrieval demonstrations. The groups used for discussing the current issue resolution can be found in Section 3. Discussed in Section 4 are some of the remaining open issues that will still need to be resolved when actual retrieval of a Hanford SST begins.

This page intentionally left blank.

2.0 TEST AND ACTIVITIES SUMMARY

This section provides the background and general information for the FY 1997 waste retrieval testing/demonstrations that were conducted to resolve issues related to waste retrieval from Hanford SSTs. Section 2.1 describes the strategy used to conduct the tests; Section 2.2 contains a brief history of ACTR Integrated Testing; and Section 2.3 discusses HTI Alternative Retrieval Technology Demonstrations (ARTDs).

2.1 Testing Strategy

During the past two years, 17 contracts have been placed in the private sector to address a broad range of issues associated with waste retrieval. In some cases, commercially available equipment was tested. When no commercial solution existed, engineering test articles were adapted from available commercial hardware to evaluate promising retrieval concepts. The contracts were progressively more complex, because industry needed to understand the problems associated with underground storage tanks and the U.S. Department of Energy (DOE) contractors needed to understand the capabilities that exist in the private sector. The strategy had three steps: component testing, integrated testing, and ARTD, which are described below.

1. *Component Testing:* This initial activity, completed in July 1996, evaluated separate retrieval components. Actual testing of various retrieval components used hydraulic and mechanical waste dislodging devices, as well as a crawler deployment device. Scale-up engineering evaluations of four manipulator-based deployment systems were completed by four commercial firms. Also included as part of this test work were two feasibility studies and a technology overview. The ACTR FY 96 Summary and Highlights report (Berglin et al. 1996) reviewed and summarized the ACTR component testing and references more detailed summaries of the individual tests.
2. *Integrated Testing:* This activity, completed in January 1997 and reported in this document, was the first step in providing partial system demonstration retrieval methods of innovative industry retrieval methods by integrating various system components.
3. *Alternative Retrieval Technology Demonstrations:* Completed in the summer of 1997 and reported in this document, this step featured larger scale demonstrations to begin addressing system-level issues associated with waste removal strategies, decontamination techniques, equipment reliability, safety, and cost.

For the last two steps, industry teams were asked to respond to the following:

1. Describe how their systems would be deployed for retrieval of radioactive waste from SSTs. These systems typically address deployment, dislodging, conveyance, decontamination, and remote operation.
2. Describe the issues that could preclude using the system and/or that require further analysis.
3. Define the tests that could resolve the issues and provide a test plan, including the testing method, key data requirements, and issues that would be addressed. Before the onset of testing, detailed test procedures were written based on this test plan and submitted for comment and approval.
4. Perform the tests. Vendor testing was witnessed by HTI test engineers to ensure the testing was executed according to plan, and to verify the inevitable changes required by hardware limitations and instrumentation failures. Eight waste simulants were used to qualify retrieval equipment performance with a full range of expected Hanford Site waste types (details in Appendix H): wet sludge, hardpan/dried sludge, hard saltcake, and soft saltcake. The consistent use of these simulants allowed cost-effective comparative testing of retrieval equipment.
5. Report the results. At the conclusion of testing, a test report was completed by each vendor describing the test performed, key performance data, and progress made in resolving issues. These documents have been made available through the HTI web site.

Responses to the first three items provided significant information about the industry's perspective on technical risks, but the information has not been released because much of it is proprietary. The non-proprietary test activities, items four and five, are summarized and analyzed in this report.

To focus the testing/demonstrations and to help understand the issues, the retrieval systems have been classified using three "tracks" sorted by the method of deployment.

Track 1: Global Systems. These are retrieval methods that use large volumes of water to dislodge and remove waste, e.g., sluicing, borehole mining, and commercial tank washing. In most cases, large quantities of water are used to mobilize the waste, so this approach may not be acceptable in a leaking tank.

Track 2: Local Systems, Vehicle-Based. Local systems comprise those tools that must traverse (or move across) the waste to dislodge and convey it from the tank. One means of deploying local systems is using vehicles or crawlers. These are widely used in nuclear and hazardous petrochemical tank cleaning campaigns.

Track 3: Local Systems, Arm-Based. A second means of deploying local systems is arms (or manipulators). Arm- or manipulator-based systems predominate in the nuclear industry in remote operations and maintenance operations. Arms are particularly useful in tank waste remediation because they do not come in contact with the waste and can be booted to provide a convenient decontamination barrier. However, there is no industry basis for using arms to clean large underground storage tanks.

2.2 Integrated Testing

In August 1996, Westinghouse Hanford Company released a request for proposal (RFP) titled "Single-Shell Tank Waste Retrieval: Integrated Testing in Support of the Acquire Commercial Technology for Retrieval (ACTR) Program, PMM-JRO-808." This RFP announcement was broadly distributed using the Internet; in addition, 61 companies were notified of the RFP directly. Twenty-eight firms responded as part of 15 integrated teams. Early in September 1996, contracts were awarded to three industrial teams, and the work was completed in January 1997.

- Los Alamos Technical Associates of Richland, Washington - Demonstrated a Track 1 global sluicer with an enhanced nozzle design over that of the Hanford past practice sluicer.
- ARD Environmental, Inc., of Laurel, Maryland - Demonstrated two Track 2 vehicles, one tracked and one wheeled, with a low-pressure confined sluicer.
- Magnox Electric PLC of Dartford Kent, England - Demonstrated a Track 3 hydraulic link manipulator.

Appendices A through C summarize these Integrated Tests. Detailed information can be obtained in the corresponding test reports or the testing summaries in the Appendices.

2.2.1 Global System (Track 1)

The goal of integrated global systems tests was to define, address, and resolve the key issues associated with traditional sluicing systems (such as borehole mining and past practice sluicing) at the Hanford Site, using commercially available equipment. These issues include removal of hard heels, capture of large particles, occluded vision, solids settling, and saltcake sluicing. Testing defined system performance by recording the overall retrieval production rate, retrieval rate as a function of time and remaining volume, quantity of fluid used to remove waste, and pressure data. Completion of this work addressed many of the primary technical risks associated with deployment of global waste retrieval systems. The detailed test report is provided in LATA (1997) and summarized in Appendix A.

2.2.2 Vehicle-Based Local System (Track 2)

Vehicle-based local system tests used both an existing vehicle proven in service and a second vehicle of a new design. Developed by ARD at their own expense, this second vehicle featured design aspects that could overcome the complex waste fields and precipitous terrain of the waste in some SSTs. A low-pressure confined sluicer designed by ARD was used, adding data to ACTR's low-pressure, water-based performance information. Tests addressed deployment and retrieval, mobility and sluicing, recovery from a "stuck" condition, and decontamination. Completion of this work resolved many of the primary issues associated with vehicle-based systems. The detailed test report is provided in ARD (1997a) and summarized in Appendix B.

2.2.3 Arm-Based Local System (Track 3)

Testing was conducted to determine the compatibility of an existing hydraulically actuated manipulator arm and prototype confined sluicing end effector. The manipulator tested was not long enough to access all areas of an SST; however, the basic design could be expanded to meet SST needs, and it represents a class of link manipulators. Using the existing system, data were obtained without the expense of fabricating a new system. The detailed test report is provided in Magnox (1997) and summarized in Appendix C.

2.2.4 Testing Summary

Table 2-1 presents a summary of the integrated testing.

Table 2-1. Summary of Integrated Testing.

Technology	LATA sluicer	ARD vehicle	Magnox arm
Criteria	Track 1	Track 2	Track 3
Rough scale relative to deployment in Hanford SST	Full	Full	1/3 - Assumes central riser deployment
System description	Advanced sluicer Two nozzle sizes - 1 & 1.25-in. diameter	Two vehicles - 1) Wheels - four wheels 2) Tracked - two tracks	18 ft multi-link, hydraulically actuated snakes manipulator arm
Size of deployment system in-tank	No data	57 x 36 x 24 in. high - wheels 59 x 28 x 30 in. high - tracked	18 ft long
Reach in-tank	NA, global system	Horizontally - 50 ft	Horizontally - 18 ft
Riser access size	Typically 12-in.diam.	38.5-in.-diameter - heels	9-in.-diameter
Conveyance system type	Suction pump	Centrifugal trash pump with end suction and automatic self priming	No test

Table 2-1. Summary of Integrated Testing.

Technology Criteria	LATA sluicer	ARD vehicle	Magnox arm
	Track 1	Track 2	Track 3
Lift tested on retrieval	Minimal	Minimal	Minimal
Maneuverability	NA, global system	Good	Very good
Water containment effectiveness (locally)	NA, global system	Minimal	Primarily collected reaction force data from ARD sluicer end-effector, but this device was an obvious mismatch for arm deployment because the end-effector weight of 400 lb exceeds the arm's 200 lb payload limit.
Jet pressure	1 in. - 77 to 97 gpm 1.25 in. - 110 gpm	400 psi	
Jet flow rate	1 in. - 350 gpm 1.24 in. - 500 gpm	100 gpm	
Weight of in-tank deployment system	No data	500 lb - Tracked Vehicle 750 lb - Wheeled Vehicle	
Payload capacity	NA, global system	400 lb plus	
Cutting path width	NA, global system	21 in.	
Unique aspects of demonstration	- Retrieval rates	- Wheeled vehicle - Low-pressure, 400-psi sluicer - Failure recovery	

2.3 Alternative Retrieval Technology Demonstrations

In November 1996, Lockheed Martin Hanford Company (LMHC) released a Request for Proposals entitled, "Single-Shell Tank Waste Retrieval, Alternative Retrieval Technology Demonstrations Statement of Work in Support of the Hanford Tanks Initiative (HTI), W-A15120-SH." Twenty-eight firms responded as part of 13 integrated teams. This work built on the ACTR Integrated Testing by resolving additional issues using larger-scale demonstrations in a nonradioactive/hazardous environment. In January 1997, four vendors were awarded contracts to demonstrate the ability of their technologies to remove simulated tank wastes from Hanford's tanks. The four companies completed testing of their equipment on simulated waste material in July 1997, providing data on various waste removal strategies, decontamination techniques, equipment reliability, safety, and cost.

- ARD Environmental, Inc. - Demonstrated a Track 2 wheeled vehicle and low-pressure confined sluicer. This was a second generation of the wheeled device tested during earlier integrated testing.

- Environmental Specialties Group LLC (ESG) - Demonstrated a Track 2 collapsible vehicle and a medium-pressure water jet-based retrieval system.
- Delphinus Engineering Inc. - Demonstrated a Track 3 heavy duty multi-articulating hydraulic arm and medium-pressure confined sluicer end effector.
- GreyPilgrim LLC - Demonstrated a Track 3 cable-driven manipulator and high-pressure water jet scarifier end effector.

The following section summarizes the ARTD. Detailed information can be obtained in the corresponding test reports or in the testing summaries in the Appendices.

2.3.1 Global System (Track 1)

Global systems were not tested as part of the ARTD because most of the issues have been resolved.

2.3.2 Vehicle-Based Local Systems (Track 2)

Vehicle-based retrieval systems can access a tank through one riser and perform waste retrieval at all locations within the tank. To evaluate this promising technology, vehicle systems were designed and fabricated to deploy dislodging end effectors in simulated tank environments. ARD Environmental, Inc., demonstrated a wheeled vehicle and low-pressure confined sluicer; this was a second-generation wheeled device of the one used during earlier integrated testing. ESG demonstrated a tracked, collapsible vehicle and a medium pressure, water jet-based retrieval system. Vehicle/crawler deployment, umbilical management, retrieval, mobility, and decontamination were the focus of both demonstrations. The results from the vehicle-based retrieval system tests are provided for ARD in their detailed test report (ARD 1997b) and summarized in Appendix D. For ESG, the results are provided in their detailed test report (ESG 1997) and summarized in Appendix E.

2.3.3 Arm-Based Local Systems (Track 3)

Arm-based retrieval systems use a long-reach manipulator to access all points in a tank through one riser. Because arms of sufficient length to access all parts of an SST are not commercially available, this technology was evaluated using existing system designs. Delphinus demonstrated a two-segment telescoping boom manipulator based on proven designs currently being used in other commercial applications. GreyPilgrim demonstrated a 33-foot cable-driven manipulator based on successful testing of a 15-foot version. Initial testing focused on validating that the manipulators had sufficient payload capacity and dexterity to retrieve waste. For the retrieval tests, both vendors chose to use water jet-based scarifiers to break up and retrieve the waste locally. The results from arm-based retrieval system tests are provided for Delphinus in Delphinus (1997) and summarized in Appendix F and for GreyPilgrim in GreyPilgrim (1997) and summarized in Appendix G.

2.3.4 Testing Summary

Table 2-2 summarizes the alternative retrieval technology demonstrations.

Table 2-2. Summary of Alternative Retrieval Technology Demonstrations.

Technology Criteria	ARD vehicle	ESG vehicle	Delphinus arm	GreyPilgrim arm
	Track 2	Track 2	Track 3	Track 3
Rough scale relative to deployment in Hanford SSTs	Full	Full	Full - May be oversized for center riser deployment	1/3 scale - for arm only, assumes central riser deployment
Deployment type	Four-wheel vehicle	Two-track crawler	Heavy-duty hydraulic manipulator	Cable tensioning manipulator
Size of deployment system in-tank	74 x 33 x 24 in. high	96 x 28 x 15 in. high	45 ft long plus vertical mast	33 ft long plus vertical mast
Reach in-tank	NA	NA	Vertical - over 45 ft Horizontal - 45 ft	Vertical - 33 ft Horizontal - 17 ft
Riser access size	36-in. diameter	24-in. diameter	41-in. diameter	24-in. diameter
Conveyance system type	2 jet eductor pumps, 2 positive displacement pumps needed	Hydraulic sludge pump	Air conveyance, positive displacement pump	Air conveyance
Lift tested on retrieval	40 ft	70 ft	40 ft	8 ft
Ability to negotiate many in-tank obstacles	Good	Good	Fair	Good
Water containment effectiveness (locally)	Minimal	Minimal	Fair	Fair
Jet pressure	400 psi	10,000 psi	20,000 psi	30,000 psi
Jet flow rate	100 gpm	48 gpm	22 gpm	2 gpm
Weight of in-tank deployment system	2,000 lb	1,000 lb	13,000 lb	1,000 lb
Payload capacity	NA	NA	Over 1000 lb	100 lb
Cutting path width	21 in.	15 in.	9 in.	6 in.

Table 2-2. Summary of Alternative Retrieval Technology Demonstrations.

Technology \ Criteria	ARD vehicle	ESG vehicle	Delphinus arm	GreyPilgrim arm
	Track 2	Track 2	Track 3	Track 3
Unique aspects of demonstration	<ul style="list-style-type: none"> - Wheeled vehicle - Tank and waste field mockup - Recirculation - Deployment - Decontamination - Recovery from vehicle failure - Remote operations 	<ul style="list-style-type: none"> - Collapsible track vehicle - Medium pressure water jets - Deployment - 70-ft lift - Mechanical dislodging tools - Decontamination - Maintenance - Umbilical management - Recovery from line clogging 	<ul style="list-style-type: none"> - Heavy duty manipulator - High-pressure water jets - Waste conditioning - Umbilical management - Computer control movement - Wall cleaning - Static/dynamic performance 	<ul style="list-style-type: none"> - Cable-driven manipulator - High-pressure water jets - Static/dynamic performance

2.4 Issue Definition

The strategy of all testing and demonstrations has been to resolve issues as they relate to waste retrieval from Hanford SSTs. A general definition of each issue follows:

1. Tank Access - Refers to the tank opening (or riser) where the retrieval system equipment enters (or accesses) an underground storage tank. Each tank has riser(s) located in various positions on top of the tank that vary in size from a few inches to 42 inches in diameter; a 12-inch diameter riser is generally available on all tanks. Risers penetrate the 4 to 6 feet of earth above the tank and terminate in shielded concrete pits below ground level.

2. Deployment - Refers to setting up the retrieval system on a tank, and operation of the retrieval system equipment in a tank. Deployment also includes removing the retrieval system from the tank for reuse, decommissioning, or maintenance. The deployment of the retrieval system during operation consists of inserting the equipment through the riser (tank access), and configuring equipment so that retrieval operations can proceed. Included are tasks such as hooking up remote equipment in the tank and umbilical management.

3. Mining Strategy - Refers to how the waste retrieval operations will be conducted to be most efficient or to meet special conditions or situations. Examples of mining strategy may include: a) creating and maintaining a low area in the waste field to allow secondary pumping to minimize standing liquid in the tank, b) following a computer-controlled path to efficiently remove waste and/or minimize personnel fatigue, or c) special operations to deal with conditions such as debris or large waste chunks that cannot be conveyed by the primary retrieval method.

4. Waste Retrieval - Refers to the rate at which waste is removed and how efficiently and completely waste is removed from a tank. Rates vary depending on the waste type being removed and its location and quantity. Near the end of a retrieval campaign, when very little waste remains in the tank, retrieval rates may be very low. Final tank cleanliness is not yet defined, but at least 99% of the waste should be removed.
5. Water Scavenging (water usage) - Refers to how well water or liquid slurries are removed (or scavenged) from the tank with retrieval systems that use water or liquid slurries to dislodge, mobilize, or convey waste from the tank. Standing water or liquid is not desirable in leaking tanks. Water usage is the amount or rate of water (or liquid) that a retrieval system uses in retrieval operations. Water usage may be different for various retrieval configurations.
6. Maneuverability - Refers to the ability of the retrieval system equipment to move around in the tank and to access areas where waste is located. This issue primarily applies to Track 2 vehicle-based and Track 3 arm-based retrieval systems with dislodging and conveying equipment that require proximity to the waste. Some examples of maneuverability are negotiating around tank hardware and varying waste terrains.
7. Positioning - Refers to the ability of the retrieval system equipment to be accurately positioned, and the ability to return to a position or follow a path. This function primarily applies to Track 3 arm-based retrieval systems.
8. Static and Dynamic Performance - Refers to the response of the retrieval equipment to static parameters such as the load of the dislodging tool and dynamic parameters, (for example, vibrations generated by the dislodging tool or kinematic motions.) This function primarily applies to Track 2 vehicle-based and Track 3 arm-based systems, and may influence position changes such as deflection or position repeatability.
9. Remote Operation - Refers to the ability of the retrieval system equipment to operate remotely in the darkness of the underground waste tank environment with fixed access points (riser) and hazardous and radioactive wastes that minimize human intervention. Examples include systems necessary to observe waste retrieval operations and remote sensing.
10. Reliability, Availability, and Maintainability/Decontamination - Refers to the ability of the retrieval system equipment to minimize failures (reliability), be ready to perform retrieval operations when needed (availability), and able to recover from a failure (maintainability). Decontamination of equipment has been included in this grouping because of its close association with the maintenance function when human intervention is required. Decontamination may also be required to make the retrieval system equipment available for operations in other tanks, or for decommissioning and disposal.

11. Tank Safety - Refers to the ability of the retrieval system to keep the tank in a safe condition. Some examples of current tank safety issues include flammable gas environments from hydrogen generation in the waste, which could cause an explosion from spark generation; maintaining tank dome load limits to prevent collapse; and maintaining tank shell integrity to inhibit waste leakage into the groundwater.
12. Cost - Refers to any costs associated with the complete retrieval system operation from start to finish (i.e., life-cycle costs). Examples of some of the costs associated with retrieval include system design, equipment procurement, system qualification, operation, and disposal costs.

This page intentionally left blank.

3.0 ISSUE RESOLUTION

The retrieval tests/demonstrations finished in FY 1997 by the HTI project resolved additional issues associated with tank waste retrieval. The primary source of issue resolution data came from the ARTD, complementing the earlier ACTR Integrated Testing. This section describes the testing results as they relate to each of the issues discussed in Section 2.4, compares the results, and summarizes the current state of the issue.

3.1 Tank Access

The ability to access tanks through the smaller riser openings would allow more flexible deployment options because, in general, a large number of tanks have 12-inch risers. Larger access requirements may necessitate installing new risers, which are costly. All tracks have at least one option that allows access through a 24-inch or smaller riser. Table 3-1 shows tank access issues that have been at least partially addressed.

Table 3-1. Tank Access Summary by Track.

Track 1, Sluicer	Design should allow access through a 12-inch-diameter riser. Similar sluicer designs have accessed Hanford tanks successfully through 12-inch-diameter risers.
Track 2, Vehicle	Demonstrated access through 24 to 36-inch-diameter riser. ESG's collapsible vehicle may be able to access risers smaller than 24 inches with some redesign. Both vendors routinely access chemical tanks through similar risers with this type of equipment.
Track 3, Arm	Sized for access through 24- to 41-inch riser. Required riser access size is reduced for shorter reach and smaller payload requirements. GreyPilgrim's and Magnox's arms may be able to access risers smaller than 24 inches with some redesign.

In summary, the smallest riser access size demonstrated for a full-scale retrieval system is 24-inch diameter for Track 2 vehicles and 41-inch diameter for Track 3 arms. Both Track 2 vehicles and Track 3 arms may be able to be designed to fit 12-inch-diameter risers.

3.2 Deployment

Deployment into an SST is feasible for all tracks. Table 3-2 shows that several deployment issues have been addressed. Track 1 sluicers are the simplest to deploy relative to the other tracks and do not warrant further discussion. Track 2 vehicles have more auxiliary equipment requirements but generally require less structure above the tank than Track 3 arm systems. Track 3 arms generally have the most auxiliary equipment and require the largest structure above the tank.

Table 3-2. Deployment Summary by Track.

Track 1, Sluicer	Deployment with similar sluicer designs has been successful in Hanford Site tanks.
Track 2, Vehicle	Deployment in a tank mockup was demonstrated by all vendors successfully. Umbilical length restricts the vehicle's reach. All vendors demonstrated umbilical lengths that would allow the furthest point in an SST to be reached through any riser location on top of the tank.
Track 3, Arm	Deployment into a tank has been simulated by computer modeling by all vendors. Arm length and access location restrict the vehicle's reach. Maximum horizontal reach demonstrated was 17 ft for the 33-ft GreyPilgrim arm and 45 ft for the Delphinus arm. Both systems use a movable vertical mast to move the main arm assembly in the vertical plane. Demonstration testing of the Delphinus arm to extend its horizontal reach to 75 ft may occur in the future. Based on this test work, GreyPilgrim's arm should be able to extend its horizontal reach beyond 17 ft.

Umbilical management is similar for Track 2 vehicles and Track 3 arms during deployment into the tank. Once inside the tank, arms generally have easier umbilical management because of the attachment to the mechanical structure of the arm, but this does increase the load on the arm. A single consolidated umbilical bundle may be desirable over multiple hose/connector wrapped system.

The Track 2 vehicles and Track 3 arms require the dislodging device to be placed within several inches of the waste to be effective; the Track 1 sluicer has a standoff distance of 10 to 30 feet or more. Track 2 vehicles are limited to whatever surface will support their weight. Track 3 arms may be able to perform wall cleaning above the waste field more easily than Track 2 vehicles.

In summary, the most difficult reach from a Hanford Site tank edge riser, approximately 75 feet horizontally and 55 feet vertically, has been demonstrated to be viable for the Track 2 vehicles. The longest reach demonstrated by a Track 3 arm was 46 feet horizontally, but the full 75 feet may be possible, even through a 12-inch-diameter riser. And the Track 2 vehicle has shown that it can negotiate a wide variety of surface terrains and types.

3.3 Mining Strategy

Mining strategy depends on the deployment device and the dislodging tool used. Water jets were the primary dislodging tool used in all these tests. Testing to date has helped develop mining strategies, but none have been fully demonstrated to completely clean the tank's interior surfaces. Mining strategies using a conveyance mechanism close to the dislodging tool were not successful at retrieving all the waste and water instantaneously because some leakage occurred even under the best scenarios. More operator feedback about visibility and position sensing is required to operate the local systems. Table 3-3 shows that the mining strategy issues have been partially addressed.

Table 3-3. Mining Strategy Summary by Track.

Track 1, Sluicer	Water jet is directed at waste to create a slurry, which is removed by a separate pumping system. Problems were encountered with: 1) retrieval of large, loose waste chunks and 2) keeping waste dislodging location clear of water and waste slurry (especially when pockets or holes were created). The sluicer is best suited for uncluttered, non-leaking tanks with softer waste. Highly congested tanks would tend to block areas to the sluicing jet, which may limit retrieval.
Track 2, Vehicle	General mining strategy is to dislodge the waste field at the higher locations so the water and waste slurry will drain toward the lower locations where it can be conveyed. Minor problems were encountered with precisely positioning the dislodging tool while traversing rough surfaces and getting caught adjacent to in-tank hardware or in waste caverns. The most maneuverable vehicles are suited for both uncluttered and congested tanks, limited access risers, the full range of waste types, and tanks requiring very localized cleaning. Cleaning of vertical surfaces, such as walls above the waste surface, is limited.
Track 3, Arm	Mining strategy can vary considerably according to how maneuverable the system is in both the horizontal and vertical planes. The most often discussed strategy was to program a mining path sequence for the dislodging device that would allow a very uniform reduction in the waste field. The most flexible arms are suited to both open and congested tanks, the full range of waste types, and tanks requiring very localized cleaning including vertical surfaces such as walls. The reach of the arms can be limited by the riser locations available on the tank and by arm control; closed loop control and operator telepresence need further development.

The higher-pressure, water jet dislodging tools used on the Track 2 vehicles and Track 3 arms were sensitive to the standoff distance between the nozzle and the waste for efficient retrieval. Therefore they require more critical positioning than the Track 1 sluicer. Larger standoff distances and lack of a confining shroud around the nozzle discharge tend to increase misting. This decreases operational visibility and may burden off-gas ventilation systems on the tank. The advanced sluicer design tested may be more effective than past-practice sluicing in some situations at the Hanford Site, but an instrument failure during testing did not allow direct comparative studies to be completed.

In summary, Track 2 vehicles must deal with variable dislodging head positioning, umbilical management, accessing small areas, and maintaining mobility (especially in small areas and cavities). Track 3 arms have the largest movement envelope of all the tracks. The mining strategy needs to address problems encountered with positioning control and navigation of the Track 3 arms. Remote handling will play a large role in the mining strategy for all systems.

3.4 Waste Retrieval

Waste retrieval rates are important because they will determine the length and cost of a tank cleanout. These rates varied considerably during testing. As expected, soft materials were more easily retrieved than hard materials. Table 3-4 shows that many waste retrieval issues have been addressed and provides a summary of retrieval rates and related parameters for a variety of waste types and retrieval tools. Retrieval rates were calculated by measuring the

volume of waste removed over a specific time period and generally includes the time required to pump water and waste, but not setup time or down time. Waste retrieval, as reported here, includes the primary functions of dislodging the waste, mobilizing it, and conveying it out of the tank. Some caution should be taken in using the values in Table 3-4 because the testing conditions and parameters varied among the different vendors and tracks. None of the systems were fully optimized or completely configured to actual in-tank conditions.

The following general conclusions can be drawn from Table 3-4:

- The ability to retrieve waste is highly dependent on the dislodging tool used, especially for the higher strength waste forms. Once a waste slurry is developed, all systems demonstrated that waste can be effectively conveyed.
- The tools that use higher pressure water are more effective at dislodging the higher-strength materials and use significantly less water per volume of waste retrieved on all waste types; these tools require a Track 2 vehicle or Track 3 arm for deployment.
- For the global sluicer, the smaller nozzle was more effective at dislodging waste, however, the larger nozzle did not obtain full pressure because of testing pump limitations.
- The global sluicer is quite effective in saltcake compared with the other localized retrieval systems; but is ineffective in the strongest hardpan, which is expected to be found at the bottom of many SSTs. Once a waste slurry is developed, all systems demonstrated that waste could be effectively conveyed.

Table 3-5 describes retrieval performance by dislodging device. Table 3-6 describes retrieval performance by simulant type.

Table 3-4. Summary of Retrieval Rates and Test Parameters.

Vendor	Track ^(a)	Simulant Recipe #	Simulant (comp #)	Simulant Strength ^(b) (psi)	Dislodging Device	Nozzle Diameter (in.)	Nozzle Flow Rate (gpm)	Nozzle Pressure (psi)	Waste Volume Removed (ft ³)	Retrieval Production Rate (ft ³ /h)	Volume of Water Used/ Volume of Waste Retrieved ^(c)
ESG	2	1	Wet Sludge	0.51 s	Water Jet Tool	Unknown ^(d)	69.9	10,000	63.0	312.1	0.3
Delphinus	3	1	Wet Sludge	0.51 s	Confined Sluicer	Unknown	22.0	20,000	29.0	435.0	0.4
LATA ^(e)	1	2	Hardpan #1	04.6 s	Global Sluicer	1.25	443.4	92	59.9	49.2	72.2
LATA ^(e)	1	3	Hardpan #2	21.8 s	Global Sluicer	1.00	312.0	110	6.0	1.5	1,668.7
LATA ^(e)	1	3	Hardpan #2	21.8 s	Global Sluicer	1.25	443.0	91	1.0	0.3	14,333.4
ARD ^(e)	2	3	Hardpan #2	21.8 s	Confined Sluicer	0.14	100.0	400	20.6	32.4	13.0
ESG	2	3	Hardpan #2	21.8 s	Water Jet Tool	Unknown	82.0	10,000	41.0	339.9	0.3
Delphinus	3	3	Hardpan #2	21.8 s	Confined Sluicer	Unknown	22.0	20,000	37.9	182.4	1.0
LATA ^(e)	1	4	Saltcake #1	3,000 c	Global Sluicer	1.00	314.0	112	29.0	32.8	76.7
LATA ^(e)	1	4	Saltcake #1	3,000 c	Global Sluicer	1.25	440.0	90	93.8	17.6	200.8
ESG	2	4	Saltcake #1	3,000 c	Water Jet Tool	Unknown	14.0	10,000	7.5	19.8	21.7
ESG	2	4	Saltcake #1	3,000 c	Mechanical Tool	NA ^(f)	NA	NA	Unknown	8.9	NA
Delphinus	3	4	Saltcake #1	3,000 c	Confined Sluicer	Unknown	22.0	20,000	24.0	23.6	7.3
GreyPiggrim	3	5	Saltcake #2	1,500 c	Confined Sluicer	Unknown	2.0	30,000	12.0	10.8	1.3
LATA ^(e)	1	6	Saltcake #3	1,500 c	Global Sluicer	1.00	314.0	112	30.0	51.4	49.0
ARD ^(e)	2	6	Saltcake #3	1,500 c	Confined Sluicer	0.14	100.0	400	38.9	5.2	79.0
LATA ^(e)	1	7	Saltcake #4	8 c	Global Sluicer	1.25	452.0	95	100.0	461.5	7.9
ARD ^(e)	2	7	Saltcake #4	8 c	Confined Sluicer	0.14	100.0	400	52.4	31.2	12.0

(a) Track 1 = global system, Track 2 = local system - vehicle deployed, Track 3 = local system - arm deployed

(b) Simulant strength: s = shear, c = compression (Powell 1996).

(c) Volume of water used is the amount of water pumped through a nozzle and does not include systems that recirculate water.

(d) Unknown = information not available

(e) LATA and ARD systems used recirculated water from the waste retrieval process (i.e., closed loop systems).

(f) NA = Not applicable.

Table 3-5. Retrieval Performance by Dislodging Device.

Water-Based Systems	
Track 1, Global Sluicer (~ 100 psi) LATA	The low pressure sluicer appears to be an effective tool for dislodging wet sludge and saltcake. It was generally ineffective against the hardest hardpan (Hardpan #2) waste simulant, but had some success against the softer hardpan (Hardpan #1) waste simulant.
Track 2, Vehicle Confined Sluicer (400 psi) ARD	The low-pressure confined sluicer does not exhibit superior performance against any waste simulant compared with the other dislodging devices, but generally used less water than the global sluicer. This tool can retrieve all waste simulant types, but generally at rates an order of magnitude less than the best system for the particular waste type.
Track 2, Vehicle Water Jet Tool (10,000 psi) ESG	The medium-pressure, water jet tool exhibited superior performance against the high-strength, hardpan waste simulants compared with the other dislodging devices. This tool has shown excellent performance with all other waste simulants.
Track 3, Arm Confined Sluicer (20,000 psi) Delphinus	The high-pressure confined sluicer was effective against all waste simulants and similar in retrieval performance to the tool demonstrated by ESG.
Track 3, Arm Confined Sluicer (30,000 psi) GreyPilgrim	The high-pressure confined sluicer testing was limited in these demonstrations. Past testing of this device at Pacific Northwest National Laboratory indicates it is effective against all waste simulants, but it is especially designed for removal of hard materials like the hardpan waste simulants.
Mechanical Systems - (no dislodging water required)	
Track 2, Vehicle Mechanical Tools ESG	The mechanical tools tested were generally ineffective in wet sludge and hardpan waste simulants. This is because the material buildup on the tools caused them to lose effectiveness. Some success in saltcake simulant was achieved but at a rate one-half that of the water jet tool. Although no water is used in dislodging with these devices, it may be required to convey the waste.

Table 3-6. Retrieval Performance by Waste Simulant Type.

Simulant (Composition #)	Results Summarized from Testing
	Wet Sludge
Wet Sludge	Easily retrieved by all water-based systems at rates greater than 300 ft ³ /h.
	Hardpan/Dried Sludge
Hardpan #1	Retrievable by all water-based systems with high-pressure dislodging tools was more effective. Higher-pressure dislodging devices (10,000 psi and greater) are estimated to have retrieval rates over 175 ft ³ /h based on hardpan #2 data. Low-pressure devices (100 psi) retrieval rates were near 50 ft ³ /h.
Hardpan #2	Higher-pressure dislodging devices (10,000 psi and greater) are obviously superior with retrieval rates over 175 ft ³ /h. The Track 1 global sluicer was ineffective at removing this waste.
	Hard Saltcakes
Saltcake #1	Retrieved by all water-based systems at rates near 25 ft ³ /h, with less water usage by the higher-pressure dislodging devices (10,000 psi and greater). Retrieval by the mechanical tool device was about half that of the water-based systems, and used no water during the dislodging process.
Saltcake #2	Retrievable by all water-based systems was greater than 10 ft ³ /h, with less water usage by the higher-pressure dislodging devices (10,000 psi and greater). This finding is based on performance with saltcake #1.
Saltcake #3	Retrievable by most water-based systems at rates estimated to be greater than 20 ft ³ /h, with less water usage by the higher-pressure dislodging devices (10,000 psi and greater). Global sluicer was able to retrieve waste at a rate of over 50 ft ³ /h.
	Soft Saltcakes
Saltcake #4	Retrieval by all systems but probably most effective by the low-pressure sluicer (around 100 psi) at rates estimated exceeding 450 ft ³ /h.
Saltcake #5	No testing was conducted with saltcake #5. Should be retrieved by all systems but most effectively by the low-pressure sluicer (around 100 psi) at rates exceeding 450 ft ³ /h, based on performance data for saltcake #4.

Other important retrieval issues that were tested are as follows.

- Conveyance lift height on retrieval - This is an important part of the process, because the waste must be removed from the tank to complete the retrieval process. Waste conveyance systems that lack sufficient lift capacity to move waste out of a tank will need a secondary system. The height of an SST from the bottom of the tank to ground level is approximately 50 feet. The highest waste simulant lift demonstrated by the retrieval systems was 70 feet by ESG; ARD and Delphinus demonstrated a lift to 40 feet, and GreyPilgrim demonstrated a lift to 8 feet. The lift demonstrations by these vendors were not necessarily the maximum capability of their conveyance systems.

- Waste conditioning - An important part of the retrieval process is ensuring that waste can be moved from the tank to the final waste staging area without plugging transfer lines and minimizing the need for further processing before treatment. Delphinus demonstrated their Conveying and Transport System (CATS). They measured the percentage of solids for the three waste types and various water blasting pressures. The CATS system can vary the solids ratio content as needed, but this was not demonstrated. The solids ratio reported for the Delphinus system, without any post processing, ranged from 10% for saltcake (very fine grains of waste dispersed in the water); just over 30% for wet sludge (small clumps of waste dispersed in the water); and nearly 40% for hardpan/dried sludge (thick viscous liquid with waste completely dispersed in the water that does not separate out over time). The percentage of solids is also governed by blasting pressure. For wet sludge and hardpan/dried sludge, the percentage of solids increased from a blasting pressure of 5,000 pounds per square inch to 20,000 pounds per square inch. However, for an intermediate blasting pressure of 15,000 pounds per square inch, the solids ratio was less in dried sludge and more in wet sludge. The cause is unknown but may be some inherent property of the materials.
- Wall Cleaning - It may be important to remove some residual waste adhering to vertical surfaces. The Delphinus system demonstrated wall cleaning on a curved surface above the waste. It was able to remove the waste as well as the paint on the simulated tank wall. Water blasting pressures from 10,000 to 20,000 pounds per square inch were used for the wall cleaning demonstration. However, significant over-spray and water leakage was observed outside of the containment shroud during the process.
- Cutting Path Width - This parameter probably has minimal effect on bulk retrieval rates but may affect cutting path speed and access to tight locations. Many of the systems are not fully developed and could be improved considerably.

In summary, demonstrations have proven that different retrieval concepts can successfully retrieve a wide range of waste materials (and debris); and that complete tank cleaning with removal of residual liquids appears to be feasible.

3.5 Water Scavenging (water usage)

Water or liquid scavenging during retrieval is important for tanks that leak or have a potential for leaking. Scavenging minimizes the driving force that could move hazardous and radioactive materials from the tank into the earth and groundwater below the tank. Water usage is also an important factor. There are currently storage capacity restrictions that limit the total volume of "new process" water that can be added during a retrieval process. Some low-pressure systems, such as the Track 1 global sluicers or the ARD low-pressure sluicer, do not require clean water (or "new process" water). It can use the liquid waste slurry in the tank or, in the case of the C-106 retrieval system, the transport slurry from the receiver tank. For these systems, it is possible that actual "new process" water usage could be zero. Table 3-7 shows that the water scavenging (water usage) issues have been partially addressed.

Table 3-7. Water Scavenging Summary by Track.

Track 1, Sluicer	No local water scavenging. Depends on separate pump for removing water. Requirements for "new process" water can be zero by using recirculated liquid waste slurry or supernate.
Track 2, Vehicle	Local water scavenging for vehicles and arms is similar and mainly depends on the type of end-effector used. Confined sluicing with a shroud and local scavenging was effective at scavenging some of the water and containing some of the over-spray. Higher-pressure devices that use less water appear to scavenge water better locally on the systems tested. Water that escapes from the local scavenging device end effector needs to be scavenged from low spots, either by a separate sump pump or by temporarily repositioning the local scavenging device to the accumulated liquid.
Track 3, Arm	Water usage requirements of "new process" water of the high-pressure systems is typically lower on the high-pressure systems than on the low-pressure systems; however, recirculation and decanting/filtering can reduce water usage significantly, possibly to zero in some cases.

For water or liquid slurry scavenging, no retrieval process captured all the liquid locally. The higher-pressure systems (> 10,000 psi), that had lower liquid usage rates, scavenged the water better than the lower-pressure systems. The global sluicer design, LATA's, for example, does not attempt to scavenge any water locally, but depends on a remote pump located near the bottom of the waste field or a pump already in the tank (i.e., tank transfer pump/salt-well pump) to remove the water. Three of the systems demonstrated a confining shroud around the water jet device, which confined the process, to some extent, and scavenged some of the water locally. Scavenging by these localized devices could be improved by turning the dislodging water off and plunging the end effector into low areas of the waste field. This operation was more effective in the softer waste simulants because the hard materials such as saltcake could physically inhibit the shroud from accessing deeper holes. These demonstrations indicate that it may never be possible to capture all the water because of voids or fractures in the waste, where water will leak away from a local scavenging device. Therefore, it seems necessary for all systems to locate a remote scavenging pump as low as possible in the tank or waste field to remove the water not captured by the local device. Important factors for all water scavenging pumps include minimal head requirements, that is, zero head (the ability to suck water dry under the pumping device), and the ability to self-prime.

Water usage depends on the dislodging system used. In general, the trade-off is between nozzle pressure and Flow Rate; low-pressure systems generally have higher flow rates than high-pressure systems. The volume of water used per volume of waste retrieved ratio for the various retrieval tests is summarized in Table 3-4. This parameter is based on the total liquid slurry or water volume that flows through the dislodging device and could potentially leak out of an unsound tank. This ratio does not, however, take into account recirculation of supernate or waste slurry that is designed into some retrieval systems, such as the global sluicer or the ARD dislodging tool (i.e., low-pressure confined sluicer). The global sluicer can use supernate, or the waste slurry directly from the retrieval tank, or transport slurry, if available, and requires little or no processing before pumping through the nozzle. The ARD retrieval system specifically limited the pressure of their dislodging tool to 400 psi to allow

direct pumping of supernate or scavenged waste liquid slurry/water by simple decanting without the expense and complication of a filter system. This is generally required in higher-pressure retrieval systems. The total "new process" water used in a recirculation system is much less than that calculated in Table 3-4 and in many cases may be zero.

For the Delphinus testing, the volumetric ratio parameter in Table 3-4 may be high because it was assumed that the water nozzle was on during the entire retrieval process. In reality, the water was not on all the time during retrieval, but there is no test data to show how long the nozzle was turned off; therefore, the worst case was assumed. A second method of using the solids ratio of waste slurry samples taken during test was attempted, but found to be inadequate due to particle settling in the Delphinus waste CATS skewing the results to unrealistic extremes. The primary assumptions required for this second method to be successful are that a single sample is typical of overall average retrieval solids ratio, and there is minimal water trapped in the waste; this obviously was not the case because these volumetric ratio values far exceeded the upper limit value reported in Table 3-4.

In summary, because of the variety of conditions that can be encountered in waste retrieval operations in a tank, three-phase conveyance of gases, liquids, and solids is typically required. Air conveyance and jet eductor systems appear to be effective methods of dealing with three-phase conveyance, but these devices are not optimum for all conditions. Air conveyance systems cannot retrieve large amounts of standing water quickly without slugging because of the inability of vacuum systems to support a large water column. This may lead to temporary loss of performance if too much water is introduced into the suction line. Positive displacement pumps easily pump large amounts of water but may not be effective in retrieving a thin layer of water. In summary, no scavenging devices appear optimum for all retrieval conditions and therefore the retrieval system approach most likely will be customized for each tank.

3.6 Maneuverability

Maneuverability within the tank is important, especially for localized systems such as the Track 2 vehicles and Track 3 arms, which require the dislodging tool to be in contact with the waste field (Table 3-8). The Track 1 global system, like the sluicer, does not require much maneuverability except the ability to point the nozzle at various parts of the waste field. The Track 1 system can benefit from a mast system that can extend the nozzle closer to the waste and point the nozzle in various directions, including at the walls. However, Track 1 systems are generally more restricted in congested tanks containing objects that may prevent the sluicer from reaching some waste locations, and the lack of force to remove high-strength waste because of large standoff distances. The use of Track 1 systems has historically been limited to tanks that do not leak. Table 3-8 shows that maneuverability issues have been partially addressed.

Table 3-8. Maneuverability Summary by Track.

Track 1, Sluicer	Minimal maneuverability required. May not be able to access localized areas, especially those shielded by in-tank obstructions.
Track 2, Vehicle	Highly maneuverability in the plane of the waste field. Umbilical management required and may be difficult in congested tanks. Tight areas may trap vehicles.
Track 3, Arm	Maneuverability is dependent on number of joints and each joint's movement range. The arms tested may not be able to access as much waste surface area as the vehicle system, but they can access areas vertically above the waste field for such operations as tank wall and dome cleaning. The cable manipulator was more maneuverable than the heavy duty hydraulic manipulator tested. The hydraulic manipulator was designed for much higher payloads and longer reach, which made this arm bulkier than cable manipulators. Advanced arm designs may be able to access more tank surface areas than a vehicle, especially in congested tanks or tanks with steep terrains.

Both the Track 2 vehicles and Track 3 arms could be maneuvered to any location on the waste field made available for testing. Track 2 vehicles are restricted by the need to be on a supporting surface; thus retrieval operations must be accessible from the waste field. The Track 3 arm systems are much freer in their movements. They can move above the waste field, which can be beneficial for cleaning vertical surfaces and tank domes, which a vehicle could not easily do. Both Track 2 vehicle and Track 3 arm systems can move around in-tank objects such as risers. The Track 2 vehicle systems demonstrated that they can move around in-tank obstacles, but management of the umbilical is critical, and in highly congested tanks could be extremely difficult. Of the Track 3 arm systems, the GreyPilgrim cable manipulator demonstrated its ability to move around in-tank objects in multiple planes. This flexibility could be increased by adding more moveable stages to the arm. The Delphinus hydraulic manipulator arm is not as flexible, and moving around in-tank hardware depends on the ability of its arm to remove obstructions. Track 3 arms may be able to enter smaller, confined spaces because the physical size near the end of the arm is generally smaller than a Track 2 vehicle.

Umbilicals are required on both the Track 2 vehicles and the Track 3 arms to provide services such as hydraulics for motivation of drives and cylinders, process water to the dislodging tool, and a waste retrieval conveyance line. Umbilical management may be easier with the Track 3 arm systems once in the tank because the umbilical can be attached directly to the arm; the vehicle systems do not provide the full support. During these demonstrations, both the Track 2 vehicle and Track 3 arm systems had some difficulties managing the umbilical during in-tank operations or during deployment and retrieval from the simulated tank. All Track 2 vehicle systems had enough power to drag the umbilical behind them as they traversed various terrains of the waste field. Attaching the umbilical to the top of one of the Track 2 vehicles would have allowed it to maneuver steep terrain better and to keep the umbilical from dragging in the waste field. A single umbilical hose that would have all the required services inside was suggested by both vehicle demonstrators and would probably benefit the arm systems. The advantage of a single umbilical system could be easier attachment, increased strength, and better decontamination. The disadvantages may be less umbilical flexibility and higher costs; it would complicate maintenance by placing a

contaminated waste line next to the service lines. Umbilical management was demonstrated on both a Track 2 vehicle-based system by ESG and a Track 3 arm system by Delphinus. During the ESG demonstration, the umbilical was retrieved into the decontamination chamber. The Delphinus demonstration found that spring-loaded umbilical reels were not adequate; powered reels would be required. Both Track 3 arm systems indicated that running the umbilical inside of the arm structure may be an option.

In summary, the maneuverability of both Track 2 vehicles and Track 3 arms was successfully demonstrated. Maneuverability was hindered to some extent by umbilical management difficulties, partially because of the lack of sufficient funding or time to construct a fully functional system. The long-term durability and automatic operation of the umbilical is also a concern. The ability of the Track 2 vehicles to operate in deep, soft sludge and the ability of both Track 2 vehicles and Track 3 arms to clean on, and around, in-tank structures has only been partially demonstrated.

3.7 Positioning

Positioning is important in waste retrieval to allow the various dislodging and conveyance tools to work properly. This is especially true for the local dislodging and conveying devices such as the high-pressure confined sluicers with localized water scavenging. In addition, positioning is important to avoid in-tank objects or tank walls that may damage the retrieval equipment or potentially jeopardize tank safety. All systems tested appeared to be able to position the dislodging and conveyance devices adequately to allow retrieval in a relatively uncongested tank. Table 3-10 shows that positioning issues have been partially addressed.

Table 3-9. Positioning Summary by Track.

Track 1, Sluicer	Minimal positional requirements: gross positioning of nozzle direction and angle.
Track 2, Vehicle	Vehicles with local dislodging tools require positioning on the order of several inches, which was demonstrated to be achievable in these systems. Positioning the dislodging device standoff distance required hydraulic actuators for both systems tested. Standoff distance is a critical parameter.
Track 3, Arm	Arms require positioning on the order of one inch, which was demonstrated to be achievable in these systems under controlled conditions. Critical parameters are path speed, drift, deflection, and positional orientation.

Track 1 global sluicers have minimal positional requirements, requiring only gross positioning of nozzle direction and angle. The Track 2 vehicles with local dislodging tools require positioning within several inches horizontally and one inch vertically. The Track 3 arms require more positional accuracy than the vehicles to avoid collisions and, most likely, a sensory feedback system (e.g., sensors that determine position or force). For the extremely soft waste simulants such as wet sludge, the positioning requirements are less critical. For the high-strength waste, the standoff distance (typically the "vertical plane") may be more critical (i.e., less than 1 inch) for high-pressure dislodging devices.

For Track 2 vehicles, it was necessary to position the dislodging device in the plane of the waste (typically the horizontal plane) within several inches to be most effective; this was demonstrated by both vehicle systems. The waste dislodging tool head of both systems used an actuator that pivoted the dislodging device into position between 45 and 90 degrees from the horizontal plane of the vehicle. Vehicles have an inherent difficulty maintaining a constant standoff distance on rough terrain because vehicle motion may not follow the surface changes at the dislodging device. Vehicles also have an inherent safety advantage because the drive mechanism generates a limited amount of force, which is essentially a force feedback that can be calculated to the upper limit. Because vehicles generally follow a surface, control is required only to steer the vehicle along the surface and to position the dislodging device, which is much simpler than controlling Track 3 arm systems.

For Track 3 arms (Table 3-10), it appeared adequate to position the dislodging device in the plane of the waste (typically the horizontal plane) within several inches of the waste and within 1 inch of an obstacle to avoid it. The standoff distance of 1 inch for the dislodging device is

Table 3-10. Positioning Test Summary for Arm-Based Systems (Track 3).

	Magnox	Delphinus	GreyPilgrim
Manipulator type	Hydraulic	Heavy duty hydraulic	Cable tension
Manipulator in-tank weight (lb)	Estimated between 2,000 - 4,000	13,000	1000
Static Deflection Tests			
Arm horizontal - extension (ft)	17	45	17
Time (minutes)	No test	No test	30
Deflection with time (in.)	No test, assumed small	No test, assumed small	1.8
End effector load (lb)	200	1180	50
Deflection with load (in.)	4.3 ^(a)	11.5	0.6
Total deflection (in.)	No test	No test	2.4
Dynamic Drift Tests			
Arm Length - Horizontal (ft)	17	45	17
Drift with Slow Motion (in.)	No test	± 1	No test
Drift with Fast Motion (in.)	No test	± 10	± 1.9 - 2.6 per stage (4 stages total)
(a) Calculated based on stiffness data.			

the same as for the vehicle systems. This requirement is independent of the deployment mechanism but depends on the dislodging device. These positional requirements were demonstrated by both arm systems as achievable. Maintaining dynamic position tolerance in arm systems depends on the speed of the arm movement and the position of the arm during the movement.

Accommodating static deflection could be a positional challenge for Track 3 arms. Both the Delphinus and GreyPilgrim systems measured static deflection; it was calculated from stiffness data for Magnox and is summarized in Table 3-9. Even though each has a different method of moving the manipulator stages (i.e., hydraulic and mechanical cable tensioning), each system has experienced static deflections under various loads and time frames. The cable system used with the GreyPilgrim arm extended horizontally 17 feet and 2,500 pounds of tension measured a change in vertical position of 1.8 inches over 30 minutes. Adding a 50-pound weight resulted in an additional deflection of 0.6 inches for a total of 2.4 inches. This total deflection was corrected by adding 400 pounds of tension to one cable. The Delphinus arm, at a much longer horizontal length of 45 feet and much higher load of 1,180 pounds, had a total measured deflection over the length of the arm of 11.5 inches. The drift over time experienced in the cable manipulator would not likely be experienced in the hydraulic system as long as hydraulic pressure was maintained. Although no comparison can be made between the two systems directly, the large hydraulic manipulator under the same conditions as the cable manipulator is expected to have significantly smaller deflections. Both systems claim that control systems can be developed to compensate for these deflections in real time for all configurations. Static drift could also be compensated for using a global positioning system, but none was tested or proposed. A static deflection test was also performed on the Magnox manipulator; it showed less deflection than the GreyPilgrim manipulator and slightly more than the Delphinus manipulator (this is based on engineering judgement of the Magnox stiffness value reported, not an actual deflection, which would have allowed a direct comparison).

Minimizing drift is a positional challenge for Track 3 arms, and testing is summarized in Table 3-9. It was demonstrated for the Delphinus arm that a slow rotational movement (controlled pivot) with an abrupt stop had approximately 1 inch of drift, whereas the maximum rotation movement (uncontrolled pivot) with an abrupt stop had about 10 inches of drift. This test was conducted in a worst-case condition: the arm was set at maximum horizontal extension of 45 feet and swung from the one end through the riser plane centerline, which physically had the least leverage in this system to restrict motion. Similar motion stops would be fewer along all other motion axes. However, for similar systems with extended reach to 75 feet, the drift would be amplified by the length ratio (i.e., 70% increase in drift for 75 feet versus 45 feet). Several points could have been adjusted to reduce some of the drift. The GreyPilgrim manipulator may exhibit similar characteristics but with less magnitude because the total mass is less and the compliant joints are always under tension.

Maintaining positional orientation is a challenge for Track 3 arms. The kinematics of the arm system depend on a variety of parameters related to multiple joint translation and angle positions. Because the arm systems are fixed to a single location by riser access, the same

rate of joint motions at different end effector locations will cause the arm to move at different rates; this problem is amplified in the longer arms. Control systems and algorithms need to be developed to move the arms in a safe and predictable manner. The Delphinus and GreyPilgrim arm systems have started to develop these control systems, but the systems were not complete at the time of the tests. The Magnox manipulator has these control systems fully developed and implemented on smaller systems.

Computer path control was successfully demonstrated only with the Track 3 arm systems, since Track 2 vehicles most likely would not require computer path control because of their "single plane" operation. The Delphinus hydraulic manipulator arm demonstrated control software that provided path programming or recording and playback of a manual path sequence. The playback feature was successfully repeated three times with no observed deviations. A sensory feedback system for the Delphinus manipulator arm computer path control system was not implemented in this demonstration. Both Track 3 arm systems have some inherent sensory controls that could be used (cable tension and hydraulic pressure), but a sensory system independent of arm control may be required.

The dislodging standoff distance requirements for all local dislodging end effectors is independent of the deployment platform and depends on the dislodging tool. In general, the higher-pressure devices use less water and require closer standoff distances to be effective. Confined sluicers with shrouds have been demonstrated to dislodge material most effectively when standoff distances of the shroud from the waste are less than 1 inch. For this case, the actual nozzle standoff distances would be several inches. For local scavenging of waste and water, the most effective scavenging is realized when the scavenging inlet is buried in or very close to the material being scavenged; however, for scavenging operations that require clearance to allow movement of the scavenging inlet, positional standoff distances up to 0.5 in. were still effective. For localized systems with a shroud, the angle of the shroud appeared to be less critical than the standoff distance. The Track 3 GreyPilgrim manipulator, with its high pressure scarifier and air conveyance system, had trouble maintaining the standoff distances of the dislodging tool and may require added control mechanisms to provide feedback to the cable tensioning system.

To position any of the dislodging devices, positional feedback is required. In all of these tests, equipment was positioned visually and, in some cases, remotely, aided by camera systems. Visual positioning appeared to be effective for most operations and for removal of bulk material. However, for safety of the tank and equipment, systems with the potential to cause damage will require positional feedback in a global sense relative to the tank's internal volume and related internal tank equipment.

In summary, tests to date were intended to demonstrate system feasibility and did not include sophisticated control features. All Track 2 vehicles and the Track 3 arms tested can achieve positional requirements for localized dislodging tools; however, some of the arms may require additional feedback on the position and proximity of the arm to the tank structures. Large overshoot of some arms during positioning was noted as a problem. In a remote environment with airborne aerosol, maintaining accurate standoff without collisions could prove to be difficult, especially with high-pressure systems. Systems to measure the standoff

distance between the retrieval end effectors and the waste or tank surface were not included in this testing. One solution is to include inverse kinematics to convert arm joint values to end-effector position and to provide a means to detect and react to tank collisions without damage. A simpler alternative could use end-point sensing and avoid compliance complications in the inverse kinematics calculations.

3.8 Static and Dynamic Performance

The ability of Track 2 vehicles and Track 3 arm systems to handle a dynamic end effector is primarily related to static and dynamic performance. Static performance is primarily associated with arms and relates to loads and deflections. The Track 1 global sluicer has little relationship to these functions.

For Track 2 vehicles, the approach to demonstrating dynamic performance was very simple, the systems were observed in operation. For example, high-pressure water blasts from a dislodging device may lift and vibrate a vehicle, and the coincident retrieval operations are observed to determine if operations are adversely affected. For all vehicle systems tested, no process dynamics appeared to adversely affect the vehicle operations. The effects of mechanical tools on vehicles were not measured or observed.

Track 3 arm systems have more significant concerns with static and dynamic performance. All the arms tested used hydraulic end effectors, which may transmit vibrations into the long arm near the arm's resonance frequency, causing damage and, ultimately, failure.

Vibration testing was done on both hydraulic arms. Magnox acquired force and vibration data on the ARD 400-pound-per-square-inch confined sluicer during ACTR Integrated Testing to determine the input loads to a Track 3 arm system. They concluded that a full-size arm could safely withstand the imposed loads during a retrieval campaign. Visual observation of the GreyPilgrim cable arm indicates that the end-effector tool vibration is relatively close to, but typically outside of, the resonance frequency, and that the arm is not excited adversely. Because each arm system (joints, size, and orientation) is unique, dynamic and static testing will be required to ensure that the arm is adequately damped for the end effectors used. A summary of the static and dynamic performance issues is given in Table 3-11.

In summary, structural failures noted during tests were attributed to premature failure of parts or limitation of systems, not end effector loading or dynamic excitation, which was a primary concern for Track 3 long-reach manipulators arm. Flexible arms such as the GreyPilgrim EMMA are more likely to be affected by dynamic loading caused by suction. Static deflection was significant for both Track 3 arm systems, and proximity feedback may be required to accurately position waste retrieval end effectors. Track 2 vehicle tests proved that static and dynamic performance is not a concern with these systems, and the weight of the vehicles was sufficient to counteract the forces generated by high-pressure end effectors.

Table 3-11. Static and Dynamic Performance Summary by Track.

Track 1, Sluicer	Not perceived to be a problem. Current operation of sluicers at the Hanford Site has been successful.
Track 2, Vehicle	Generally not a problem for hydraulic dislodging tools, as long as vehicles can support the tool and have enough weight to resist the dislodging load; mechanical dislodging tools may cause problems, however.
Track 3, Arm	Long-length arms may potentially be affected by end-effector loads and the loads of the arm itself. Resonance frequencies of arms (typically 0.5-5 Hz) are relatively close to frequencies that can be generated by end effectors, which could severely damage the arm system and cause failures. Kinematics of arm are affected by position, joint type, and movement rate. Because each arm is unique, static and dynamic testing will be required.

3.9 Remote Operation

Remote operation is an integral part of any in-tank retrieval process. Two vendors demonstrated remote operations, (ARD, its Track 2 vehicle and Delphinus, its Track 3 arm system.) The darkness that exists in the SST was not simulated in the Track 2 tank; all tests were accomplished above ground, outdoors, during daylight. All vehicle movement and retrieval operations for the ARD test were performed successfully by viewing camera images from various locations. For the Delphinus test, Track 3 arm movements to specific targets were successfully demonstrated using two low-technology cameras; depth perception was a problem. Both of these operations would have benefitted from more cameras providing more viewing angles (i.e., better depth perception) and the ability to zoom, pan, and tilt. For remote viewing, it appears that commercially available remote surveillance equipment and standard industry practices should be adequate for retrieval, assuming that the environment is not occluded from water spray. Table 3-12 shows that remote operation issues have been partially addressed.

Table 3-12. Remote Operation Summary by Track.

Track 1, Sluicer	Remote operations are fairly simple. Operation viewing requirements are minimal. Final characterization of waste cleaning is similar for all tracks and may be the most difficult task.
Track 2, Vehicle	Remote operations are more complex. Operations can be viewed with video camera systems. Manned control is required for all retrieval operations.
Track 3, Arm	Remote operations are most complex. Operations can be viewed with video camera systems, but additional sensory devices may be needed for control and feedback. Computer path control may be possible for some retrieval operations, but manned monitoring is expected for all retrieval operations.

In summary, demonstrations to date for Track 2 vehicles and Track 3 arms proved that fully remote operations can be accomplished, but actual in-tank conditions will be significantly more complex. Not fully modeled in any of the testing was the large size of the tank, the darkness of the tank that requires lighting to view remote operations, and other global positional feedback systems, such as range finders, that may be needed. One of the Track 2 systems made a good attempt at fully remote operation, and some of the arm systems showed computer control by path mapping to a small extent. All retrieval operations requiring remote operation will need to demonstrate that the operation is reliable.

3.10 Reliability, Availability, Maintainability (RAM)

For waste retrieval to be successful, the equipment has to be highly reliable, be available when needed with the proper tooling, be able to recover from a failure, and be able to be maintained. Because the waste in the tank is hazardous and highly radioactive, decontamination of equipment is important for maintenance and for possible reuse of equipment in other tanks. Table 3-13 shows that RAM and decontamination issues have been partially addressed.

Table 3-13. RAM and Decontamination Issues by Track.

Track 1, Sluicer	System proven at Hanford to be highly reliable and to require little maintenance.
Track 2, Vehicle	System is generally simpler than a Track 3 arm system. Track 2 vehicle systems have proven reliable in hazardous industrial tank-like applications, but for relatively short periods of time compared to what might be encountered in a Hanford tank retrieval operation. Maintenance was demonstrated. Recovery from failure was demonstrated, but conditions exist in which a vehicle could be unrecoverable and, operationally, need to be avoided. Decontamination was demonstrated.
Track 3, Arm	Track 3 systems are generally the most complex of the three tracks with the possible exception of the cable manipulator. Large arms have not been proven in large hazardous tank applications, but these demonstrations have proven its feasibility. Reliability and maintenance are unknown but are expected to have risk similar to the Track 2 vehicles. Decontamination was partially demonstrated.

Maintenance is an important function of in-tank retrieval because even the best designed equipment can have failures and will need to be fixed or removed and replaced. ESG performed maintenance testing in their simulated chamber using a decontamination wash system at the entrance and glove box ports on the sides. In this demonstration, ESG successfully changed a track in 1.8 hours and a pump motor in 0.23 hours. Important knowledge gained from this testing includes the need to simplify equipment design for remote maintenance and to make the maintenance chamber accessible to all in-tank equipment. Track 3 arms should have maintenance issues of the same complexity as vehicles. The size and length of the arm system may make maintenance more difficult. No arm's maintenance demonstration was done.

Recovery from failure is a key function during waste retrieval. The inability to recover from a failed condition could be quite costly and may require the abandonment of a tank riser in a worst-case scenario. Track 1 global sluicers are simple devices that can fit through relatively small risers and should be easy to recover from a failed condition. Track 2 vehicles have a key failure mode of the inability to move due to a drive failure or being stuck. ARD demonstrated that a stuck vehicle could be recovered from a tank by pulling on the umbilical; maximum umbilical force measured was 1,000 pounds of tension. The Track 3 arms' key failure mode is its inability to retract through the riser because it cannot be moved properly. No arm failure modes were demonstrated. The cable tensioning arm appears to be the simplest arm system able to recover from an in-tank failure.

In summary, demonstrations to date have partially addressed the reliability, availability, and maintenance issues in actual tank configuration for Track 2 vehicles and the more complex Track 3 arms. These have more contact with the radioactive and caustic tank environments because of the localized dislodging and conveyance systems. A successful simulated maintenance demonstration was performed for a full-scale Track 2 vehicle, which included one of the more difficult tasks of replacing a track. No full-scale maintenance demonstrations were done on Track 3 arms, although the smaller-scale Magnox arm has been used successfully in radiation environments. Failure recoveries for Track 2 vehicles proved that in most cases, a dead or stuck vehicle could be recovered from the top of the tank by pulling on the umbilical. No arm failure recovery was demonstrated, but some of the procedures were outlined.

3.11 Decontamination

Equipment inserted to the tank has the potential to become contaminated, and all equipment that is removed from the tank for maintenance, reuse, storage, or disposal will need to be decontaminated. In-tank retrieval equipment not exposed directly to the waste in the tank, such as the Track 1 global sluicer, has been easily cleaned with simple spray wash systems and does not need further discussion. The Track 2 vehicles and Track 3 arm are more complex, and their use of localized dislodging devices results in a much higher probability of becoming contaminated.

Decontaminating Track 2 vehicles may be more difficult than decontaminating Track 3 arms because the Track 2 vehicles come in direct contact with the waste surface, whereas booting the arm covers the crevices where particles may become lodged. In simple decontamination tests with tracked and wheeled vehicles, ARD determined that they were less successful with their tracked system than with their wheeled vehicle when attempting to decontaminate with a high-pressure spray wash. Later testing of the wheeled vehicle showed that this vehicle could be decontaminated to adequate levels using high-pressure moveable spray nozzles. ESG reported that a high-pressure spray wash in a simulated decontamination chamber appeared to decontaminate their tracked vehicle adequately, in contrast to the ARD results. For both of these tests, no quantitative decontamination data were acquired, and results were determined by visual inspection of waste particles lodged on the vehicle. As expected, simulated waste

particles were found in vehicle cavities and on the vehicle umbilical hose bundle, but it is believed that these particles can be eliminated by booting the umbilical and by designing the vehicle to minimize cavities.

Decontamination of a Track 3 arm end effector and the lower part of an arm was demonstrated by Delphinus with a high-pressure hand washer to simulate a high-pressure wash chamber. Visually, the high-pressure wash appeared to clean these components. However, no quantitative data are available. Arm system decontamination has historically relied on booting to avoid contamination of the arm. Retractable arms, such as the Delphinus arm, are believed to be more difficult to boot than fixed-length arms, such as the GreyPilgrim cable or Magnox link arms, because of the need to accommodate translation motion as well as rotary motion.

Both ARD and Delphinus tried to measure the decontamination process by using a fluorescent dye tracer in the simulated waste and observing the results with black light. This test was unsuccessful because it was very difficult to observe even in dark conditions. Rinse water used in these tests ranged from 1,000 to 5,000 pounds per square inch. These high-pressure systems appeared visually to be effective at cleaning the in-tank components; however, the high force cut the outer sheathing on the ARD umbilical in one instance, showing the need to design components to survive these conditions. ESG investigated various umbilical materials and determined that polyurethane was the best choice for in-tank conditions; polyvinyl chloride was the second choice. Thus, the simulated decontamination demonstrations did not obtain any quantitative data.

3.12 Tank Safety

Tank safety is of utmost importance in any hazardous/radioactive tank retrieval process. One safety concern is tanks that have the possibility of being exposed to flammable gas environments. The ability to operate in a flammable gas environment was not demonstrated as a part of these tests, but all systems could be designed to do so. A summary of tank safety issues is given in Table 3-14.

Table 3-14. Tank Safety Summary by Track.

Track 1, Suicer	Minimal tank safety concerns. They have recent operational experience in Hanford Site tanks. High water recirculation flowrate may limit use in leaking tanks.
Track 2, Vehicle	Minor tank safety concerns. Similar vehicles have been used in industrial applications with potentially explosive environments, such as petrochemical tanks. In-tank electrical components are limited by using hydraulic devices. The threat of sparking can be eliminated by design. High-pressure, low-flow dislodging devices and local water scavenging may allow use in leaking tanks.
Track 3, Arm	Minor safety concerns, but higher than Track 2 vehicles because of potential to impart large forces. Electrical components in-tank are limited by using hydraulic devices or mechanical cables. Sparking can be eliminated by design. Feedback systems may be required to limit arm positional envelope and forces. High-pressure, low-flow dislodging devices and local water scavenging may allow use in leaking tanks.

The forces generated by the various devices operating in the tank must be controlled to maintain tank wall integrity. The Track 1 global sluicer system applies limited force to the tank walls. Track 2 vehicles are limited to the forces imparted by the vehicle; these are limited by the vehicle weight of about 1,500 pounds and a drive system that depends on surface friction. It is possible that vehicles cannot generate sufficient force to damage a tank wall. Some Track 3 arms have the potential to generate high forces; but most of the systems tested had a limited payload capability of around 200 pounds, which implies that these systems are force-limited. The exception was the Delphinus heavy-duty hydraulic arm, which can generate much higher loads than the other arm systems. To prevent possible tank damage, this Track 3 system may require feedback devices to limit applied forces.

Although the forces generated by the hydraulic dislodging devices may be rather high (demonstrated up to 30,000 pounds per square inch) to allow high-strength waste to be retrieved, previous testing shows that there is apparently little risk of breaching a structurally sound tank wall, as long as the water jet is not allowed to dwell on one area for a long period of time. Mechanical tools that are generally considered for dry retrieval in leaking tanks have a much higher risk of damaging a tank wall than hydraulic methods, although the risk may be minimal for a structurally sound tank wall. In these demonstrations, no hydraulic dislodging device was found to cut or wear metal.

In summary, demonstrations to date have not fully addressed the tank safety issues in actual tank configuration for Track 2 vehicles and Track 3 arms. To address the issue of Hanford Site tanks with flammable gases, all tracks tested had in-tank systems that did not rely on electrical power for operation of the main retrieval equipment; however, the tests did not address all the sources of potential sparking. Extensive use of Track 2 vehicles in petrochemical tanks with highly flammable and potentially explosive atmospheres, demonstrates that these vehicles most likely can be qualified for use in flammable gas tanks at the Hanford Site.

One of the Track 3 arms could generate forces high enough to damage the tank if the arm is not controlled properly. Although most devices do not generate enough force to breach a tank wall, some of the very high-pressure dislodging devices have demonstrated the ability to cut metal. Mechanical dislodging devices are typically considered for use in leaking tanks; however, there are two potential issues: 1) these devices have a higher potential for generating sparks, which is not desirable in a flammable gas tank; and 2) liquid addition may still be required for conveyance, which is undesirable in a leaking tank.

3.13 Costs

No costs were discussed by any of the testing vendors.

4.0 OPEN ISSUES REMAINING

The two FY 1997 HTI retrieval demonstrations, Integrated Testing and ARTD, have been completed, and many open issues remain. These issues will best be resolved through the actual deployment of a retrieval system in a Hanford SST. A summary of the open issues may be found in Section 4.13 and includes a detailed listing for each issue area. Issue areas are defined in Section 2.4.

4.1 Tank Access

Tank access needs to demonstrate the ability of the above-tank components to mate with, and the ability of the in-tank components to fit through, the specific tank riser(s) required to deploy all in-tank systems. Any related supporting systems (such as a maintenance and decontamination chamber, deployment support structure, and radioactive shielding) that affect the tank access process will need to be considered. For Track 2 vehicles and Track 3 arms, demonstrating access through smaller, more common riser sizes, ideally a 12-inch diameter riser, would expand the viability of these systems in Hanford SSTs.

4.2 Deployment

Deployment needs to demonstrate the ability of the above-tank deployment system to insert all in-tank systems to all areas of the tank required for retrieval, and to remove the equipment when retrieval is complete. Any related supporting systems (such as crane equipment needed to place the in-tank hardware, surrounding tank hardware, and constraints) that affect the deployment process will need to be considered. For Track 3 arms, demonstrating deployment with longer reach (more than 40 feet) and smaller cross sectional size (24 inch diameter or less, ideally 12 inches) would expand the viability of this retrieval system in Hanford SSTs.

4.3 Mining Strategy

The ability of the retrieval system to completely clean a tank needs to be demonstrated; this includes contingencies for dealing with specific problems that could be encountered (e.g., debris handling, in-tank hardware obstructions, and a wide range of waste types). For a specific tank retrieval operation, the mining strategy may be quite different for the various tracks (Track 1 global sluicer, Track 2 vehicles, and Track 3 arms) based primarily on the combination of devices chosen for deployment, dislodging, mobilizing, and conveyance.

4.4 Waste Retrieval

Waste retrieval includes the ability to dislodge, mobilize, and convey the range of waste materials present in the tank, condition the waste to the desired weight percent solids and particle size, eliminate undesirable gaseous components, and pump the resulting slurry into a pipeline. Complete waste retrieval demonstrations must be conducted under actual conditions

that includes factors such as operator inefficiency, fatigue, and downtime for repositioning of tools. Demonstrations also need to include complete tank cleaning, which entails dealing with inevitable material clumps and debris and removal of residual liquids.

4.5 Water Scavenging (water usage)

Water scavenging is primarily required for leaking tanks using hydraulic retrieval devices. Minimizing water/liquid within the tank throughout a complete waste retrieval process needs to be demonstrated under actual conditions, including removal of residuals.

4.6 Maneuverability

Maneuverability includes the ability of the waste retrieval equipment to traverse a potentially complex tank environment without becoming entangled or immobilized. This applies primarily to Track 2 vehicles and Track 3 arms. The retrieval equipment must demonstrate that it can be maneuvered to the degree required for efficient cleaning in an actual tank. Tank conditions (such as internal tank risers, or soft waste) or equipment features (such as umbilicals) that impact the ability to maneuver the retrieval equipment within the tank need to be considered.

4.7 Positioning

Positioning entails the ability to place the retrieval end effector throughout the tank environment accurately (dictated by the retrieval device) and without collisions; this applies primarily to Track 2 vehicles and Track 3 arms. The waste retrieval equipment needs to demonstrate that it can safely acquire and maintain the various positions required for all operations of the waste retrieval process. Devices that acquire and control position and movement will need to be proven in actual tank conditions.

4.8 Static and Dynamic Performance

Deployment system static and dynamic performance includes the ability to withstand structural loading without damage or loss of control or efficiency. This applies mainly to Track 3 arms, but might apply to Track 2 vehicles if the vehicle is used as a platform for deploying a Track 3 manipulator. Loadings are the result of gravity, inertia, end-effector operation, water-jet thrust, effects from spinning motors, and suction. The deployment system must be fully tested under the maximum combination of loads to demonstrate structural integrity and the ability to provide accurate positioning.

4.9 Remote Operation

All retrieval operations are complicated by the need for remote operation which includes the functions of deployment, maneuvering, positioning, conveyance, maintenance, failure recovery, and decommissioning of retrieval equipment. Remote operation needs to demonstrate the ability of the retrieval system to operate equipment in a safe and productive manner in an actual Hanford Site tank environment.

Demonstrations to date for Track 2 vehicles and Track 3 arms indicate that full remote operations can be accomplished, but actual in-tank conditions will be significantly more complex. Not fully modeled in any of the testing was the large size of the tank; the darkness of the tank, requiring lighting for viewing remote operations in an occluded environment; and global positional feedback systems, such as range finders, that may be needed. One of the Track 2 systems made a good attempt at fully remote operation, and some of the arm systems showed computer control by path mapping to some extent. All retrieval operations requiring remote operation will need to demonstrate that the operation is reliable.

4.10 Reliability, Availability, Maintainability and Decontamination

RAM needs to demonstrate the ability of the retrieval system to complete a tank waste retrieval with low risk of campaign interruption due to maintenance problems. This risk is minimized if the reliability of the system is high and appropriate failure recovery operations are considered. Waste retrieval equipment that becomes contaminated with hazardous and radioactive waste will need to be decontaminated to levels required for maintenance, reuse, or disposal, as applicable.

4.11 Tank Safety

The retrieval system needs to demonstrate that tank safety is maintained during tank waste retrieval and that the risk is low for damaging the tank, degrading the environment surrounding the tank, or increasing health risks.

4.12 Cost

The costs of retrieving the waste from an SST needs to be determined. The accuracy of predicting the cost factors depends on demonstrations that all the risks relating to waste retrieval are fully understood and addressed.

4.13 Summary

The open issues that still remain for retrieval of Hanford SSTs are summarized in Table 4-1. Many of the open issues have been partially defined, and many are unique to the retrieval

system used, the tank accessed, and the waste being removed. This list may not be complete, some issues listed may need to be further defined, and some may need to be added. Each open issue is keyed to the following:

- The track for which the issue primarily applies (i.e., Track 1 - global systems, Track 2 - vehicle-based systems, and Track 3 - arm-based systems)
- Special conditions for which the issue may apply; examples include tank conditions relating to riser size, waste level, and in-tank hardware
- Whether the issue may be addressed by the HTI C-106 Retrieval Demonstration.

The system to be used for the retrieval of Hanford Tank C-106 has not been determined at this time. Some of the open issues associated with a specific retrieval system type (i.e., track) will depend on the final system chosen.

Table 4-1. Open Issues Remaining after HTI FY 1998 Testing and Issues To Be Addressed by the Tank C-106 Retrieval Demonstration.

Issue Item	Open Issue Description	Track 1	Track 2	Track 3	Special	C-106 Demo
Tank Access						
1.	Fit of all full-scale, in-tank systems through tank riser(s) in actual tank configuration		x	x		x
2.	Tank access through a 12-inch-diameter riser by full-scale equipment. This is the most common large riser size on all Hanford SSTs, and most tanks have one riser of this size located near the center of the tank		x	x	x	x
Deployment						
1.	Deployment of all above-tank systems and mating to tank riser(s) in real tank operational configuration following operational procedures		x	x		x
2.	Remote placement and removal of all in-tank components following operational procedures		x	x		x
3.	Umbilical(s) management during all retrieval processes		x	x		x
4.	Remote reach of in-tank components to all areas of tank necessary to complete a full retrieval process as dictated by the mining strategy		x	x		x
5.	Deployment over various terrains and surface types; the later applies primarily to Track 2 vehicles		x	x		p
6.	Deployment in a Hanford SST full of waste with minimal tank headspace, approximately 13 ft, which may have liquid or solid waste				x	
7.	Deployment and reach capabilities in congested tanks that include vertical in-tank structures, support wires, etc.				x	

Table 4-1. Open Issues Remaining after HTI FY 1998 Testing and Issues To Be Addressed by the Tank C-106 Retrieval Demonstration.

Issue Item	Open Issue Description	Track 1	Track 2	Track 3	Special	C-106 Demo
8.	Deployment to allow cleaning of waste from walls, domes, and other in-tank structures				x	p
9.	Maximum in-tank reach capability from a tank edge riser of 75 feet horizontal and 55 feet vertical distance; primarily for Track 3 arms			x	x	
10.	Remote hookup in-tank				x	d - 2, 3
Mining Strategy						
1.	Mining strategy for complete retrieval operation, including bulk waste removal and final tank cleaning	x	x	x		x
2.	Effects of in-tank debris on mining strategy	x	x	x		p
3.	Mining strategy in congested tanks				x	
4.	Mining strategy for cleaning waste from walls, domes, and other in-tank structures				x	p
5.	Mining strategy for various terrains and surface types				x	p
6.	Mining with unmanned control and feedback for Track 3 arm systems only			x	x	d - 3
Waste Retrieval						
1.	Ability to control wt% solids and maximum particle size of slurry introduced into cross-site transfer line	x	x	x		x
2.	Bulk retrieval of large volumes of simulants	x	x	x		p
3.	Abrasion and plugging resistance of conveyance lines	x	x	x		p
4.	Effect of debris on retrieval rates	x	x	x		p
5.	Effectiveness and retrieval rates during final cleaning, where behavior of small clumps of waste will dictate response	x	x	x		x
6.	Ability to convey waste under lift/head conditions that match tank physical environment	x	x	x		x
7.	Validate dilution ratio	x	x	x		x
8.	Recirculation of liquid for higher pressure systems (greater than 400 psi) if required for retrieval approach		x	x	x	d - 2, 3
Liquid Scavenging (Liquid Usage)						
1.	Localized liquid containment optimization	x	x	x		p
2.	Ability to pump liquid under low head conditions	x	x	x		x
3.	Liquid containment while cleaning vertical surfaces	x	x	x		p
4.	If air conveyance is used, the system must demonstrate the ability to entrain air continuously while pumping liquid to improve performance and eliminate plugging	x	x	x	x	d

Table 4-1. Open Issues Remaining after HTI FY 1998 Testing and Issues To Be Addressed by the Tank C-106 Retrieval Demonstration.

Issue Item	Open Issue Description	Track 1	Track 2	Track 3	Special	C-106 Demo
5.	Remote filter cleaning (especially for air conveyance)	x	x	x		d
Maneuverability						
1.	Umbilical management system demonstration for Track 3 arm systems		x	x		d - 3
2.	Durability of umbilical under all operating conditions		x	x		p
3.	Maneuverability of Track 2 vehicles to operate in deep, soft sludges		x			d - 2
4.	Ability to clean completely around in-tank hardware		x	x	x	p
Positioning						
1.	Systems to measure standoff distance in remote, occluded environments			x		d - 3
2.	Development of control mechanics (such as inverse arm kinematics)			x		d - 3
3.	Feedback sensors that measure force to prevent damage to tank or deployment systems			x		d - 3
4.	Reduction of uncontrolled overshoot during positioning			x		d - 3
Static and Dynamic Performance						
1.	Dynamic and static testing of any actual arm will be required because of the unique characteristics of those systems			x		d - 3
2.	Static deflection compensation control algorithms need to be developed for accurate tank navigation			x		d - 3
Remote Operations						
1.	Effects of remote operation on the performance of various retrieval systems	x	x	x		p
2.	Control requirements and demonstration of remotely operated equipment	x	x	x		x
3.	Optimum camera and lighting placement for observing tank operations	x	x	x		p
4.	Qualification of mapping systems for use and safe operation in a tank		x	x		d
5.	Final waste characterization that measures tank cleanliness to determine retrieval completion	x	x	x		p

Table 4-1. Open Issues Remaining after HTI FY 1998 Testing and Issues To Be Addressed by the Tank C-106 Retrieval Demonstration.

Issue Item	Open Issue Description	Track 1	Track 2	Track 3	Special	C-106 Demo
Reliability, Availability, Maintenance						
1.	Long-term reliability of all components and systems that address failure modes and associated impacts to other systems as appropriate. Specific tank reliability issues to be addressed include radiation environments up to 500 rem/hour, caustic environments greater than 12 pH, and temperatures that can exceed 180°F		x	x		p
2.	Recovery from failure of all components and system failure modes		x	x		p
3.	Decontamination of equipment as required for maintenance, failure recovery, or reuse		x	x		x
4.	Maintenance of equipment as required to maintain reliability, recover from a failed condition, or remove from in-tank service for reuse or disposal		x	x		p
Tank Safety						
1.	Qualifying components for use in flammable gas environments		x	x		p
2.	Qualifying components for use in leaking tanks		x	x		p
3.	Safety qualification tests, procedures, and documentation		x	x		x
4.	Loadings - dome, riser, tank wall		x	x		x
5.	Personnel safety measures for radiation and hazardous environments during all tank retrieval operations and maintenance		x	x		x
Cost						
1.	Cost of Track 2 vehicle and Track 3 arm systems		x	x		d - 2, 3
2.	Life-cycle costs of Track 2 vehicle and Track 3 arm systems		x	x		d - 2, 3
3.	Cost to install new riser on tank if required				x	d - 2, 3
4.	Cost to dispose of potentially contaminated equipment		x	x		x
5.	Cost for permitting and obtaining operational approval to proceed with retrieval		x	x		x
<p>Key to Terms:</p> <p>x - Applies.</p> <p>p - Partially applies.</p> <p>d - Depends on track chosen (tracks that apply identified after -).</p>						

5.0 CONCLUSIONS

HTI's Integrated Testing and Alternative Retrieval Technology Demonstration (ARTD) completed in the FY 1997, succeeded in resolving many issues, (see Section 3). The remaining open issues (see Section 4) will be addressed by the C-106 Waste Retrieval Demonstration work.

The technologies tested by the commercial vendors showed innovative thinking in solving the challenges of retrieving waste from Hanford SSTs. The technologies are, by track:

Track 1. Global Systems

- LATA Enhanced Global Sluicer - By observation, the flow pattern in this nozzle appears to be more cohesive than the past practice sluicing nozzle, which should make this device more effective at removing all waste types.

Track 2. Vehicle-Based Systems

- ARD Wheeled Vehicle - This vehicle demonstrated the benefits of a fully independent four-wheel drive system that can compete with a tracked vehicle for mobility and may be easier to decontaminate and maintain.
- ESG Tracked Vehicle - This system demonstrated that its high-pressure dislodging system can retrieve all waste types and that its conveyance pump is especially good at dealing with debris and pumping heavy material to high elevations (over 70 feet).

Track 3. Arm-Based Systems

- Magnox Hydraulic Multi-link Manipulators - This manipulator is highly developed, and its many links allow it to move in congested areas. These fully qualified and functioning manipulators have been used in radioactive environments for more than 10 years; however, they must be scaled up for use at the Hanford Site.
- Delphinus Heavy-Duty Hydraulic Manipulator - This manipulator is unique among the manipulators tested because of its high load capacity, which may allow it to detach and move large in-tank components. The high-pressure scarifying dislodging device was effective at removing all waste types. The conveyance system tested shows promise of being able to condition the waste slurry's solids content.
- GreyPilgrim Cable Link Manipulator - This manipulator is newly developed and shows promise for providing a mechanically simple, lightweight system compared with the other manipulators tested. This manipulator also must be scaled up for use at the Hanford Site.

6.0 REFERENCES

- ARD. 1997a. *Task 5 Test Report: Demonstration of Low Pressure Confined Sluicer and Vehicles for SST Tank Waste Retrieval at Hanford*. HNF-MR-0534, ARD Environmental, Inc., Laurel, Maryland, for Fluor Daniel Hanford, Inc., Richland, Washington.
Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=50.
- ARD. 1997b. *Alternative Retrieval Technology Demonstrations Program--Test Report*. HNF-MR-0542, ARD Environmental, Laurel, Maryland, for Fluor Daniel Hanford, Richland, Washington.
Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=286.
- Berglin EJ et al. 1996. *Acquire Commercial Technology for Retrieval Fiscal Year 1996 Summary and Highlights*. WHC-SD-WM-RPT-269, Westinghouse Hanford Company, Richland, Washington.
Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=286.
- Delphinus. 1997. *Final Test Report--Demonstration Testing in Support of the Track 3 System Waste Dislodging, Retrieval and Conveyance Concepts*. HNF-MR-0543, Delphinus Engineering, Eddystone, Pennsylvania, for Fluor Daniel Hanford, Richland, Washington.
Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=288.
- ESG. 1997. *Hanford Tanks Initiative Vehicle-Based Waste Retrieval Demonstration Report Phase II, Track 2*. HNF-MR-0544, Environmental Specialties Group, LLC, Tulsa, Oklahoma, for Fluor Daniel Hanford, Richland, Washington.
Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=284.
- GreyPilgrim. 1997. *Hanford Tanks Initiative Alternative Retrieval System Demonstrations--Final Report of Testing Performed by GreyPilgrim LLC*. HNF-MR-0545, GreyPilgrim LLC, Gaithersburg, Maryland, for Fluor Daniel Hanford, Richland, Washington.
Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=287.
- LATA. 1997. *Advanced Sluicing System Test Report for Single Shell Tank Waste Retrieval Integrated Testing*. HNF-MR-0539, Los Alamos Technical Associates for Fluor Daniel Hanford, Richland, Washington.
Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=240.
- Magnox. 1997. *SNAKES Manipulator and ARD Sluicer Testing*. HNF-MR-0538, Magnox Electric PLC, Berkeley, Gloucestershire, for Fluor Daniel Hanford, Richland, Washington.
Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=243.

Powell MR. 1996. *Initial ACTR Retrieval Technology Evaluation Test Material Recommendation*. PNNL-11021, Pacific Northwest National Laboratory, Richland, Washington.

Internet address: http://www2.hanford.gov/ratlib/DocMetaData.asp?doc_id=169.

APPENDIX A

LATA Sluicer Retrieval System (Track 1) - Integrated Testing

Test Report: HNF-MR-0539, 1997, *Advanced Sluicing System Test Report for Single Shell Tank Waste Retrieval Integrated Testing*, Los Alamos Technical Associates, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

A team consisting of Los Alamos Technical Associates, Inc. (LATA), and ARD Environmental, Inc., conducted tests to resolve issues associated with deploying an advanced sluicer retrieval system. All tests were conducted at ARD in their Laurel, Maryland, facility. All retrieval equipment systems tested were the full-scale size that would be proposed for cleaning a single-shell tank (SST) at the Hanford Site.

Sluicing has been used successfully at Hanford and at other U.S. Department of Energy sites to retrieve soft waste; however, its effectiveness with more stubborn waste or complex waste fields is unproven. In addition, sluicing has generally been regarded as a retrieval method for use in non-leaking tanks because of the large volume of liquid that must pass through the tank per unit of waste retrieved. The benefits of sluicing are its simplicity and low cost compared with other more complex retrieval systems requiring the use of vehicles (Track 2) and mechanical arms (Track 3).

Technology Description

LATA/ARD Advanced Sluicing System (LAASS) is a closed-loop, low-pressure system consisting of a large nozzle (approximately 1-inch in diameter), that provides the sluicing jet to dislodge the waste; a sluicer pump, which provides water and pressure to the sluicer; and a slurry pump, which removes the sluicer water and resulting waste slurry. The sluicer system is designed for closed-looped operation that allows the water/waste slurry to be recirculated. Recirculation generally requires that no new process water needs to be added to the system. The large nozzle and low-pressure system generally does not require any decanting or filtering of the water/waste slurry pumped from the tank for feeding the sluicer nozzle, and the addition of particulates may enhance the sluicing process. This type of sluicer is defined as a "global system," because waste is dislodged and removed by a jet stream emitted from a single nozzle located some distance from the waste (typically 20 to 50 feet). This retrieval system mimicked sluicing a 75-foot-diameter Hanford Site SST through a riser near the center of the tank and approximately 20 feet above the bottom of the tank floor. Two different nozzle sizes (1-inch and 1.25-inch diameter) were tested to gauge performance benefits.

Testing Focus Areas

Two major test phases were conducted to resolve the issues associated with using this waste retrieval system in an underground storage tank:

- **Nozzle Force Testing** - Measure nozzle performance of the Advanced Sluicer system proposed by LATA/ARD with two nozzles, including stream impact (recoil) forces, pressures, and sluice stream coherence.
- **Simulated Sluice Testing** - Demonstrate the ability of the Advanced Sluicer system to dislodge and convey waste simulants.

Test Results

Nozzle Force Testing. Nozzle performance was measured by aiming the nozzle jet at a government supplied instrumentation box, consisting of a pressure transducer array, to record the jet cross-section pressure pattern; and a load cell array to record total force at various distances from the sluicer jet outlet. Difficulties experienced with the instrumentation box allowed only one data point to be recorded for the 1-inch-diameter nozzle on the Advanced Sluicer system. The single data point recorded was at a jet distance of 8.33 feet, a nozzle pressure of 152 pounds per square inch, a nozzle flowrate of 288 gallons per minute, and a measured impact force of 234 pounds. With a single data point, the optimal pressure, flow, and nozzle diameter combination to use in the Simulated Sluice Testing could not be evaluated. No conclusive information was gained from this testing because of the instrumentation failure, and the performance benefits of the two different nozzle sizes (1-inch and 1.25-inch diameter) were not determined.

Simulated Sluice Testing. Retrieval simulation was done using a test mockup that mimicked retrieval of waste from a Hanford Site SST through a riser at the center of the tank (Figure A-1). Various waste simulants were poured into rectangular containers to an approximate size of 7 feet wide, by 14 feet long, by 1 foot deep. The sluicer head was located at a position approximately 20 feet above the waste simulant field and 35 feet horizontally from the waste field centerline; this resulted in the nominal sluicer jet angle of 29 degrees relative to the top of the waste field.

As expected, the retrieval rates were higher for the softer waste simulants than for the harder simulants. The smaller 1-inch nozzle appears to be more effective at waste retrieval and water usage than the larger nozzle. Results are somewhat inconclusive because pump limitations did not allow the large nozzles to be tested at full pressure, and the early conclusion of nozzle force testing did not allow nozzle performance to be completed. The sluicer retrieval rates in the saltcake and the lower-strength hardpan were high. Because retrieval rates in wet sludge was proven in past sluicing work, no tests were conducted. The sluicer may not be the optimal system for retrieval of higher-strength hardpan because

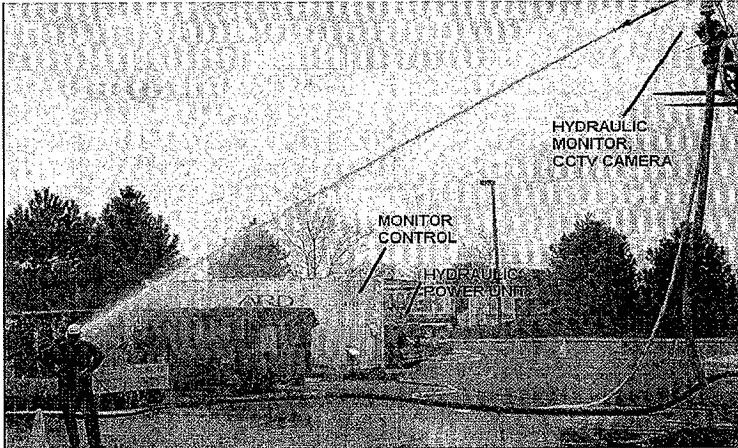


Figure A-1. Sluicing Test Hardware Configuration

its performance was lower than other retrieval systems tested. The tested retrieval rates could have been higher and the water usage lower if the retrieval system could have effectively removed large, loose waste chunks and if the pumping system could have kept the waste surface clear.

In conclusion, the sluicing system was able to retrieve and convey all of the simulated waste materials. The most significant factor affecting the retrieval rate of hardpan simulant was the inability to “trap” the waste where it could be broken down sufficiently to be conveyed from the tank by the slurry pump. Design features that would enhance the slurry pump operation include the ability to trap waste for mechanical reduction of waste particle size by the sluicing stream, and a self-priming pump that would work continuously to keep the surface of the waste exposed to the full impact of the sluicing stream. During this testing, the slurry pump proved its capabilities in keeping liquid levels low, handling solids, and discharging against a simulated 340-foot head. Recommendations for further investigations into this system include determining the minimum hydraulic pressure required to mobilize waste simulants and enhancing the vision system to provide more effective feedback to the operator of the retrieval system. The retrieval rates are summarized in Table A-1.

Table A-1. Retrieval Rates - LATA.

Simulant	Test parameters	Volume retrieved, ft ³	Retrieval rate ^(a) , ft ³ /h	Volume of water used/ volume of waste retrieved ^(b)
Hardpan composition #1	Nozzle size: 1.25-in.-diameter Pressure ^(c) : 92 psi Sluicer flow ² : 443 gpm	59.9	49.2	72.2
Hardpan composition #2	Nozzle size: 1.00-in.-diameter Pressure: 110 psi Sluicer flow: 443 gpm	6.0	1.5	1668.6
	Nozzle size: 1.25-in.-diameter Pressure: 91 psi Sluicer flow: 443 gpm	1.0	0.3	14333.4
Saltcake composition #1	Nozzle size: 1.00-in.-diameter Pressure: 110 psi Sluicer flow: 443 gpm	29.0	32.8	76.7
	Nozzle size: 1.25-in.-diameter Pressure: 90 psi Sluicer flow: 440 gpm	93.8	17.6	200.8
Saltcake composition #3	Nozzle size: 1.00-in.-diameter Pressure: 112 psi Sluicer flow: 314 gpm	30.0	51.4	49.0
Saltcake Composition #4	Nozzle Size: 1.25-in.-diameter Pressure: 95 psi Sluicer Flow: 452 gpm	100.0	461.5	7.9
<p>(a) Overall retrieval rate - no downtime included.</p> <p>(b) Volume of water used is that measured during retrieval operations. Sluicer systems typically use recirculated waste slurry; thus the total new process water may be zero.</p> <p>(c) Average over time sluiced.</p>				

This page intentionally left blank.

APPENDIX B**ARD Vehicle Retrieval System (Track 2) - Integrated Testing**

Test Report: HNF-MR-0534, 1997, *Task 5 Test Report: Demonstration of Low-Pressure Confined Sluicer and Vehicles for SST Tank Waste Retrieval at Hanford*, ARD Environmental, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

ARD Environmental, Inc., conducted tests to resolve issues associated with using a confined sluicing end effector that is deployed by wheeled and tracked vehicles. Most tests were conducted by ARD in their Laurel, Maryland, facility with an auxiliary testing site at Southern Maryland Machine in Deale, Maryland. All retrieval equipment systems tested by ARD were near the full-scale size that ARD would propose for cleaning out a single-shell tank (SST) at the Hanford Site.

Technology Description. ARD tested two hydraulically driven deployment platforms: 1) an ARD standard equipment "two-track" crawler vehicle (equipment designation "XT110") designed for cleaning deeper sludge and sediments accumulations from tanks and ponds and 2) a newly developed "wheeled vehicle" ("Big Wheels"), having four independently driven wheels mounted on a pivoting frame assembly (Figure B-1). Both vehicles are hydraulically operated with a modular design that allows the flexibility of mounting a variety of auxiliary devices (in this case, a confined sluicer). The sluicer on each vehicle was mounted on hydraulic arms that allowed the sluicer head to be moved in a variety of positions on the waste surface for effective waste removal and also allowed some washing of vertical walls close to the vehicle. The two tracked vehicles with an attached sluicer head are similar in length (59 and 57 inches), but vary slightly in width (28 and 36 inches) and height (30 and 24 inches).

The ARD low-pressure confined sluicer consists of an external shroud, suction pipe, and nozzle manifold. The external shroud is 24 inches wide, 8 inches deep, and 12 inches high. A central 3-inch-diameter suction pipe is inserted into the shroud. Fourteen water nozzles are arranged on a manifold around the inside of the shroud, which is used to minimize spray and provide suction path for water scavenging with the eductor. The nozzles point downward at an angle of 22.5 degrees to the mount axis and direct the streams of water that will dislodge and mobilize waste material. Water was provided at 200 gallons per minute and 400 pounds per square inch through two 75-horsepower centrifugal pumps connected in parallel. Suction at the shroud inlet was generated by a self-priming centrifugal pump.

The in-tank component weight of the tracked vehicle is about half that of the wheeled vehicle (500 versus 750 pounds). An umbilical consisting of hydraulic hoses for powering the vehicle hydraulics, pressurized water hoses for sluicer and eductor operation, and a 3-inch-diameter waste conveyance hose were attached to the rear of each vehicle.



Figure B-1. ARD Remote Wheeled Vehicle

Testing Focus Areas

Four major test phases were conducted to resolve the issues associated with using this waste retrieval system in an underground storage tank:

- Deployment and Retrieval - Demonstrate the ability to deploy and retrieve the wheeled vehicle through a mockup riser, land on the surface, and move freely with the umbilical attached.
- Mobility - Demonstrate the mobility of each vehicle to negotiate rough terrain and recover from burial in a pit.
- Sluicing - Demonstrate the ability of each vehicle system to dislodge and convey waste simulants.
- Decontamination - Demonstrate the ability to decontaminate each vehicle for maintenance or reuse.

Test Results

Deployment and Retrieval. The wheeled vehicle was successfully deployed and retrieved through a 38.5-inch-diameter mockup riser with 1-inch clearance to the vehicle cross-section. A simple design modification to the wheel profile will allow deployment through the targeted 36-inch-diameter riser. The vehicle was successfully landed, driven 50 feet from the riser, driven back to the riser, and retrieved through the riser. Although the landing was done on a flat surface, it appears that the vehicle should be capable of deployment on variable terrain with slopes up to 45 degrees. Some remote operations were demonstrated using a camera and video monitor while the vehicle was deployed and retrieved through the riser section. Deployment and retrieval tests were not conducted on the tracked vehicle because success with the larger wheeled vehicle implied success with the smaller tracked vehicle.

Mobility. The wheeled vehicle negotiated conditions that stopped the tracked vehicle. It appears that this wheeled vehicle, using its independent four-wheel drive and demonstrating the ability to recover from failures such as side tipping using the axle articulation capabilities, may provide superior performance over a tracked vehicle in dislodging and breaking up material. Although the tracked vehicle was generally easier to steer than the wheeled vehicle, maneuverability was not a critical parameter. The ability to lift either rear wheel further improves the steering of the wheeled vehicle. Trailing an umbilical behind the vehicle, either on the ground or in the air, did not significantly impact the ability to drive the vehicle. However, the complexity of the current control system in the wheeled vehicle needs to be redesigned to permit simpler controls for the operator. Mobility issues that should be pursued further include an assessment of the ability of the vehicles to recover from rollovers and holes, the relationship of tread design to traction, and evaluation of mining strategies for various situations including conditions that may inhibit vehicle mobility.

The primary mobility tests were performed by driving the vehicle on earth terrain with up to 30-degree slopes and into a pit approximately 2 feet deep, 5 feet wide, and 8 feet long. Both vehicles negotiated the 30-degree slope and flat terrain without difficulty. The wheeled vehicle had some erratic control problems during this initial testing because a hydraulic flow limitation resulted in a one-third reduction of rated motor drive torque; later testing with this flow limitation eliminated most of the erratic control problems.

A recovery from a stuck condition was tested by burying the vehicle in the earthen pit under approximately 10 cubic feet (1,200 pounds) of earth material. In the attempt to free itself from the dry pit, the tracked vehicle shed much of its earth load but failed to climb out of the pit. The tracked vehicle was jammed repeatedly with small rocks in its tracks, which were successfully unjammed. However, a very hard object in a track creates a failure mode from which recovery might prove difficult. Where the tracked vehicle was unsuccessful in recovering from a stuck condition, the wheeled vehicle was able to free itself from possible harsher

conditions when the pit was filled with rainwater. The tracked vehicle appears to have an edge over the wheeled vehicle for maneuverability; overall, however, the wheeled vehicle's mobility and its ability to recover from a failed condition appear to be much better.

Sluicing. The sluicer, deployed on either vehicle, proved capable of breaking up and dislodging test simulants, although the retrieval rate was significantly lower for the hard waste simulants than the soft simulants. The articulation of the sluicer could be further refined to allow more flexibility for positioning against vertical and horizontal surfaces. In general, waste conveyance at the sluicer head was not effective because the complexity of the waste field made system suction difficult to maintain. Complex waste fields are expected to be encountered frequently in the Hanford tanks. Improved sluicer performance may be obtained by the addition of more nozzles with adjustments to flowrate and pressure. Other conveyance mechanisms, including water-jet eductors and air conveyance systems, should be studied. Long-term testing is needed to determine realistic production rates and to help develop an operational strategy and procedures. The mobilization and conveyance process tested using sluicing can be effective if sufficient water can be used and if the waste simulant can be mobilized to a separate pump.

Material removal rates from sluicing at 400 pounds per square inch and approximately 200 gallons per minute were not determined; however, the sluicer was able to dislodge all materials. The sluicer required 15 minutes to penetrate 8 inches in saltcake composition #1 and 12 minutes to penetrate 12 inches in saltcake composition #3. During sluicing activities, very little of the injected water or dislodged and diluted simulants were captured by the system, as indicated by large amounts of free water flowing from beneath the simulant and escaping at the surface. Effective water scavenging by the suction pump occurred only when the sluicer was buried in solid simulant with no cracks or fissures and carefully balanced with the incoming flow to maintain the pump suction. Had a suitable pump been installed in the bottom of the waste field and the water level been allowed to rise sufficiently to provide prime, the water and dislodged simulants would have been conveyed from the test tank. The grooves cut by the water jets indicate that keeping the sluicer in motion is a more effective means of dislodging material than the "cookie cutter" approach. The measured static thrust load from the sluicer jets is 177 pounds.

When the sluicer was mounted on a vehicle, simulants were dislodged and conveyed much the same as if the sluicer were attached to a backhoe. Ineffective water scavenging was encountered here as well. Material that broke into lumps was crushed by the vehicle or further reduced using the sluicer. The wheeled vehicle itself could be used as a means of dislodging and breaking up the simulants by operating the front and rear wheels in opposite directions, which tends to keep the unit stationary while grinding material beneath the wheels with their aggressive treads. The inability to continuously scavenge the water and simulants prevented any meaningful measurement for determining production rate. Hardpan was broken up successfully, and the production rate for that material was at least five times that of some saltcake simulants.

Decontamination. The mechanical complexity of the tracked vehicle made it much more difficult to decontaminate than the wheeled vehicle. The tracks of the tracked vehicle were the most difficult area to decontaminate, and redesigning the track system to provide for better decontamination is inherently more complex than the wheeled vehicle. A better method of evaluating the decontamination process must be developed because visual inspection misses hidden areas, and weighing the small amount of residual waste is too crude to provide useful results. It is recommended that detailed decontamination testing be done on equipment design as it progresses.

Following the mobility tests, both vehicles were suspended from hooks and decontaminated (in this instance the contamination was mud and dirt) by washing with a pressure washer held outside the envelope of the vehicle to simulate spray nozzles in a decontamination chamber. Bulk contamination was easily removed, but residual material was more difficult to remove, particularly in areas where visibility was difficult. On the tracked vehicle, cleaning the tracks was the most difficult task, and some material was impossible to remove. The wheeled vehicle was generally easier to decontaminate, although the hydraulic hose bundle, the region around the sluicer lift arms at the motor shaft, and the chassis boxes were difficult to decontaminate. Weighing the vehicle before and after decontamination showed that 37 pounds of material were removed; it is estimated that 2 pounds of material remained. The wheeled design concept lends itself to booting, which would greatly reduce the number of sites where contamination could be trapped.

This page intentionally left blank.

APPENDIX C

Magnox Arm-Based Retrieval System (Track 3) - Integrated Testing

Test Report: HNF-MR-0538, 1997, *SNAKES Manipulator and ARD Sluicer Testing*,
Magnox Electric PLC for Fluor Daniel Hanford, Inc., Richland, Washington.

A team consisting of Magnox Electric PLC and ARD Environmental, Inc., conducted tests to resolve issues associated with deploying a long-reach manipulator with a sluicing end effector. Tests were conducted by Magnox in the United Kingdom to measure dynamic characteristics of a Magnox Electric multi-link, hydraulically actuated manipulator arm. Tests were undertaken in ARD's Maryland facility to measure the operational performance and loading forces from a low-pressure confined sluicer.

Technology Description. Magnox Electric has had a range of heavy-duty, hydraulically actuated, multi-link manipulators (designated by Magnox as SNAKES) in service for the nuclear power industry for more than 10 years. The unit used for this series of tests has 16 degrees of freedom, a horizontal reach of 17 feet 6 inches, and a payload of 200 pounds force at full extension (see Figure C-1). The manipulator arm is made of nine links and extends out of the manipulator support tube under the control of a vertical drive. Each link is hydraulically powered by an independent supply to avoid interaction between circuits during operation. The individual link controllers incorporate a "position hold" feature to automatically restore the joint position to a preset value. This feature adjusts to the effect of slow load changes (such as from a waste retrieval end effector), small hydraulic leakage, and thermal expansion effects. Because redundant degrees of freedom are used, the overall

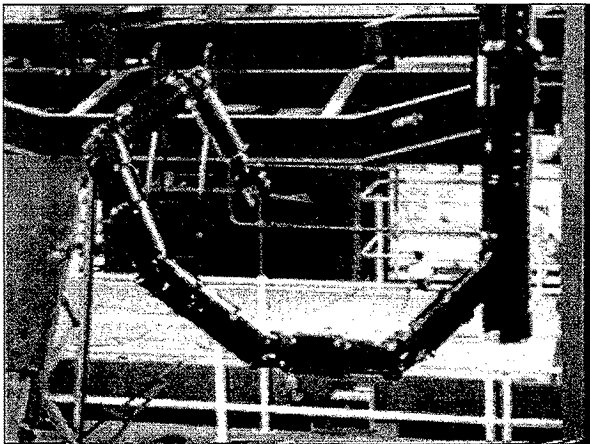


Figure C-1. Magnox SNAKES Manipulator

configuration provides significant dexterity for reaching around in-tank hardware. The retrieval deployment system tested by Magnox was one-third the size required for arm deployment into a single-shell tank from a centrally controlled riser.

The ARD low-pressure confined sluicer consists of an external shroud, suction pipe, and nozzle manifold and weighs about 400 pounds. The external shroud is 24 inches wide, 8 inches deep, and 12 inches high. A central 3-inch-diameter suction pipe is inserted in the shroud. Fourteen water nozzles are arranged on a manifold around the inside of the shroud. The nozzles point downward at an angle of 22.5 degrees to the mount axis and direct streams of water to dislodge and mobilize material. Water was provided at 200 gallons per minute and 400 pounds per square inch through two 75-horsepower centrifugal pumps connected in parallel. Suction at the shroud inlet was generated by a self-priming centrifugal pump.

Testing Focus Areas. To characterize its structural capacity, the manipulator arm was subjected to multi-directional impulse excitation to determine manipulator stiffness, natural frequencies, damping values, and mode shapes. A baseline test, conducted with the manipulator fully extended in a horizontal attitude, was conducted to establish a basic understanding of the dynamic response of the arm; and to formulate a sensitivity study of changes expected during operation, including payload, arm configuration, and force level.

The sluicer was mated to a backhoe to simulate installation on a long-reach arm, and tests were performed to determine the forces generated and the effectiveness of the sluicer. To determine the effectiveness of the sluicer in mobilizing and removing waste, tests were conducted on saltcake and hardpan 1) with the sluicer blocked to determine the maximum forces generated and 2) with the sluicer suspended to determine reaction forces.

Test Results. The tests were conducted in two independent phases: dynamic testing of the manipulator arm and performance testing of the sluicing end effector. The test results for the arm and end effector are presented separately, followed by a discussion of their potential compatibility.

Manipulator Arm - The manipulator arm static stiffness, determined from the measured deflection during the addition and subsequent removal of incremental loads at the tool post, is presented in Table C-1. These results show significant tolerances, particularly along the axis of the arm, which correspond to the load increasing and load decreasing. This difference is caused by hysteresis in the rig mounting, not in the arm.

Table C-1. Manipulator Arm Static Stiffness.

Load Direction	Along the arm axis		In the vertical plane	
	+X	-X	+Y	-Y
Stiffness lbf/in	2600±340	1100±40	47±0.6	45±6.9
Stiffness N/mm	460±60	195±7	8.2±0.1	7.8±1.2

The stiffness in the direction of the arm's length is higher in compression than tension. In the vertical plane, the stiffness of the arm is nearly constant in both directions and much lower than along the arm's length. The stiffness in the vertical plane is relatively low in both directions. Examination of the frequencies in the baseline test suggests that impulses along the axis of the arm have excited frequencies at 1.5, 3.3, 30, and 35 Hz, which correspond to the natural frequencies in the vertical plane. Whereas, frequencies at 19, 30, and 53 Hz correspond to those transverse to the axis of the arm. Increasing the payload from 10 kg (22 lb) to 32 kg (70 lb), and 62 kg (136 lb), progressively reduces the fundamental natural frequency (up to 13%) in the vertical. However, this same addition of mass did not affect all natural frequencies in the same manner and had the effect of increasing some of the frequencies transverse to the axis of the arm.

Sluicing End Effector - During the tests on saltcake and hardpan, significant thrust loads were required to prevent excessive leakage at the sides of the sluicer. These thrust loads induced by the backhoe peaked at over 3,000 pound force but were not sufficient to prevent all leakage. Thrust loads were required to overcome resistance from the surrounding material as the sluicer was driven into it. During the "blocked shroud" tests, the reaction forces increased further because of pressure buildup within the shroud. Here, the pressure reached 25 pounds per square inch with a thrust load of 4,280 pound force, at which point leakage occurred (having lifted the backhoe to produce a small clearance between the sluicer and the mat).

The sluicer required 15 minutes to penetrate 8 inches in saltcake composition #1 and 12 minutes to penetrate 12 inches in saltcake composition #3. The breakthrough to the bottom of the saltcake and waste simulant container surface was first evidenced by large amounts of free water pouring out of the waste simulant container from beneath the simulant. In addition, large amounts of free water also escaped at the surface during sluicing. The sluicer was also deployed against hardpan. Material removal rates were not determined, but the sluicer was successful in breaking up some of the hardpan waste simulant.

Manipulator and Sluicing End Effector Compatibility - The sluicer was primarily designed for deployment with a remote vehicle. There is clearly a mismatch in the 200-pound force payload for an arm deployment system and the 400-pound weight of

the sluicer, which will need to be accommodated in the optimization of the sluicer design. Reaction forces from the confined sluicer are more significant, however. The main cause for the high reaction forces is the inability to scavenge the large flow of water from the sluicing nozzles; pressurized water not scavenged will tend to lift the end effector from the surface, which results in high reaction forces and leakage. The sluicer produces relatively large, broadband dynamic forces, which will inevitably excite some of the natural frequencies in the manipulator arm. The fault condition of a blocked suction line could also generate unacceptably high upthrust. These forces depend on the stiffness of the deployment structure. The deflection of a flexible manipulator could release this upthrust pressure, possibly before any damage could occur. The sluicer spray nozzle system has been shown to be effective in breaking up saltcake and hardpan materials, albeit at low efficiencies and with prodigious water loss.

APPENDIX D

ARD Vehicle-Based Retrieval System – (Track 2)
 Alternate Technology Retrieval Demonstrations

Test Report: HNF-MR-0542, 1997, *Alternate Retrieval Technology Demonstrations Program--Test Report, Section 6.0*, ARD Environmental, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

A team led by ARD Environmental, Inc., conducted tests to resolve issues associated with deploying a confined sluicing end effector with a wheeled vehicle deployment device. This demonstration built on earlier work contracted with ARD under the Integrated Testing phase (see Appendix B), but now included more realistic system testing with a completely new improved vehicle system. All tests were conducted by ARD in their Laurel, Maryland, facility. All retrieval equipment systems tested by ARD were mocked up to full scale to model potential use in a single-shell tank (SST) at the Hanford Site.

Technology Description. The retrieval system consisted of a wheeled vehicle deployment platform with a sluicer dislodging system using an array of fixed nozzles (Figure D-1), and two jet eductor pump conveying systems. One system was attached to the vehicle sluicing head, and the second was deployed separately in the low point of the waste field, where water and dislodged material would accumulate. All retrieval system components were assembled by ARD Environmental, Inc., using standard components that require no electrical power in-tank. Tests were conducted using a simulated waste tank mockup that was scaled down to 20 feet in diameter and had simulated waste, in-tank obstacles, debris, a 36-inch riser for tank access, and a decontamination chamber.

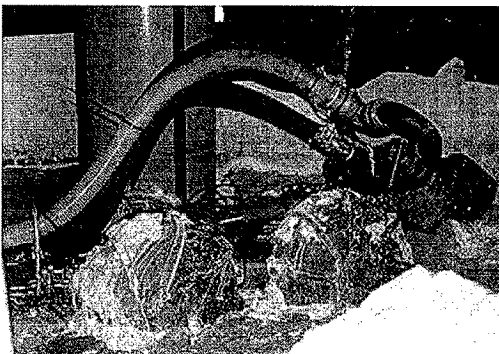


Figure D-1. ARD Wheeled Vehicle During Retrieval.

This vehicle was a new, second generation ARD design which was based on the vehicle originally designed, assembled, and tested by ARD for the Acquire Commercial Technology for Retrieval (ACTR) Integrated Testing series (Appendix B); but with many improvements, including larger hydraulic drive motors for each of the independently driven wheels and a new wheel design for increased traction and mobility. The deployment platform is a four-wheel hydraulically driven vehicle weighing approximately 2,000 pounds. The vehicle is equipped with hydraulic actuators to permit positioning of the sluicer dislodging device over

a wide range of positions. These positions ranged from excavating beneath the vehicle, to washing down walls and other structures up to about 40 inches above the waste field. The vehicle with attached sluicer head is 73.9 inches long, 32.9 inches wide, and 24.0 inches high, with a maximum cross-section of 34.7 inches during deployment through a riser. An umbilical attached to the rear of the vehicle consists of hydraulic hoses to power the vehicle hydraulics, pressurized water hoses for sluicer and eductor operation, and a 3-inch-diameter waste conveyance hose.

The sluicer dislodging system is used to break up the waste and is equipped with 14 sluicing nozzles, each with a nominal diameter of 0.140 inch and 0 degree spray angle. The nozzles are recessed inside an oval cavity shroud, which is used to minimize spray and provide suction for water scavenging with the eductor. The nozzles do not point straight down but are tilted inward at 22.5 degrees so that the jet pattern crosses beyond the bottom of the shroud. The nozzles were set to operate at a total flow rate of 100 gallons per minute at 400 pounds per square inch.

The waste/water scavenging conveyance system consists of two waste scavenging/pumping modules: one scavenges waste and water from the vehicle water jet eductor located in the sluicer head, and the other scavenges waste and water that escapes from the sluicer head using an eductor conveyance system pump located in the low part of the tank mockup waste field. Each of the two eductor pumps uses fluid to provide suction at a rate of 25 gallons per minute at 400 pounds per square inch. The waste was conveyed through a 3-inch hose from each of the pumps into decanting tanks, which were used to settle out waste particles. The decanted waste water was reused for feeding the sluicer head and two eductor pumps using centrifugal pumps to boost the pressure, thus creating a closed-loop system.

The decontamination system consisted of a simulated decontamination chamber attached to the top of a simulated riser with three moveable internal spray rings located within the circumference of the chamber near the bottom, and a manually operated spray wand that could be inserted through various external ports in the chamber. The decontamination chamber dimensions were 84 inches high with an internal diameter of 71.5 inches. Each moveable spray ring had eight nozzles spaced equally around the circumference of the ring pointing inward with the following nozzle orientation: top ring -45 degrees downward; middle ring--0 degrees (horizontal); and bottom ring--45 degrees upward.

Testing Focus Areas. Four major test phases were conducted to resolve the issues associated with using this waste retrieval system in an underground storage tank:

- System insertion and positioning - Demonstrate deployment of a waste retrieval system into an underground storage tank that includes insertion of in-tank systems, impact of insertion on the tank risers, and management of the umbilical during insertion.
- Extended mobility and production rate - Demonstrate the mobility of the in-tank system around rugged surfaces and its ability to operate for extended periods;

determine possible production rates; and demonstrate the ability to operate in the presence of tank waste debris.

- Failure mode demonstrations - Demonstrate the ability to extract a failed vehicle from the tank.
- System retrieval and decontamination - Demonstrate the ability to retrieve the vehicle from the tank for decontamination, maintenance or reuse (Figure D-2).

Test Results. The following test results are specific to the ARD waste retrieval system, which successfully dislodged and conveyed saltcake, hardpan, and sludge waste simulants. The retrieval process consisted of moving and stopping the vehicle over the waste field with the scarifier head in proximity to the waste field. A pivot on the scarifier head allowed the scarifier head to be rotated 90 degrees in both directions in the vertical plane. A free-water scavenging eductor, separate from the vehicle eductor, was placed in the low spot of the waste field to pick up water escaping from the vehicle eductor chamber. The mining strategy was to 1) clear a path to the free-water scavenging eductor by sluicing and excavating and 2) attempt to move waste and water along that path. Isolated pockets of waste and water were removed by the vehicle scavenging eductor. The retrieval rates achieved during testing with saltcake, hardpan, and sludge are provided in Table D-1.

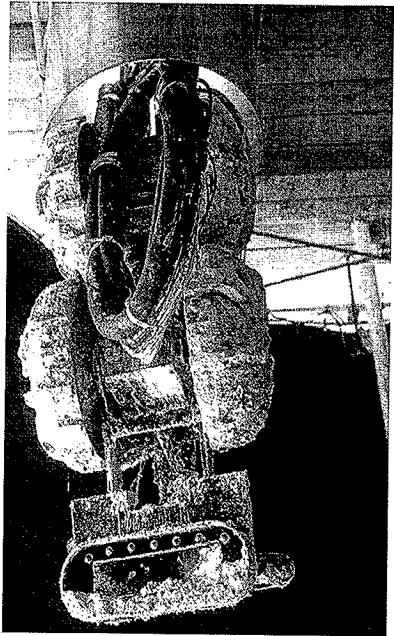


Figure D-2. ARD Vehicle During Retrieval for Decontamination Testing.

The retrieval rates for the higher-strength waste simulants were low because the 400 pounds per square inch nozzle pressure did not dislodge this material very effectively. It is recommended that high-pressure capability be added to the sluicer system to deal effectively with higher-strength waste.

Before the onset of testing, a test plan, including the testing method, key data requirements, and issues that would be addressed, was submitted.

Table D-1. Retrieval Rates - ARD.

Simulant	Test parameters	Volume retrieved, ft ³	Retrieval rate, ^(a) ft ³ /h	Volume of water used per volume of waste retrieved ^(b)
Hardpan composition #2 and sludge	Pressure: 400 psi Sluicer flow: 100 gpm Eductor flow: 25 gpm Rotational speed: NA Traverse speed: Varies Path width: 21 inches	20.6	32.4	13.0
Saltcake composition #3		38.9	5.2	79.0
Saltcake composition #4		52.4	31.2	12.0
(a) Average value.				
(b) Volume of water used is that measured during retrieval operations. Total volume of water used is much less because all water was recirculated after decanting and could be zero in some cases.				

Several hardware-related failures occurred during the demonstration testing but are mainly attributed to cost-cutting moves to minimize overall cost and maximize testing. The remote conveyance system pump had two sealing disc failures attributed to debris: 1) pea gravel lodged in the disc and 2) a small stone lodged in the eductor motive water nozzle caused a reduction in pump capacity. The remote conveyance system pump was not designed for this application; however, harder replacement sealing discs are available and are expected to work better. A leaking vehicle motor seal was attributed to case drain lines that were too small; a replacement seal and larger drain lines appeared to fix the problem. Some of the umbilical rubber hose sheathing was cut quite deeply either by the aggressive action of vehicle wheels driving over the hoses, or by the high pressure spray from the decontamination spray nozzles. The umbilical would be improved during actual in-tank operation by having a robust sheath over the umbilical hoses and a tensioned power umbilical reel that would manage the umbilical near the vehicle. On two occasions the vehicle became stuck and had to be removed manually. Minimizing the wheel spacing, allowing full vehicle rotation, and sluicing the waste around the vehicle to free itself are expected to alleviate the stuck vehicle problem.

The ARD design team is considering the following system design enhancements to refine the system and prepare for possible tank deployment. The sluicing system would be capable of injecting high-pressure water for effective removal of the harder waste simulants. The umbilical attachment would be relocated from a solid stinger off the back of the vehicle to a pivoting joint on the top of the vehicle. The remote conveyance pump would be replaced by a pump that can handle larger debris. The vehicle wheels on each side would be moved closer together to keep vertical obstructions from getting between the wheels. The umbilical would be sheathed and have a powered tensioning system to protect the umbilical hose and minimize contamination traps. Contamination traps would be removed (e.g., the cavity at the top of the vehicle). Table D-2 summarizes the progress made in addressing these issues during the course of testing.

Table D-2. ARD Vehicle-Based Waste Retrieval System Issues.

Issue Addressed During Testing	Status
Tank Access	This retrieval system requires a 36-inch-diameter riser at ANY location on top of the tank.
Deployment	Deployment of the in-tank hardware was without incident. The secondary conveyance module, not attached to the vehicle, had to have the sluicer discharge hose attached manually. A fitting for remote make and break will need to be found or designed for actual in-tank operations.
Mining Strategy	Moving waste continually from the high locations in the tank to the lowest, where the second remote conveyance unit was located, appears to be an effective mining strategy and minimizes standing water in the tank. The aggressive tread on the vehicle wheels and the ability to drive the wheels in opposite directions allowed a grinding action on the harder waste to supplement waste dislodging. The issue of how to deal with tank debris is still open. The waste field for this test included distributed debris, but testing was ended before this debris was encountered.
Waste Retrieval	Waste removal rates varied considerably. Soft materials were easily retrieved but hard material much more difficult. Retrieval of hard materials could be improved by adding high pressure capability to the sluicer and equipping the vehicle wheels with a more aggressive tread. A total of 11.9% of the waste field was removed during testing.
Water Scavenging	Recirculation of water without a filter was demonstrated using a simple decanting process for this 400-psi system; this greatly minimizes the volume of water that would be radioactively contaminated. Standing water on the order of several inches was observed during testing, but operation of the eductors could draw the water down only to nearly dry. The vehicle eductor was effective in removing pooled water and waste wherever they were encountered; however, it was generally not possible to remove water as it was injected by the sluicer. Any ventilation of the shroud would result in air being taken up by the eductor, not water or waste. When the shroud was buried in the waste and angled properly, it could remove sluicing water almost as fast as it was injected. Tank water level sensors had a slow response time to the standing water observed at times in the tank, indicating very slow water travel through this simulated waste field.
Maneuverability	The vehicle could be maneuvered to any location in the tank. The principal impediment to maneuvering was the umbilical jutting out directly behind the vehicle. Improvements to umbilical system design and layout, and the means of attaching it to the vehicle, would improve vehicle mobility. The vehicle does not appear best suited for small confined spaces and a large number of obstacles.
Positioning	The positioning of the sluicer head was largely dependent on the waste surface on which the vehicle sits. The moveable sluicer head could be tilted in one vertical plane to accommodate some imperfection of the waste surface. The vehicle may not be able to hold position on steep inclines. It appears that the vehicle can position the sluicer head adequately in most cases.
Static/Dynamic Performance	The force from the sluicing operation at 100 gpm at 400 psi did not appear to lift the vehicle or hinder vehicle movement. Vibration does not appear to be an issue.

Table D-2. ARD Vehicle-Based Waste Retrieval System Issues.

Issue Addressed During Testing	Status
Remote Operations	<p>All operation of the vehicle in-tank was done remotely using cameras and was quite successful. Most of the lighting was natural because tests were done above the ground, outdoors, and during daylight. Only one of the tank cameras was equipped with a pan and tilt; it would be desirable to have multiple tank cameras, all equipped with zoom, pan, and tilt, so the operator could view the work face no matter where the vehicle was in the tank.</p> <p>Operator Efficiency - Experienced operators were much more effective at retrieving waste and minimizing water usage. The inexperienced operators used the sluicer water 62.4% of the time, whereas experienced operators used the sluicer water 19% of the time. This is roughly three times the water for similar retrieval rate by an inexperienced operator. Training and experience in operating the equipment are key factors in waste retrieval operations. Operator fatigue did not appear to be a factor in this testing, probably because of the novelty of the situation and the longest run was only 3 hours and 20 minutes.</p>
Reliability, Availability, Maintenance	<p>Recovery from Failure - Moving a stuck vehicle from a waste hole in the tank by pulling on the umbilical was demonstrated even with vehicle wheels locked or with the vehicle lying on its side. Measured line tensions for the test ranged from 775 to 3,480 pounds with maximum riser loadings of 1,195 pounds horizontal and 430 pounds vertical. An actual tank that is bigger than the test tank may have higher tensions and loads than observed in this testing. The vehicle was able to right itself when tipped on its side. The four independently driven wheels produce redundancy in the drive mechanism. Recovery of the vehicle from around in-tank objects or deep holes with lips may be a problem. The decontamination process appeared to clean the vehicle very well using water at 1,000 to 3,000 pounds per square inch. Waste material was found trapped in the umbilical hoses and on the top vehicle cavity; these dose traps could most likely be removed by modifying the design. Some waste material was observed to be thrown upward into previously cleaned areas and on the walls of the decontamination chamber above the spray rings. This may be remedied by repeated rewashing of the vehicle and adding a system to wash the upper chamber walls. Operator visibility of the equipment during its decontamination process and inspection afterward is expected to be an issue that will need to be resolved.</p>
Tank Safety	<p>Flammable gas - The entire in-tank retrieval system was hydraulically driven. The only in-tank systems expected to require electrical power are the vision systems consisting of lights and cameras. All in-tank components with potential for contacting a metal surface inside the tank could be made of non-sparking material.</p>
Cost	<p>The cost of the in-tank components may be low enough that these components could be left in the tank for disposal instead of being retrieved for reuse or separate disposal.</p>

APPENDIX E

**ESG Vehicle-Based Retrieval System -
Alternate Technology Retrieval Demonstrations**

Test Report: HNF-MR-0544, 1977, *Hanford Tanks Initiative Vehicle-Based Waste Retrieval Demonstration Report Phase II, Track 2*, Section 6.0, ARD Environmental, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

A team led by Environmental Specialties Group (ESG), LLC, conducted tests to resolve issues associated with deploying a medium-pressure confined sluicing end effector with a tracked vehicle deployment device. All tests were conducted by ESG in their Holden, Louisiana, facility. All retrieval equipment systems tested by ESG were at full scale to model potential use in single-shell tanks (SSTs) at the Hanford Site.

Technology Description. ESG developed a vehicle-based waste retrieval system using the H&H Pump and Dredge Company TracPump™ as the main deployment component.¹ This retrieval system consists of in-tank and out-of-tank systems to deploy, mobilize, and transfer the waste out of SSTs at the Hanford Site. The TracPump has been used to clean out various tanks, piping systems, ponds, and sumps (Figure E-1). It consists of a hydraulically driven pump and waste mobilization equipment mounted on dual hydraulically driven tracks. The tracks have been designed to maneuver in all types of waste from sludge to saltcake.

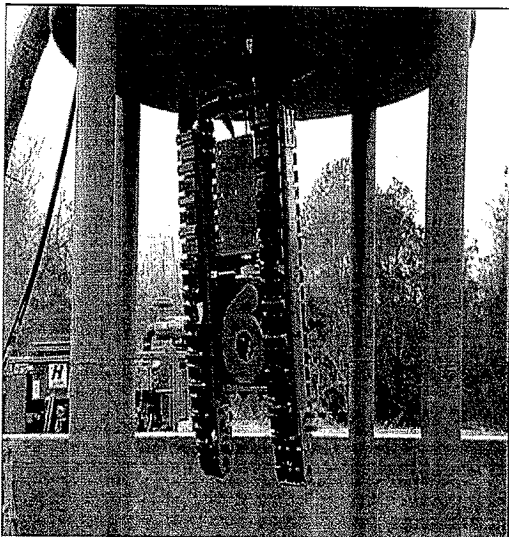


Figure E-1. Deployment of TracPump.™

The in-tank vehicle system consists of the TracPump and assorted interchangeable tooling designed for dislodging waste, removing foreign objects, or deploying waste sampling and characterization systems. The platform may be fitted with a variable-height grinding tool, water-jetting assemblies, rotating cutter heads, or mechanical

¹TracPump is a trademark of H&H Pump and Dredge Company.

arms. The high-pressure water tool package consists of an oscillating header with various types of nozzles. Oscillation of the header is motivated by hydraulic motors, and position of the tool is controlled by hydraulic cylinders. The high-pressure water tool package is capable of dislodging all types of waste found at the Hanford Site. The umbilical consists of hydraulic supply and return hoses, water supply hose, waste discharge hose, and control lines. The TracPump vehicle weighs approximately 1,000 pounds and is approximately 96 inches long, 28 inches wide, and 15 inches high when fully deployed. The base TracPump vehicle was designed to access a tank through a 36-inch-diameter riser, and the capability to fold up for access into a 24-inch-diameter riser.

The out-of-tank systems are housed in a decontamination chamber referred to as the Decontamination Containment Capture Vessel (DCCV). A full-scale mockup of the decontamination chamber was constructed for testing and development (see Figure E-2) and acts as the primary containment barrier for operation and maintenance of the TracPump vehicle system. The TracPump vehicle and umbilical hose are deployed into and retrieved from the tank by hydraulic winches located in the decontamination chamber. The decontamination chamber is equipped with an umbilical apron for storing the umbilical after waste retrieval or during TracPump vehicle maintenance. Decontamination spray jets designed to operate at over 30 gpm and 20,000 psi are installed at numerous locations on the decontamination chamber shell interior; this is the primary decontamination technique to be used in preparing for maintenance. These spray jets will be used to wash the TracPump vehicle assembly as it is retrieved into the decontamination chamber, which contains gloveports and viewing windows to facilitate maintenance of the TracPump vehicle system. The decontamination chamber also has the ability to back flush a clogged discharge hose in the event of system plugging.

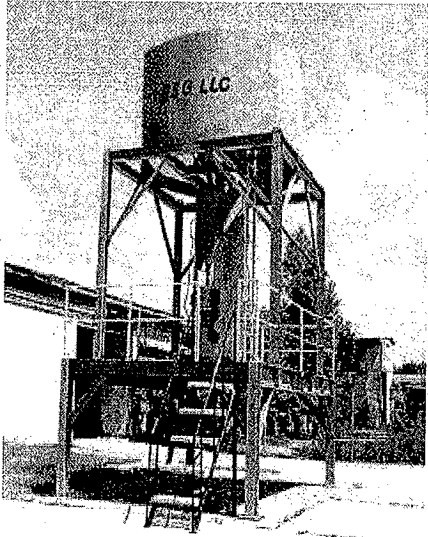


Figure E-2. Decontamination Containment Capture Vessel.

Testing Focus Areas. As the TracPump vehicle is a proven piece of industrial equipment, the bulk of the testing focused on refining the retrieval, containment, and maintenance requirements for the retrieval of tank waste at the Hanford Site. The testing can be classified in the categories of in-tank and out-of-tank.

In-tank testing focused on determining equipment modification requirements to the existing TracPump vehicle configuration. The following main areas were addressed:

- Testing of various types of retrieval tool packages on three types of simulated tank waste to determine optimum configurations
- Determining retrieval rates
- Testing of the maneuverability and control of a TracPump vehicle in a simulated tank environment
- Determination of optimum tread design for anticipated terrains that will be encountered in the SSTs at the Hanford Site
- Determination of required design modification to configure the vehicle to operate in the contaminated environment of a tank.

The out-of-tank testing focused on developing equipment and system requirements for the deployment, retrieval, containment, and maintenance of the TracPump vehicle in a typical Hanford Site tank environment. The following main areas were addressed:

- Development and testing of the decontamination chamber
- Determination and testing of the decontamination equipment and requirements
- Deployment and retrieval of the TracPump vehicle in and out of the decontamination chamber
- Determination of equipment requirements to maintain the TracPump vehicle during operation.

The overall program focus was to develop a deployable and maintainable retrieval system for use in a typical Hanford Site waste tank.

Test Results. A total deployment, retrieval, and maintenance system was tested by ESG during this program. The waste simulant retrieval tests successfully retrieved waste from three trays of each simulant type (sludge, hardpan, and saltcake) in plywood containers approximately 4 feet wide, 60 feet long, and 1 foot deep. Maneuverability was demonstrated in a cross-section mockup of a full-scale 75-foot-diameter SST with vertical obstructions. A quarter section of the tank that was filled with a random mixture of hardpan and saltcake waste simulants. Table E-1 provides retrieval rates.

Table E-1. Retrieval Rates - ESG

Simulant	Test Parameters	Volume Retrieved, ft ³	Retrieval Rate, ^(a) ft ³ /h	Volume of Water Used per Volume of Waste Retrieved
Wet sludge	Pressure: 10,000 psi Sluicer flow: 28.2 gpm	63.0	312.1 (64)	0.3
Hardpan composition #2	Rotational speed: NA Traverse speed: Varies	41.0	339.9 (65)	0.3
Saltcake composition #1	Path width: 15 inches	7.5	19.8 (16)	21.7
Saltcake composition #1	Mechanical tool ^(b)	Unknown	8.9	Not applicable
(a) Overall retrieval rate - includes pumping time and mining time only. The retrieval rate in () includes the additional estimated downtime for such things as maintenance.				
(b) Mechanical tool does not require water for dislodging, but water may be required for conveyance, depending on the system used.				

Several design improvements were identified during testing. Some were implemented immediately, and some will be implemented during further development. Many design modifications need to be completed on the equipment before it could be installed in the tank. Mechanical dislodging tools were generally not effective in hardpan and wet sludge because of waste materials caking on the tools and rendering them ineffective. Decontamination and maintenance areas still need to be addressed, but the design size and fit to the tank appear to be viable. The cam and groove coupling used to attach the umbilical to the pump discharge failed; a fitting capable of withstanding in-tank loads will need to be selected. Retrieval of the umbilical uncovered some minor problems with umbilical storage and mechanical interference that appear solvable with some minor design modifications.

Lessons learned during the course of this testing will result in numerous design modifications to the system. There were no failures in the pumping system; the pump on the TracPump vehicle system was able to transfer heavy sludges and solids over long distances. Heads required just a few inches of head to prime, and would pump the tank virtually dry. A design modification to fit the TracPump vehicle system through risers smaller than 24 inches in diameter is being pursued. Table E-2 summarizes the progress made in addressing these issues during testing.

Table E-2. ESG Vehicle-Based Waste Retrieval System Issues.

Issue addressed during testing	Status
Tank access	This retrieval system requires a 36-inch diameter riser unfolded or a 24-inch-diameter riser in the folded condition at ANY location on top of the tank.
Deployment	The TracPump vehicle needs minor modifications to provide more clearance during insertion and retrieval through the 24-inch-diameter riser; two solutions are provided. Analysis indicates that a bundle hose umbilical design is preferred to separate cables because of increased mobility, simpler decontamination, and increased toughness and strength. Umbilical design criteria have been developed, and the preferred jacketing material appears to be polyurethane for its resistance to attack by alkalies, mechanical damage, abrasion damage, and degradation by nuclear radiation. With the bundled umbilical design, ESG recommends a pinch roller rather than a hose reel assembly. The umbilical storage system needs minor modifications to ensure successful retrieval and deployment.
Mining strategy	The mining strategy for the water jet dislodger consisted of moving the vehicle and dislodging device across the waste surface to create a slurry pool of a waste/water mixture. The vehicle advanced at a velocity determined by the material retrieval rate. Water from the water jet tool and dislodged solids were collected in the low point of the waste field. When mining of a section of the waste simulant was complete, the vehicle was moved to the low point of the waste field, and the water jet device was used to agitate the slurry to suspend the solid particles. Make-up water was added to lower the solids concentration below 30% before the slurry was pumped. This process would be repeated until the tank was cleaned. A secondary pump will be required to inject discharge slurry into the 140-pound-per-square-inch gauge recirculation loop.
Waste retrieval	Waste removal rates varied considerably. Soft materials were easily retrieved, but retrieval of hard material took longer. Waste was dislodged at rates from 0.2 cubic feet per meter in saltcake to more than 3 cubic feet per meter in the hardpan and wet sludge simulants. Conveyance pumping rates of 150 gallons per minute to a 70-foot height through 210 linear feet of 3-inch hose were demonstrated. Water jets effectively dislodged all three waste stimulants. Initial testing with mechanical mills and grinders proved to be ineffective for most waste simulants. Further testing with these dislodging devices was not pursued except for the face mill in saltcake, which had about half the retrieval rate of the water jet tool.
Water scavenging	Water usage could be reduced by recirculating the discharge slurry. A recirculation loop could be used to provide further solids processing, such as increasing or decreasing the solids content. The mechanical face mill dislodging process did not require water but would need to have water added to obtain slurry for pumping.
Maneuverability	The TracPump vehicle was able to maneuver and traverse fields of waste simulants and around in-tank risers while dragging a simulated umbilical (consisting of a 5-inch tank car hose attached to the pump discharge and four hydraulic lines required for operation of the tracks); however, waste was not pumped during these tests. This testing indicates that umbilical design will greatly affect in-tank mobility because the measured turning radius of unit was approximately 8 feet. During actual waste retrieval operations in the waste boxes, the TracPump vehicle was maneuvered while discharging through a 4-inch discharge hose.

Table E-2. ESG Vehicle-Based Waste Retrieval System Issues.

Issue addressed during testing	Status
Positioning	The positioning of the sluicer head depended largely on the waste surface on which the vehicle was sitting. The movable sluicer head could be tilted in one vertical plane to accommodate some imperfection of the waste surface. The vehicle may not be able to hold position on steep inclines. In general, it appears that the vehicle can position the sluicer head adequately.
Static/dynamic performance	The force from the sluicing operation did not appear to lift the vehicle or hinder vehicle movement. Vibration did not appear to be an issue.
Remote operations	Review of commercially available remote surveillance equipment and standard industry practices indicates that they appear to be adequate for tank retrieval. Camera requirements and placement were studied, and the strategy of camera placement specific for each tank requires further investigation.
Reliability, availability, maintenance	<p>The ability to store and retrieve a vehicle into the decontamination chamber for maintenance was demonstrated, and the overall concept needs continued review. Expected maintenance tasks were demonstrated inside the decontamination chamber and requirements were established. Several equipment modifications were identified to simplify the maintenance operations. A projected maintenance schedule and spare parts requirements need to be established.</p> <p>The ability of the high-pressure water lance to dislodge a clogged pump discharge hose was demonstrated, and the concept proved to be viable. The insertion point location for the water lance in the discharge line needs to be determined. Procedures need to be established to eliminate a plugged line event, and the water flow path during a plugged line event needs to be addressed.</p> <p>The umbilical design minimizes the possibility of TracPump vehicle overturning in the tank. The tipping point of the vehicle was tested by driving it up an incline ramp and was determined to be greater than 65 degrees, at which point the vehicle lost forward motivational power because of lack of tread contact with the surfaces.</p>
Tank safety	Flammable gas - The entire in-tank retrieval system was hydraulically driven. The only in-tank systems expected to require electrical power are the vision systems, consisting of lights and cameras.
Cost	The cost of the in-tank components may be low enough that these components could be left in the tank for disposal instead of being retrieved for reuse or separate disposal.

APPENDIX F

**Delphinus Arm-Based Retrieval System (Track 3) -
Alternate Retrieval Technology Demonstration**

Test Report: HNF-MR-0543, 1997, *Final Test Report--Demonstration Testing in Support of Track 3 System Waste Dislodging, Retrieval and Conveyance Concepts*, Delphinus Engineering, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

A team led by Delphinus Engineering conducted tests to resolve issues associated with a heavy duty hydraulic manipulator deploying a scarifying end effector. The testing took place on a remote farm in Wellington, Ohio, to facilitate the assembly of a full-scale prototype system. All retrieval equipment systems tested were marked up to full scale to model potential use in a single-shell tank (SST) at the Hanford Site.

Technology Description. The manipulator consisted of a vertical telescoping boom section and a lateral telescoping boom section with a detachable dual arm gripper designed by Eagle Tech (Figure F-1). The jib boom assembly, which extends horizontally, has an overall effective working length of 75 feet, and consists of the primary fixed main boom section and four telescoping stage sections. The jib boom assembly weighs 12,800 pounds. When fully operational, the geometry of the manipulator arm will allow the arm to reach anywhere inside an SST when fully extended through a lateral riser near the side of the tank. The manipulator affixes to, and is supported by, a mobile undercarriage and vertical extend/retract mast assembly. A dual arm gripper is designed to quickly attach/detach from the jib boom and can be customized to accept various types of end effectors for service tasks to be performed within the tank. Engineering studies are being performed to determine the weight of these structures.

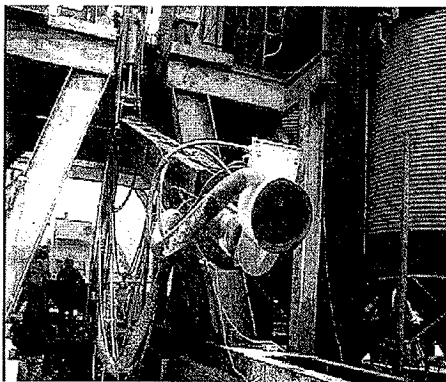


Figure F-1. Manipulator and WALDO End Effector.

For the retrieval tests, waste dislodging was performed by a Waste and Liquid Dislodging Orbiter (WALDO) scarifying device. The WALDO consists of a spin jet nozzle mounted at the center of a containment shroud. A 4-inch-diameter vacuum pipe is attached to the shroud wall of the WALDO scarifier. The water jets are driven by a high-pressure water pump provided by National Liquid Blasting (NLB). The arm is controlled by a host computer

capable of managing up to 12 axes. The arm simultaneously controls the valves, gathers data from the motion sensors, monitors analog throttle input, responds to commands from the keyboard, sets and adjusts movement limits, checks for and reacts to emergency conditions, and displays and records telemetry.

Dislodged waste and the water used for the sluicing operation was retrieved using two separate systems. In one set of tests, the waste was retrieved by suction and discharged into a vacuum truck using a twin-lobe blower that could provide up to 14 pounds per square inch vacuum. In the second set of retrieval tests, a vacuum was used to transfer the waste from the tank to an intermediate holding tank called Conditioning and Transfer System (CATS). CATS consists of a vertical cylindrical shell 20 inches in diameter and 15 feet high. A pump placed at the bottom of the shell is capable of discharging the waste present in CATS. By opening and closing appropriate valves, more water can be added to the waste present inside CATS, and the waste can be recirculated to produce a uniform slurry.

The umbilical management system (Figure F-2) comprises an array of retracting spools in addition to six roller assemblies attached to the vertical and jib boom assemblies. The function of the umbilical management system is to ensure that umbilicals that provide services to the system are easily maintainable, accessible, and serviceable. The umbilical management system also ensures that umbilical lines do not become entangled or severed and that the minimum length umbilical is exposed to the in-tank environment. The types of umbilicals serviced by the umbilical management system include an air, water, and vacuum line; eight hydraulic lines; and low-voltage power lines used to operate the cameras mounted to the manipulator.

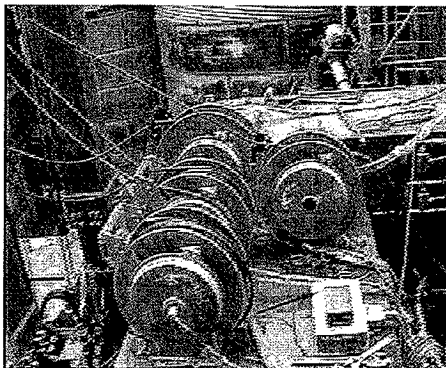


Figure F-2. Umbilical Management Retracting Reels.

Testing Focus Areas. Four major test phases were conducted to resolve the issues associated with deploying the system in an underground storage tank:

- Position Management - Demonstrate the capability of the manipulator deployment system to operate safely within the confines of a tank that contains risers, cables, structural members, and miscellaneous debris.
- Waste Dislodging and Conveyance - Demonstrate the capability of the retrieval system to effectively dislodge various simulated waste types. These tests also evaluated the capability of the system to retrieve and convey waste out of the tanks to

a remote location for storage or processing. Three types of waste simulants were retrieved: saltcake, wet sludge, and dried sludge. The capability of a proposed method of decontamination to effectively remove simulants splattered on the end effector was also demonstrated.

- **Dynamic Response** - Measure the mode shapes and frequencies of the arm structures to determine the compatibility of the arm with excitation sources such as retrieval end effectors. Dynamic testing was performed by placing accelerometers along the arm and then striking the structure with a hammer to produce vibrations.
- **Safe Response** - Demonstrate design features of the system to operate safely during off-normal occurrences. Tests were conducted to measure the dynamic drift of the manipulator and to assess the actions to be performed if the knuckle cylinder failed during tank operations.

Test Results: The system successfully retrieved wet and dried sludge and saltcake simulants. Dislodging and retrieval operations involved blasting the simulant with medium pressure water jets and retrieving the dislodged waste and the sluicing water using a vacuum system. Though a vacuum was deployed throughout the operation, water blasting was used intermittently to minimize the continuous use of water. Typically, blasting was deployed for one minute and turned off. The waste liquid created by the blasting operation was then suctioned off by lowering the scarifying end effector into the pool of liquid, displaying the ability to scavenge water. The blasting operation was again deployed after the removal of the waste liquid. The mining operation continued until the bottoms of the simulant tanks were exposed.

When a conditioning and transfer system (CATS) was used as an intermediate slurry conditioner, the simulants from the tank were pumped into CATS and then discharged by way of an internal pump. The rate of discharge from the slurry conditioner was 9.1, 7.1, and 8.7 ft³/min for saltcake, wet sludge, and dried sludge, respectively. Separate tests were conducted to determine the actual retrieval efficiency of the waste retrieval end effector. The retrieval rate from the scarifying end effector was somewhat lower than the pumping capacity of the slurry conditioner. Retrieval rates are summarized in Table F-1. Before testing began, a test plan, including the testing method, key data requirements, and issues that would be addressed, was submitted.

Table F-1. Retrieval Rates - Delphinus.

Simulant	Test parameters	Volume retrieved, ft ³	Retrieval rate, ^(a) ft ³ /h	Volume of water used per volume of waste retrieved ^(b)
Wet sludge	Pressure: 20,000 psi Flow: 22 gpm Rotational speed: NA Traverse speed: Varies Path width: 6 inches	29.0	435.0	0.4
Hardpan/dried sludge composition #2		37.9	182.4	1.0
Saltcake composition #1		24.0	23.6	7.5

(a) Calculations include unproductive dwell time caused by operator delay.
(b) Although the water was not always on during the retrieval operation, it was assumed to be on because of a lack of data when the water was off. This value is an upper limit value and actual ratio may be lower.

The testing was accomplished essentially as planned, with one exception: the manipulator knuckle joint assembly failed during early testing and had to be redesigned. This modification increased the required riser size for deployment from 36 to 41 inches. Even after this modification, the capacity of the knuckle joint cylinder limited the extension of the arm to 45 feet. Although the knuckle joint assembly could conceivably have been modified again to demonstrate full 75-foot extension, jib boom extension was limited to 45 feet to complete the tests within the time allocated.

The Delphinus team is considering several system design enhancements to refine the system and prepare for possible tank deployment. Modifications are needed to eliminate umbilical management concerns, including rerouting the umbilical through the boom section; using power tensioning reels; and using a single custom, multi-service umbilical line.

Table F-2 summarizes the progress made in addressing these issues during the course of testing.

Table F-2. Delphinus Arm-Based Waste Retrieval System Issues.

Issue addressed during testing	Status
Tank access	Arm requires at least a 41-inch-diameter riser for access. Knuckle assembly must be redesigned to fit within a 36-inch riser. When fully operational, the geometry of the manipulator arm will allow it to reach anywhere inside an SST when fully extended through a lateral riser.
Deployment	Deployment through a riser was not demonstrated but may be included in follow-on testing. Manipulator operation was interrupted more than 10 times as a result of umbilical interferences.
Mining strategy	A cavity in each of the simulant tanks was carved out by guiding the arm within the tank. Changing the angle of the end effector with respect to the waste did not significantly affect dislodging efficiency. Testing indicated that retrieval performance decreased rapidly with standoff distances and that the optimum standoff distance was 1-2 inches. Misting was observed at large standoff distances.
Waste retrieval	To determine the weight percent solids of retrieved simulants and process water, slurry was discharged to a sampling station 40 feet above grade. The results were 10, 32, and 39 weight percent solids for saltcake, wet sludge, and dried sludge retrieval, respectively. To avoid plugging, wet and dried sludge will require water addition before it can be pumped. Large chunks of saltcake were retrieved into the slurry conditioner and were well tolerated by the pumping system. Chunks not-drawn into the pumping station were dislodged manually. Discharge of the slurry conditioner was clogged at one point by dried sludge. The clog was easily removed by applying vacuum or back-flushing with water.
Water Scavenging	For wet and dried sludge, the process water was easily scavenged by plunging the scarifying end effector into low areas of the simulant. This operation was conducted with the water jets off to maximize water scavenging. This maneuver was not possible on saltcake because of the hardness of the material, and some process water could not be scavenged. Design enhancements to the shroud could improve its water containment capability during saltcake retrieval.
Maneuverability	In-tank navigation testing was performed by placing four targets within the working envelope of the manipulator at various elevations and planar locations. The operator successfully moved the manipulator and touched each target. Vertical wall cleaning was also demonstrated.
Positioning	After a safe manipulator trajectory was determined through manual operation, tests demonstrated the ability of the arm to negotiate the same path without operator intervention within an envelope of +/- 4 inches at maximum joints velocities. A tighter envelope (+/- 1) could be achieved with slower joint velocities.

Table F-2. Delphinus Arm-Based Waste Retrieval System Issues.

Issue addressed during testing	Status
Static/dynamic performance	<p>The total horizontal static deflection with 1,180-pound load was 11.5 inches at 45-foot extension. The control system did not include static compensation features.</p> <p>Tests were conducted to determine the distance traversed by the manipulator from a referenced position as the result of inertia after ceasing operations. This distance ranged from 1 inch for slow motion to 10 inches for fast motion. Vibration data were collected and will be analyzed to determine frequencies and mode shapes.</p>
Remote operations	<p>Remote cameras on the jib boom and in the peripheral test field provided feedback to the operator on manipulator position. Depth perception was noted as a problem. Better positioned cameras with zoom, pan, and tilt capabilities may have alleviated this problem to some extent. It was noted that video cameras alone may not be adequate to allow the operator to discern safe routes; laser range finders and mapping systems are needed to facilitate the teach-and-learn process and augment depth perception.</p>
Reliability, availability, maintenance	<p>Sodium-fluorescence was added to the wet sludge simulant to evaluate the success of the decontamination process. At the conclusion of the retrieval demonstration, the end effector was rinsed with 5,000 pounds-per-square-inch water to remove simulant materials. No quantitative data were collected on the effectiveness of the decontamination; however, the end effector did not reveal any fluorescence under black light examination.</p>
Tank safety	<p>No structural damage to the steel simulant tanks was detected because of collisions or water jet bombardment.</p> <p>In the event that a knuckle cylinder failed during waste removal operations, the jib boom could not be operated safely. Three removable pins have been included in the design of the knuckle to allow the vertical boom and mast assembly to withdraw the jib boom from the inside of the tank during this failure condition. This feature was described but not tested.</p>
Cost	<p>It is expected that the in-tank portion of the manipulator may be more expensive than a GreyPilgrim cable tensioning type manipulator, but it still may be more cost-effective to leave the arm inside the tank than to decontaminate the structure for reuse. Final determination will require tank closure requirements.</p>

APPENDIX G**GreyPilgrim Arm-Based Retrieval System**

Test Results: HNF-MR-0545, 1977, *Hanford Tanks Initiative Alternate Retrieval System Demonstrations--Final Report of Testing Performed by GreyPilgrim LLC*, Section 6.0, GreyPilgrim LLC for Fluor Daniel Hanford, Inc., Richland, Washington.

GreyPilgrim led a team to resolve issues associated with a cable-driven manipulator deploying a scarifying end effector. The tests were conducted in a National Institute of Science and Technology (NIST) facility in Gaithersburg, Maryland. The arm used for these tests is not long enough to reach all points in a 75-foot-diameter tank, which would require at least a 75-foot long arm if deployed through an off-center riser. The size of the Easily Manipulated Mechanical Armature (EMMA™)¹ manipulator arm used for tests (33 feet) was approximately one-third the scale required for deployment at the Hanford Site and could be economically constructed. Whereas, the high-pressure scarifier end effector was nearly full-scale.

Technology Description. The retrieval system consists of the EMMA™ robotic manipulator provided by GreyPilgrim LLC and the Light Weight Scarifier (LWS) provided by Waterjet Technology, Inc. The EMMA arm is a cable-driven serpentine manipulator system consisting of multiple stages. Cable drive allows the controls and actuation system to be located outside a hazardous tank environment. The EMMA arm used in testing was 33 feet long with a 17-foot horizontal reach capability, 24 inches in diameter, and has 10 degrees of freedom that can be used to curl the arm around tank obstructions (Figure G-1). Weighing 975 pounds, the arm has a demonstrated payload of 100 pounds at full extension. The deployment frame to which the manipulator was attached can be moved vertically through five feet of travel. The length of the individual arm stages was 12, 7, 8, and 6.3 feet for stages one through four, respectively. The scarifier was mounted on an interface bracket on EMMA arm; the angle of the bracket can be changed through a cable actuator, allowing the scarifier to be kept perpendicular to the waste simulant.

¹EMMA is a trademark of GreyPilgrim LLC.

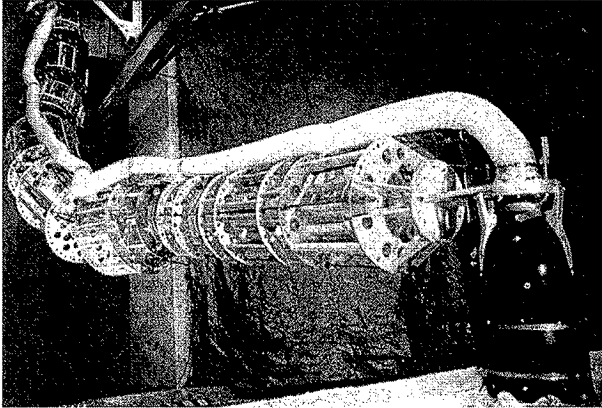


Figure G-1. EMMA Arm With End Effector and Conveyance Hose.

The LWS was developed through a collaborative effort of Waterjet Technologies, Incorporated (WTI) and Pacific Northwest National Laboratory (PNNL). It was funded through the Department of Energy EM-50 Tanks Focus Area. The scarifier uses ultra-high-pressure water jets (up to 50,000 pounds per square inch) as the working fluid to fracture and dislodge the waste. The water jets provide extreme power density to dislodge waste at low water-consumption rates. The scarifier is coupled to an air conveyance system to pneumatically remove the dislodged waste and process water. Two water jets are mounted on a manifold and are rotated by an electric motor to mill a wide channel in the waste material as the scarifier is moved across the surface. The scarifier weighs approximately 55 pounds and is 9 inches in diameter and approximately 19 inches high. The ancillary equipment for the dislodging system includes a high-pressure hose and a 36,000 pounds per square inch diesel-powered high-pressure pump. A conveyance line, a wet/dry separator, a collection hopper, and an air blower comprise the conveyance system.

Testing Focus Areas. Three major test phases were conducted to resolve the issues associated with deploying the system in an underground storage tank:

- **Advanced Stage Testing** - Demonstrate that the EMMA manipulator could provide sufficient stiffness and load-bearing capability to ensure acceptable waste retrieval performance. Because the arm used for the testing was designed and constructed as part of the testing program, it was necessary to understand the mechanics of the arm structure and control system before integrated retrieval testing was attempted. Each component was tested individually and on multiple stages as part of the integration

process. Test data confirmed component sizing, support structure layout, and conveyance hose and end-effector capacity.

- Control System Testing - Demonstrate a simple, intuitive operator interface to the waste retrieval system, the ability to acquire and hold end-effector position, and to achieve motion trajectories. The control system consists of a data acquisition and control computer, joystick controller, and sensory feedback through load cells attached to the control cables. Tests were conducted to determine system performance, pointing accuracy, and dynamic response.
- Integrated Retrieval Testing - Determine system operating characteristics, demonstrate system flexibility over a range of retrieval scenarios, and measure retrieval rates of the integrated system. In this phase, the scarifier end effector was integrated into the manipulator structure, and retrieval tests were conducted using tele-operation on simulated hardpan and sludge waste materials.

Test Results. Using this first-of-a-kind cable-driven deployment system, saltcake and sludge simulant were successfully dislodged and conveyed. The retrieval rates achieved during tests using dried sludge and saltcake are summarized in Table G-1.

The total amount of simulant retrieved was low (less than 16 cubic feet) because retrieval testing focused on the compatibility of the scarifier and manipulator, rather than retrieval of large volumes of simulant. The retrieval rates were somewhat lower than desired, because of several factors, the most important of which was the failure of the scarifier motor speed

Table G-1. Retrieval Rates - GreyPilgrim.

Simulant	Test parameters	Volume retrieved, ft ³	Retrieval rate, ^(a) ft ³ /h ¹	Volume of water used per volume of waste retrieved
Saltcake composition #2	Pressure: 30,000 psi Flow: 2 gpm Rotational speed: 100-300 rpm (erratic)	12.0	10.8	1.5
Hardpan/dried sludge composition #2	Traverse speed: 3.5-4 in./sec. Path width: 7 inches	4	No data	No data
(a) Calculations include unproductive dwell time caused by operator delay. Sludge retrieval rate was estimated.				

sensor. This failure limited the spin rate of the water jets to 300 revolutions per minute. The nominal spin rate for the motor is 600-1,000 revolutions per minute. Test engineers

reduced the translational rate of the arm to compensate for the reduced rate of revolutions, but some efficiency was lost. It is believed that the failure of the sensor occurred during assembly and does not reflect an inherent reliability problem.

Before the onset of testing, a test plan was submitted that included the testing method, key data requirements, and issues that would be addressed.

Two hardware-related failures occurred in the course of development. The coupler design was modified several times to overcome failures caused by high stresses in the material. These modifications appeared to solve the problems; however, full-scale proof testing should ensure design adequacy. In addition, cable conduits frequently became kinked because of the bending required to fit them within the physical constraints of the test facility. These failures required splints to reinforce the damaged areas. In addition, the tension required to overcome friction was higher than should be expected in a deployed configuration. Alternative conduit arrangements are being considered to overcome these failures. Failures during this testing never completely incapacitated the arm, but some movement capability was still available.

Several system design enhancements are being considered by the design team to refine the system and prepare for possible tank deployment. Based on the stiffness and structural integrity of the current arm (at 33 feet), it is believed that the basic design could be scaled up in length (without major design changes) to 40 feet (or more) to access the inside of a 75-foot-diameter SST from a central tank riser less than 24 inches in diameter. The open cross-section of the arm design could be exploited to route conveyance lines and high-pressure hose, which would simplify hose management. Also, because the arm is controlled by cable forces, force control at the end effector could be added using existing sensors. Finally, the control of the arm would be enhanced by the development of the inverse kinematics to relate cable tensions and lengths with arm position.

The LWS is pictured in Figure G-2. Table G-2 summarizes the progress made in addressing these issues during the course of testing.

APPENDIX H

Waste Simulant Information

Waste simulant test materials for all testing described in this report were developed by Pacific Northwest National Laboratory (PNNL) to simulate the range of waste that may be found in a Hanford Site tank. The eight waste simulants (recipes 1 through 8 in Table H-1) are designed to model four different types of tank waste. Simulant recipes are given for wet sludge, hardpan/dried sludge, hard saltcake, and soft saltcake. The specified simulants are made from relatively inexpensive, nonhazardous materials that present no unusual disposal problems. Comparisons of the relevant waste and simulant properties are provided in Table H-2. These comparisons provide the justification for the properties of the specified simulants. In most cases, the simulants are shown to be reasonably similar to the known and estimated waste properties in the relevant respects. The specified simulants cannot be considered validated, however, until more waste characterization and retrieval process data are obtained.

Table H-1. Waste Simulant Compositions and Properties.

Recipe #	Description (Composition #)	Strength kPa (lb/in ²)	Density g/cm ³ (lb/ft ³)	Composition
1	Wet sludge (NA)	3.5 (0.51)	1.65 (103)	66 wt% clay, 34 wt% water
2	Hardpan/dried sludge (Composition #1)	32 (4.6)	1.48 (92.4)	30 wt% plaster, 27.5 wt% clay, 42.5 wt% water
3	Hardpan/dried sludge (Composition #2)	150 (21.8)	1.65 (103)	40 wt% plaster, 22.5 wt% clay, 37.5 wt% water
4	Hard saltcake (Composition #1)	20,700 (3,000)	2.25 (140)	84 wt% K-Mag, 16 wt% water
5	Hard saltcake (Composition #2)	10,300 (1,500)	1.94 (121)	88 wt% K-Mag, 12 wt% water
6	Hard saltcake (Composition #3)	10,300 (1,500)	2.27 (142)	75 wt% K-Mag, 25 wt% water
7	Soft saltcake (Composition #4)	55 (8.0)	1.20 (74.9)	86 wt% salt, 9.33 wt% plaster, 4.67 wt% water
8	Soft saltcake (Composition #5)	10 (1.5)	1.20 (74.9)	95 wt% salt, 3.33 wt% plaster, 1.67 wt% water
clay = kaolin clay K-Mag = potassium magnesium sulfate			plaster = plaster of paris salt = sodium chloride rock salt	

Table H-2. Waste and Simulant Properties Relevant to Retrieval.

Waste type (Recipe #)	Retrieval technique basis	Properties assumed important to retrieval
Wet sludge	Water jet	Shear strength Sensitivity Cohesiveness Density Water-absorption rate
Hardpan/dried sludge	Water jet, mechanical	Shear strength Density Salt dissolution rate*
Hard saltcake	Mechanical	Shear strength Compressive strength Tensile strength
Soft saltcake	Water jet	Salt dissolution rate Salt crystal grain size Bulk porosity Pore connectedness Tensile strength Salt solubility Fracture toughness

*Property not modeled in current waste simulant.

APPENDIX I

Information Sources

Sources for additional information relating to the Hanford Technical Initiative (HTI) programs and testing are listed in this appendix. The HTI programs do not restrict the sharing of any or all of the information related to this test work.

OBTAINING DOCUMENTS

This report and related documents are available free through the Retrieval Analysis Tool (RAT) database listed under the Internet Links below.

Hard copies of publically available documents regarding the Hanford Site can be purchased by contacting:

Public Requests Hanford Documents
Document Service Center
Telephone: (509) 372-2420
Fax: (509) 376-4989
e-mail internet address: public_requests_hanford_docs@rl.gov.

Internet Links of Interest

HTI Homepage: <http://www.hanford.gov/twrs/hti/hti.htm>
Retrieval Analysis Tool (RAT): <http://www2.hanford.gov/ratlib/index.asp>
DOE Storage Tank Remediation: <http://www.tanks.org/>
Hanford: <http://www.hanford.gov/hanford.html>

HTI FY97 RETRIEVAL TESTING SUMMARY AND TEAMS

Integrated Testing

These tests were completed in January 1997. This was the first step in providing partial system demonstration retrieval methods of innovative industry solutions. Contract awards were placed in early September 1996 to:

- Los Alamos Technical Associates of Richland, WA
- ARD Environmental, Inc. of Laurel, MD
- Magnox Electric PLC of Dartford Kent, England

ARD demonstrated vehicle-based systems; LATA demonstrated a sluicer system; and Magnox demonstrated a robotic arm-based system. The Request for Proposals (RFP Number-WA 15104-SJ) was released on July 29, 1996, and many questions from industry were answered in an August 8, 1996, briefing.

LATA Sluicer Retrieval System (Track 1)

- Los Alamos Technical Associates (LATA) - Team Lead
- ARD Environmental Inc.

LATA led the team and provided the advanced sluicer design and had primary responsibility for managing the tasks, for preparing the test plans and reports, and for all necessary analytical work. ARD provided the sluicing nozzles and performed the testing.

ARD Vehicle-Based Waste Retrieval System (Track 2)

- ARD Environmental Inc. - Lead

ARD tested and resolved other issues related to the application of a track and wheeled vehicle systems for waste retrieval. ARD built a wheeled vehicle and used an existing tracked vehicle, both equipped with the confined sluicer, to determine suitability for use in the tanks at the Hanford Site.

Magnox Arm-Based Waste Retrieval System (Track 3)

- Magnox Electric PLC - Team Lead
- ARD Environmental Inc.
- Technical Resources International (TRI)

Magnox tested and resolved other issues related to the application of an hydraulic link arm system for waste retrieval. For testing, Magnox used an existing hydraulic link manipulator called SNAKES with a 17.5-foot horizontal reach. A confined sluicer built by ARD Environmental, Inc., was tested by both Magnox and ARD independent of the arm to determine the range of input loads that an arm may experience and the resulting suitability for use in the tanks at the Hanford Site. TRI provided technical input to Hanford Site tank waste retrieval issues related to tank farm design, engineering, and operational procedures.

Alternate Retrieval Technology Demonstration

These demonstrations were completed in July 1997. This second step featured larger scale demonstrations to begin addressing system-level issues associated with waste removal strategies, decontamination techniques, equipment reliability, safety, and cost. Contract awards were placed in January 1997 with four companies:

- ARD Environmental, Inc. of Laurel, MD
- Environmental Specialties Group (ESG) of Holden, LA
- Delphinus Engineering of Eddystone, PA

- GreyPilgrim of Gaithersburg, MD

ARD and ESG demonstrated Track 2 vehicle-based systems. Delphinus and GreyPilgrim demonstrated Track 3 arm-based systems. The Request for Proposals (RFP Number W-A15120-SH) was released on November 26, 1996.

ARD Vehicle-Based Waste Retrieval System (Track 2)

- ARD Environmental Inc. - Team Lead
- Science Applications International Corp. (SAIC)

The ARD project team tested and resolved issues related to the application of a wheeled vehicle equipped with a unique confined sluicer and pump for waste retrieval. ARD successfully built and tested a wheeled vehicle, as well as an existing tracked vehicle, both equipped with the confined sluicer, to determine suitability for use in the tanks at the Hanford Site. These tests integrated the wheeled vehicle, confined sluicer, and a conveyance pump system to demonstrate system performance in a mock-up tank using a complex simulated waste field. SAIC was responsible for identification and analysis of nuclear safety and other safety issues, operational requirements and issues, regulatory issues, and design review support for the project.

ESG Vehicle-Based Waste Retrieval System (Track 2)

- Environmental Specialties Group (ESG) LLC - Team Lead
- Numanco, LLC - Support Organization
- H&H Pump and Dredge Company - Support Organization

The ESG project team used the patented H&H TracPump™ vehicle, which forms the base platform to mount robotic arms with a variety of end effectors for specific waste retrieval operations. The wide foot print and low center of gravity provides a very stable platform for tools designed specifically for dislodging and conveying tank waste. The TracPump and containment systems can access the tank, dislodge the waste, and mobilize the waste for conveyance, while monitoring and maintaining the integrity of the controls, hoses, and instruments as tested. The design allows for folding the 36-inch wide base to a geometry that will pass through a 24-inch circular opening.

Delphinus Arm-Based Waste Retrieval System (Track 3)

- Delphinus Engineering Inc. (DEI) - Team Lead
- EagleTech

The retrieval system components of the Delphinus team demonstration included a compact, multi-articulating, heavy duty, manipulator arm designed and built by EagleTech consisting of a vertical telescoping boom section capable of extending

vertically into the tank, and a lateral telescoping boom section with detachable dual arm gripper. The system was designed to allow the manipulator arm to reach anywhere inside the tank from a side access riser and to lift 3,200 pounds when fully extended in the most challenging moment loading position. The manipulator design could deploy other end effectors such as an air cutter, vacuum extractor, water cutter, and pumping scarifier. The system design concept uses a mobile, self-propelled bridge to support mast and boom sections for actual tank deployment.

GreyPilgrim Manipulator Waste Retrieval System (Track 3)

- GreyPilgrim LLC - Team Lead
- Waterjet Technology, Incorporated (WTI)
- National Institute of Standards and Technology (NIST), Intelligent Systems Division
- Schilling Robotic Systems

GreyPilgrim LLC has developed and patented a sinuous, hollow-core, long-reach manipulator technology functionally similar to an elephant's trunk. The technology, known as EMMA™, combines strength and agility with the capacity to guide a hose or conduit through which liquids, slurries or particulates can be retrieved. The system integrates GreyPilgrim's EMMA, a mast-mounted serpentine robotic manipulator, with waste conveyance subsystems and end-effectors by Waterjet Technology. Control and sensory hardware and software are jointly developed by NIST and Schilling. Arm insertion and extraction is conceptually designed to be performed by a NIST gantry crane for actual tank deployment.

HTI FY97 RETRIEVAL DEMONSTRATION COMMERCIAL CONTACTS

ARD Environmental, Inc.
9115 Whiskey Bottom Road, Laurel, MD, 20723, USA
Contact: Jim Ridgely
Phone: (800) 969-2731

Business Experience: Services include the cleaning confined spaces such as nuclear fuel pools and containments, storage tanks, large basins and lagoons, cooling towers, wastewater discharge lines, and similar difficult-to-access areas.

Delphinus Engineering Inc.
340 Baldwin Tower, Eddystone, PA, 19022, USA
Contact: David B. Shaffer, Vice-President
Phone: (610) 874-9160

Business Experience: Architect/engineering firm with management and technical expertise in nuclear power, environmental remediations, demolition and decontamination, and radioactive and hazardous waste disposal.

EagleTech

33610 Solon Road, Suite B4, Solon, OH, 44139, USA

Contact: Victor Trost, President

Phone: (440) 542-0440

Business Experience: Develops, engineers, and fabricates heavy duty, compact, multi-articulating manipulator arms, many of which are man-rated for use in bridge repair work.

Environmental Specialties Group L.L.C. (ESG)

30070 Dan Pierson Rd, PO Box 431, Holden, LA, 70744, USA

Contact: Randy Carter

Phone: (504) 567-3031

Business Experience: Together, Numanco and H&H Pump and Dredge Company, Inc., as ESG offers experience in pumping and dredging of hazardous petrochemical and other chemical waste, nuclear decontamination, health physics, and engineering and mechanical capabilities.

GreyPilgrim L.L.C.

P.O. Box 3426 Building 220, Rm B127, Gaithersburg, MD, 20885, USA

Contact: Robert Kent, VP - Business, Development

Website: <http://www.greypilgrim.com>

Phone: (301) 975-5432

Business Experience: Developed and patented a sinuous, hollow-core, long-reach manipulator technology functionally similar to an elephant's trunk known as EMMA.

H & H Pump & Dredge Co., Inc.

30070 Dan Pierson Rd, Holden, LA, 70744, USA

Contact: Henry Allen

Website: <http://www.pumpit.com>

Phone: (504) 567-9200

Business Experience: See Environmental Specialties Group L.L.C. (ESG).

Los Alamos Technical Associates, Inc. (LATA)

309 Bradley Blvd., Richland, WA, 99352, USA

Contact: George L. Crawford, Chief Engineer, Pacific Northwest Division

Phone: (509) 946-8100

Business Experience: More than 20 years experience at the Hanford Site in designing, building, and qualifying equipment to be used in radioactive and hazardous environments.

Magnox Electric PLC

A Offices, Littlebrook Manor Way, Dartford, Kent, DA1 5PZ, England

Contact: Stuart A. Barnes, Remote Technology Associates Ltd, Acting on Behalf of Magnox

Phone: 44 (0) 1322 290022

Business Experience: Owns and operates nine nuclear power plants in England and has developed in-house remote operations engineering capabilities that include the design, development, and application of high-performance hydraulically and electrically-driven

manipulators, remotely controlled vehicles and devices with high precision for welding or high-payload capacity for carry out repairs for operation in high radioactive and other hostile environments.

National Institute of Standards and Technology

Dr. James S. Albus, Division Chief

Manufacturing Engineering Laboratory, Intelligent Systems Division

Metrology Building, Room B124

Gaithersburg, MD 20899-0001

Website: <http://isd.cme.nist.gov/>, <http://www.nist.gov/>

Phone: (301) 975-3418

Business Experience: Provides "state of the art" testing facilities and substantial experience in remote control methodologies.

NUMANCO

One Memorial Place, 7633 East 63rd Place, 4th Floor, Tulsa, OK, 74133, USA

Contact: Richard H. Smith, Chief Executive Officer

Phone: (918) 252-9111

Business Experience: See Environmental Specialties Group LLC (ESG).

Schilling Robotic Systems, Inc

1632 DaVinci Court, Davis, CA, 95616, USA

Contact: David W. Bennett, Director, Nuclear and Defense, Marketing

Phone: (916) 753-6718

Business Experience: Provider of high-resolution manipulators expressly designed for nuclear service, and producer of custom automation and remote handling systems for specific application within the nuclear industry.

Science Applications International Corp. (SAIC)

3250 Port of Benton Blvd., Richland, WA, 99352, USA

Contact: James A. Naber, Manager, Specialty Engineering

Web site: <http://www.saic.com>

Phone: (509) 372-7737

Business Experience: Consulting firm with specialties at Hanford in environmental services including data management, engineering services, remedial design of projects for toxic, hazardous and radiological wastes, and the operation and maintenance of remediation projects.

Technical Resources International (TRI)

J. Mark Henderson, Vice President

723 The Parkway, Suite 200, Richland, WA, 99352, USA

Phone: (509) 943-5319

Business Experience: Leads and participates in many Hanford Site projects related to tank waste retrieval (W-320 sluicing) and treatment (High-level Waste Vitrification Plant -

HWVP) in the functions of project management, design, engineering, safety, and operational interfaces.

Waterjet Technology, Inc.
21414 68th Avenue South, Kent, WA, 98032, USA
Contact: Dave Lierman
Website: <http://www.waterjet-tech.com/>
Phone: (206) 872-9500

Business Experience: Pioneered the development of advanced waterjet technology for industrial applications.

HTI CONTACTS

HTI Retrieval Team

Larry B. McDaniel, HTI Retrieval Task Leader
Numatec Hanford Company, Richland WA 99352
Phone: (509) 372-0305, Fax: (509) 372-0065, e-mail: Larry_N_McDaniel@rl.gov

Vince F. Fitzpatrick, C-106 Retrieval Acquisition Lead
Mactec, 630 Cullum, Richland WA 99352
Phone: (509) 372-5602, Fax: (509) 372-0065, e-mail: Vince_F_Fitzpatrick@rl.gov

Jim A. Yount, HTI Technology Lead
Pacific Northwest National Laboratory, Richland WA 99352
Phone: (509) 375-2005, Fax: (509) 372-0065, e-mail: JA_Yount@pnl.gov

Eric J. Berglin, HTI Technology
SGN Eurisys Services Corporation (SESC), P.O. 840, Richland WA 99352
Phone: (509) 372-1824, Fax: (509) 372-0065, e-mail: Eric_J_Berglin@rl.gov

HTI Support

Pacific Northwest National Laboratory
Richland, WA 99352
Contact: Brian K. Hatchell, Phone: (509) 375-2762, Fax: (509) 375-6736
Contact: Michael R. Powell, Phone: (509) 376-2334, Fax (509) 376-0166

Pete W. Gibbons, EM-50 Interface
Numatec Hanford Company, Richland, WA 99352
Phone: (509) 372-0095, Fax: (509) 372-0065, e-mail: Pete_W_Gibbons@rl.gov

DISTRIBUTION SHEET

Name	MSIN	Text With All Attach.	Text Only	Attach./Appendix Only	EDT/ECN Only
<u>Department of Energy</u>					
M. J. Glasper	K8-50	X			
J. P. Hanson	K8-50	X			
C. D. West	S7-53	X			
<u>Duke Environmental Services Hanford</u>					
J. S. Bloom	H6-12	X			
<u>Fluor Daniel Northwest</u>					
M. W. Manderbach	S2-47	X			
J. J. Huston	H5-61	X			
<u>Informatics Corporation</u>					
R. W. Root	H6-12	X			
<u>Lockheed Martin Hanford Company</u>					
D. A. Bragg	S5-05	X			
V. F. Fitzpatrick	H5-61	X			
<u>Numatec Hanford Company</u>					
M. Cremonini	H5-61	X			
P. W. Gibbons	H5-61	X			
J. S. Hertzfel	H5-61	X			
R. P. Marshall	H5-61	X			
T. H. May	H5-61	X			
L. B. McDaniel	H5-61	X			
<u>Pacific Northwest National Laboratory</u>					
B. K. Hatchell	K5-22	X			
M. W. Rinker	K5-22	X			
T. L. Stewart	K9-69	X			
J. A. Yount	H5-61	X			
<u>SGN Eurisys Services Corporation</u>					
E. J. Berglin (15)	H5-61	X			
J. A. Hunter	B4-51				
HTI Project File (2)	H6-08	X			
Central Files	B1-07	X			