ORNL/TM-13630

ornl

OAK RIDGE NATIONAL LABORATORY

LOCKHEED MARTIN

North Tank Farm Data Report for the Gunite™ and Associated Tanks at Oak Ridge National Laboratory Oak Ridge, Tennessee

V. A. Rule
XL Associates, Inc.
Oak Ridge, Tennessee 37830

B. L. Burks
The Providence Group
Knoxville, Tennessee 37933

S. D. Van Hoesen
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

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

ORNL-27 (3-96)

DISCLAIMER

Portions of this document may be illegible electronic image products. Images are produced from the best available original document.

ORNL/TM-13630

NORTH TANK FARM DATA REPORT FOR THE GUNITE™ AND ASSOCIATED TANKS AT OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE

Date Published—May 1998

Prepared by
V. A. Rule
XL Associates, Inc.
Oak Ridge, Tennessee 37830
Under subcontract 1BX-KEP59V

B. L. Burks
The Providence Group
Knoxville, Tennessee 37933

S. D. Van Hoesen
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

Prepared for the
U.S. Department of Energy
Office of Environmental Management

Environmental Management Activities at
OAK RIDGE NATIONAL LABORAOTRY
Oak Ridge, Tennessee 37831
managed by
BECHTEL JACOBS COMPANY LLC
for the
U.S. DPEARTMENT OF ENERGY
under contract DE-AC05-96OR22700

PREFACE

This document, *North Tank Farm Data Report for the Gunite and Associated Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee*, was developed under Work Breakdown Structure number 1.4.12.6.1.01.41.12.04.03.07 for the Gunite and Associated Tanks (GAAT) Remediation Project. This document presents the data collected during the "hot tests" of the waste retrieval equipment in two tanks of the GAAT North Tank Farm (NTF) at Oak Ridge National Laboratory. Upon completion of the waste retrieval operations in each tank, the U. S. Environmental Protection Agency and the Tennessee Department of Environment and Conservation agreed that the goals of the treatability study and the record of decision for waste retrieval had been achieved. Testing performed in the NTF verified that the waste retrieval equipment will be effective in removing waste from the larger South Tank Farm tanks. The data presented in this report will be used to assist in the planning and preparation for remediation activities in the South Tank Farm, which is categorized as a Category 3 nuclear facility.

CONTENTS

LIST OF FIGURES V

LIST OF TABLES VII

ABBREVIATIONS IX

EXECUTIVE SUMMARY X

1. INTRODUCTION 1-1

2. SITE CHARACTERIZATION 2-1

2.1 TANKS INTERNALS 2-1
2.2 TANK CONTENTS 2-1

3. NTF TEST OBJECTIVES 3-1

4. TECHNOLGY DESCRIPTION 4-1

4.1 WASTE RETRIEVAL EQUIPMENT 4-1
4.1.1 MLDUA 4-1
4.1.2 ROV 4-1
4.1.3 WD&C 4-2
4.1.4 End Effectors 4-2
4.1.5 BOP 4-3
4.1.6 Decontamination 4-4
4.1.7 OCT 4-4
4.2 TANK CHARACTERIZATION EQUIPMENT 4-4

5. TANK W-3 ACTIVITIES AND SYSTEM PERFORMANCE 5-1

5.1 DATA COLLECTED 5-4
5.2 INITIAL TANK CHARACTERIZATION 5-4
5.3 EQUIPMENT MOVE TO NTF 5-4
5.4 ROV TANK OPERATIONS 5-4
5.5 MLDUA OPERATIONS 5-6
5.6 WALL CLEANING 5-7
5.6.1 Rate of Wall Cleaning 5-7
5.6.2 Water Added for Wall Cleaning 5-10
5.7 SLUICING 5-10
5.7.1 Supernatant Retrieval 5-10
5.7.2 Sludge Retrieval 5-13
5.7.3 Scale Retrieval 5-18
5.8 DEBRIS REMOVAL 5-18
5.9 BALANCE OF PLANT 5-21
5.10 DECONTAMINATION WATER USED 5-21
5.10.1 ROV 5-21
5.10.2 MLDUA 5-21
5.10.3 HMS 5-24
5.11 PERSONNEL EXPOSURES 5-24
5.12 PPE USAGE 5-25
5.13 SOLID WASTES GENERATED 5-25
5.14 WASTE CHARACTERIZATION INFORMATION 5-25
5.15 TANK CHARACTERIZATION INFORMATION 5-25

6. TANK W-4 ACTIVITIES AND SYSTEM PERFORMANCE 6-1
6.1 INITIAL TANK CHARACTERIZATION 6-4
6.2 EQUIPMENT MOVE FROM W-3 6-6
6.3 ROV TANK OPERATIONS 6-6
6.4 MLDUA OPERATIONS 6-8
6.5 HOSE MANAGEMENT SYSTEM 6-9
6.6 WALL CLEANING 6-9
6.6.1 Rate of Wall-Cleaning 6-9
6.6.2 Water Added for Wall Cleaning 6-9
6.7 SLUICING 6-9
6.7.1 Sludge Retrieval 6-11
6.7.2 Dewatering Following Wall Cleaning and Decontamination 6-11
6.8 DEBRIS REMOVAL 6-15
6.9 DECONTAMINATION WATER USED 6-15
6.9.1 ROV 6-15
6.9.2 MLDUA 6-15
6.9.3 HMS 6-15
6.10 PERSONNEL EXPOSURES 6-17
6.11 PPE USAGE 6-17
6.12 SOLID WASTES GENERATED 6-17
6.13 WASTE CHARACTERIZATION INFORMATION 6-17
6.14 TANK CHARACTERIZATION INFORMATION 6-18
7. MAINTENANCE 7-1
7.1 ROV SYSTEM MAINTENANCE 7-1
7.1.1 ROV Maintenance 7-1
7.2 MLDUA SYSTEM MAINTENANCE[5] 7-6
7.3 WD&C SYSTEM MAINTENANCE 7-7
7.4 BOP MAINTENANCE[8] 7-8
7.4.1 High-Pressure Pump Skid L-01 7-8
7.4.2 High-Pressure Pump Skid L-02 7-8
7.4.3 High-Pressure Pump Skid L-03 7-9
7.4.4 Water Supply Pump Skid L-04 7-9
7.4.5 Air Compressor Skid 7-9
8. ON-THE-JOB TRAINING DOCUMENTATION 8-1
9. WASTE RETRIEVAL SYSTEM COST SUMMARY 9-1
10. OBSERVATIONS AND LESSONS LEARNED 10-1
11. SUMMARY AND CONCLUSIONS 11-1
11.1 WATER USAGE 11-2
11.2 RESIDUAL INVENTORY 11-7
11.3 PERFORMANCE ESTIMATE 11-7
11.4 CONCLUSIONS 11-10
11.4.1 Equipment operation 11-10
11.4.2 Tank Characterization 11-11
APPENDIX A CORE SAMPLE DATA A-1

LIST OF FIGURES

Figure		Page
5-1	GAAT W-3 operations schedule	5-2
5-2	CSEE water added for sluicing vs water pressure in a daily operation	5-8
5-3	Cross section of ntf tank (typical)	5-9
5-4	Wall cleaning path	5-9
5-5	Total CSEE water usage for wall-cleaning activities during W-3 operations	5-11
5-6	Example of saturated signal from slurry Coriolis flow meter FIT-204	5-12
5-7	Typical readings from FIT-204 vs water added at jet pump (FIT-121)	5-14
5-8	Typical readout from FQIT-204 during one day of sluicing operations in W-3	5-15
5-9	Total Csee water used for sluicing during W-3 Operations	5-16
5-10	Total motive fluid water to jet pump during W-3 operations	5-17
5-11	Flush water events for typical day of W-3 operations	5-19
5-12	Total flush water used during W-3 operations	5-20
5-13	Decontamination water flow rate vs water pressure	5-22
5-14	Total decontamination water used during W-3 operations	5-23
5-15	W-3 process slurry sample density	5-26
5-16	W-3 baseline survey with characterization end effector	5-27
5-17	W-3 post-cleaning survey with characterization end effector	5-28
6-1	GAAT W-4 operations schedule	6-2
6-2	W-4 tank sludge sample density	6-5
6-3	Process water used for W-4 wall cleaning operations	6-10
6-4	Process water used as jet pump motive fluid water in W-4 operations	6-12
6-5	CSEE water used for sluicing during W-4 operations	6-13
6-6	Flush water used during W-4 operations	6-14
6-7	Decontamination water used in W-4 operations	6-16

6-8 W-4 baseline survey of beta with characterization end effector 6-19

6-9 W-4 baseline survey of gamma with characterization end effector 6-20

6-10 W-4 post cleaning survey of beta with characterization end effector 6-21

6-11 W-4 post cleaning survey of gamma with characterization end effector 6-22

11-1 W-3 Water usage chart 11-3

11-2 W-4 Water usage chart 11-4

11-3 Total water used in W-3 operations 11-5

11-4 Total water used in W-4 operations 11-6

11-5 Ratio of gallons of water used per gallons of sludge transferred 11-8

11-6 Estimated maximum water usage for STF 11-9

LIST OF TABLES

Table		Page
1	Performance Estimate	x
5-1	Tank W-3 operations performance	5-1
5-2	ROV operations	5-5
5-3	Tank W-3 MLDUA operating statistics	5-6
5-4	W-3 radiation work permits with exposures of more than 10 mrem	5-24
5-5	In-line process sample results	5-25
5-6	Estimate of activity in tank W-3 wall	5-29
6-1	Tank W-4 operations performance	6-1
6-2	Tank W-4 sludge sample analytical results from August 11, 1997	6-4
6-3	Tank W-4 sludge sample analytical results from August 14, 1997	6-4
6-4	Tank W-4 sludge sample analytical results from August 25, 1997	6-4
6-5	ROV W-4 operations	6-6
6-6	Tank W-4 MLDUA operating statistics	6-8
6-7	RWP with exposures higher than 10 mrem	6-17
6-8	In-line process sample results	6-18
6-9	Estimate of activity in tank W-4 wall	6-18
7-1	ROV W-3 maintenance operations	7-2
7-2	ROV system maintenance summary	7-4
7-3	ROV W-4 maintenance operations	7-5
7-4	MLDUA system maintenance summary	7-7
7-5	WD&C system maintenance summary	7-8
7-6	BOP maintenance summary	7-9
8-1	MLDUA individual hours of operation	8-1
8-2	BOP individual hours of operation	8-1
8-3	GUI system individual hours of operation	8-2

8-4 ROV individual hours of operation 8-2

9-1 Waste retrieval system cost summary 9-1

10-1 GAAT hot test lessons learned 10-1

11-1 Tanks W-3 and W-4 operations performance 11-1

11-2 Performance estimate 11-10

ABBREVIATIONS

ALARA	as low as reasonably achievable
BOP	balance of plant
CB	confinement box
CEE	characterization end effector
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSEE	confined sluicing end effector
DOE	U.S. Department of Energy
DSR	decontamination spray rings
EPA	U.S. Environmental Protection Agency
FCE/CB	flow control equipment and confinement box
FCEE	floor-cleaning end effector
GAAT	Gunite and associated tanks
GEE	gripper end effector
GIMP	Gunite isotopic mapping probe
gpm	gallons per minute
GSEE	Gunite scarifying end effector
GUI	graphical user interface
H&SM	health and safety manager
HMA	hose management arm
HMS	hose management system
HPU	hydraulic power unit service skid
LLLW	Liquid low-level waste
LMER	Lockheed Martin Energy Research Corporation
MLDUA	modified light duty utility arm
NTF	North Tank Farm
OCT	operations control trailer
OJT	on-the-job training
ORNL	Oak Ridge National Laboratory
PPE	personal protection equipment
psi	pounds per square inch
RCT	radiological control technician
ROV	remotely operated vehicle
RWP	radiation work permit
ST	storage tube
STF	South Tank Farm
THS	tether handling system
TMADS	tether management and deployment system
TRIC	tank riser interface and confinement
TS	treatability study
TTCTF	Tanks Technology Cold Test Facility
VPM	vertical positioning mast
WD&C	waste dislodging and conveyance

EXECUTIVE SUMMARY

This report presents the data collected during the "hot tests" of the waste retrieval equipment developed as part of a treatability study (TS) for the Gunite and associated tanks (GAAT) at Oak Ridge National Laboratory (ORNL). The TS was performed to develop and test an effective waste retrieval system for removing radiochemical sludge heels from the GAAT underground storage tanks.

The TS was performed in two phases. The first phase incorporated equipment design, testing and modification of the waste retrieval system at the Tanks Technology Cold Test Facility and provided for performance testing of each piece of equipment and for the integrated system. The second phase of the TS, which began in June 1997, was to prove the system in a radioactive environment [the GAAT North Tank Farm (NTF)] through the transfer of tank waste from one tank (W-3) to another tank (W-4) and then from W-4 to W-9 in the GAAT South Tank Farm (STF). This testing, known as NTF operations, or the hot test, built upon the testing performed in the first phase.

The NTF operations were used to verify that operating procedures and ORNL radiological protection procedures were sufficient for the protection of workers and the environment before proceeding to the GAAT STF, a Category 3 nuclear facility. The remedial action phase following the TS will complete waste retrieval activities for the remaining tanks in the STF.

The following table shows the estimated performance of the waste retrieval system for operations in each NTF tank and in the NTF overall. Upon completion of the waste retrieval operations in each tank, the U.S. Environmental Protection Agency and the Tennessee Department of Environment and Conservation agreed that the goals of the TS and the record of decision for waste removal had been achieved.

Table 1. Performance Estimate

Parameter	W-3 tank	W-4 tank	NTF overall
Initial inventory	340 Ci (5500 gal) in sludge 7.3 Ci in scale on wall 6.4 Ci in wall Total: 353.7 Ci	916 Ci (13,500 gal) in sludge 328 Ci from W-3 sludge and scale 3.7 Ci in scale on wall 4.2 Ci in wall Total: 1251.9 Ci	916 + 340 = 1256 Ci 11 Ci in scale 10.6 Ci in wall Total: 1277.6 Ci
Residual inventory	5.9 Ci (100 gal)in sludge 6.4 Ci in wall Total: 12.3 Ci	6.7 Ci (100 gal) in sludge 4.2 Ci in wall Total: 10.9 Ci	12.6 Ci in sludge 10.6 Ci in wall Total: 22.6 Ci
Performance	12.3 / 353.7 = 3.5% residual, or 96.5% cleaning efficiency	10.9 / 1251.9 0.87% residual, or 99.13% cleaning efficiency	22.6 / 1277.6 1.7% residual, or 98.3% cleaning efficiency

Testing performed in the NTF verified that the waste retrieval equipment will be effective in removing waste from the larger STF tanks. The phased approach used in the development and testing of the equipment first as components, then as an integrated system in a cold test environment, and finally in a radioactive environment has culminated in the following to provide a safe and effective waste retrieval system for the STF remedial action:

- a waste retrieval system design that is expected to be successful in waste retrieval operations in the STF,
- establishment of safe and effective operating parameters for the equipment,
- establishment of clear, concise procedures and practices,
- training of operators, and
- definition of preventive maintenance requirements for the equipment.

The data presented in this report will be used to assist in the planning and preparation for the STF remedial action.

1. INTRODUCTION

The U. S. Department of Energy (DOE) Office of Science and Technology, in cooperation with the Oak Ridge Environmental Management Program, has developed and demonstrated the first full-scale remotely operated system for cleaning radioactive liquid and waste from large underground storage tanks. The remotely operated waste retrieval system developed and demonstrated at Oak Ridge National Laboratory (ORNL) is designed to accomplish both retrieval of bulk waste, including liquids, thick sludge, and scarified concrete, and final tank cleaning.

The system was developed for use at the ORNL Gunite and associated tanks (GAAT). Remediation of the tanks is required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as part of a remedial design/remedial action effort. Before initiating remediation activities, a feasibility study was performed to ensure that the most effective and cost-efficient method would be employed in the remediation of the tank farm. In performing this feasibility study, the determination was made that further information on the applicable technologies was needed to further evaluate the effectiveness and efficiency of the waste retrieval system. This additional information has been collected as part of a treatability study (TS).

The TS was performed in two phases. The first phase incorporated equipment design, testing, and modification of the waste retrieval system at the Tanks Technology Cold Test Facility (TTCTF) and provided for performance testing of each piece of equipment and for the integrated system. TTCTF testing was performed using a simulated sludge with characteristics similar to the sludge contained in the GAAT. The testing in this first phase provided information for the following before entering the GAAT North Tank Farm (NTF):

- Support of the acceptance and functional tests of the waste retrieval instrumentation and equipment;
- definition of the operating parameters for the equipment;
- development, testing, and refining of operating procedures;
- on-the-job training for equipment operators; and
- identification of routine maintenance requirements.

The second phase of the TS, which began in June 1997, was to prove the system in a radioactive environment through the transfer of tank waste from one tank (W-3) to another tank with similar waste (W-4) and then from W-4 to W-9 in the GAAT South Tank Farm (STF). These tanks were selected for the TS because their lower contaminant inventory presented less risk to workers and the environment for the first field deployment of the waste retrieval systems. This testing, known as NTF Operations, or the "hot test," built upon the testing performed in the TTCTF. The NTF operations were used to verify that operating procedures and ORNL radiological protection procedures were sufficient for the protection of workers and the environment before proceeding to the GAAT STF, a Category 3 nuclear facility. The remedial action phase following the TS, or STF operations, will complete waste retrieval and wall-cleaning activities for the remaining tanks. The data from the hot tests will be used to assist in the planning and preparation for remediation activities in the STF.

There are several major subsystems that compose the waste retrieval system used in the NTF operations: the modified light-duty utility arm (MLDUA), the Houdini™ remotely operated vehicle (ROV), the waste dislodging and conveyance (WD&C) system, cameras and lights, controls, and the balance of plant (BOP) equipment. Section 4 contains a more detailed description of the complete system.

This report provides a summary of the NTF operations data and an assessment of the performance and efficiency of the waste retrieval system during NTF operations. The organization of this report is as follows: Section 1 provides an introduction to the report. Section 2 describes the NTF tank structures (W-3 and W-4 only) and the contents of the tanks. Section 3 outlines the objectives of the NTF testing and explains how these objectives were met. Section 4 provides a description of the various operating systems used in the NTF operations. Sections 5 and 6 present a summary of the data collected during NTF operations. Section 7 summarizes the maintenance activities performed and Section 8 summarizes the on-the-job training performed in the NTF. Section 9 summarizes the capital cost for the waste retrieval and characterization equipment and operating costs for performing the NTF work. Section 10 provides observations and lessons learned, and Section 11 provides a summary and conclusions.

2. SITE CHARACTERIZATION

The GAAT tank farms incorporate 12 Gunite tanks and 4 stainless steel tanks that were built in the 1940s to collect, neutralize, store, and transfer the liquid portion of radioactive and/or hazardous chemical wastes. Various sludges and solids accumulated during the treatment and storage of the liquids in the tanks. Treatment involved chemically precipitating the radioactive, heavy metal, and solid constituents out of the liquid waste. The tanks now contain varying amounts of liquids, sludges, and solids composed of wastes containing organics, heavy metals, and various radionuclides, including transuranics.

Although most of the accumulated liquid and solid waste material in the six large tanks in the STF was removed in 1982 through 1984 during a sludge disposal campaign, residual liquid, sludge, and solid waste material and additional liquids from infiltration (fluids leaking into the tanks from the environment) remain in most of the tanks. The residual material in the tanks, contaminated components of the containment system (including appurtenances in the tank farms), contaminated buildings, and contaminated soil and groundwater represent a potential threat to human health and the environment. The NTF tanks were not sluiced previously.

2.1 TANKS INTERNALS

Tanks W-3 and W-4 are of similar construction, each with a diameter of 25 ft and a tank thickness at the side walls of 8 to 9 in. The capacity of each tank is approximately 44,000 gal. Very few penetrations into the tanks existed after tank construction, although additional penetrations have been made to accommodate the waste retrieval equipment. Before NTF operations were initiated, the interiors of the tanks were relatively uncluttered. Tank W-3 contained three or four 1 in. pipes, cables, and conduit in the north side of the tank that extended to the tank floor. Tank W-4 contained three pipes, also in the north side of the tank, that extended to the floor and one 3 in. pipe located on the south side of the tank. Before sluicing operations began in W-3, the pipes were successfully removed using a hydraulic shear. The pipes in the north side of W-4 were removed on January 13. The 3 in. pipe was never removed.

The tanks were constructed using the Gunite process, which involves spraying a cement slurry against a lattice of reinforcing bars. Gunite, or dry-mix shotcrete, is a mixture of cement and sand introduced to a cement gun, pressurized, and conveyed pneumatically through a rubber hose. In Gunite tanks, the Gunite is proportioned by weight to have three to four parts sand mixed with one part cement. The final wall thickness of the tanks was 6 in. at the outer wall, lined with (approximately) a 0.5 in. bituminous layer, and then (approximately) a 2 in. Gunite inner tank liner.

The compressive strength of Gunite is much higher than conventional ready-mix concrete. Typical compressive strength test results range from 5,000 lbs per square inch (psi) to as high as 12,000 psi, whereas standard concrete has a typical compressive strength of 4,000 psi. Investigations performed in 1995 revealed that the tank walls were generally sound. The interior coatings on tanks W-3 and W-4 were still intact, and little or no deterioration of the walls was evident.[1]

2.2 TANK CONTENTS

Before NTF operations began, the estimated sludge volume was 5,500 gal in W-3 and 13,500 gal in tank W-4.[2] The curie concentration in the W-3 sludge (95 percentile) is estimated to be 5.42×10^5 Bq/g, and 1.25×10^3 Bq/mL in the supernate. The curie concentration estimate in the sludge of W-4 (95 percentile) was 5.20×10^5 Bq/g, and 2.06×10^4 Bq/mL in the supernate.[3] The total curie inventory in the sludge in each of the tanks is estimated to be 340 Ci in W-3 and 916 Ci in W-4.

The tank walls in both tanks were covered with a white scale, later determined to be aluminum hydroxide. This scale was approximately 0.13 in. thick on the W-3 walls and 0.063 in. thick on the W-4 walls and was estimated to contain 7.3 Ci in W-3 and 3.7 Ci in W-4.

Video inspection and physical measurement for W-3 and W-4 have indicated that the sludge level was the lowest in the area near the original riser, most likely because of historic waste transfers and the length of the waste removal dip leg installed in the tank. Waste addition and removal would have occurred at a depth near the top of the sludge in this area, preventing the sludge from accumulating to the same depth as the rest of the tank. However, the floor of the tank tends to remain level or slope slightly toward the south, and the sludge estimate reflects the measured depths. Unlike W-3, W-4 had a crystallized layer, or crust layer, between an upper layer of soft sludge and a lower layer of significantly more dense sludge.

Debris found in the NTF tanks includes plastic bags, rubber gloves, wire, various tools, piping, ceramic tile, and plastic tie wraps.

3. NTF TEST OBJECTIVES

The TS focused on the ability of the confined sluicing technology to safely and effectively remove sludge from the interior of the Gunite underground storage tanks. The NTF operations were to accomplish several critical goals:

1. *Provide information on expected residual contamination remaining in the tank shell at the completion of cleaning for use in the Bethel Valley Watershed Closure decision process.*

   Residual contamination in each of the tanks is present in two media: residual sludge that could not be retrieved and contamination embedded in the tank walls. Each tank, W-3 and W-4, has an estimated 0.5 in. of sludge (100 gal) remaining in the tank, most likely diluted by all the final tank washing operations. Even if this sludge were not diluted, it is estimated to contain, at the most, 6 Ci in each tank.

   The core sample collected for each tank indicated that wall washing was not successful in removing much of the Gunite material. The tank walls are estimated to contain 6.4 Ci in tank W-3, and 4.2 Ci in tank W-4. More than 80% of the W-3 wall inventory was found in the first 0.13 in. of the tank wall, and more than 95% of the W-4 wall inventory was found in the first 0.063 in. of the tank wall.

2. *Evaluate the previously established operating envelopes for equipment.*

   Each major system was operated successfully during the NTF campaign. The actual operating envelopes for the equipment are well established and are sufficient for future STF operations as designed, with the following exceptions. (1) The confined sluicing end effector (CSEE) performed wall cleaning operations but did not successfully scarify the tank walls. This was determined early in cold testing at the TTCTF, and a high-pressure Gunite scarifying unit is being tested for future scarification activities. (2) Calculations show that when the MLDUA is at full extension, the torque applied by the Gunite Scarifying End Effector (GSEE) at full pressure (30 kg/cm^2) may exceed the allowable load on the shoulder yaw joint. This will be tested further in the STF.

3. *Verify the sufficiency of all procedures in a radiological environment before using them in a Category 3 nuclear facility.*

   Following W-3 and W-4 operations, each procedure was further reviewed and modified, as appropriate, to meet the requirements for STF operations. All procedures are currently approved for STF operations.

4. *Refine mining strategies for using each piece of equipment in its most efficient and effective mode, depending on the activity being performed (sludge retrieval, Gunite scarification, debris management, etc.)*

   The GAAT operators are experienced with the most effective mode of operation for each piece of equipment in mining various tank wastes.

5. *Provide information to estimate personnel exposures for activities to be performed during STF operations.*

NTF exposures were not significant enough to use in estimating STF exposures (see Sect. 5.11). However, the actual task times logged for various tasks on the radiation work permits (RWPs) have been used together with expected STF radiation fields to estimate exposures for STF activities.

6. *Provide information to support implementing the as-low-as-reasonably-achievable (ALARA) philosophy during operations and to confirm safety procedures and requirements before entering the STF.*

   The times required for implementing various tasks and the actual radiation measurements have been logged on RWPs. This information, together with expected STF radiation fields, has been used to plan STF activities using ALARA philosophies. Some equipment modifications and procedural changes were implemented during and after NTF operations to reduce exposures in the STF.

4. TECHNOLGY DESCRIPTION

Equipment used in the GAAT NTF waste retrieval and tank characterization activities includes

- the MLDUA;
- WD&C system, consisting of the hose management arm (HMA), CSEE, and various other end effectors;
- the Houdini™ ROV with a plow and a manipulator arm with four degrees of freedom;
- the BOP equipment, including the flow control equipment and confinement box (FCE/CB), process water supply system, high-pressure water supply systems, air supply system, tank ventilation system, tank-level monitoring system, and instrumentation and controls;
- the GSEE and tether handling system (THS);
- the decontamination spray rings (DSRs);
- cameras and lighting;
- a characterization end effector (CEE) and THS;
- the Gunite isotopic mapping probe (GIMP);
- the sludge-sampling system;
- the core-sampling equipment;
- the scrape-sampling equipment; and
- the operations control trailer (OCT)

4.1 WASTE RETRIEVAL EQUIPMENT

4.1.1 MLDUA

The MLDUA is used to deploy a variety of end effectors to perform waste retrieval, wall cleaning, and tank or sludge characterization operations. The MLDUA is equipped with a removable general-purpose gripper end effector. It is telerobotically operated by an operator in the control trailer and has seven degrees of freedom and a telescoping vertical mast. In the NTF 25-ft-diam tanks, the MLDUA can reach the walls from a central riser.

The MLDUA tank riser interface and confinement (TRIC) is attached to the tank riser for the MLDUA. The TRIC contains glove ports and a door for maintenance to the MLDUA. The door can also be used to remove and add tools as necessary. A spray wand is mounted in the TRIC and can be used for additional decontamination of the MLDUA.

4.1.2 ROV

The ROV, or Houdini, is a track-driven vehicle that is also used to deploy various characterization and retrieval tools within the tank. The ROV is operated from the control trailer by an operator who can view the vehicle through overhead cameras and cameras mounted on the ROV. The ROV is equipped with a plow or blade on the front and a Schilling arm with a manipulator grip on the vehicle behind the blade. Depending on the mining strategy being used, the front blade can be used to push sludge to the CSEE, or the Schilling arm can be used to hold the CSEE for waste retrieval operations. The Schilling arm is also used to hold the coring tool, a hose for providing decontamination to the ROV, and other tools.

The ROV tether management and deployment system (TMADS) houses the tether reel that is used to deploy the ROV. The TMADS also provides a contained storage location when the ROV is removed from the tank. A water-supplying hose reel in the TMADS provides additional decontamination for the ROV in addition to the DSRs. The hose can be unreeled and lowered through the tank riser to the ROV. The Schilling arm manipulator grasps the hose end and provides a water rinse to the ROV before the

ROV passes through the DSR. The hose reel also can be used while the ROV is stored in the TMADS. The hose reel can be accessed through the glove ports in the TMADS and can be used for additional ROV decontamination.

4.1.3 WD&C

The WD&C system, used to dislodge and retrieve sludge from the GAAT, is composed of the HMA, a confinement box (CB), a storage tube (ST), and end effectors such as the CSEE and the floor-cleaning end effector (FCEE). The HMA, a four–degree-of-freedom arm, is designed to provide access to all points within a 50-ft-diam or smaller tank. The arm links and the mast of the HMA contain the piping and jet pump required for conveyance of the tank waste. The jet pump, mounted in the vertical section of the HMA, operates on the venturi principle. A high-pressure water flow (the "motive fluid") to the jet pump provides the vacuum to retrieve the waste from the tanks. The jet pump motive fluid required for waste retrieval is approximately 7 to 8 gal per minute (gpm), at a pressure of 6000 to 6300 psi.

The waste conveyance piping is contained by the CB and then by the FCE/CB before being connected to the receiving tank through doubly contained piping. The CB contains a mast elevate table used to provide elevation and mast rotate capability to the HMA. The CB also houses necessary hoses and cables for operating the HMA and the waste retrieval equipment (CSEE). It also is equipped with glove port access for operational needs and limited maintenance. The ST contains the HMA hoist and housing. The hoist is used to support deployment and retraction of the HMA.

4.1.4 End Effectors

The CSEE is a sluicing tool that is connected to the HMA suction hose and that is positioned by the MLDUA or ROV across the tank bottom and wall. It is used to dislodge and retrieve the sludge from the tank bottom by means of a sluicing and suction operation. In deployment of the HMA, the CSEE is positioned in the tank within reach of the MLDUA or ROV for pickup. CSEE operations are controlled remotely by an operator from the control trailer. The CSEE contains three high-pressure water jets capable of spraying water at a rate of approximately 10 gpm. High-pressure water is supplied to the cutting jets at a supply pressure of up to 7000 psi. An electric motor rotates the cutting jets between 0 and 600 rotations per minute, as commanded remotely by the operator. The dislodged sludge is directed by the cutting jets to the center intake pipe of the CSEE for retrieval.

The GSEE is also manipulated by the MLDUA and the ROV for tank wall scarification activities. The GSEE is deployed either through the ROV TMADS or through the MLDUA TRIC component using a drum reel contained in a portable THS. The GSEE is lowered into the tank by the THS and is grasped by the MLDUA or ROV. The GSEE includes the scarification head and high-pressure hoses. The high-pressure water is supplied by a separate ultrahigh-pressure water supply system. The ultrahigh-pressure water system was not available for the NTF operations, so the CSEE high-pressure water pump was used in testing the GSEE in tank W-4.

During operations, two other end effectors that were used included the supernate retrieval end effector, constructed of a 2 in. pipe with a screen, and the FCEE, equipped with an inlet similar to a carpet cleaner head. The FCEE was shaped so that it could be used to either scoop sludge from the floor or be placed flat on the tank floor for dewatering to levels of approximately 0.25 in. deep.

4.1.5 BOP

The BOP system is composed of:

- the FCE/CB, which houses:
  - the Coriolis flow meter, designed to provide flow measurements, density measurements, total flow, and mass inventory,
  - the Isolok Sampler, a proportional sampler designed to capture samples of liquid and slurry solutions, and
  - the flush system valves and piping;
- a process water supply system (L-04), which supplies water to the high-pressure water pumps and the flush water system;
- the DSR high-pressure water supply System (L-01);
- the CSEE cutting jet high-pressure water supply system (L-02);
- the jet pump high-pressure water supply system (L-03);
- the transfer line between the FCE/CB and the receiving tank;
- the air compressor, which supplies air to the MLDUA, ROV, pumps, and pressure-control valves,
- the tank ventilation system; and
- the tank level sensing system.

From the WD&C, the sludge flows through the FCE/CB into a transfer line before entering the receiving tank. The FCE/CB serves three basic functions:

1. providing secondary containment for the waste piping,
2. providing structural support and containment for process control instrumentation, and
3. providing operator access for operational and maintenance activities.

The FCE/CB contains a Coriolis flow meter, the Isolok Sampler, and the flush water piping and valving. The FCE/CB is equipped with a pass-through and two tool-storage trays located directly under the glove ports on the large windows. The pass-through incorporates a bag-in/bag-out type door and a sliding tray that can pass items as large as 18 by 18-in.

Flush water is introduced to the piping in the FCE/CB through a remotely controlled valving arrangement. Back-flushing can be achieved either by using the jet pump motive fluid water or by adding process water. To flush using the jet pump motive fluid water, a valve downstream of the jet pump is closed, forcing the motive fluid water to be diverted back to the CSEE pipe inlet. This method is preferred because it uses a lower water addition rate than flushing using the process water pump. Also, it does not require diversion of water from the high-pressure pumps and therefore does not interrupt sluicing operations for long. However, this operation provides a lower pressure back-flush than the process water system.

Forward-flushing or back-flushing using the process water system requires diverting water from the high-pressure water pumps to the flush water valve, closing the upstream (HV-200) or the downstream (HV-201) valve, and opening the flush water valve (HV-104). This water is delivered at a pressure of 45 psi and a flow rate of 50 to 70 gpm.

The process water supply system includes a holding tank and a recycle water pump that continuously supplies water to the high-pressure pumping systems for the CSEE, the jet pump, and the decontamination system. Process water can be diverted from the high-pressure pumping systems to the flush system by opening valve FV-104 and switching (three-way) valve FV-102 to the flush mode. This system is insulated for freeze protection.

The Isolok Sampler is used to collect in-line samples of the sludge as it is being transferred to the receiving tank. The sludge sampling system consists of an in-line-sampling valve and a sample bottle located inside the FCE/CB. The sample valve can be controlled from a local control panel to collect a sample or to automatically collect samples at a predetermined rate. The sample rate and volume can also be controlled from the control panel. Sample bottles are removed from the Isolok Sampler through an access panel on the FCE/CB.

4.1.6 Decontamination

Equipment decontamination is provided by spraying with hand wands and by spray from the DSRs. The DSRs are installed on three of the tank risers, primarily for the MLDUA, ROV, and WD&C HMA. When equipment is removed through the riser, the water spray from the DSR washes the equipment. A DSR contains eight equally placed spray nozzles on a 40 in. diam. ring. Various nozzle configurations are available. The nozzles are installed based on the size of equipment to be cleaned, water volume, and the pressure needed to achieve optimum cleaning for each piece of equipment. The DSRs are operated remotely from the control trailer and are activated when equipment is removed from the tank. The decontamination water is supplied to the DSRs at various flow rates and pressures that have been optimized for the specific equipment. Hand-held spray wands in each piece of equipment's confinement box can remove residual contamination not removed by the DSRs. All decontamination water drains back into the tank and is later pumped from the tank during sludge retrieval activities.

4.1.7 OCT

The OCT houses the remote operating stations for the WD&C, HMA, MLDUA, ROV, and BOP systems. The WD&C, HMA, and BOP systems have remote-operating capabilities through the graphical user interface (GUI) station. Remote controls for the CEE, GSEE, and CSEE are also provided through the GUI. The GUI is used to collect and store operating data as needed for the project historic records.

The OCT also houses

- the video recording equipment,
- remote controls for the overhead cameras and lighting mounted within the tanks,
- the low vacuum alarms, and
- the high-radiation monitor alarms.

4.2 TANK CHARACTERIZATION EQUIPMENT

The GIMP is a system designed to characterize the curie content of tank shells by measuring gamma and beta radiation on a given area of the tank wall. The system consists of a shielded, collimated detector and a scraper device and is used on the Gunite tanks to map the radiation levels detected at the walls.

The CEE, is used to characterize the tank walls and floors for residual radioactivity and for some specific radioactive compounds. The CEE houses a camera, a light, and radiological instrumentation and is connected to a drum reel contained in a portable THS. The CEE THS is attached to the MLDUA TRIC and is deployed into the tank while being grasped by the MLDUA. The CEE is moved by the MLDUA to predetermined locations in the tank, and the resulting measurements are recorded in the control trailer. Following characterization, the CEE is retracted as the MLDUA is retracted. The CEE also can be deployed by the ROV but was only deployed using the MLDUA in the NTF.

The coring tool is equipped with a coring bit used to collect core samples in specific areas of concern in the Gunite surface to characterize the residual contamination in that area. The coring end effector consists of an electrically powered drill with a one-in. core bit that is connected by tether to a drum reel contained in a THS. The THS is attached either to the TMADS containment bezel of the ROV or to the TRIC component of the MLDUA. The core drill is lowered into the tank by the THS and is grasped by the ROV. The ROV positions the core drill at the sample location, and the core drill is remotely operated from the platform. A water-actuated bellow is used to drive the drill bit into the tank wall. Once the proper coring depth is achieved, the core drill is retracted and the bit is removed, bagged-out of the containment structure, and transferred to the laboratory for analysis.

Scrape sampling is conducted at various locations in each tank to verify the wall condition before sluicing and wall-cleaning activities. The scrape-sampling tool consists of a 1-ft curved stainless steel tool with a removable 2- by 3 in. steel scraping blade with indentations for sample collection. The scraping tool is deployed through either the TRIC or TMADS containment bezel and is grasped by the ROV or MLDUA. The scraping tool is positioned at the scraping location, and the surface is scraped. The tool is retracted and the blade is removed, bagged-out of the containment structure, and transferred to the laboratory for analysis.

5. TANK W-3 ACTIVITIES AND SYSTEM PERFORMANCE

The first characterization activities for W-3 began with the survey using the GIMP system from April 21 through May 13, 1997. The move of waste retrieval equipment from the TTCTF to W-3 was started on May 15. Equipment checkout was conducted from June 12 through June 24. Operations began on June 25 with the deployment of the ROV.

The sequence of operations that resulted in cleanup of W-3 is provided in Fig. 5-1. Performance parameters and operating envelopes are provided in Table 5-1.

System performance can be defined by the percentage of curies removed from the tanks. However, this performance measure is limited by the accuracy of the characterization technologies. On an overall basis for W-3, before operations:

- the sludge volume was approximately 5500 gal containing an estimated 326 Ci;
- the supernate, containing an estimated 2 Ci, had been transferred to the active liquid low-level waste (LLLW) system; and
- the tank walls contained an estimated 6.4 Ci and were covered by an aluminum hydroxide scale containing approximately 7.3 Ci;

Following W-3 waste retrieval operations:

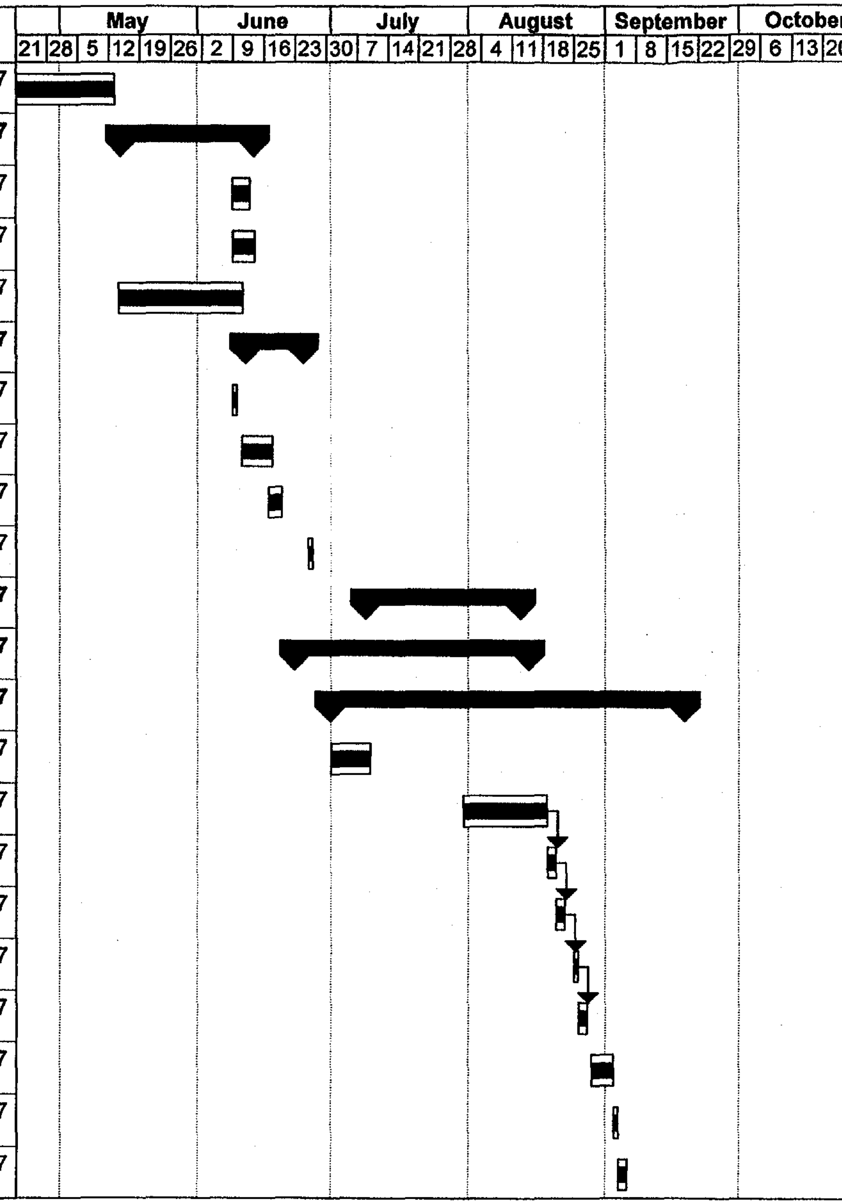
- approximately 100 gal of diluted slurry remain in the tank, containing an estimated 6 Ci and
- the tank walls contain an estimated 6.4 Ci.

Therefore, 96.5% of the original curies in the sludge and in scale on the tank walls was removed by waste retrieval operations.

Table 5-1. Tank W-3 operations performance

Performance parameters	Optimum operating envelope
Days of operation	June 25 to September 19, 1997; 61 days
Wall cleaning water pressure	6000 to 7000 psi
Wall cleaning traverse rate	0.25 to 0.50 in. per second or 0.15 ft^2 per minute of MLDUA hold time
Wall cleaning water flow	8 gal per minute or 19 gal per ft^2
Wall cleaning stand-off	Up to 18 in., usually 10 in.
Supernatant retrieval rate (instantaneous)	70 to 110 gal per minute, including motive fluid
Motive fluid rate	9.5 to 10.5 gal per minute
Motive fluid pressure	6000 to 7100 psi
Sludge retrieval rate (daily)	458 gal per day of sluicing operations
Sludge retrieval rate (instantaneous)	4.35 gal sludge per minute of jet pump operating time
Average slurry pumping rate, including all water added	37.4 gal per minute of jet pump operating time
Water added for sluicing	4.44 gal water per gal of sludge retrieved
Water added at CSEE for sludge retrieval	0.55 gal water per gal of sludge retrieved
Flush water added	94 events using flush water; 30 gal average per event
Flush events using jet pump	59 events
Decontamination water used (not counting spray wands)	ROV – 10 to 32 gpm at 500 to 2000 psi – avg 137 seconds and 45 gal per event MLDUA – 11 to 17 gpm at 200 to 500 psi – avg 58 seconds and 272 gal HMS – 13 to 26 gpm at 1000 to 2000 psi – avg 122 seconds and 35 gal per event

ID	Task Name	Duratic	Start	Finish
1	Survey tank W-3 and W-4 with GIMP	15d	Mon 4/21/97	Tue 5/13/97
2	**Equipment relocation to tank W-3 (HMS, ROV and MLDUA)**	**22d**	**Thu 5/15/97**	**Fri 6/13/97**
32	Supernate transfer from W-3 and W-4 to LLLW	4d	Mon 6/9/97	Thu 6/12/97
33	Emergency Drills / Training	5d	Mon 6/9/97	Fri 6/13/97
34	Install Pipeline to W-9	20d	Wed 5/14/97	Wed 6/11/97
35	**System Checkouts**	**9d**	**Thu 6/12/97**	**Tue 6/24/97**
42	Site walkthrough / confirmation of physical condition	1d	Mon 6/9/97	Mon 6/9/97
43	I&C Connection to ATIE and WOC	5d	Wed 6/11/97	Tue 6/17/97
44	Fill L-04 tank	3d	Tue 6/17/97	Thu 6/19/97
45	Install MLDUA Secondary Boot	1d	Thu 6/26/97	Thu 6/26/97
46	**Maintenance Activities**	**25d**	**Wed 7/9/97**	**Tue 8/12/97**
51	**W-3 initial tank inspection and debris consolidation**	**37d**	**Mon 6/23/97**	**Thu 8/14/97**
59	**W-3 sludge retrieval / mining operations**	**59d**	**Tue 7/1/97**	**Thu 9/18/97**
60	Scarifying Effectiveness Evaluation	5d	Tue 7/1/97	Wed 7/9/97
61	Retrieve sludge using ROV, MLDUA and CSEE	14d	Thu 7/31/97	Mon 8/18/97
62	Coring Tool Test	2d	Tue 8/19/97	Wed 8/20/97
63	Scarify walls	2d	Thu 8/21/97	Fri 8/22/97
64	Collect Core Samples	1d	Mon 8/25/97	Mon 8/25/97
65	Scarify Walls #2	2d	Tue 8/26/97	Wed 8/27/97
66	Collect Core Samples #2	2d	Fri 8/29/97	Tue 9/2/97
67	Deploy Hydraulic Shears - cut piping	1d	Wed 9/3/97	Wed 9/3/97
68	Scarify walls #3	2d	Thu 9/4/97	Fri 9/5/97



Project: NTF
Date: Wed 5/13/98
By: XL Associates, Inc.

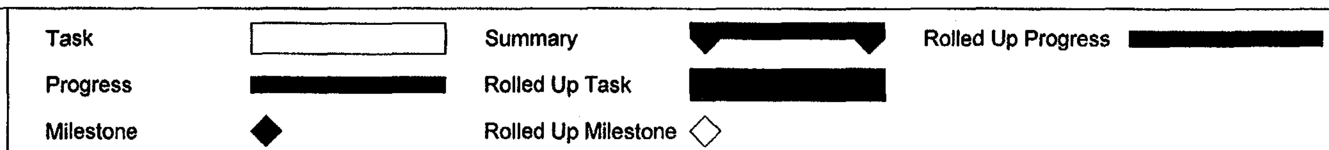
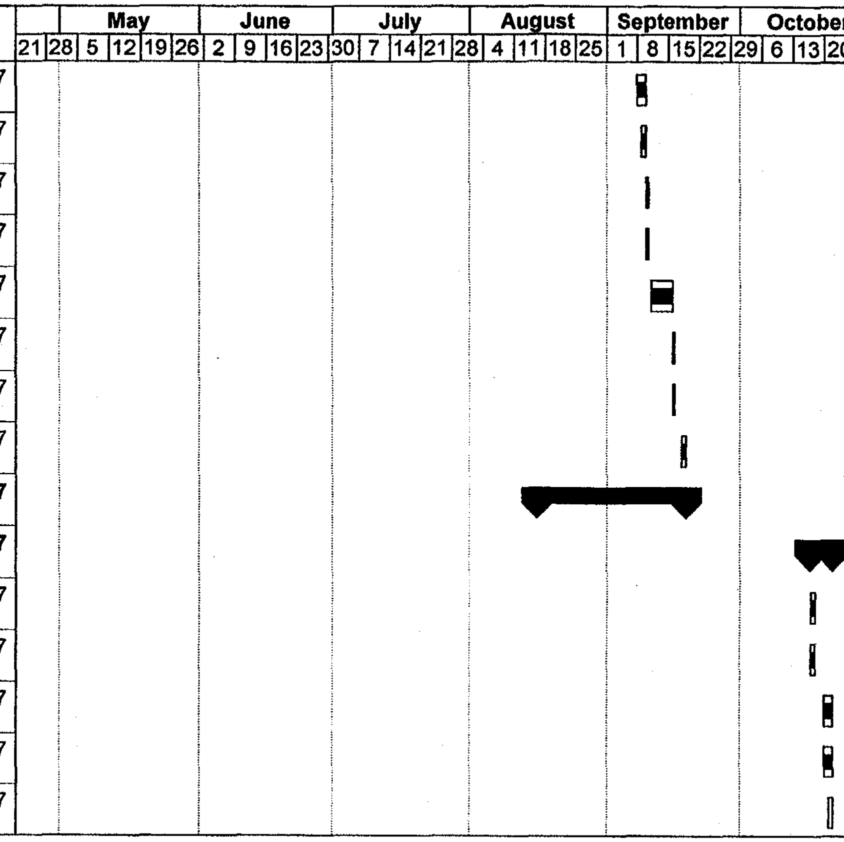


Fig. 5-1. GAAT W-3 operations schedule.

ID	Task Name	Duratic	Start	Finish
69	Repair CSEE Swivel	2d	Mon 9/8/97	Tue 9/9/97
70	Obtain wall scraping w/ Houdini	1d	Tue 9/9/97	Tue 9/9/97
71	Scarify walls #4	0.5d	Wed 9/10/97	Wed 9/10/97
72	Collect Core Samples #3	0.5d	Wed 9/10/97	Wed 9/10/97
73	W-3 Final Cleanup	3d	Thu 9/11/97	Mon 9/15/97
74	Collect Debris	0.5d	Tue 9/16/97	Tue 9/16/97
75	Deploy CEE	0.5d	Tue 9/16/97	Tue 9/16/97
76	Sluice Remaining Liquids w/ MLDUA	1d	Thu 9/18/97	Thu 9/18/97
77	**Supernate Transfers from W-4 to W-9**	**26.9d**	**Sat 8/16/97**	**Thu 9/18/97**
83	**Final W3 cleanup with scoop**	**3d**	**Fri 10/17/97**	**Tue 10/21/97**
84	Deploy ROV	1d	Fri 10/17/97	Fri 10/17/97
85	Collected debris	1d	Fri 10/17/97	Fri 10/17/97
86	Install 35 gal drum and shovel	2d	Mon 10/20/97	Tue 10/21/97
87	Shovel sludge w/ ROV	2d	Mon 10/20/97	Tue 10/21/97
88	***W-3 Operations Complete***	1d	Tue 10/21/97	Tue 10/21/97



Project: NTF
Date: Wed 5/13/98
By: XL Associates, Inc.

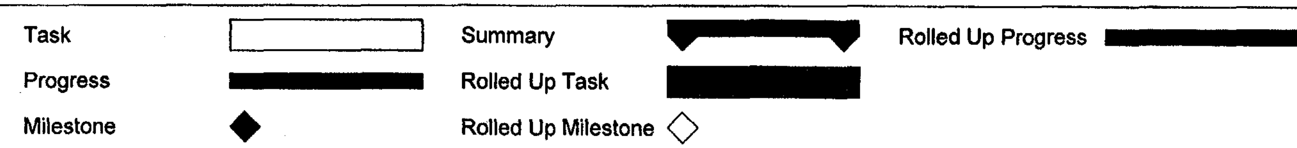


Fig. 5-1. (continued)

5.1 DATA COLLECTED

Data collected during NTF operations included the following:

- shift supervisor daily log,
- WD&C and BOP systems notebook,
- Houdini daily operations notebook,
- electronic data,
- video tapes,
- RWPs and sign-in/exposure tracking sheets,
- work authorization forms,
- sampling logs, and
- analytical data.

Electronic data on process operations and equipment status were collected throughout the operations period. The electronic data included equipment status information, which was collected purely for historic information, in case any abnormal event required review of equipment status and operations data. All electronic data were transferred in batches for daily review, filtering of the operations data from the historic status information, and compilation.

5.2 INITIAL TANK CHARACTERIZATION

The CEE was deployed three times: initially to obtain baseline surveys of the tank walls before cleaning, halfway into the W-3 sludge retrieval campaign, and a third time to define the effectiveness of the wall-cleaning operations.

The examination points were at levels roughly 4, 6, and 8 ft above the tank floor and were at four locations around the perimeter of the tank at each level. These four locations were at compass angles of 60, 120, 240, and 300 degrees from north (0 degrees). Various distances to the wall were tried; however, distance did not seem to have much effect on the readings. The baseline readings were taken with roughly 2 ft of water covering the sludge. The figure (Fig. 5-16) depicting the readings collected during the baseline survey is provided in Sect. 5.15 along with data from characterization activities following wall-cleaning operations.

5.3 EQUIPMENT MOVE TO NTF

The equipment move from the TTCTF to the NTF began with the transfer of the ROV maintenance platform (starting May 15, 1997), the MLDUA, the ROV, and then the WD&C System. Equipment move activities were completed on June 12, and system checkouts were completed on June 24.

5.4 ROV TANK OPERATIONS[4]

During the month of June 1997, the ROV system, also known as the Houdini was disconnected from the TTCTF and moved to the NTF. The system was positioned over the north riser of tank W-3 and was powered up for the first time on June 12 using the suitcase controller. During the next four months, the vehicle was deployed and retracted from W-3 a total of 24 times. In all, the system logged approximately 150 hours of tank operations and was deployed in the tank on 27 workdays.

The specific operating activities undertaken during the Tank W-3 campaign are cataloged in Table 5-2.

Table 5-2. ROV operations

Activity	Frequency (days)
Core	4
Floor cleaning end effector	1
Deploy	24
Move cradle for MLDUA	3
Plow	12
Scarify	3
Sluice	11
Aid HMA deployment	1
CSEE handoff	10
Decontaminate	13
Provide camera view	2
Remove debris	11
Retract	24
Shop vacuum end effector	1
Take oil samples	1
Take solid sample	1
Take wall scraping	2

On June 25, the ROV was the first of the GAAT sludge retrieval equipment to enter a tank. The vehicle was lowered through the riser to just above supernate level to test the strength and flexibility of some pipes mounted within the tank. These pipes were subsequently removed by the ROV using a hydraulic shear, the "Jaws-of-Life," on July 24.

The ROV completed its first full deployment into tank W-3 on August 1, 1997. Although the system completed 6 hours of operation and performed very well overall, hydraulic leaks were an issue. Hydraulic leaks continued to be the most consistent failure of the system. The most common failure point was at the 90° fittings to the track drive manifolds, which loosened during normal operations. As a preventive maintenance measure, these connectors were tightened weekly.

On August 6, the ROV was used to take a bulk sludge sample from tank W-3. This was accomplished by bagging in and lowering a paint bucket and scoop. The Titan III manipulator used the scoop to fill the bucket, which was then pulled out of the tank by a rope.

On August 19, the first wall core samples were collected using the ROV. A total of 12 cores were taken on four separate shifts; however, one of the cores broke off in the wall. The cores were from 1.5 to 3 in. long and showed the distinct layers of the Gunite tank walls including the inner Gunite, bituminous layer, and Gunite liner. The ROV did not have any major problems handling the coring end effector; however, it was somewhat difficult to get the four stabs of the end effector lined up properly before taking the core.

The ROV was used on numerous occasions to remove debris from the tank. The objects removed included tape, steel pipes and cord, assorted hand tools, and plastic bags and bottles. These items were placed in a wire mesh debris bucket that had been lowered down through the ROV riser with a rope and pulley. The bucket was then manually retrieved, and the contents were sprayed down and bagged out through the 20 in. port.

On September 15, the ROV deployed the FCEE, which had been designed to vacuum sludge out of the tank without adding water to the interior of the tank.

By this time, several maintenance items that could not be accomplished in TMADS had been stacking up in the queue; therefore, a decision was made to erect the on-platform maintenance tent. The tent was erected, moved into place, and secured to the platform by September 19. An inner lining was built inside the tent to protect it from contamination and to mate it to the TMADS. Once equipment was received for operating airline respirators inside the tent, one of the storage compartment panels was removed and the vehicle was driven out of TMADS onto a maintenance table that had been installed in the tent. This occurred on September 26. An engine hoist had also been installed in the tent so that the vehicle could be lifted onto jack stands as necessary for repairing/replacing hoses and fittings and for replacing the vehicle's tracks.

The ROV was deployed into tank W-3 for the final time on October 17 to perform a final plowing and scraping of the tank floor and to pick up any remaining visible debris and place it in the debris bucket. A shop vacuum unit equipped with the FCEE was also deployed in the tank. The shop vacuum unit consisted of a 35-gal drum with a shop vacuum attached to the top of it. The other end of the shop vacuum hose terminated in the FCEE, which was designed to scrape up the very thin (<0.25 in.) layer of sludge and water remaining on the tank floor. The end effector appeared to work well; however, the vacuum hose broke away from it after only a few minutes of operation. At this time, tank W-3 was approved for discontinuation of its tank-cleaning operations.

5.5 MLDUA OPERATIONS[5]

The MLDUA was first deployed into tank W-3 on June 26, 1997. The first deployment served as the system checkout and as an opportunity to perform wall inspections and to determine joint motions for automated deployments. Because of the MLDUA's positioning repeatability and accuracy, it was used to deploy the CEE.

The MLDUA operated as designed for performing tasks requiring repeatability or accuracy in positioning tools. The dynamic effects of the CSEE during sluicing and wall scarifying were not sufficient to impact MLDUA operations. However, the dynamics of the DSR impinging on the MLDUA mast did cause sufficient problems so that the decontamination had to be conducted at pressures of about 500 psi, well below the 2100 psi maximum available from the DSR, but adequate for gross decontamination of the MLDUA.

Table 5-3 provides the MLDUA operating statistics for tank W-3 operations.

Table 5-3. Tank W-3 MLDUA operating statistics

Operations	Events
Total number of times the vertical positioning mast (VPM) Housing was raised	5
Total number of times the VPM was deployed (off limit switches)	6
Total number of times the gripper end effector (GEE) was attached to the robot arm	3
Total number of times the robot arm was deployed into the tank	20
Total number of times the GEE grasps the CSEE for Sluicing	18
Total number of times the GEE grasps the CEE	3
Total number of times the GEE grasps the CSEE for wall cleaning	17
Total number of times the DSR was turned on for Decontamination	21
Amount of time the robot arm was inside the tank (below the TRIC floor)	686.0 hrs
Amount of time the GEE grasped the CSEE for sluicing	68.8 hrs
Amount of time the DSR was spraying the robot arm	1.2 hrs

5.6 WALL CLEANING

As described in Sect. 2., the tank W-3 walls were covered with approximately 0.13 in. of aluminum hydroxide scale before wall-cleaning operations began. This scale was estimated to contain 7.3 Ci.

The WD&C system was first deployed into tank W-3 on June 30, 1997, for initial checkout of the system. Wall cleaning of W-3 was initiated on July 1, 1997. Initial efforts were performed to determine the required operating water pressure and MLDUA parameters (traverse rate, standoff distance, etc.) for wall-cleaning operations. Approximately four areas of 4 by 6 ft at different quadrants of the tank were tested. Following sluicing operations and removal of most of the tank sludge, final wall cleaning operations were performed. Fifteen high-pressure wall-cleaning events were performed using the CSEE.

Initial results revealed that to effectively remove the scale, the CSEE operating pressure should be 6000 to 7000 psi, the traverse rate 0.25 to 0.5 in. per second, and the standoff distance from 4 to 18 in. During wall-cleaning operations, visibility in the tank was impaired by the water vapors generated by the jets impacting the Gunite surface. Therefore, before operations, the MLDUA with the CSEE in its grasp performed a dry run to determine tag points and to ensure that the MLDUA could safely operate within the defined envelope for robotic operations. Once the tag points were defined, the MLDUA's robotic mode was used for all wall-cleaning operations, permitting continued operations during low to zero visibility periods.

Most of the scale was removed, and the tank wall was cleaned to the Gunite surface. However, there are a few, small areas that could not be cleaned at the maximum pressure of the system (7000 psi) and at a standoff distance of 1 to 2 in. It is not clear whether any Gunite material was removed in the wall-cleaning operations. A diagram depicting the CSEE water flow rate vs the water pressure is provided in Fig. 5-2.

The tank internal wall areas that were cleaned are depicted in Fig. 5-3. The tank wall and floor interface is actually a curved joint. The vertical sides of the tank start at a point approximately 2 ft above the tank floor surface. The interface of the tank wall and ceiling is also a curved surface. The actual height of the tank is 12 ft 1.5 in. from the tank floor to just above the beginning of the junction of the tank wall and ceiling.

To minimize repositioning of the HMA, the upper half of the wall was cleaned first followed by the lower half. The wall-cleaning motion by the MLDUA was preprogrammed for cleaning a path of 50 in., moving to the right or left by 2 degrees, cleaning another vertical strip of 50 in., turning another 2 degrees, and continuing this pattern until the tag point was reached. The standoff distance for cleaning activities was started at 4 in., and was changed to 6 in. for most of the cleaning activities (see Fig. 5-4). The CSEE footprint at a standoff distance of 6 in. was approximately 4 in. in diameter. The preprogrammed path for the MLDUA resulted in an overlap of the CSEE footprint for each pass. Final wall-cleaning efforts resulted in deposition of an approximately 1 in. depth of descaled hardened sludge, material onto the tank's floor.

5.6.1 Rate of Wall Cleaning

The components of the wall-cleaning rate are the area cleaned divided by the time required for cleaning. The time required for wall cleaning can be evaluated in two ways:

(1) the time that the CSEE high-pressure water pump was operating, which includes some idle pump running time, and
(2) the total time that the MLDUA was operated to manipulate the CSEE to clean the tank walls.

The total area cleaned in W-3 is 707 ft^2. Although the MLDUA held the CSEE for 76.42 hours for wall cleaning operations, wall-cleaning time 28.07 totaled hours and was performed in 17 intervals. Therefore,

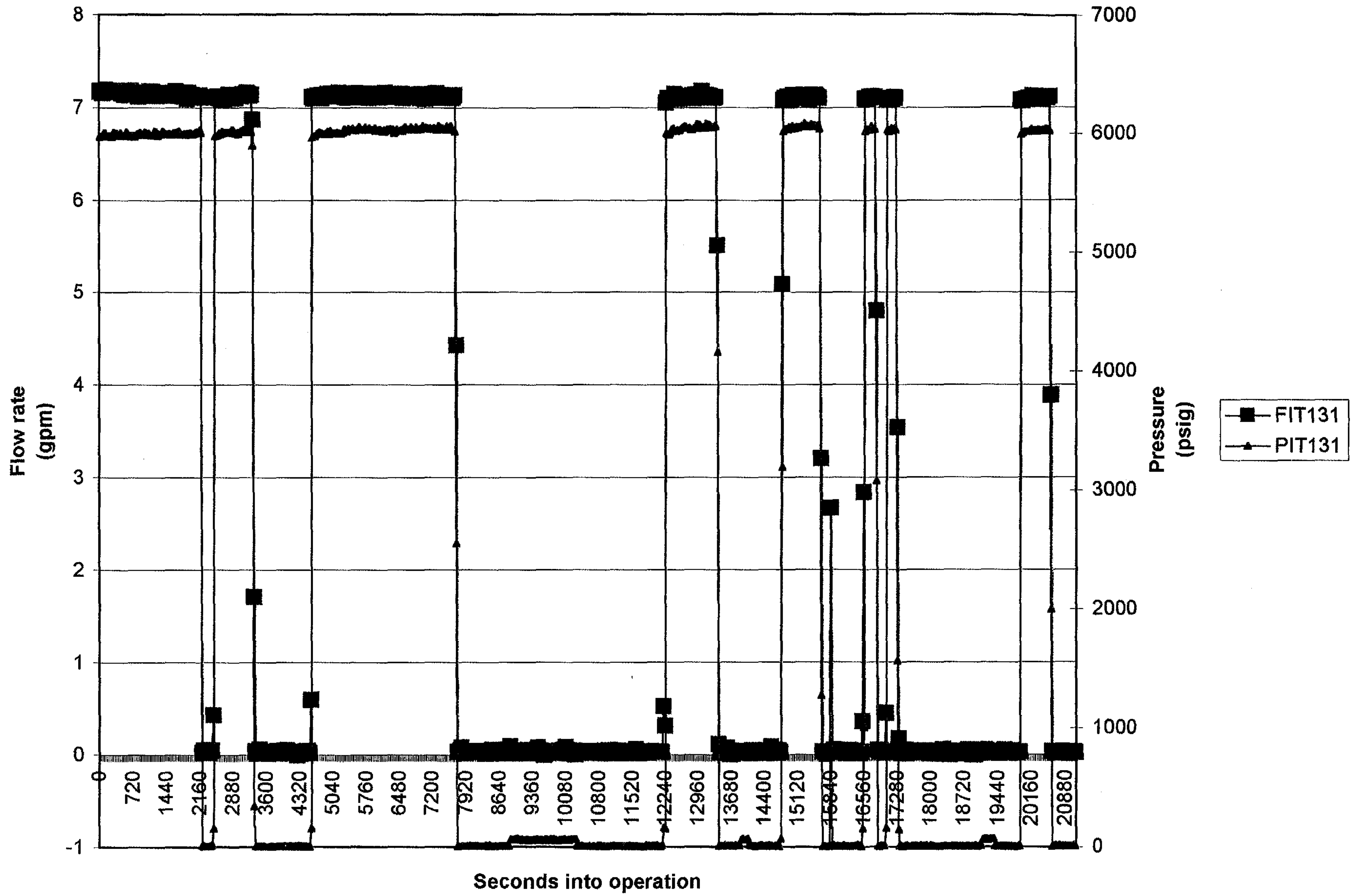


Fig. 5-2. CSEE water added for sluicing vs water pressure in a daily operation.

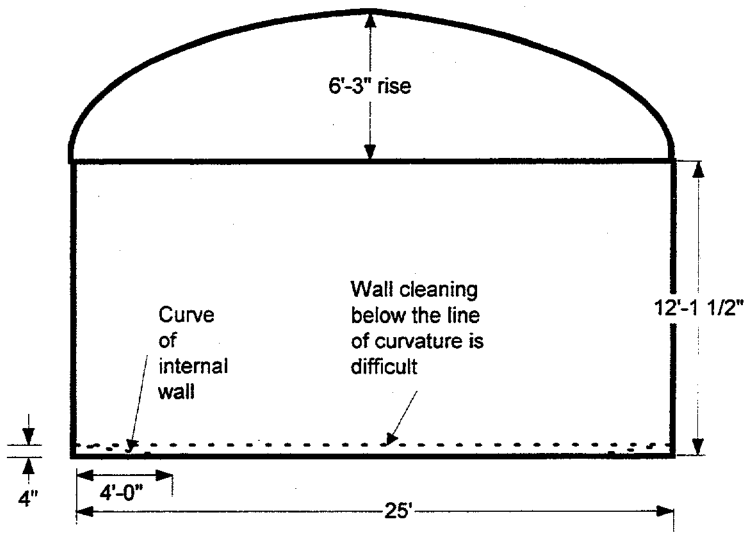


Fig. 5-3. Cross section of NTF tank (typical).

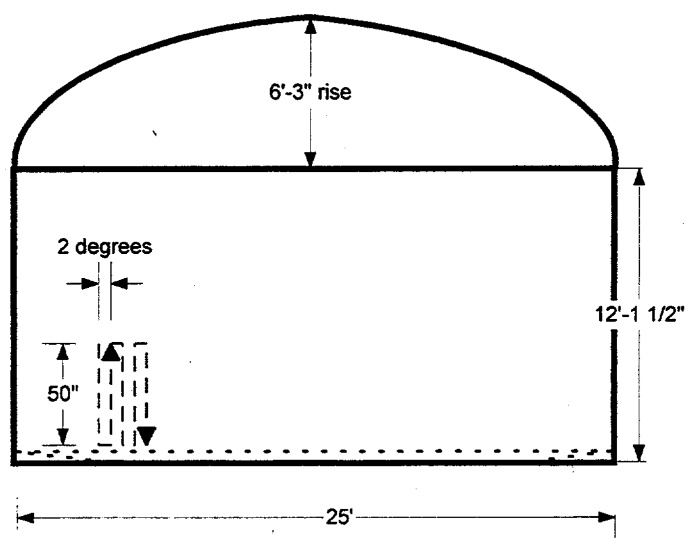


Fig. 5-4. Wall cleaning path.

on a large scale, wall cleaning was performed at an overall rate of 41.6 ft^2 per interval or shift.[5] During the time that the MLDUA held the CSEE, 9.25 ft^2 of wall was cleaned per hour, or 0.15 ft^2 per minute. Counting only the time that the CSEE pump was operating at high pressure, the cleaning rate is calculated to be 0.42 ft^2 per minute. This indicates that the MLDUA held the CSEE 2.8 minutes for each minute of actual wall-cleaning time. Stated another way, two-thirds of the time that the MLDUA held the CSEE, wall-cleaning operations were not being performed. This time was spent positioning the arm and waiting for the fog to clear before starting new swaths.

5.6.2 Water Added for Wall Cleaning

The electronic data source for tank wall cleaning included the CSEE water flow transmitter (FIT-131), which also provided a totalized flow rate in total gal per period. A total of 13,477 gal of water was used to clean the walls of W-3, or 19.1 gal of water per square foot of wall. Figure 5-5 depicts the total water used for wall-cleaning activities.

Scarification activities with the GSEE were not performed in W-3.

5.7 SLUICING

A total of 25 sluicing events were conducted. Two events were supernatant retrieval; approximately 5 were for descaled sludge retrieval from the wall, and the remainder were either residual sludge retrieval or flush and decontamination water retrieval.

The waste slurry line contained a Coriolis flow meter (FIT-204) designed to provide real-time data to the operators on slurry flow rate and slurry density. However, the pumped slurry frequently contained entrained air greater than 5% by volume, which resulted in erratic readings from the flow meter. The Coriolis flow meter design is limited to flow streams containing <5% (by volume) air. When air was entrained in the slurry line, the flow meter indicated a saturated signal, making the readings from the Coriolis flow meter erroneous. The maximum instantaneous retrieval rate, including jet pump motive fluid, indicated by the Coriolis flow meter during sluicing operations with a full slurry transfer line was approximately 110 gpm. This phenomenon is indicated in Fig. 5-6.

Another method for evaluating sluicing rate is evaluating the change in level in each of the tanks. The W-3 tank level, as indicated by LE-160, was inconsistent because of the tank operations occurring within the tank. The level changes were caused not only by sludge transferred to W-4 but also by jet pump water, flush water, decontamination water, and water from wall-washing activities.

This all means that even with an operable flow meter in-line, it would be difficult to determine actual sludge transfer rates since the added process water is combined with the sludge. Most of the sluicing activities occurred between July 11 and August 20, or for 34 operating days (including one double shift for a total of 35 operating shifts). Most of the 5500 gal of sludge was transferred in this time, for a transfer rate of 157 gal per shift. Sluicing may not have been performed on all these shifts (because of maintenance activities, etc.); but because the operations approach was to sluice, if possible, on all shifts, a scheduling number can be estimated based on W-3 performance.

5.7.1 Supernatant Retrieval

Following wall cleaning and characterization and before sluicing operations began, the supernatant was removed from the tank. The first supernatant removal action was performed as a maintenance action by the ORNL Waste Management organization. This action removed supernate down to approximately 12 in. above the sludge.

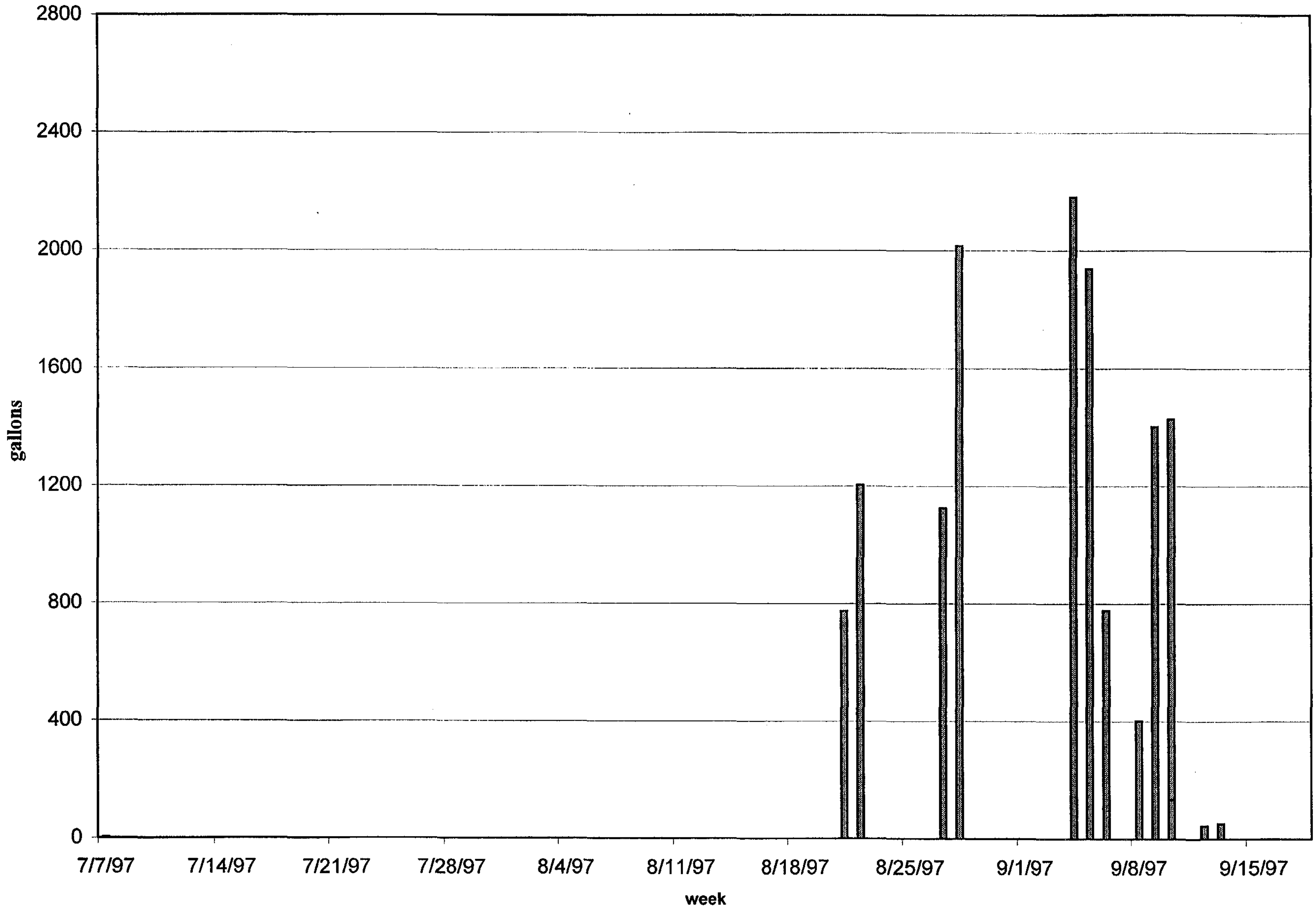
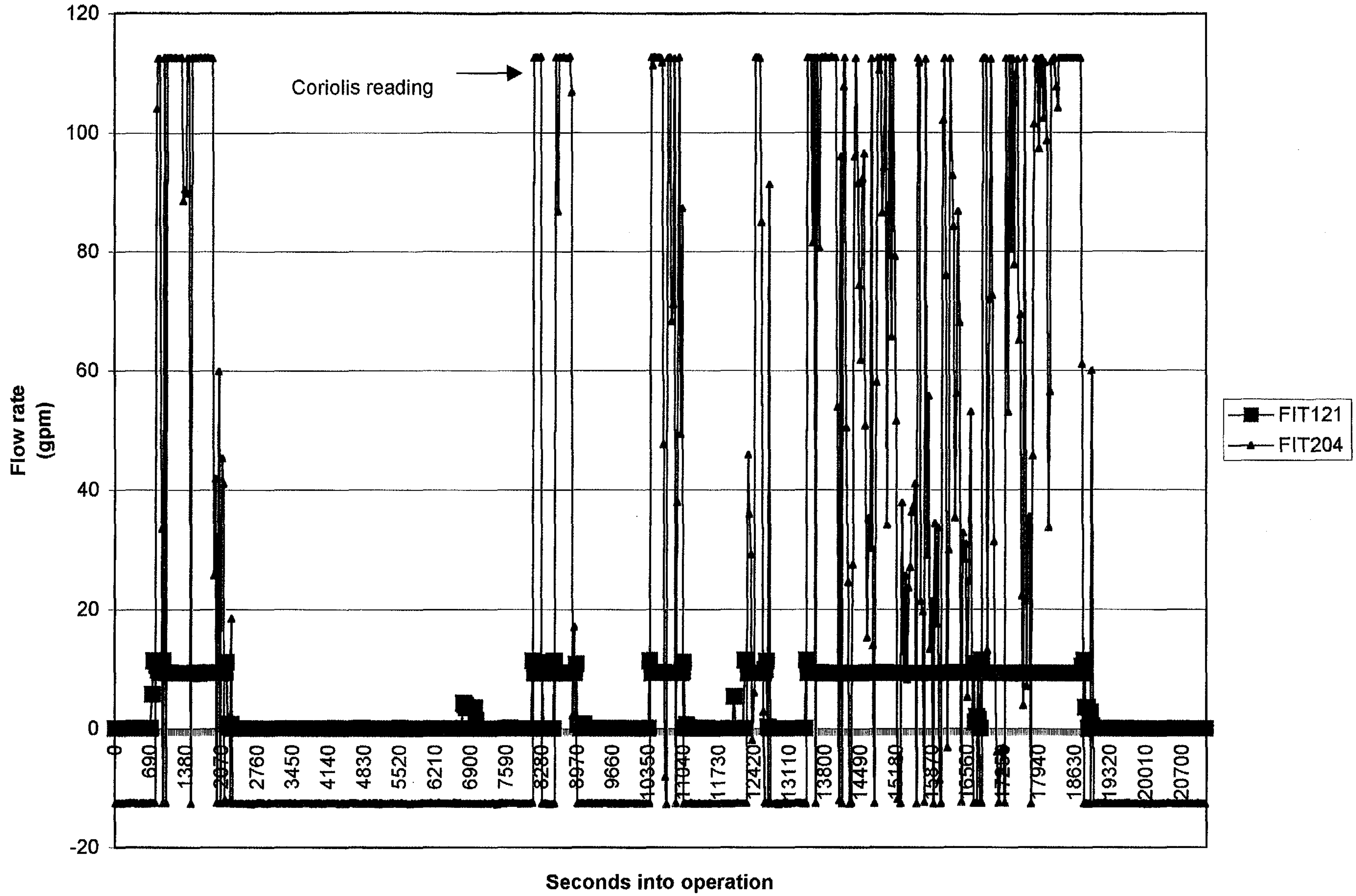


Fig. 5-5. Total CSEE water usage for wall cleaning activities during W-3 operations.



9/13/97

Fig. 5-6. Example of saturated signal from slurry Coriolis flow meter FIT-204.

Using the jet pump and the supernate retrieval end effector, the supernatant was removed in two events with retrieval rates of 70 to 110 gpm minimum*, including motive fluid water for the jet pump. Motive water rate for the high-pressure water jet pump was 9.5 to 10.5 gpm, at a pressure of 6000 to 7100 psi.

5.7.2 Sludge Retrieval

Once the supernatant was removed, the sludge layer was clearly visible. One important note of interest is that the original sludge-depth measurements taken in 1995 were inaccurate. The original information indicated that the total sludge depth was 6 to 8 in. An in-tank measurement made using the MLDUA and a ruler indicated the true depth of the sludge to be approximately 24 in. Preoperations planning included a mining strategy to plane the waste surface to permit a layered retrieval effort. However, the sludge was very mobile when sluicing, and dewatering resulted in "mud slides." Therefore, an alternative mining strategy was developed. The most productive method was to mine an area of approximately 6 by 6 ft down to the floor surface as a landing area for the ROV. Once this area was mined, the ROV was deployed to manipulate the CSEE for additional sludge retrieval.

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

Variation in sludge retrieval rates is dependent, in part, on the particular operation being performed. For example, when retrieving large sludge volumes a high retrieval rate can be achieved, but when retrieving small volumes or when near the floor, the system also entrains air, resulting in poor retrieval rates. Typical readings from FIT-121, FIT-204, and FQIT-204 are depicted in Figs. 5-7 and 5-8. Retrieval rates are also dependent on the amount of debris contained in the sludge. A screen integrator was attached to the CSEE inlet for screening out objects larger than 0.5 in. In the early phase of sludge retrieval, either debris or sludge or both frequently plugged the screen. Back-flushing easily cleared the majority of the material from the screen.

5.7.2.1 Retrieval Rate

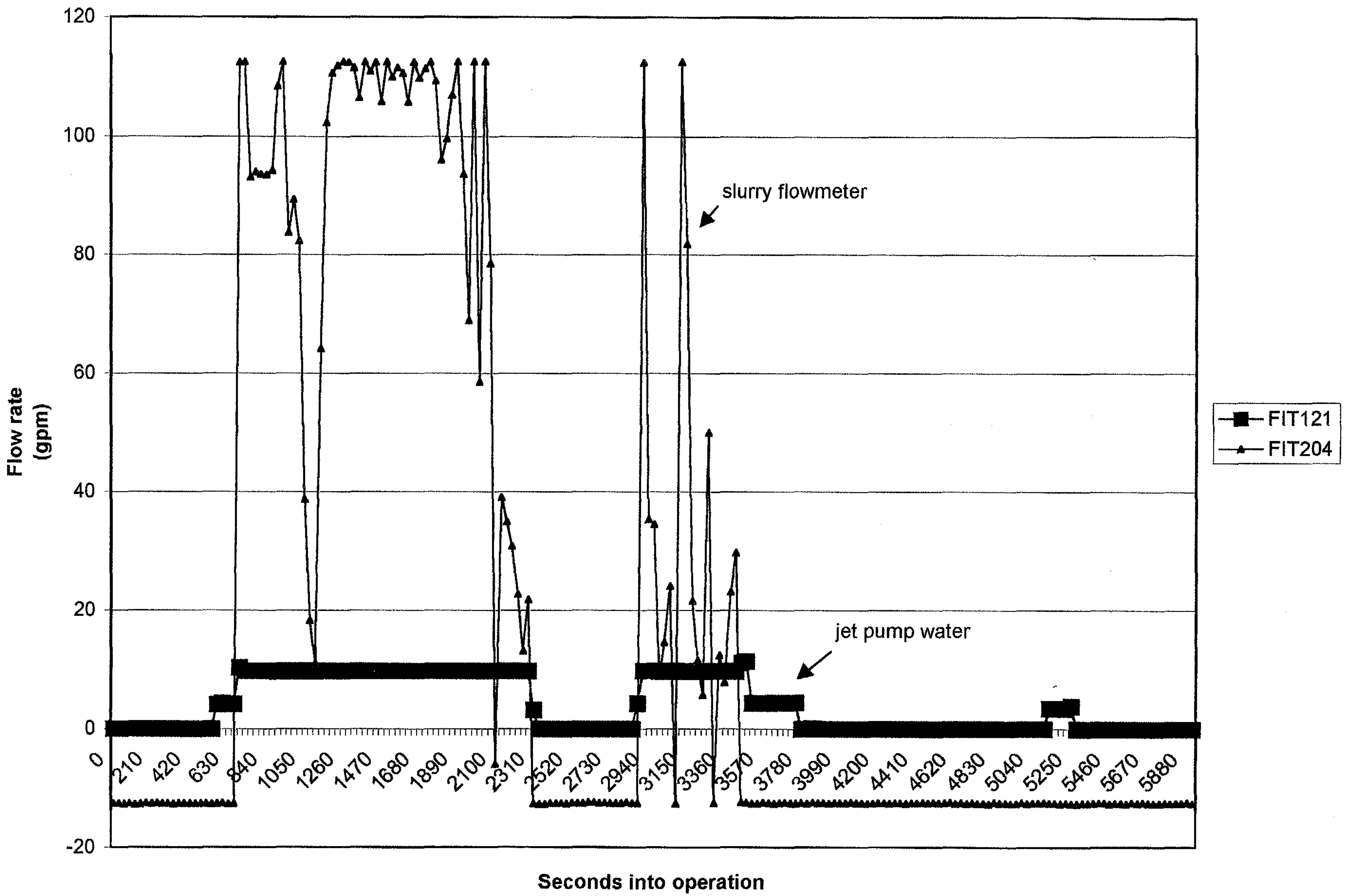
The 5500 gal were transferred in 12 days for an average daily retrieval rate of 458 gal per day. The total jet pump operating time for sluicing operations, as logged in the shift supervisor's log, was 1265 minutes, plus 277 additional minutes for transferring water that accumulated during wall-cleaning operations. The sludge retrieval rate for actual jet pump operating time is 4.35 gal per minutes of jet pump operating time.

The total water added to W-3 and W-4 combined during operations was logged at 41,797 gal. Therefore, the total fluids transferred by the jet pump, including the jet pump motive fluid water, is 47,297 gal. The average slurry pumping rate, including all the water added, is 37.4 gpm.

5.7.2.2 Water Added

Water added for sluicing activities includes water added at the CSEE to fluidize the sludge for pipeline transfer (FIT-131), the motive fluid water added at the jet pump (FIT-121), and flush water (FIT-102). Water added at the CSEE for sluicing activities is depicted in Fig. 5-9. Water added at the jet pump is depicted in Fig. 5-10.

* The Corolis flow meter used to log the supernatant retrieval rate experienced a saturated signal at 110 gpm. Flow at these times could have been higher than the 110 gpm indicated. However, the maximum observed liquid transfer rate in cold testing was 100 gpm, plus 10 gpm of motive fluid.



9/10b/97

Fig. 5-7. Typical readings from FIT-204 vs water added at jet pump (FIT-121).

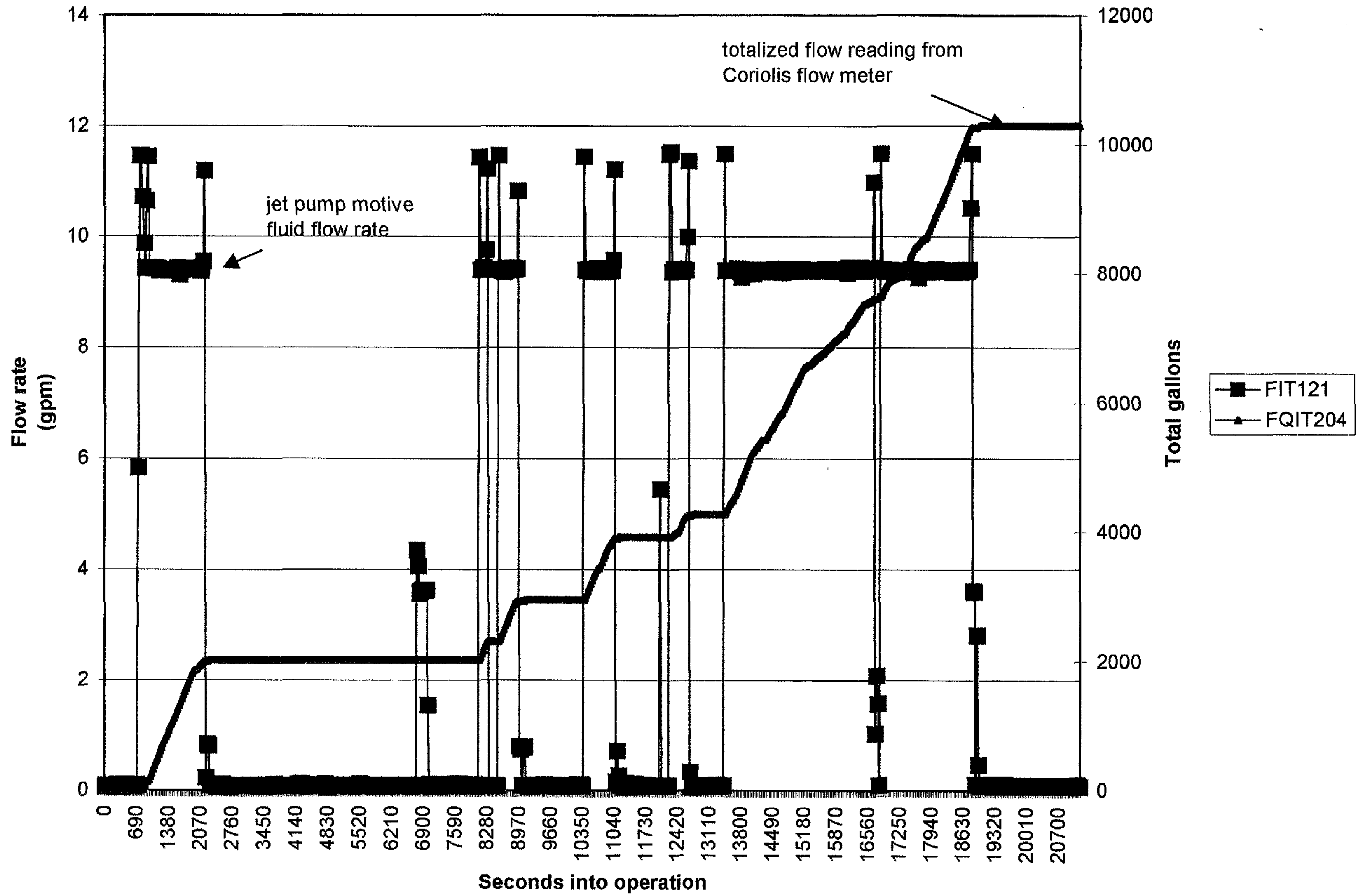


Fig. 5-8. Typical reading from FQIT-204 during one day of sluicing operations in W-3.

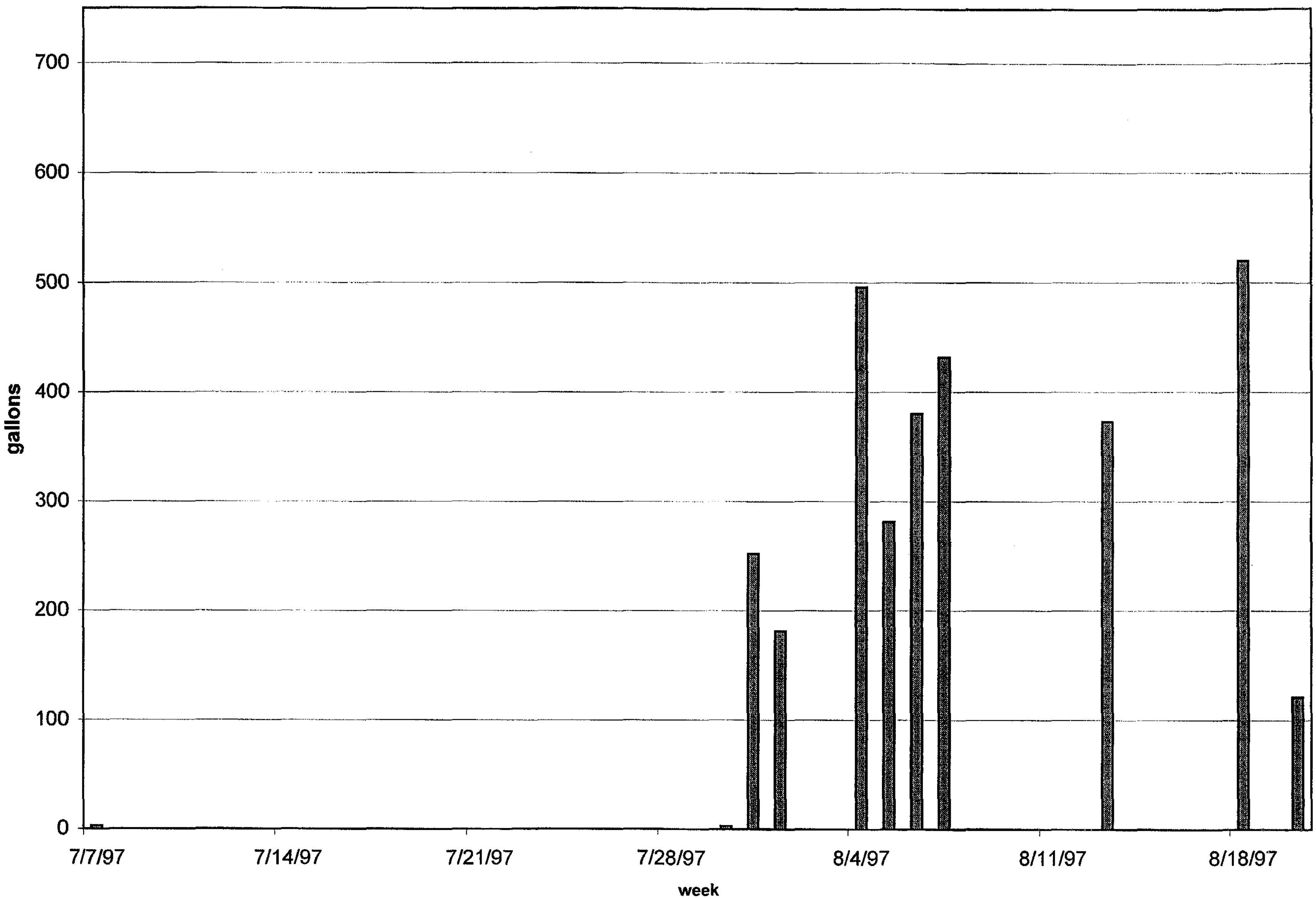


Fig. 5-9. Total CSEE water used for sluicing during W-3 operations.

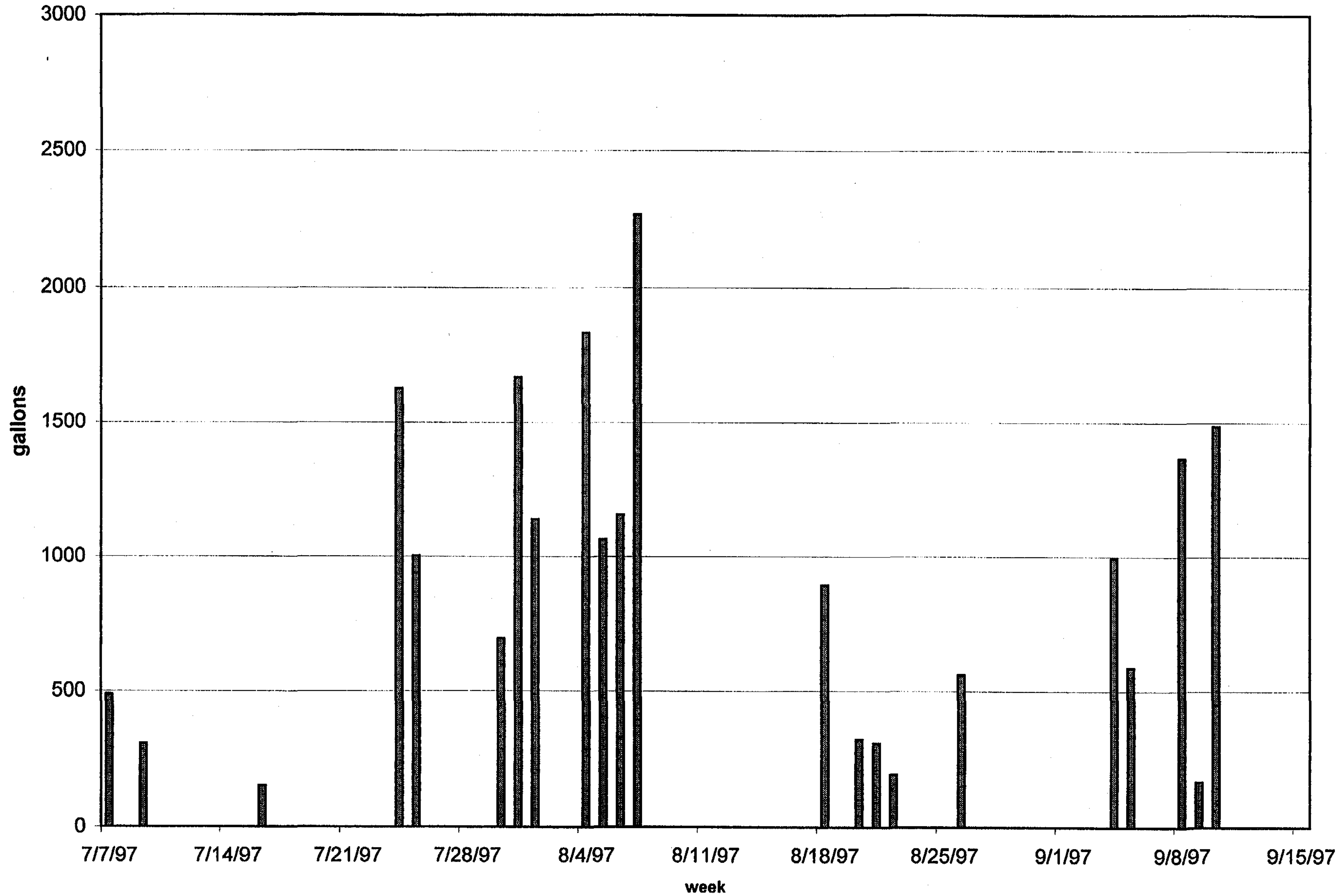


Fig. 5-10. Total motive fluid water to jet pump during W-3 operations.

Again, the validity of the readings from the CSEE water flow transmitter (FIT-131) are in question because of periods of inoperability and indications that the meter was reading lower flow than the actual flow through the meter. Likewise, the jet pump motive fluid flow transmitter (FIT-121) is believed to have been reading lower than true flow.

The water added for sluicing activities (as recorded electronically) only in removing 5500 gal of sludge from W-3 was 24,439 gal, 21,397 gal added at the jet pump and 3041 gal added at the CSEE to provide fluidizing of the sludge for pumping. Water was added at a ratio of 4.44 gal per gallon of sludge pumped. If the sludge is relatively flowable and does not need additional slurrying by the CSEE, this ratio can drop to 3.89 gal of water added at the jet pump to transfer the sludge in future transfer operations.

5.7.2.3 Flush Water Used

To ensure that objects would not get lodged in the throat of the jet pump, or in the slurry transfer line, a screen was attached to the CSEE inlet for screening out objects larger than 0.5 in. However, plugging of the screen with either debris or sludge or both occurred frequently during sluicing operations. Back-flushing easily cleared the majority of the material from the screen.

The flushing system provided the ability to dislodge a blocked line during operations and to clean the process line at the end of each sluicing operation. This system proved invaluable and was used as necessary to dislodge material from a clogging event. The flow volume delivered to the flush line is 20 gpm at a pressure of approximately 60 psi. The system is arranged to provide either back flush or forward flush. Figure 5-11 shows the flush water events that occurred that required the addition of water during operations of a typical day. Efforts to minimize water addition to the tank were made during each flushing operation.

The total flush water added (FIT-102) during W-3 operations was 2853 gal (see Fig. 5-12). A total of 153 flush events were performed during the 25 sluicing events. These flush events were performed in two ways: by adding flush water at approximately 70 gpm or by using the water to the jet pump at approximately 10 gpm. The flush water was added during 94 separate events, for an average flush water addition of 30 gal per event. The duration of the flush events ranged from 10 to 164 seconds. Sixty-two of the events were back-flushing, and 32 events were forward-flushing. Flushing operations were also performed by closing a valve downstream of the jet pump, thereby diverting jet pump motive fluid water forward to the CSEE to clear any plug at the hose inlet. A total of 59 of these events were performed.

5.7.3 Scale Retrieval

At the conclusion of supernatant and sludge retrieval exercises a full effort was given to wall cleaning. This resulted in approximately 1 in. of descaled hardened sludge material collecting on the tank's floor. The CSEE was used to retrieve 50 to 70% of this material. However, the CSEE was not capable of retrieving the remaining scale.

Another end effector was designed and fabricated for attachment to the WD&C HMA. This end effector, shaped like a carpet cleaner nozzle, was used to retrieve approximately 10 to 20% of the remaining scale but was not very effective beyond that point.

5.8 DEBRIS REMOVAL

The ROV was used on numerous occasions to remove debris from the tank. The objects removed included tape, steel pipes and cord, assorted hand tools, and plastic bags and bottles. These items were placed in a wire mesh debris bucket that had been lowered down through the ROV riser with a rope and pulley. The bucket was then manually retrieved and the contents were sprayed down and bagged out through the ROV 20 in. port.

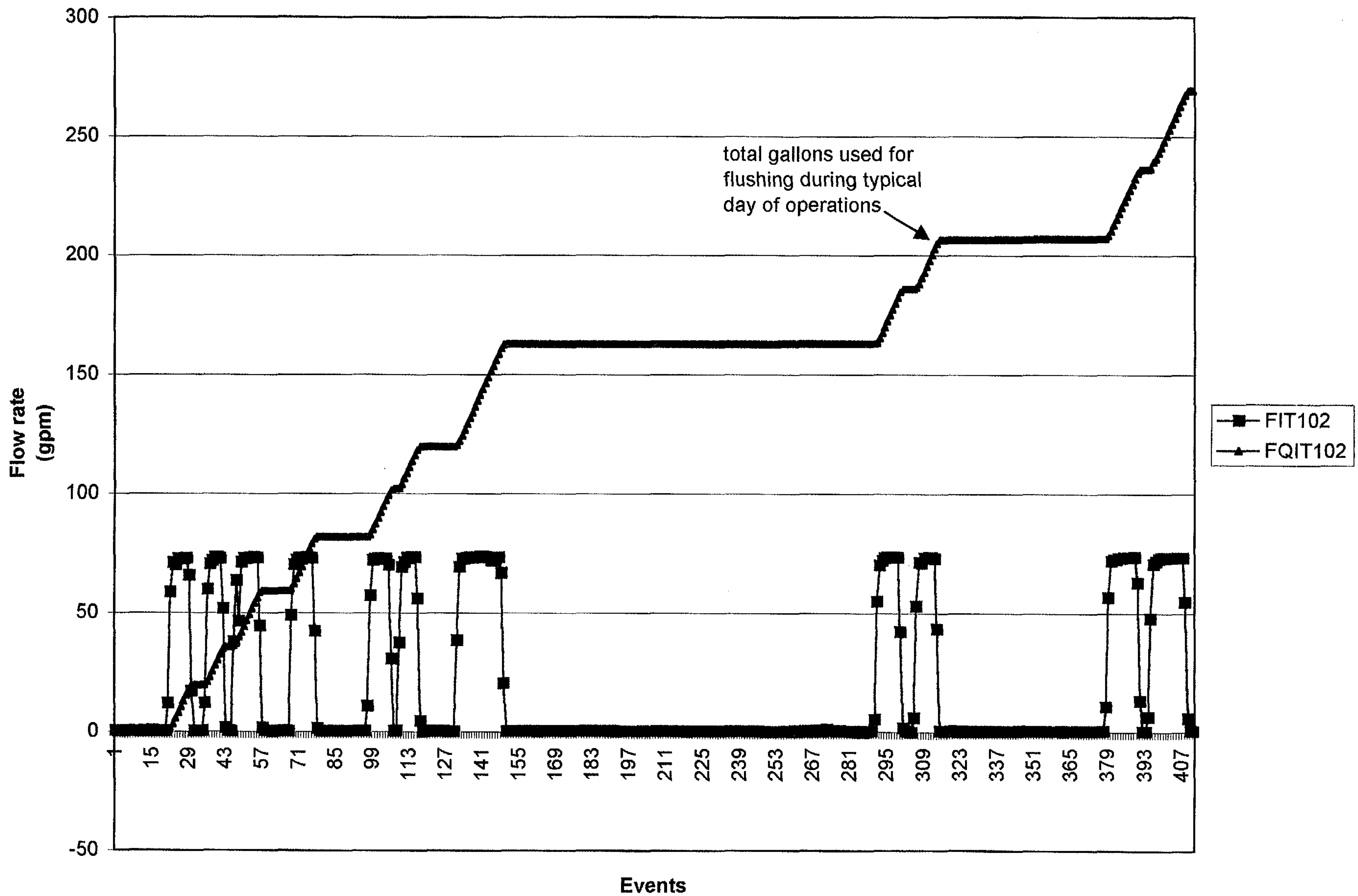


Fig. 5-11. Flush water events for a typical day of W-3 operations.

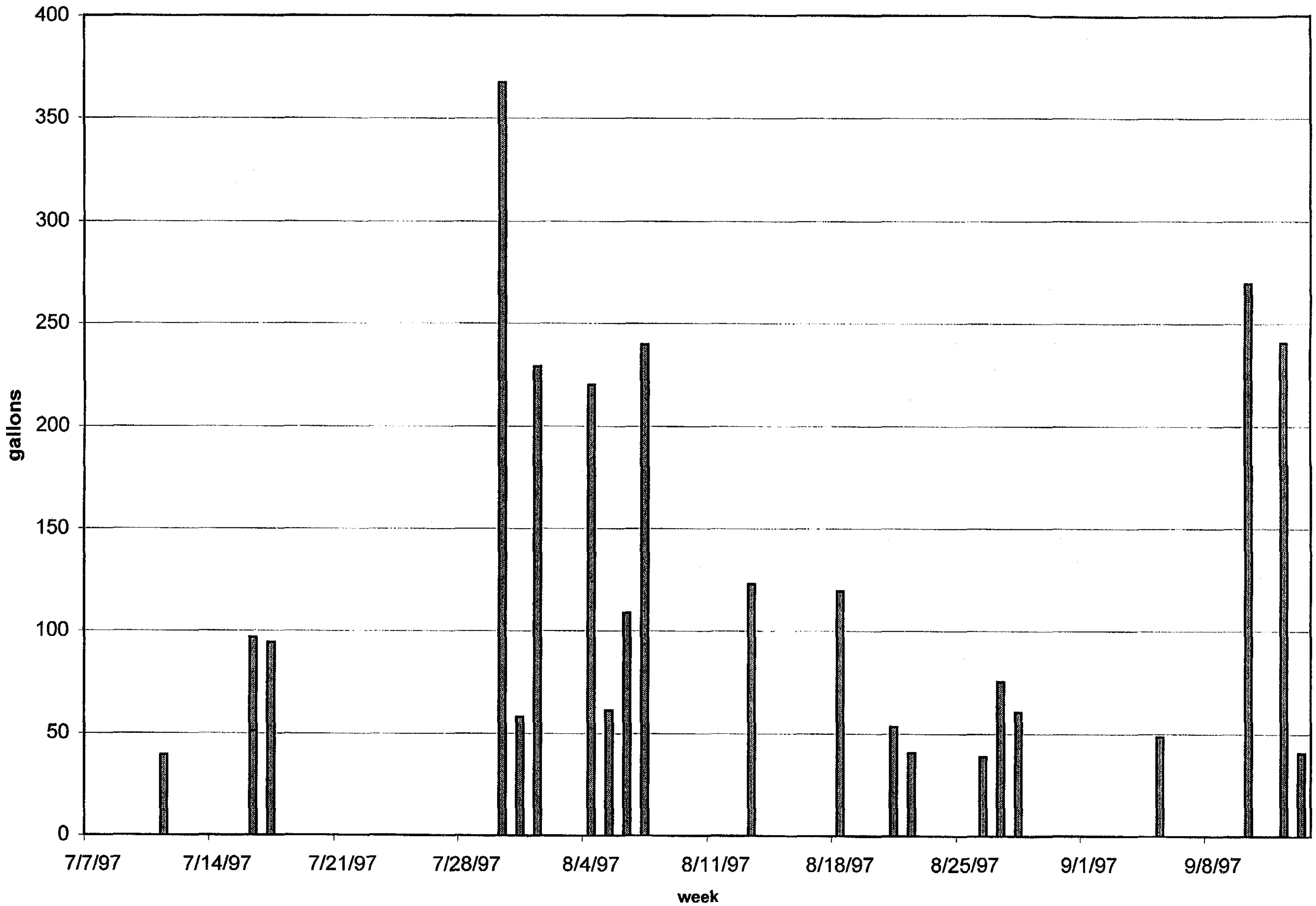


Fig. 5-12. Total flush water used during W-3 operations.

5.9 BALANCE OF PLANT

The Isolok Sampler is designed to collect a predetermined number of 10-mL aliquots in a sample bottle until the composite sample is collected for analysis. The sampler did not obtain a 10-mL sample as designed because the slurry pipe was not full but contained entrained air as previously discussed. The sample bottle was removed and replaced with an empty sample bottle after 35 aliquots were collected in the same sample bottle. If the sample was not a sufficient volume for analysis, it was saved at the laboratory to be combined with the next sample.

The HMA and most of the BOP systems have remote control capabilities and are operated from the OCT's WD&C and BOP graphical users interface station. These control systems were the primary operations systems, and no manual (field operations) was performed. Only a few software problems were experienced. The control engineer provided some enhancements to the system during the operations period.

Two samples were collected using the Isolok Sampler and were submitted for analysis. The only problem noted for the sampler was a slight, slow leakage at the mating of the bottle to the sampler. The sampler was cleaned, and a tight seal was obtained by the next bottle.

5.10 DECONTAMINATION WATER USED

Decontamination water, introduced through spray rings at the top of the tank risers, was used to decontaminate the MLDUA, ROV, and HMS. Figure 5-13 depicts the relationship of decontamination water flow vs water pressure applied.

The electronic data source for decontamination activities was from the decontamination water flow meter, FIT-141. A maximum of 32 decontamination events was performed. The total decontamination water used was 1239 gal (Fig. 5-14). This is only 3% of the water used in tank W-3 cleaning activities, indicating that decontamination activities do not add a large amount of water. The decontamination water flow rate and pressure were varied to obtain the most effective cleaning for each piece of equipment without damaging the equipment.

The decontamination water was delivered to each spray ring from a manifold system equipped with remotely operated valves, which provided a signal to the computer indicating whether the valve was open or closed. This allowed the determination of how much decontamination water was used to clean each piece of equipment.

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

5.10.1 ROV

For decontamination of the ROV, the decontamination water flow rate ranged from 10 to 32 gpm at a pressure that ranged from 500 to 2000 psi. The average time for decontamination was 137 seconds per event, at an average total water added of 45 gal per event. The total water used during W-3 operations for decontamination of the ROV through the DSR was 721 gal. Further decontamination of the ROV that was performed with a hand-held spray wand was not recorded.

5.10.2 MLDUA

For decontamination of the MLDUA, the decontamination water flow rate ranged from 11 to 17 gpm at a pressure of 200 to 500 psi. The average total water added was 17 gal per event. The total water used during W-3 operations for decontamination of the MLDUA through the DSR was 272 gal. Further decontamination of the MLDUA that was performed with a hand-held spray wand was not recorded.

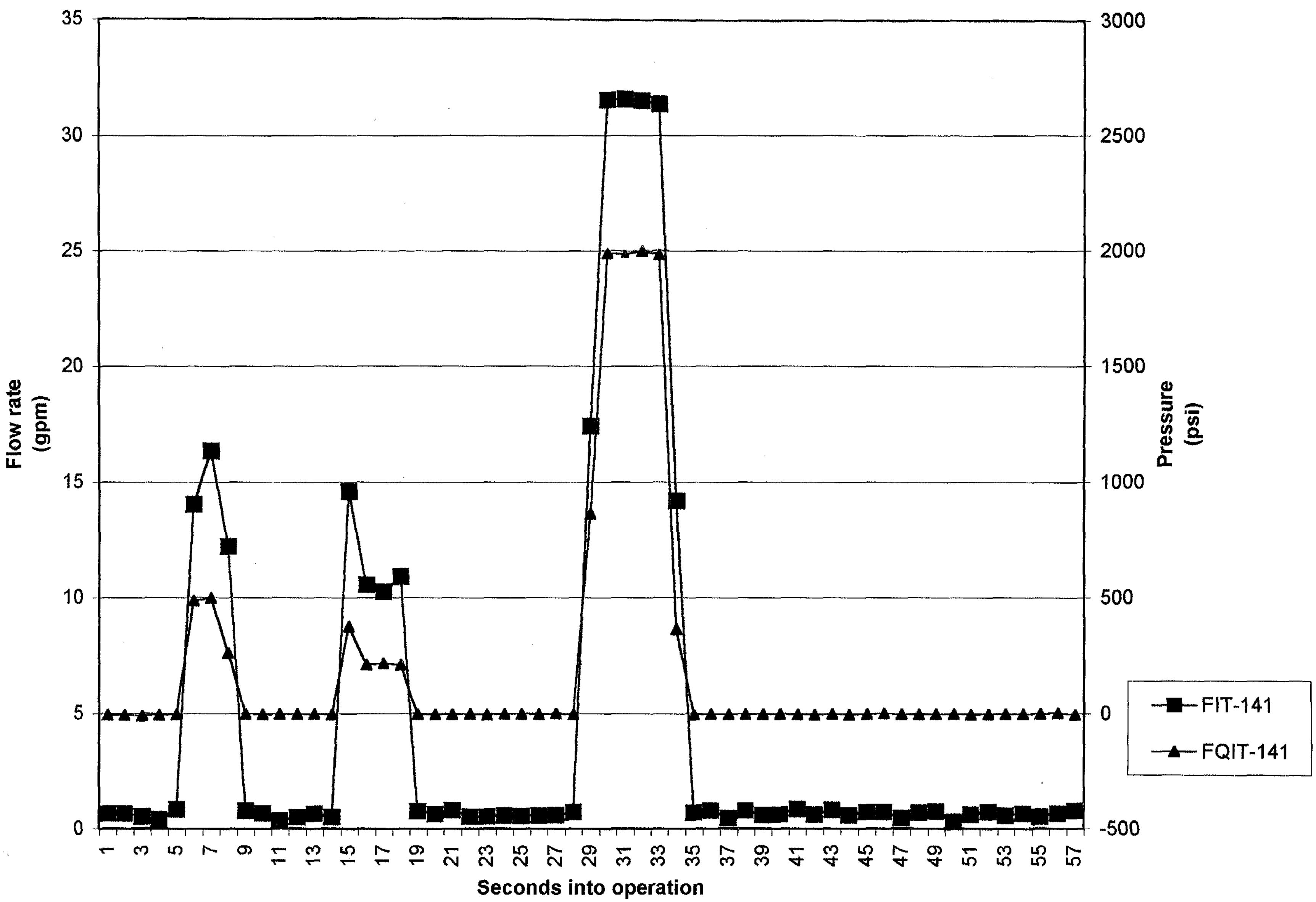


Fig. 5-13. Decontamination flow rate vs water pressure.

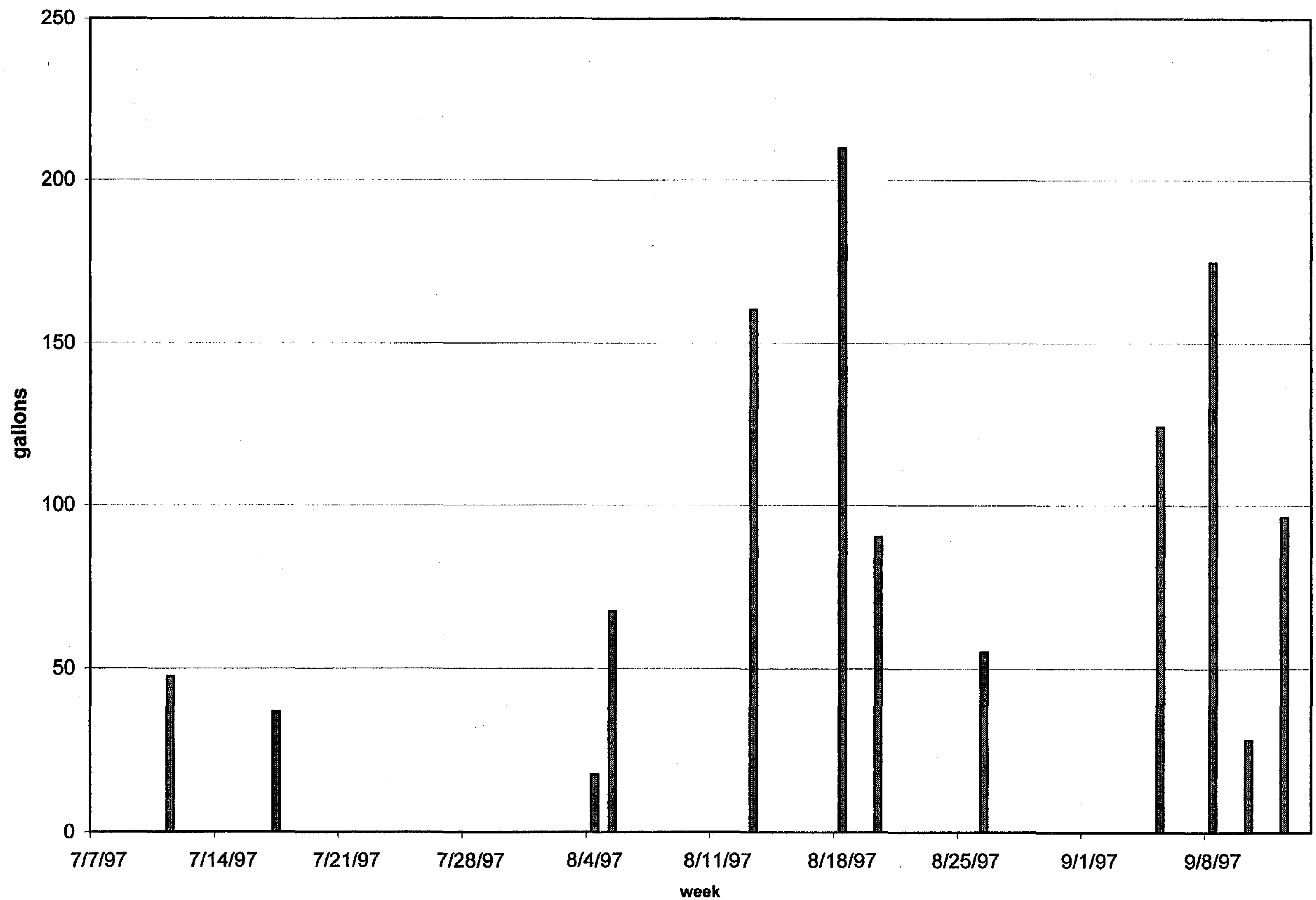


Fig. 5-14. Total decontamination water used during W-3 operations.

The dynamics of the DSR impinging on the MLDUA mast did cause sufficient problems so that the decontamination had to be conducted at pressures of about 500 psi, well below the 2100 psi maximum available from the DSR.

5.10.3 HMS

For decontamination of the HMS, the decontamination water flow rate ranged from 13 to 26 gpm at a pressure of 1000 to 2000 psi. The average time for decontamination was 122 seconds per event, at an average total water added of 35 gal per event. The total water used during W-3 operations for decontamination of the HMS through the DSR was 247 gal. Further decontamination of the HMS that was performed with a hand-held spray wand was not recorded.

5.11 PERSONNEL EXPOSURES

Seventy-two RWPs and 14 subtask RWPs were issued during NTF W-3 activities. Most activities logged a total employee exposure of less than 10 mrem, with the exceptions noted in Table 5-4.

Table 5-4. W-3 radiation work permits with exposures of more than 10 mrem

RWP No.	Task	Dose (mrem)	Total time (h)	Calculated dose rate (mrem/h)
1513	ROV operators to perform the following routine activities through the use of glove ports or pass through ports: (1) unlatch/latch safety chain, (2) pressurize/depressurize pneumatic door seal, (3) assist in deployment/retraction of the Houdini, and (4) visual inspection.	25	132.8	0.19
1514	MLDUA operators to perform the following routine activities through the use of glove ports, pass-through ports, or by visual inspection: (1) Prestart checks, (2) raising/lowering of the vertical positioning mast, (3) installation/removal of the secondary boot, and (4) decontamination.	12	250.0	0.048
1524	Relocation of DSRs, riser inserts, MLDUA, ROV, HMS, and FCE/CB from W3 to W4. Personnel to place plastic bags over the ends of the equipment and secure before each piece is hoisted out for relocation	33	153.4	0.22
1558	Visual observation of work and prestart checks on the platform. No glove port work or any intrusive work on the MLDUA, ROV, or WD&C is allowed.	27	282.5	0.096
1627	Health and Safety Manager (H&SM) and Radiological Control Technician (RCT) surveillance as needed. Includes RCT routines and rad waste/laundry collection and processing.	10	406.3	0.025
1974	Personnel to perform maintenance on Houdini in Rubb™ tent. Additional activities included unbolting and removing steel panel on TMADS	34	121.7	0.28
1984	Visual observation of work, light duty work and prestart checks on the platform. No glove pot work or any intrusive work.	33	321.8	0.10

5.12 PPE USAGE

Personal protective equipment (PPE) costs are much less than originally estimated because of the use of the ORNL laundry services and minimal use of disposable PPE.

5.13 SOLID WASTES GENERATED

Solid wastes generated during W-3 operations were reported to be 400 ft^3 of solid low-level waste. This consisted primarily of used PPE, plastic, and trash from the contamination zone.

5.14 WASTE CHARACTERIZATION INFORMATION

Data indicate that a total of three samples were collected via the Isolok Sampler and were submitted for analysis. The only problem noted for the sampler was a slight, slow leakage at the mating (seal point) of the bottle to the sampler for the first sample. The sampler was cleaned, and a tight seal was obtained by the next bottle.

The density measurements performed on the samples are shown in Fig. 5-15. Analysis of the samples is presented in Table 5-5.

Table 5-5. In-line process sample results

Sample ID/Analytes	Units	970808-014	970826-020	970915-046
Project ID		**W3 Compl**	**W3-013**	**W3-022**
^{238}U	Bq/g	74	800	42
$^{233}U+^{234}U$	Bq/g	150	1200	54
$^{239}Pu/^{240}Pu$	Bq/g	320	2000	120
$^{238}Pu/^{241}Am$	Bq/g		170	8
^{137}Cs	Bq/g	2700	7700	400
^{241}Am	Bq/g	74	150	
Total Rad –Strontium	Bq/g	20,000	180,000	8500
G-Alpha	Bq/g	630	4200	220
G-Beta	Bq/g	44,000	430,000	18,000
Bulk density	G/mL	1.086	1.135	1.020
Density (dry solids)	G/mL		7.763	
Density (wet solids)	G/mL		1.484	1.53
Total solids	mg/L	17,700	130,000	6000

5.15 TANK CHARACTERIZATION INFORMATION

As explained in Sect. 5.2, the CEE was deployed a total of three times. Twelve points were surveyed during each campaign. Figure 5-16 shows the baseline characterization data for W-3 before wall cleaning.[6] Figure 5-17 shows the CEE data collected following wall-cleaning activities. Comparisons of these data to the baseline CEE readings indicates that wall cleaning was marginally effective for the highest points characterized but was not effective for the lower points in the tank. A possible explanation for this may be that the baseline test was performed with water completely covering the sludge in the tank while the final readings were taken with relatively no water covering any remaining sludge and the tank floors, therefore providing no shielding from potential beta components on the floor of the tank. Coring tests, as described subsequently, show greater cleaning efficiencies than indicated by the CEE.

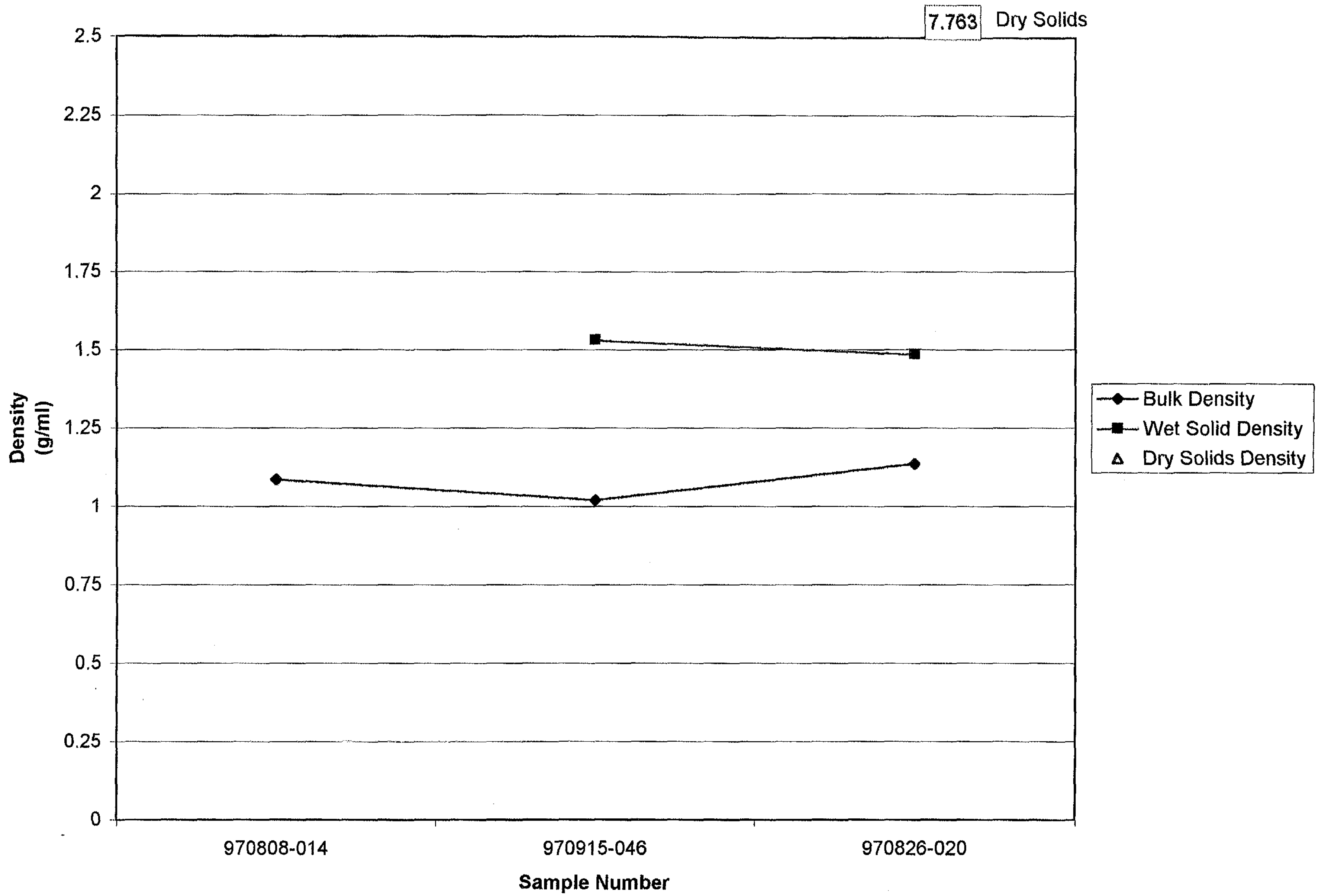
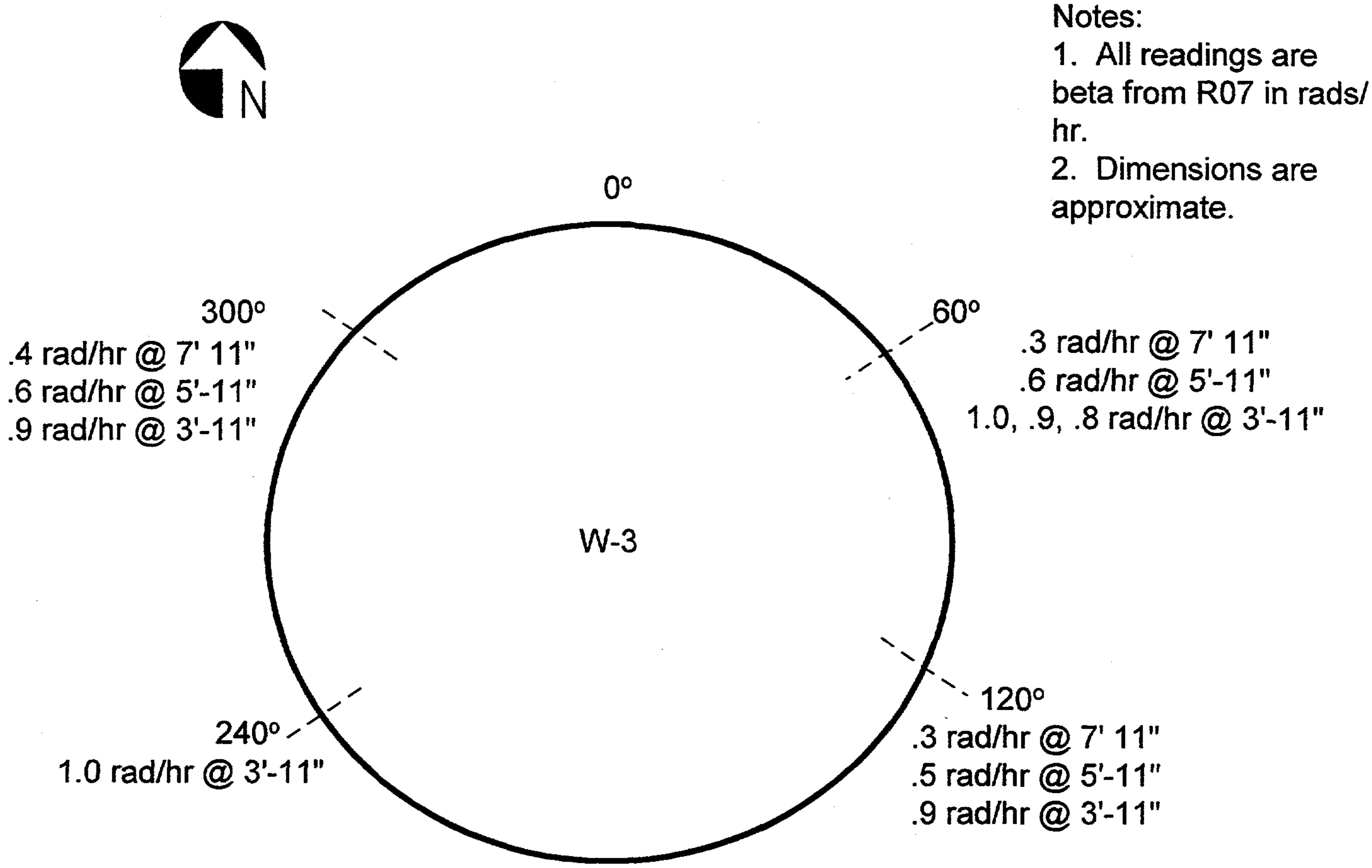
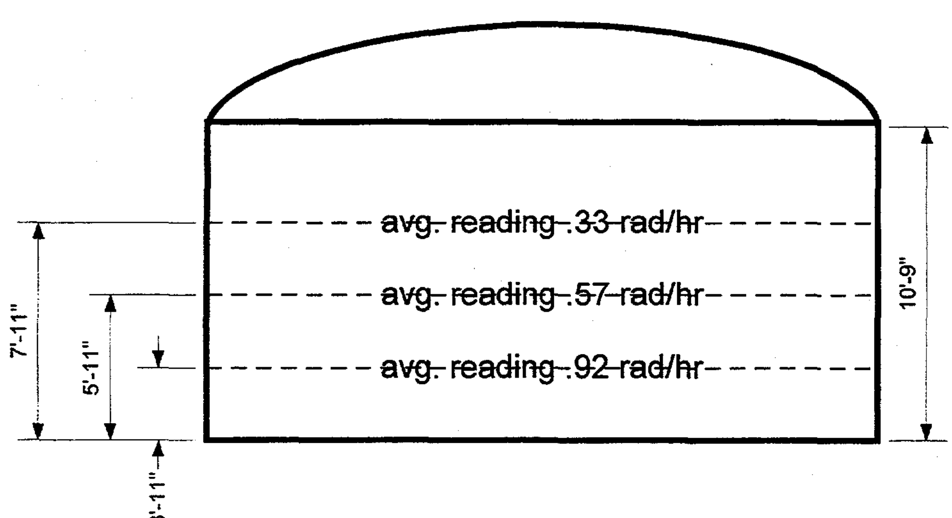


Fig. 5-15. W-3 process slurry sample density.



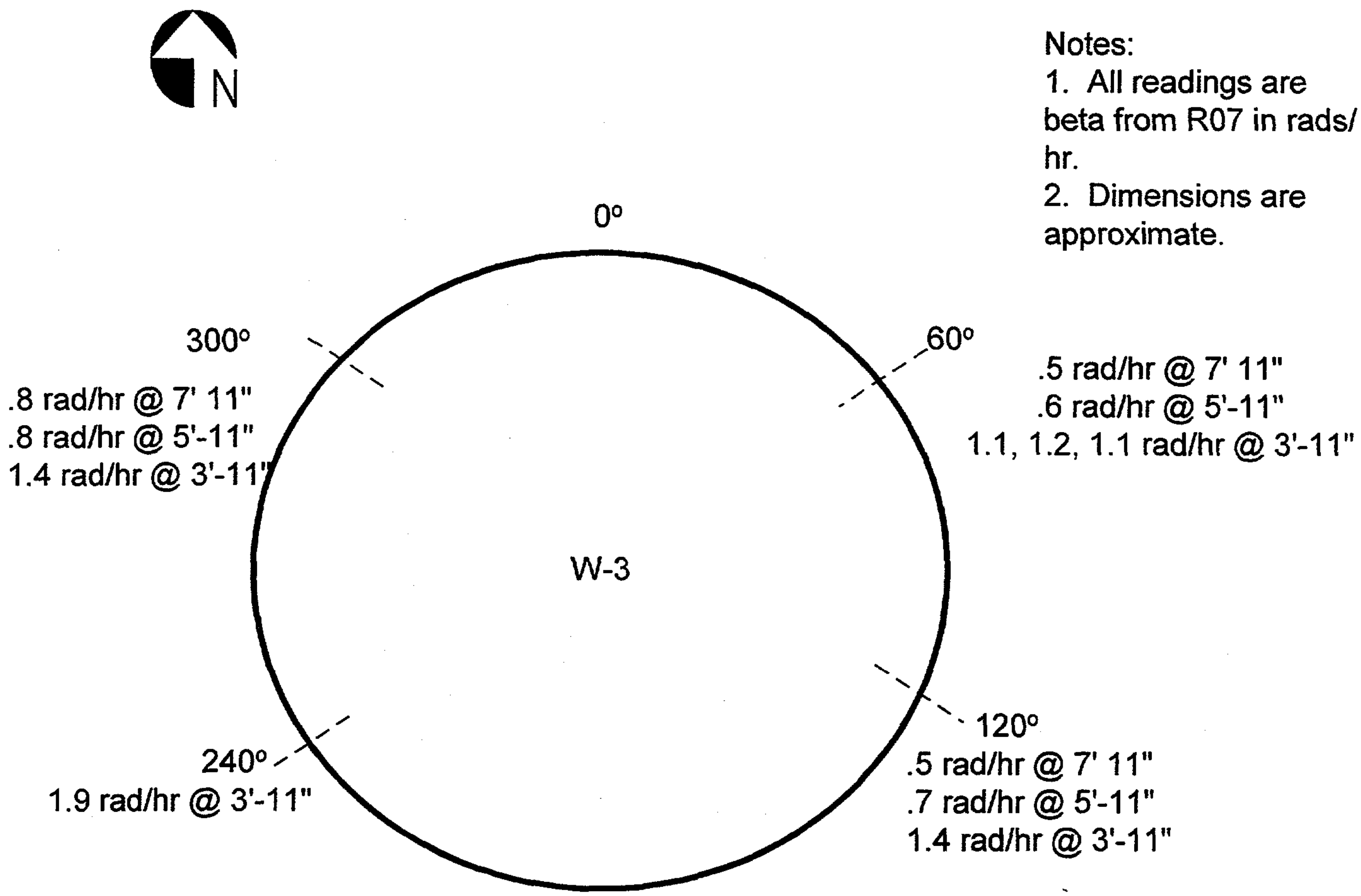
Plan View of Tank



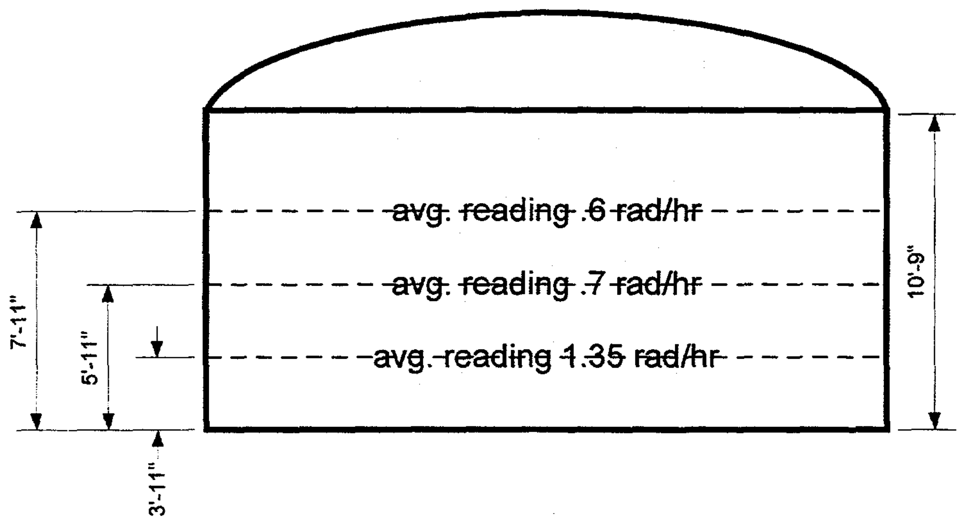
Cross Section of Tank

Fig. 5-16. W-3 baseline survey with characterization end effector (6/30/97).

Notes:
1. All readings are beta from R07 in rads/hr.
2. Dimensions are approximate.



Plan View of Tank



Cross Section of Tank

Fig. 5-17. W-3 post-cleaning survey with characterization end effector (9/14/97).

Following wall-cleaning operations, wall coring samples were collected to determine the depth of isotopic migration and the type of isotope(s) bonded with the Gunite. The samples were collected at different elevations and core depths of up to 3 in. The Gunite tank walls were initially constructed of a 6 in. outer wall, a maximum 0.5 in. bituminous layer, and an approximately 2 in. inner Gunite layer. Wall core sample results revealed the Gunite inner tank liner to be 1.5 to 1.75 in. in depth and the bituminous sealant to have a varying depth of up to 0.5 in. The core also penetrated the main wall by approximately 0.5 in. Analysis of the wall core samples showed that more than 90% of the remaining contamination is contained within the inner 0.125 in. of the wall surface and that contamination did not exceed 0.2 in. into the inner Gunite layer.

Core samples were collected at various locations on the wall of tank W-3. The core samples have been evaluated for the constituents that contribute to the risk/transport drivers for the tanks as a measure of the following:

1. the effectiveness of the wall-cleaning operations, and
2. the depth that constituents have infiltrated the tank walls during years of saturation with sludge and supernate.

The beta/gamma emitters, particularly ^{90}Sr and ^{137}Cs, are considered significant variables in the transport and human health and environmental risk modeling for the GAAT. The stacked bar charts in Appendix A show the ^{90}Sr and ^{137}Cs concentrations for each core sample. As illustrated in the graphs, the contaminant concentration decreases as the depth into the wall increases.

The core samples were evaluated to estimate the total curie content remaining within the tank W-3 walls, based on ^{137}Cs, ^{90}Sr, and ^{238}Pu concentrations. Of the estimated curie activity, 80% is contained in the first 0.063 in. of the tank wall, and 88% of the activity is contained in the first 0.3 in. of the tank wall. More than 90% of the gross alpha detected in the core samples was from ^{238}Pu. However, the ^{238}Pu resulted in less than 1% of the total curies detected in the tank walls see (Table 5-6).

Table 5-6. Estimate of activity in tank W-3 wall

Slice (in.)	^{137}Cs (Ci)	^{90}Sr + ^{90}Y[a] (Ci)	^{239}Pu (mCi)	Total[a] (Ci)	(%)
#1 (0.063)	1.59	3.55	17.385	5.16	80.55
#2 (0.063)	0.43	0.06	0.396	0.49	7.60
#3 (0.25)	0.53	0.00	0.120	0.53	8.26
#4 (0.25)	0.23	0.00	0.099	0.23	3.59
Total	2.77	3.61	18.00	6.40	100.00

[a] Total includes ^{90}Y in secular equilibrium with the ^{90}Sr. For the purpose of these estimates, all of the alpha activity is assumed to be ^{239}Pu.

6. TANK W-4 ACTIVITIES AND SYSTEM PERFORMANCE

On an overall basis for W-4, before operations:

- the sludge volume originally contained in W-4 was approximately 13,500 gal containing an estimated 916 Ci;
- to this was added the sludge from W-3, containing approximately 5,400 gal and an estimated 320 Ci and the wall scale from W-3 wall-cleaning operations, containing an estimated 6 Ci;
- the supernate, containing an estimated 63 Ci, had been transferred to the active LLLW System; and
- the W-4 tank walls contained an estimated 4.2 Ci and were covered by an aluminum hydroxide scale containing approximately 3.5 Ci,

Following W-4 waste retrieval operations:

- approximately 100 gal of diluted slurry remained in the tank, containing an estimated 6.7 Ci; and
- the tank walls contain an estimated 4.2 Ci following high-pressure cleaning using the CSEE and GSEE, which removed an estimated 1.4 Ci.

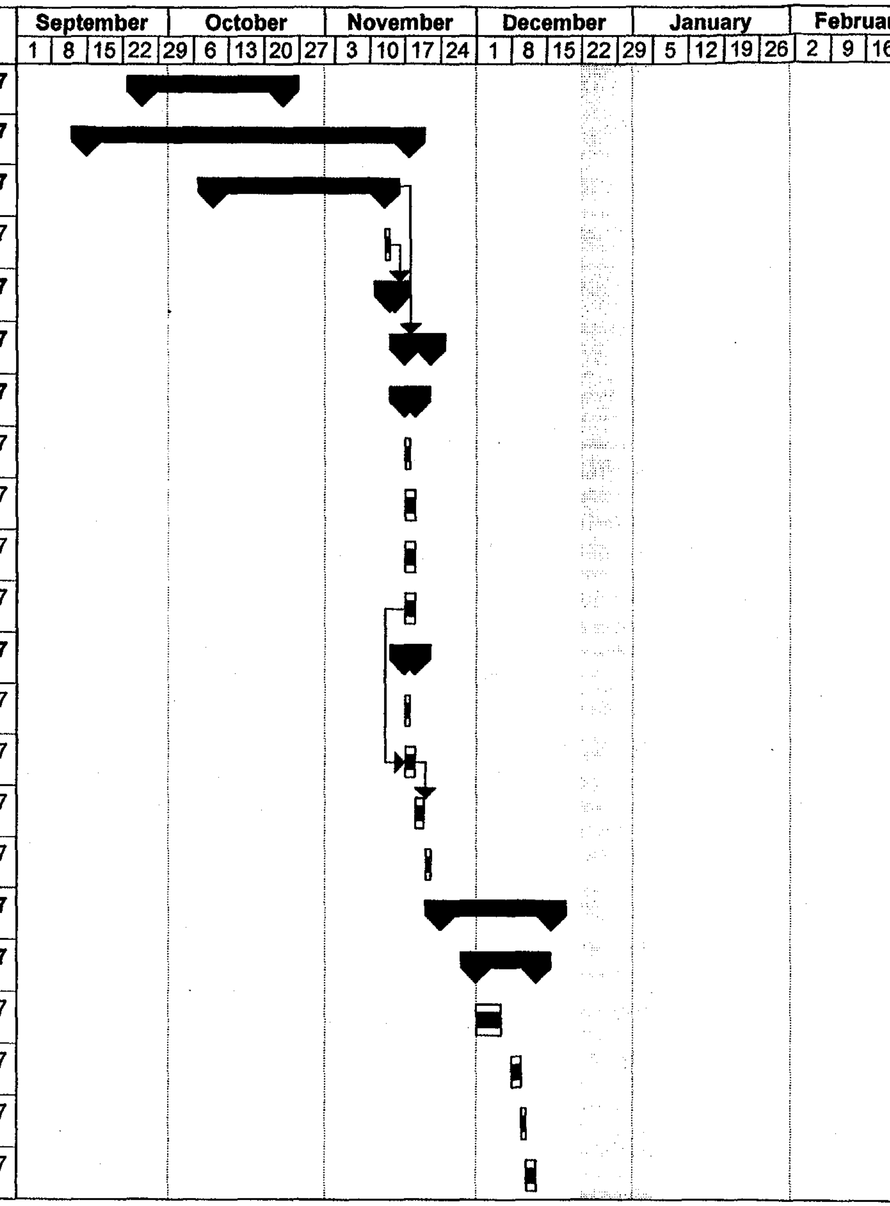
Therefore, 99% of the original curies in the sludge and in the scale on the tank walls was removed by waste retrieval operations. Performance parameters and operating envelopes for tank W-4 operations are provided in Table 6-1.

Table 6-1. Tank W-4 operations performance

Performance parameters	Optimum operating envelope
Number of operating shifts	72 shifts in 54 operating days
Wall-cleaning water pressure	6000 to 7000 psi
Wall-cleaning traverse rate	0.25 in. per second or 0.08 ft^2 per minute of MLDUA hold time
Wall-cleaning water flow	8 gal per minute or 15 gal per ft^2
Wall cleaning standoff	6 in.
Jet pump motive fluid rate	9.5 to 10.5 gal per minute
Jet pump motive fluid pressure	6000 to 7100 psi
Sludge retrieval rate (daily)	950 gal per day during sluicing operations
Sludge retrieval rate (instantaneous)	3.4 gal of sludge per minute of jet pump operating time
Average slurry pumping rate, including all water added	17.7 gal per minute of jet pump operating time
Water added for sluicing	3.98 gal of water per gal of sludge retrieved
Water added at CSEE for sludge retrieval	1.15 gal of water per gal of sludge retrieved
Flush water added	123 gal per day during sluicing operations
Decontamination water used (not counting spray wands)	ROV – 9 to 30 gpm at 210 to 2410 psi – avg 157 seconds and 47 gal per event MLDUA – 10 to 19 gpm at 200 to 640 psi – avg 145 seconds and 32 gal HMS – 7 to 27 gpm at 230 to 2000 psi – avg 236 seconds and 61 gal per event

The sequence of operations that resulted in cleanup of W-4 is provided in Fig. 6-1 (W-4 schedule).

ID	Task Name	Duratic	Start	Finish
1	**Equipment relocation to tank W-4 (HMS, ROV, and ML**	**20d**	**Fri 9/26/97**	**Thu 10/23/97**
20	**Maintenance No.1 on MLDUA, ROV & WD&C**	**46d**	**Mon 9/15/97**	**Mon 11/17/97**
115	**System Checkouts**	**24d**	**Fri 10/10/97**	**Wed 11/12/97**
150	Site walkthrough / confirmation of physical condition	1d	Thu 11/13/97	Thu 11/13/97
151	**Initial Tank Inspection**	**1d**	**Fri 11/14/97**	**Fri 11/14/97**
156	**W-4 sludge retrieval / mining operations**	**6.8d**	**Mon 11/17/97**	**Fri 11/21/97**
157	**MLDUA**	**2d**	**Mon 11/17/97**	**Tue 11/18/97**
158	Deploy depth probe	1d	Mon 11/17/97	Mon 11/17/97
159	Deploy arm	2d	Mon 11/17/97	Tue 11/18/97
160	Grasp CSEE	2d	Mon 11/17/97	Tue 11/18/97
161	Initiate Sluicing operation	2d	Mon 11/17/97	Tue 11/18/97
162	**HMA**	**2d**	**Mon 11/17/97**	**Tue 11/18/97**
163	Deploy and Perform In-Tank Test	1d	Mon 11/17/97	Mon 11/17/97
164	Initiate Sluicing operation	2d	Mon 11/17/97	Tue 11/18/97
165	Perform Sluicing (24-hour operations)	3d	Tue 11/18/97	Thu 11/20/97
166	Retract and decon equip	1d	Fri 11/21/97	Fri 11/21/97
167	**Maintenance Break**	**14d**	**Mon 11/24/97**	**Mon 12/15/97**
190	**Continue W-4 sludge retrieval / mining operations**	**10d**	**Mon 12/1/97**	**Fri 12/12/97**
191	Begin Wall Cleaning (16 hr operation)	5d	Mon 12/1/97	Fri 12/5/97
192	Begin MLDUA/Sluicing Ops (16 hr operation)	2d	Mon 12/8/97	Tue 12/9/97
193	Begin ROV/Sluicing Ops (16 hr operation)	1d	Wed 12/10/97	Wed 12/10/97
194	Continue MLDUA/Sluicing (16 hr operation)	2d	Thu 12/11/97	Fri 12/12/97



Project: NTF
Date: Wed 5/13/98
By: XL Associates, Inc.

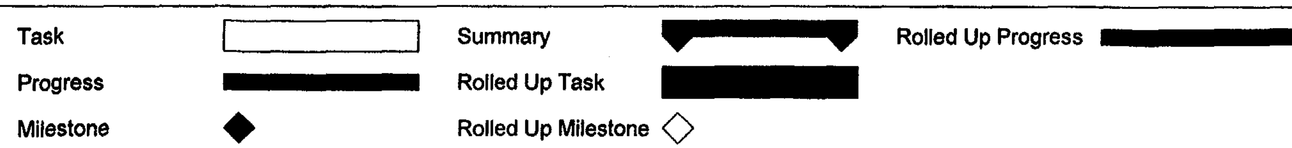
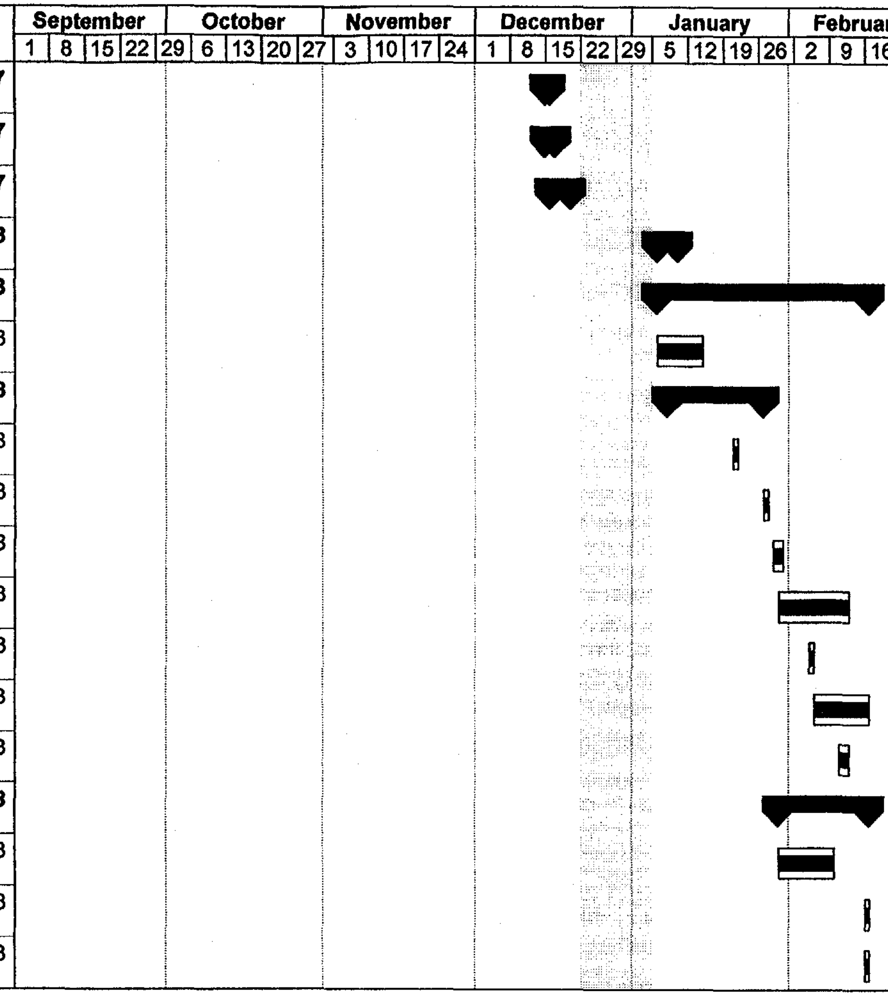


Fig. 6-1. GAAT W-4 operations schedule.

ID	Task Name	Duratic	Start	Finish
195	**W-4 Characterization**	**1d**	**Mon 12/15/97**	**Mon 12/15/97**
198	**Clean W-4 Walls**	**2d**	**Mon 12/15/97**	**Tue 12/16/97**
202	**Continue Sluicing Operations (16 hr)**	**4d**	**Tue 12/16/97**	**Fri 12/19/97**
211	**Repairs**	**4d**	**Tue 1/6/98**	**Fri 1/9/98**
218	**Continued Operations**	**29d**	**Tue 1/6/98**	**Mon 2/16/98**
219	Scarify W4 Lower Walls w/CSEE	7d	Tue 1/6/98	Wed 1/14/98
220	**GSEE**	**12d**	**Thu 1/8/98**	**Mon 1/26/98**
225	ROV debris retrieval and sluicing	1d	Wed 1/21/98	Wed 1/21/98
226	Scarify w/ MLDUA/GSEE	1d	Tue 1/27/98	Tue 1/27/98
227	Complete sluicing of W-4	2d	Thu 1/29/98	Fri 1/30/98
228	Remove Debris from W-4 (Intermittent)	10d	Fri 1/30/98	Thu 2/12/98
229	Pump rainwater from W-3	1d	Thu 2/5/98	Thu 2/5/98
230	Final W-4 Sluicing (Intermittent)	7d	Fri 2/6/98	Mon 2/16/98
231	Further GSEE testing	2d	Wed 2/11/98	Thu 2/12/98
232	**Characterization**	**12d**	**Fri 1/30/98**	**Mon 2/16/98**
233	Collect core drill samples	7d	Fri 1/30/98	Mon 2/9/98
234	Deploy CEE and perform surveys	1d	Mon 2/16/98	Mon 2/16/98
235	***W-4 Operations Complete***	1d	Mon 2/16/98	Mon 2/16/98



Project: NTF
Date: Wed 5/13/98
By: XL Associates, Inc.

Task — Summary — Rolled Up Progress
Progress — Rolled Up Task
Milestone — Rolled Up Milestone

Fig. 6-1. (continued)

6.1 INITIAL TANK CHARACTERIZATION

On August 11, 1997, during W-3 operations, samples of W-4 sludge were collected at 2, 4, and 4.5 ft below the W-4 supernate level. Results of that sampling are provided in Table 6-2.

Table 6-2. Tank W-4 sludge sample analytical results from August 11, 1997

Sample No.	Units	970811-016	970811-017	970811-018
Location below supernate surface		2 ft	4 ft	4 ft 6 in.
Liquid/Sludge		Liquid	Liquid	Liquid
% Solids	%	0.5	13.5	0.4
Density	g/cc	1.07	1.17	1.04
Wet solid density	g/mL		1.94	
^{137}Cs	Bq/mL	5.70E+02	8.20E+03	5.10E+02
G-Alpha	Bq/mL	1.70E+02	4.40E+03	1.60E+02
G-Beta	Bq/mL	8.90E+03	4.10E+05	7.70E+03

Further sampling was performed on August 14 in preparation for transfer of W-4 supernate to tank W-9. These samples were collected at 1, 3, 4, and 4.5 ft below the supernate. Results of that sampling are provided in Table 6-3.

Table 6-3. Tank W-4 sludge sample analytical results from August 14, 1997

Sample No.	Units	970814-017	970814-018	970814-019	970814-020
Location below supernate surface		1 ft	3 ft	4 ft	4.5 ft
Liquid/sludge		Sludge	Sludge	Sludge	Sludge
% Solids	%	0.5	8.5	12.2	14.2
Density	g/cc	1.039	1.102	1.14	1.163
Wet solid density	g/mL		1.903	1.671	1.584
G-Alpha	Bq/mL	2.10E+02	4.00E+03	4.60E+03	4.80E+03
G-Beta	Bq/mL	1.50E+04	4.10E+05	3.90E+05	4.20E+05
Total Rad – Strontium	Bq/mL	6.00E+03	2.00E+05	1.90E+05	1.90E+05
^{137}Cs	Bq/mL	7.10E+02	5.70E+03	7.30E+03	9.20E+03

On August 16, 14,500 gal of supernate were transferred from W-4 to W-9. Additional samples of the sludge in W-4 were collected on August 25, 1997. These samples were collected at 2, 4, and 4.33 ft below the supernate level. Results of that sampling are provided in the Table 6-4. Figure 6-2 presents the density measurements for each of the sludge samples collected from W-4.

Table 6-4. Tank W-4 sludge sample analytical results from August 25, 1997

Sample No.	Units	970825-057	970825-058	970825-059
Location below supernate surface		2 ft	4 ft	4.5 ft
Liquid/sludge		Slurry	Slurry	Slurry
% Solids	%	0.4	19	18
Density	g/cc	1.024	1.194	1.194
G-Alpha	Bq/mL	1.00E+02	6.80E+03	6.40E+03
G-Beta	Bq/mL	6.70E+03	6.50E+05	6.00E+05
Total Rad – Strontium	Bq/mL	2.60E+03	3.00E+05	2.60E+05
^{137}Cs	Bq/mL	3.30E+02	1.20E+04	1.40E+04
^{238}U	Bq/mL			2.10E+03

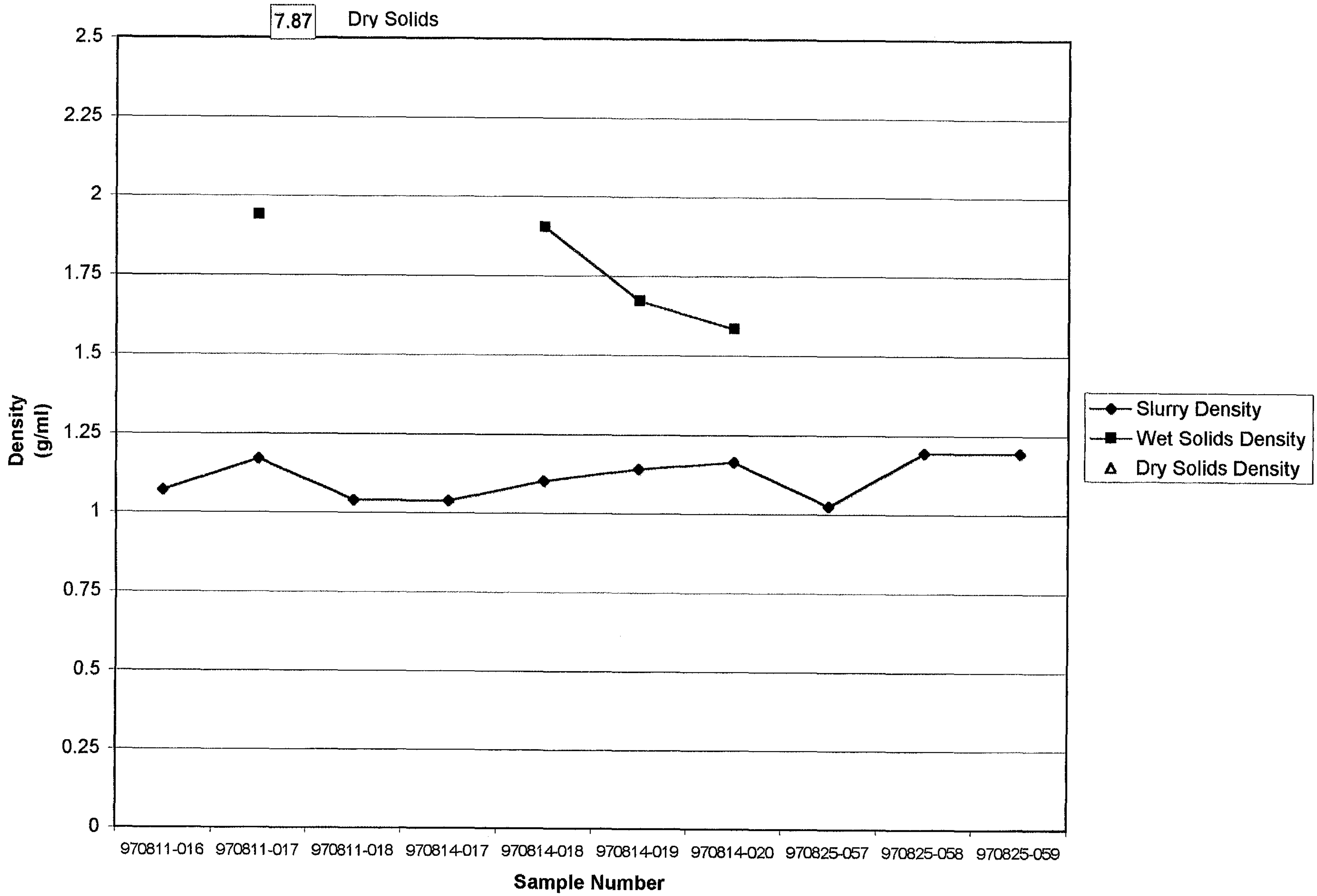


Fig. 6-2. W-4 tank sludge sample density.

In September, an additional 10,500 gal of supernate were transferred from W-4 to W-9.

A baseline of the radiation levels (beta and gamma) in the tank W-4 walls were determined by the CEE on October 22, 1997. Readings could not be collected at the 4-ft level because the sludge and water covered the tank wall at this level at the time of characterization. The baseline characterization data is presented in Figs. 6-8 and 6-9 in Sect. 6.14, "Tank Characterization Information."

6.2 EQUIPMENT MOVE FROM W-3

Following W-3 operations, the waste sludge retrieval equipment was removed from W-3 and repositioned for maintenance and repair and then installed onto W-4. All equipment removed was decontaminated to the extent possible and was contained by bags, sheet plastic, or engineered containment structures.

Before moving the ROV system to W-4, a containment tent was constructed alongside TMADS and maintenance was performed as described in Sect. 7. Section 7 also outlines the maintenance performed on the WD&C, BOP, and MLDUA systems.

Operations for Tank W-4 began on October 23, 1997, with the deployment of a "medicine ball" to compact the sludge beneath the west riser in W-4 to ensure that enough headspace was present to deploy the HMA. Following the medicine ball, a depth probe was deployed by the MLDUA on November 17, 1997, to measure the depth and relative thickness of the sludge. This verified that enough headspace existed in the tank to deploy the HMA, which was performed that day.

6.3 ROV TANK OPERATIONS[7]

The TMADS was positioned over the north riser of Tank W-4 and was powered up for the first time on November 18, 1997. Over the course of the next three and a half months, the vehicle was deployed and retracted from W-4 a total of 12 times and logged approximately 128 hours of tank operation.

The specific activities undertaken during the Tank W-4 campaign are shown in Table 6-5.

Table 6-5. ROV W-4 operations

In-tank activity	Frequency (days)
Cut Pipes	1
Core	2
Deploy	12
Plow	6
Sluice	8
Aid HMA deployment	1
CSEE handoff	4
Decontaminate	11
Provide camera view	1
Remove debris/equipment	11
Retract	12
Take solid sample	3

On November 17, 1997, the ROV system move to Tank W-4 was completed. The shoulder bolt that had fallen out of the frame cylinder in Tank W-3 was replaced. Loctite and lock washers were used on the new shoulder bolt to prevent it from coming loose again. A minor hydraulic leak on the vehicle was also repaired at this time.

Although the ROV system was essentially in position and ready to go at this point, it could not actually be deployed into the tank for full-scale operations until the MLDUA had succeeded in lowering the supernatant level and clearing off a landing pad for the vehicle. This delay was necessary because the ROV's tether was not watertight. The ROV was powered up for the first time on November 18 for a general system checkout but was not actually deployed into the tank until December 4 when the MLDUA needed assistance in holding the confined sluicing end effector while repositioning its wrist. Even this operation was completed with the ROV hanging suspended above the supernate by its tether.

The ROV was first fully deployed into tank W-4 on December 9, 1997, to begin plowing. However, once the vehicle landed it became apparent that the left track was not operating properly. The track did not turn at full speed and would occasionally stall out completely. The problem was eventually traced to a broken wire in the servo valve. The vehicle was retracted, and once the proper equipment was staged and the pipefitters were available, the faulty servo valve was replaced. This delicate maintenance activity was completed through the containment bezel glove ports with the vehicle suspended over the riser opening. The MLDUA had continued scarifying while the repair was completed; therefore, the extra water in the tank produced by scarifying had to be removed before the ROV could reenter the tank.

Finally, on December 16, 1997, full-scale operation of the ROV began. The system was deployed and used to break up and move around the hard sludge in the tank. The vehicle was also used to sluice in several areas. These operations continued, generally without incident, throughout the remainder of the tank W-4 waste removal campaign. Because much of the damage sustained by the vehicle in tank W-3 occurred during deployment and retractions, a concerted effort was made to reduce the frequency of those operations on tank W-4. Retractions were still necessary for complete inspection of the vehicle (in particular, to check for loose fittings or fasteners). However, on many occasions the vehicle was washed down at the end of the final shift for the day and, depending on the next day's planned activities, either left on the tank floor or suspended just inside the riser opening to the tank dome. No ill effects to the vehicle were noted.

Several floor-to-ceiling pipes left over from previous tank operations were mounted just west of the ROV's riser. Some other pipes were also discovered tangled up in the sludge beneath the riser opening, and these pipes occasionally made landing the ROV difficult. Therefore, on January 13, 1998, the Jaws-of-Life hydraulic shear was bagged in and grasped by the ROV. The vehicle was deployed and began cutting the pipes into 1-ft sections starting at the tank floor. Once the Schilling manipulator could no longer reach the pipes, the vehicle was partially retracted and continued cutting the upper sections of pipe while suspended in midair. The pipe pieces were later loaded into a debris bucket and bagged out through the containment bezel 20 in. port.

The ROV was used on numerous occasions to remove debris from the tank. The objects removed included tape, steel pipes and cord, assorted hand tools, and plastic bags and bottles. These items were placed in either a wire mesh debris bucket or a plastic 5-gal bucket that had been lowered down through the ROV riser with a rope and pulley. The bucket was then manually retrieved, and the contents were sprayed down and bagged out through the 20 in. port. The ROV operators were also able to demonstrate their skills on a couple of occasions. For instance, when the WD&C riser cover and a vise were inadvertently dropped into the tank, a rope noose was lowered down after them and the ROV's manipulator was used to lasso and retrieve the equipment. Another operator lowered a large nut tied to a string and speared several pieces of pipe through the nut so that they could be removed from the tank.

Core samples were collected by the ROV on February 9 and 10, 1998, using a new, improved coring tool. Positioning of the coring end effector was somewhat difficult because the Schilling manipulator wrist behaved erratically. The end effector had to be aligned with the wrist in rate (continuous rotate) mode and then the wrist function had to be frozen to maintain that position. According to the manipulator vendor, a damaged slave controller cable probably caused this behavior. A spare cable was already on backorder, and in the meantime, the ROV operators were able to adapt to the situation. The only other difficulty encountered while coring was that some of the cores stuck in the wall and did not come out when the end effector was retracted. When that occurred, the end effector was simply moved over a few inches and another attempt was made to collect a core sample.

A shovel with a handle modified so that the manipulator could easily grasp it was deployed into the tank on February 16, and the ROV was used to shovel sludge into 5-gal buckets. During these operations, the manipulator's shoulder may have lain on the upraised plow forcefully enough to damage the plow lift mechanism. The vehicle was retracted and inspected in TMADS, but with the vehicle folded, an exact determination of the damage was not possible. Because tank cleanup operations had already been completed to the satisfaction of the regulators, a decision was made to inspect and repair the plow once the ROV system had been relocated to the STF maintenance tent. Routine maintenance and inspection activities had already been planned before deployment of the system in tank W-6.

In summary, the Houdini system remains a valuable workhorse for performing remote in-tank operations. Lessons learned from tank W-3 operations were incorporated where possible to minimize downtime and increase efficiency on tank W-4. These changes appeared to be quite effective.

6.4 MLDUA OPERATIONS

The MLDUA was first deployed into tank W-4 during the first week of October 1997, to perform a system checkout, define the autosequence for deployment and retraction, and define the reach of the arm inside the tank. On October 22, 1997, the MLDUA was deployed to measure the baseline level of radiation on the tank walls using the CEE. Table 6-6 provides the MLDUA operating statistics. In tank W-4, the MLDUA was also used to collect a tank waste sample for the first time. The MLDUA used a can to scoop a sample of waste material.

The MLDUA had no major operating problems in tank W-4. One minor operating problem developed in tank W-4 when the hydraulic oil cooler dropped off line twice during operations. This required an operator to open the front panel of the cooler to reset the cooler's computer. This problem will be tracked in future tank operations. Because the Hydraulic Power Unit (HPU) Service Skid will be placed off of the STF platforms, any required cooler computer resets will be quicker and easier than for tank W-4 where the HPU was on the tank platform.

Table 6-6. Tank W-4 MLDUA operating statistics

Operation	Events
Total number of times the vertical positioning mast housing was raised	3
Total number of times the vertical positioning mast was deployed (off limited switches)	4
Total number of times the GEE was attached to the robot arm	1
Total number of times the robot arm was deployed into the tank	15
Total number of times the GEE grasped the CSEE for sluicing	10
Total number of times the GEE grasped the CEE	2
Total number of times the GEE grasped the CSEE for wall cleaning	16
Total number of times the DSR was turned on for decontamination	20
Amount of time the robot arm was inside the tank (below the tric floor)	834.3 h
Amount of time the GEE grasped the CSEE for sluicing	124.3 h
Amount of time the DSR sprayed the robot arm	1.0 h

6.5 HOSE MANAGEMENT SYSTEM

The Hose Management System (HMS) was operated for 54 days on tank W-4 with only one day when it was unavailable for operations. The HMS was used for the removal of approximately 18,800 gal of sludge and 92,337 gal of additional process water. The walls were cleaned at pressures of up to 7000 psi to a height of approximately 10-ft from the tank floor using the CSEE attached to the HMA. The CSEE was used primarily for material removal. However, the FCEE was tried in place of the CSEE to recover materials less than 1 in. deep on the tank floor. The FCEE worked very well when materials were scooped into its suction area and worked well for liquid removal down to 0.5 in. deep.

6.6 WALL CLEANING

As discussed in Sect. 2., the tank W-4 walls were covered with an approximately 0.063 in. aluminum hydroxide scale before wall-cleaning operations began. This scale was estimated to contain 3.7 Ci.

Thirteen high-pressure wall-cleaning events were performed using the CSEE, controlled by the MLDUA. Wall-cleaning operations were performed at an average pressure range of 5980 to 6020 psi and a rate of 0.25 in. per second.

As with W-3 operations, most of the scale was removed and the tank wall was cleaned to the Gunite surface. However, there were a few areas that could not be cleaned at the maximum pressure of the system. It is not clear whether any Gunite material was removed in the wall-cleaning operations.

6.6.1 Rate of Wall-Cleaning

The total area cleaned in W-4 is 707 ft^2. On a particularly good day of wall-cleaning, 20% of the tank wall was cleaned (74° of the top half of the wall) in 380 minutes of operations, or 0.37 ft^2 per minute.

The tank walls were cleaned in 2093 minutes (34.9 hours) of CSEE pump operation, for a total cleaning rate of 0.34 ft^2 per minute. The MLDUA grasped the CSEE 16 times and held the CSEE for 148 hours specifically for wall-cleaning operations. During the time that the MLDUA held the CSEE, 4.76 ft^2 of wall was cleaned per hour or 0.08 ft^2 per minute. This indicates that the MLDUA held the CSEE 4.24 minutes for each minute of actual wall-cleaning time, or three-quarters of the time that the MLDUA held the CSEE, wall-cleaning operations were not being performed.

6.6.2 Water Added for Wall Cleaning

A total of 10,618 gal of water were used to clean the walls of W-4, or 15.0 gal of water per square foot of wall. Figure 6-3 depicts the total water used for wall-cleaning activities.

Trial scarification activities with the GSEE were performed on January 27. Scarification was performed using the CSEE high-pressure water pump at a supply pressure of 6000 psi and a rotational speed of 265 rotations per minute. True scarification operations with the GSEE were not possible without the ultrahigh-pressure water pump.

6.7 SLUICING

There were a total of 28 days of sluicing operations, 20 for transferring sludge and 8 for dewatering following wall-cleaning and decontamination operations. Initially, operations were performed 24 hours per day for 3 days straight. Also, 2-shift (17 hours) operations were performed when possible. The volume of waste slurry contained in W-4 before sluicing operations began was 13,500 gal of sludge

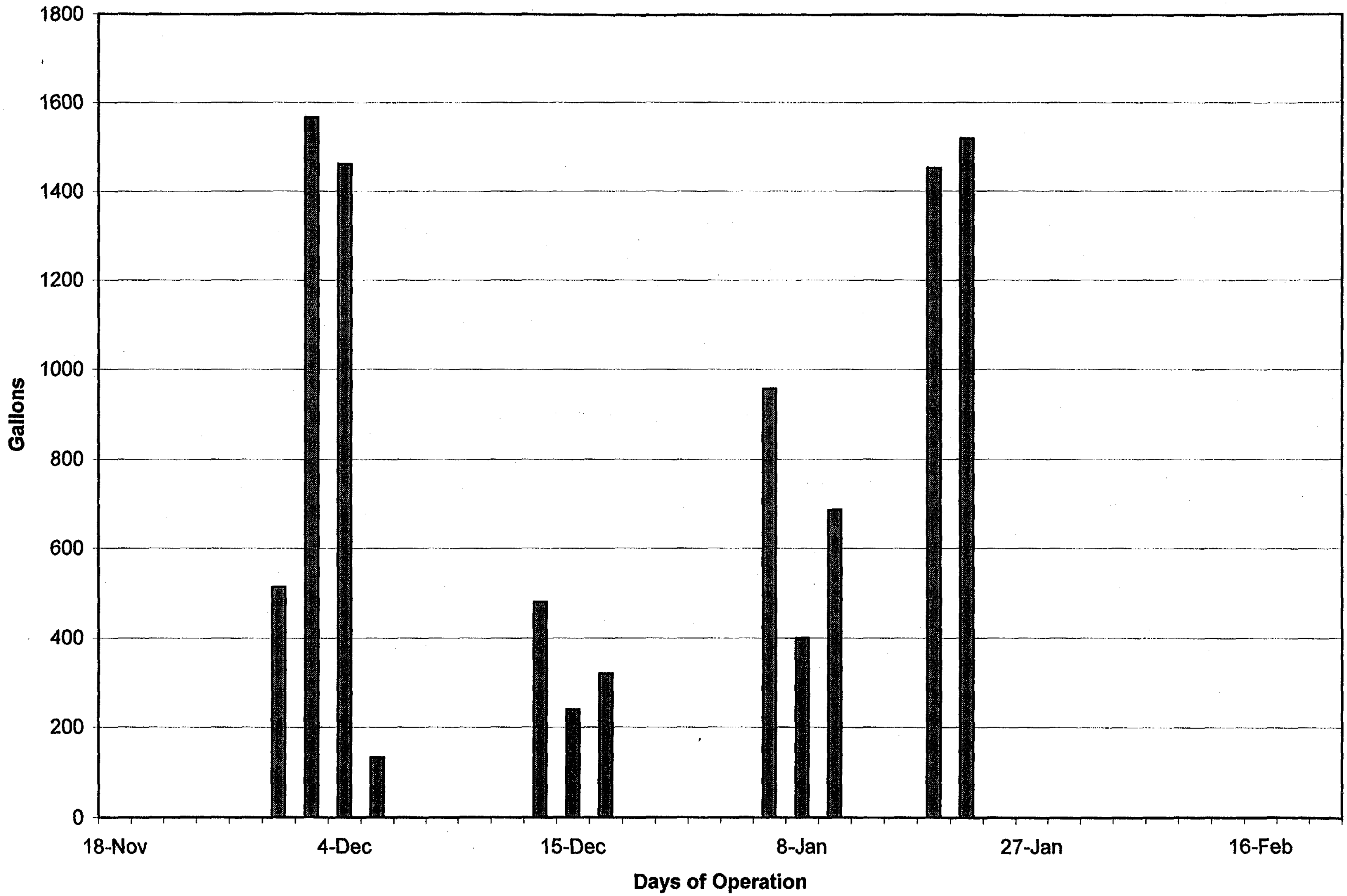


Fig. 6-3. Process water used for W-4 wall cleaning operations.

originally in W-4 before NTF operations began (estimated specific gravity of 1.275 g/cm^3, and 5,500 gal of sludge originally in W-3 (estimated specific gravity of 1.07 g/cm^3), for a total of 19,000 gal of sludge. Underneath a soft layer of sludge (probably the W-3 sludge), a hard, crystalline layer of sludge existed near the east riser, between the south and west risers, and near the north area of tank. The hard sludge contains some rocklike material that could not be easily broken by the CSEE at pressures of 6300 psi.

6.7.1 Sludge Retrieval

Sludge retrieval began on November 18, 1997, with the deployment of the HMA and the MLDUA. Continuous operations were performed from November 18 through 21. A total of 33.6 hours of actual sluicing occurred during this 53.5-hour interval for an operating efficiency of 63%. Unfortunately, the tank levels do not accurately represent how much sludge was transferred during this time. On December 16, the ROV was successfully deployed to assist sluicing operations by plowing sludge to the CSEE and to maneuver the CSEE for sluicing operations.

6.7.1.1 Retrieval Rate

On a per-shift basis, sluicing activities occurred between November 18 and February 11, or 68 operating shifts (in 54 operating days). A total of 19,000 gal of sludge was transferred in 68 operating shifts, at a rate of 279 gal per shift. Sluicing was not performed on all these shifts, but since the operations approach was to sluice, if possible, on all these shifts, this gives a scheduling number based on W-4 performance.

Accounting only for the days that sluicing actually occurred, the total 19,000 gal (counting the previously slurried W-3 sludge) were transferred in 20 days for an average daily retrieval rate of 950 gal per day. The total jet pump operating time for sluicing operations, as logged in the shift supervisor's log was 5615 minutes, plus 689 additional minutes for transferring water that accumulated during wall-cleaning and decontamination operations. The sludge retrieval rate for actual sluicing operations time is 3.4 gal per minute of jet pump operating time for sluicing operations.

The total water added to W-4 and W-9 combined during operations was logged at 92,337 gal. Therefore, the total fluids transferred by the jet pump, including the jet pump motive fluid water, is 111,337 gal. The average slurry pumping rate, including all the water added, is 17.7 gpm.

6.7.1.2 Water Added

Water added for sluicing activities includes the water added at the CSEE to fluidize the sludge for pipeline transfer (FIT-131), the motive fluid water added at the jet pump (FIT-121), and flush water (FIT-102).

The water added for sluicing activities (as recorded electronically) only in removing 19,000 gal of sludge from W-4 was 75,705 gal, 53,770 gal added at the jet pump (Fig. 6-4) and 21,935 added at the CSEE for fluidizing the sludge for pumping (Fig. 6-5). Water was added at a ratio of 4.0 gal per gallon of sludge pumped.

6.7.1.3 Flush Water Used

Flush water was used to dislodge material from the line when it became plugged and at the end of each sluicing operation to flush the line of contaminants. The total flush water added (FIT-102) during W-4 operations was 3440.4 gal (see Fig. 6-6). Given that there were 28 days of sluicing operations, this averages to 123 gal of flush water per day of sluicing operations.

6.7.2 Dewatering Following Wall Cleaning and Decontamination

Dewatering operations were performed on 8 days following wall-cleaning activities. The water used for dewatering activities totaled 3952.5 gal, for an average rate of 494 gal per dewatering event.

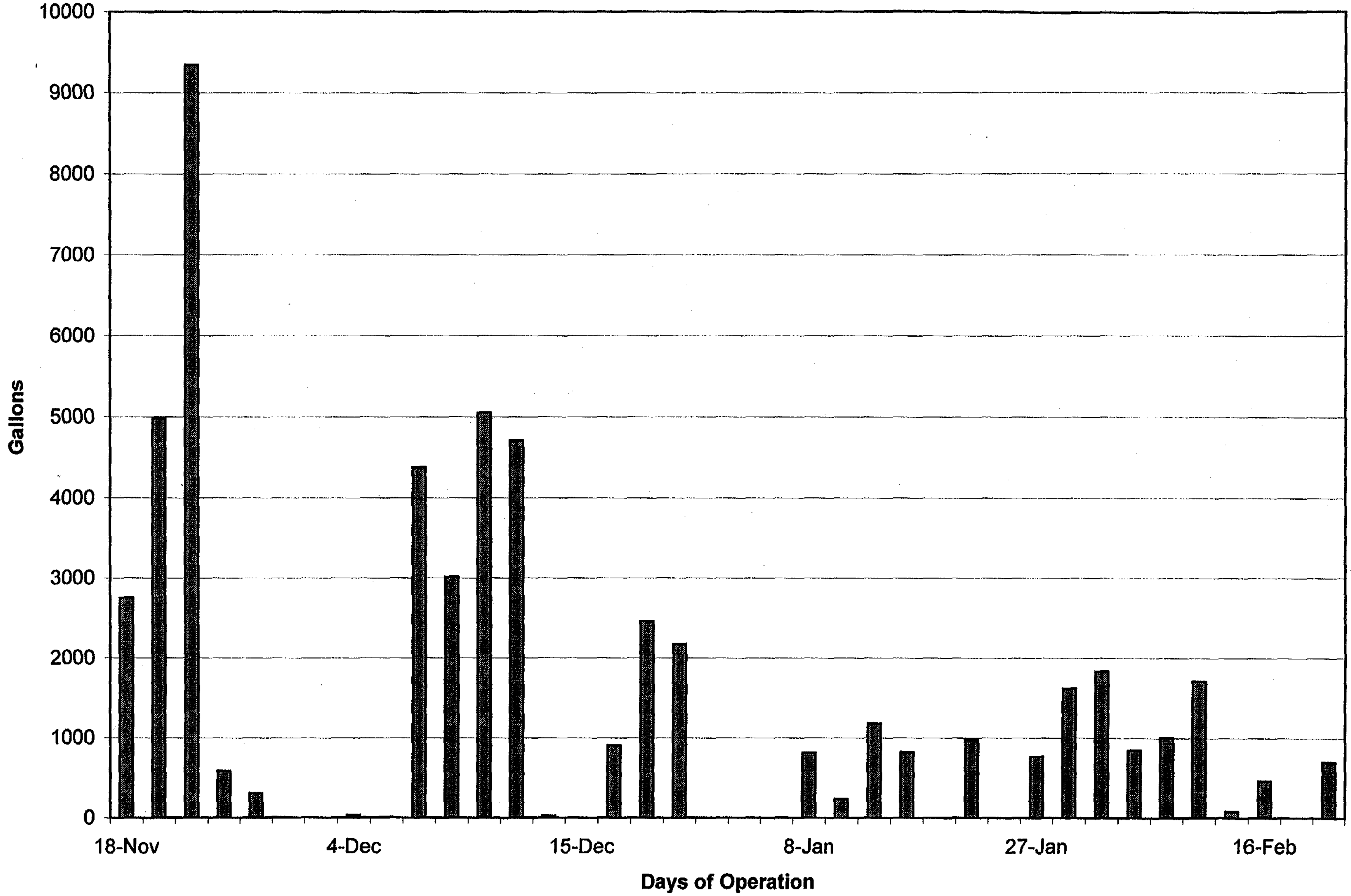


Fig. 6-4. Process water used as jet pump motive fluid water in W-4 operations.

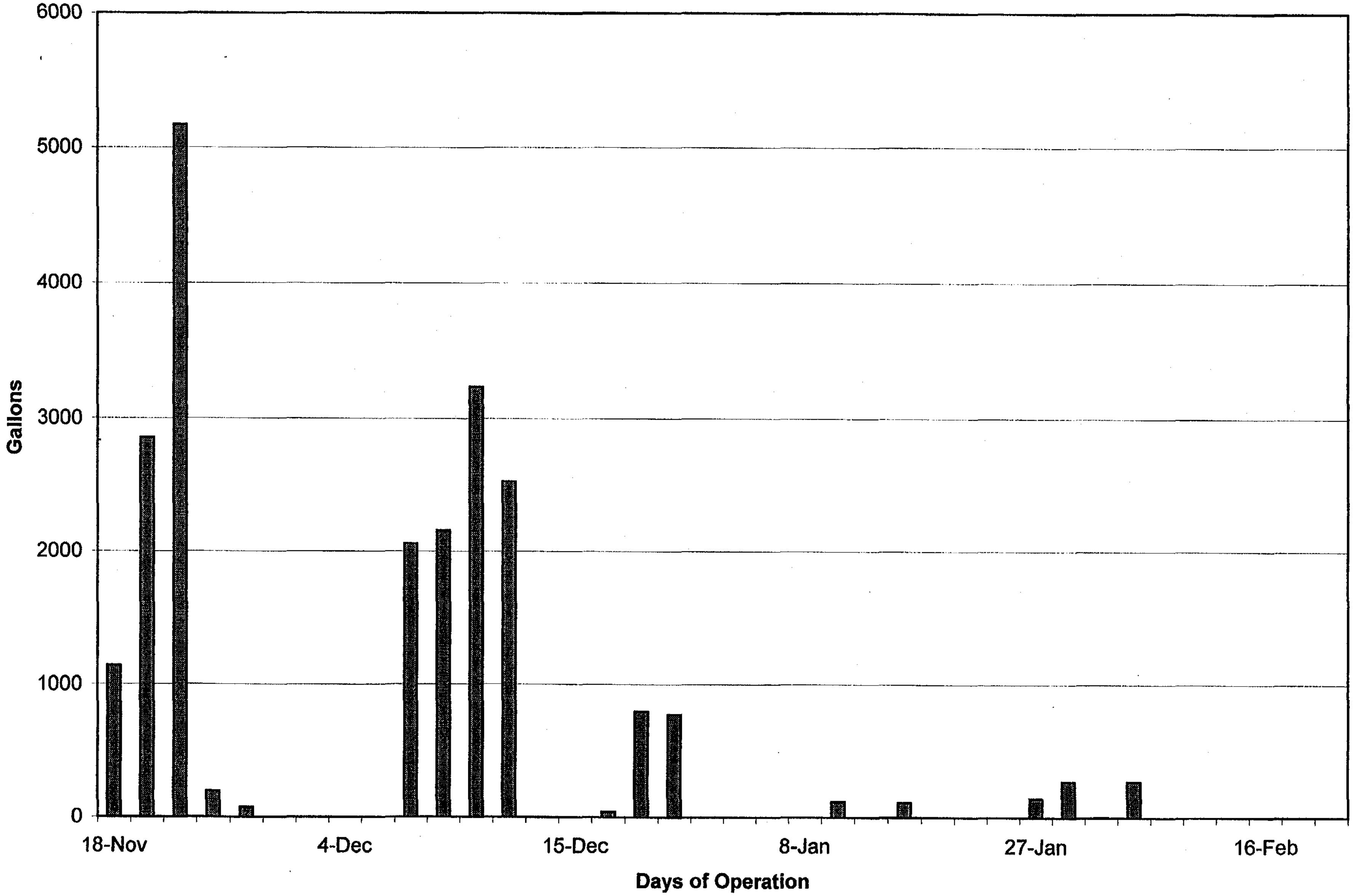


Fig. 6-5. CSEE water used for sluicing during W-4 operations.

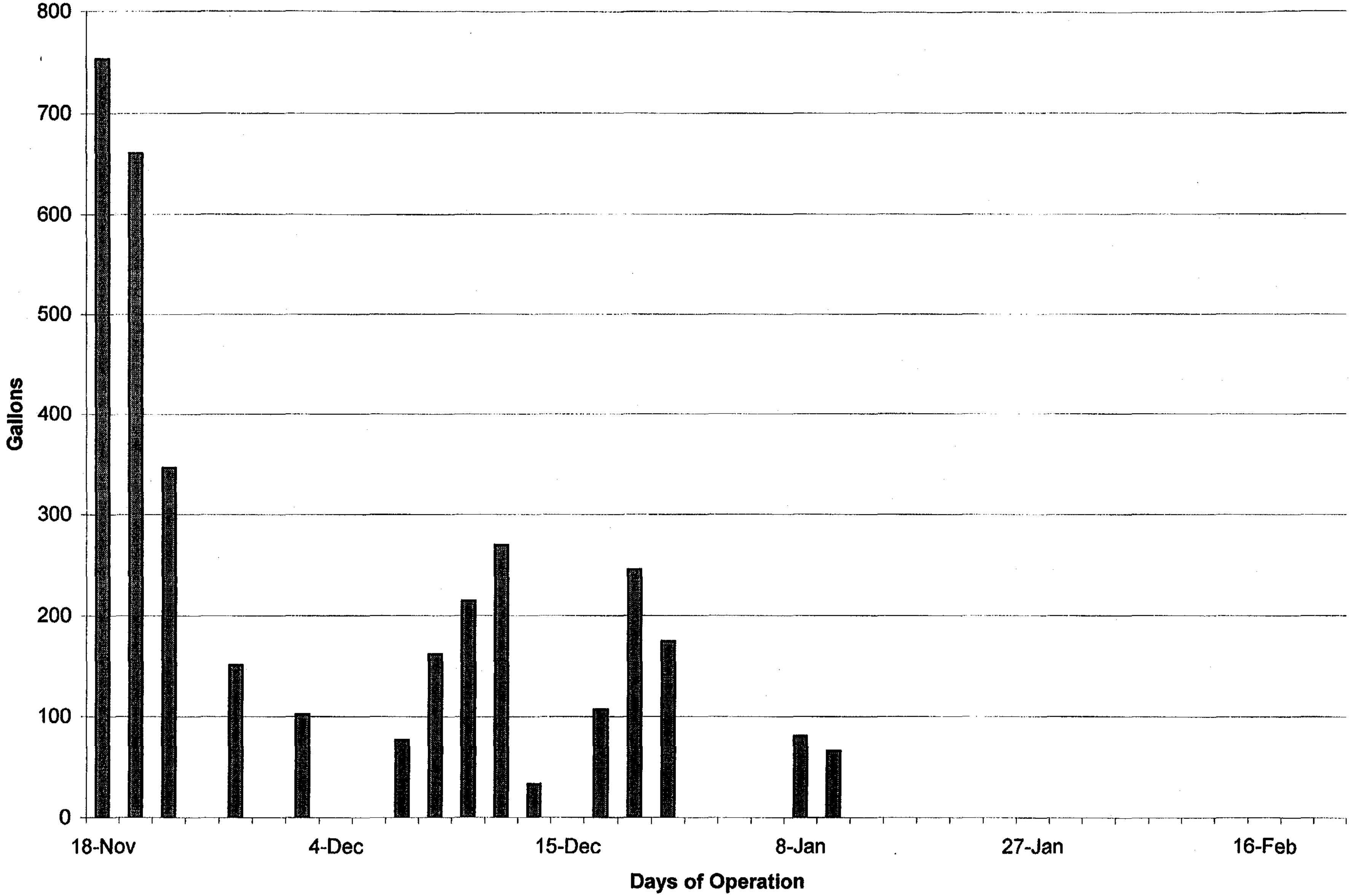


Fig. 6-6. Flush water used during W-4 operations.

6.8 DEBRIS REMOVAL

Debris consolidation was performed on 9 different days. The debris consisted of piping, tile, and various tools. The debris was placed in a wire mesh debris bucket that had been lowered down through the ROV riser with a rope and pulley. The bucket was then manually retrieved and the contents were sprayed down and bagged out through the 20 in. port. A "nut hanger" also was used to lift piping from the tank.

The hydraulic shear was deployed on one occasion to cut pipes, which were hanging from the tank dome into 1-ft sections. This was accomplished with the ROV suspended under the ROV riser. The remaining pipes were then cut at the top section of each pipe. These pipe sections were collected during debris consolidation efforts. One pipe remains in the south side of the tank that the ROV was unable to reach with the hydraulic shear.

6.9 DECONTAMINATION WATER USED

Decontamination water, introduced through spray rings at the top of the tank riser, was used to decontaminate the MLDUA, ROV, and HMS.

The electronic data source for decontamination activities was from the decontamination water flow meter, FIT-141. A total of 45 decontamination events were performed that were logged by the GUI. Two additional events were performed before transfer of the equipment to the STF that were not logged by the GUI. The total decontamination water used was 2574 gal (Fig. 6-7). As with W-3 operations, this is less than 3% of the water used in W-4 sludge retrieval operations.

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

6.9.1 ROV

For decontamination of the ROV (using the decontamination events that were logged by the GUI), the decontamination water flow rate ranged from 9 to 30 gpm at a pressure of 210 to 2410 psi. The average time for decontamination was 157 seconds per event, at an average total water added of 47 gal per event. The total water use logged by the GUI during W-4 operations for decontamination of the ROV through the DSR was 809 gal. Further decontamination of the ROV that was performed with a hand-held spray wand was not recorded.

6.9.2 MLDUA

For decontamination of the MLDUA, the decontamination water flow rate ranged from 10 to 19 gpm at a pressure of 200 to 640 psi. The average time for decontamination was 145 seconds per event, at an average total water added of 32 gal per event. The total water used during W-4 operations for decontamination of the MLDUA through the DSR was 520 gal. Further decontamination of the MLDUA that was performed with a hand-held spray wand was not recorded.

6.9.3 HMS

For decontamination of the HMS, the decontamination water flow rate ranged from 7 to 27 gpm at a pressure of 230 to 2000 psi. The average time for decontamination was 236 seconds per event, at an average total water added of 61 gal per event. The total water used during W-4 operations for decontamination of the HMS through the DSR was 736 gal. Further decontamination of the HMS that was performed with a hand-held spray wand was not recorded.

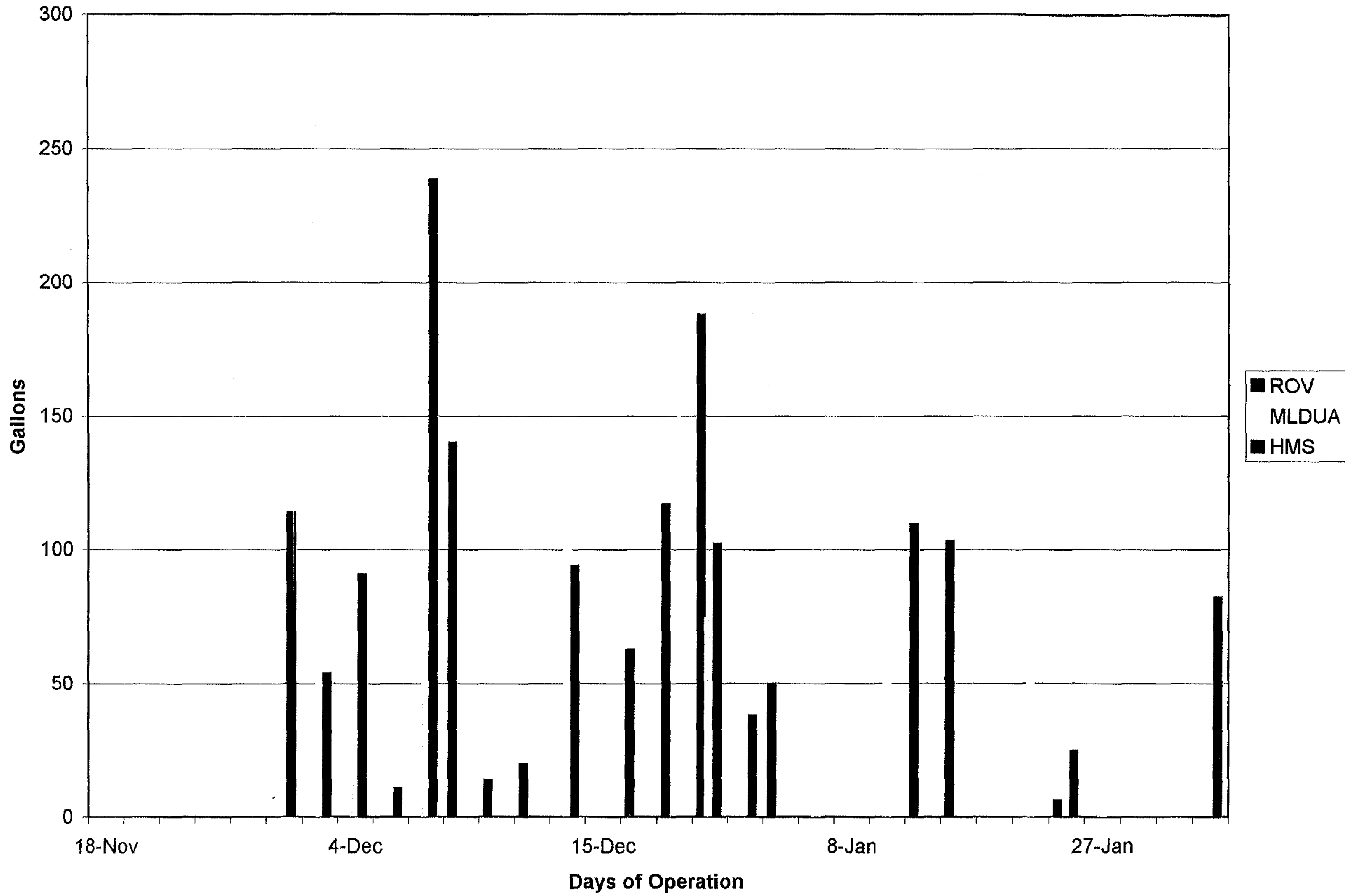


Fig. 6-7. Decontamination water used in W-4 operations.

6.10 PERSONNEL EXPOSURES

Seven RWPs, were issued during NTF W-4 activities. The activities, which logged exposures of more than 10 mrem, are listed in Table 6-7.

Table 6-7. RWP with exposures higher than 10 mrem

RWP No.	Task	Dose (mrem)	Total time (h)	Calculated dose rate (mrem/h)
1513C	ROV operators to perform the following routine activities through the use of glove ports or pass-through ports: (1) unlatch/latch safety chain, (2) pressurize/depressurize pneumatic door seal, (3) assist in deployment/retraction of the ROV, (4) visual inspection, (5) glove and bag inspection/replacement, (6) bag-in/bag-out tools or debris, (7) decontamination using hand-held spray wand.	53	132.4	0.40
1514C	MLDUA operators to perform the following routine activities through the use of glove ports or pass-through ports: (1) installation/removal of secondary boot, (2) perform decontamination using hand-held spray wand, (3) glove and bag inspection/replacement, (4)GEE attachment/removal, (5) bag-in/bag-out tools or debris, (6) repair inner boot.	27	130.8	0.21
1627A	Health and Safety Manager and Radiological Control Technician (RCT) surveillance as needed. Also includes RCT routines and rad waste/laundry collection and processing.	21	367.4	0.06
1847A	HMS Personnel to perform the following activities through the use of the glove ports or bag-in/bag-out ports: (1) deploy and retract HMS arm, (2) connect and disconnect hoses and cables, (3) spray down HMS with hand-held spray wand, (4) perform light-duty required maintenance, (5) glove and bag inspection/replacement, (6) bag-in/bag-out tools or debris	31	150.1	0.21
1984A	Visual observation of work, light-duty work and pre-startup checks on the platform. No glove port or intrusive work with contamination/internally contaminated equipment/material is allowed under this RWP.	60	554.3	0.11

6.11 PPE USAGE

PPE costs are much less than originally estimated because of the use of the ORNL laundry services and minimal use of disposable PPE.

6.12 SOLID WASTES GENERATED

Solid wastes generated during W-4 operations were as follows:

- 1000 ft^3 of (SLLW),
- 55 gal of mixed waste, and
- 110 gal of used oil.

6.13 WASTE CHARACTERIZATION INFORMATION

Three samples were collected via the Isolok Sampler and were submitted for analysis. The analysis of key analytes in these samples is presented in Table 6-8.

Table 6-8. In-line process sample results

Sample ID/analytes	Units	980108-013	980108-015	980227-011
4.20 MeV ^{238}U	%	31.4	31.2	400 Bq/g
4.80 MeV $^{233}U/^{234}U$	%	27.7	30.5	420 Bq/g
5.15 MeV $^{239}Pu/^{240}Pu$	%	37.5	35.7	160 Bq/g
5.50 MeV $^{238}Pu/^{241}Am$	%	3.4	2.6	9 Bq/g
^{137}Cs	Bq/mL	4.8E+4	3.8E+4	4.6E+3 Bq/g
G-Alpha	Bq/mL	6.5E+3	7.3E+3	9.9E+2 Bq/g
G-Beta	Bq/mL	3.0E+5	3.1E+5	3.3E+4 Bq/g
Total organic carbon	%	< 0.1	< 0.1	

6.14 TANK CHARACTERIZATION INFORMATION

Following wall-cleaning operations, the CEE was deployed to determine the remaining activity in the tank W-4 walls. Figures 6-8 and 6-9 indicate the baseline reading (beta and gamma) collected before wall cleaning operations.[6] Figures 6-10 and 6-11 indicate the activity remaining in the walls following wall-cleaning operations. Comparison of these data indicates that wall-cleaning operations removed up to 80% of the gamma components. However, evaluation of the beta survey results is inconclusive.

Following CEE operations, wall coring samples were collected to determine the depth of isotopic migration and the type of isotope(s) bonded with the Gunite. The samples were collected at different elevations and core depths of up to 3 in.

The core samples have been evaluated for the constituents that contribute to the risk/transport drivers for the tanks as a measure of the following:

1. the effectiveness of the wall-cleaning operations, and
2. the depth to which constituents have infiltrated the tank walls over years of saturation with sludge and supernate.

A graphical portrayal of the ^{90}Sr and ^{137}Cs concentrations for each core sample is presented in the stacked bar charts in Appendix A. As illustrated in the graphs, the contaminant concentration decreases as the depth into the wall increases, with more than 96% contained in the first 0.063 in.

Table 6-9 presents an estimate of the total curie content remaining within the tank W-4 walls based on ^{137}Cs, ^{90}Sr, and ^{238}Pu concentrations.

Table 6-9. Estimate of activity in tank W-4 wall

Slice	**^{137}Cs (Ci)**	**$^{90}Sr+^{90}Y^{a}$ (Ci)**	**^{239}Pu (mCi)**	**Total^{a} (Ci)**	**(%)**
#1 (0.063)	0.938	3.127	7.578	4.073	96.55
#2 (0.063)	0.087	0.038	0.397	0.125	2.97
#3 (0.25)	0.014	0.001	0.060	0.015	0.36
#4 (0.25)	0.004	0.000	0.253	0.005	0.12
Total	1.044	3.167	8.288	4.219	100.00

[a] Total includes ^{90}Y in secular equilibrium with the ^{90}Sr. For the purpose of these estimates, all of the alpha activity is assumed to be ^{239}Pu.

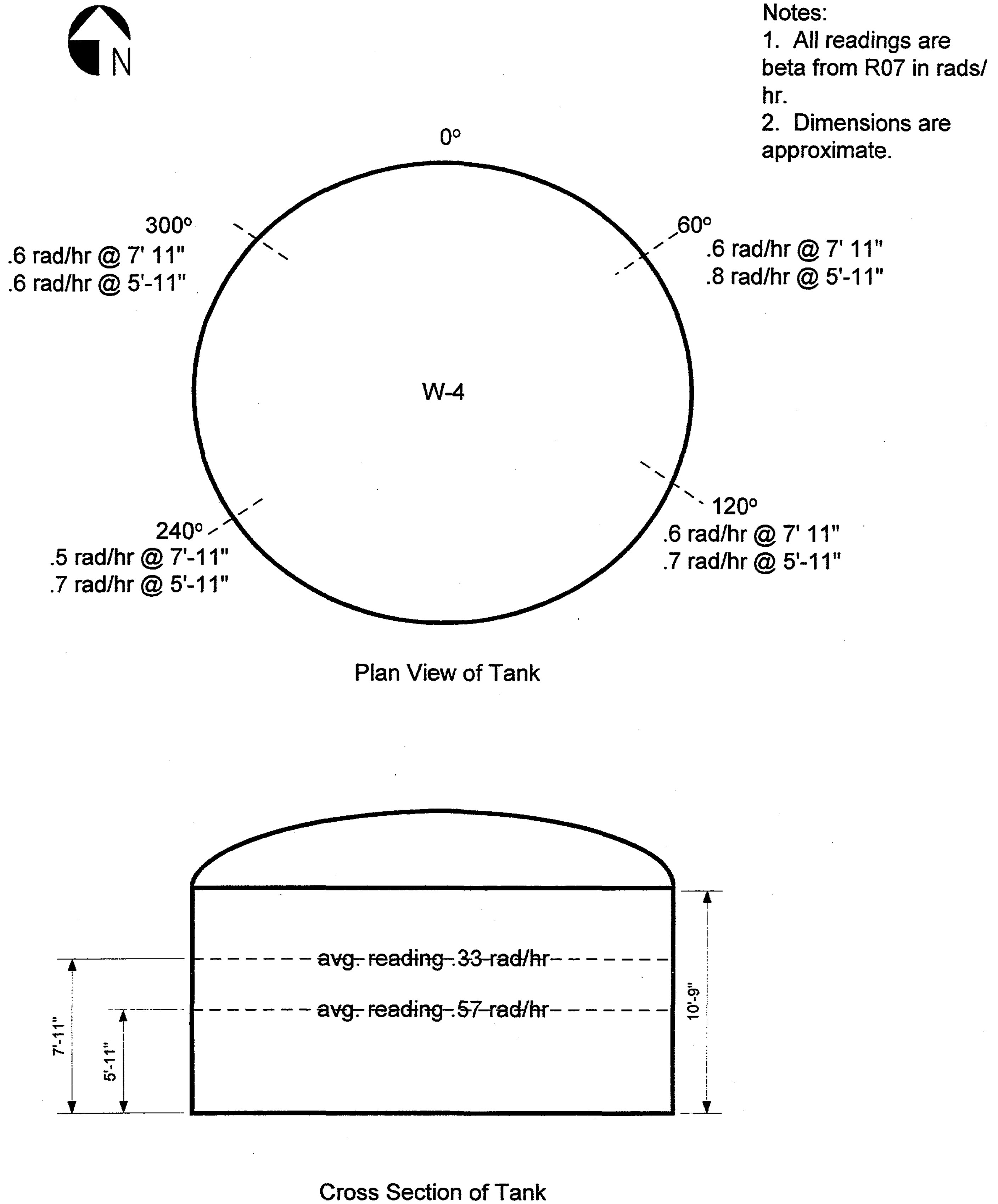
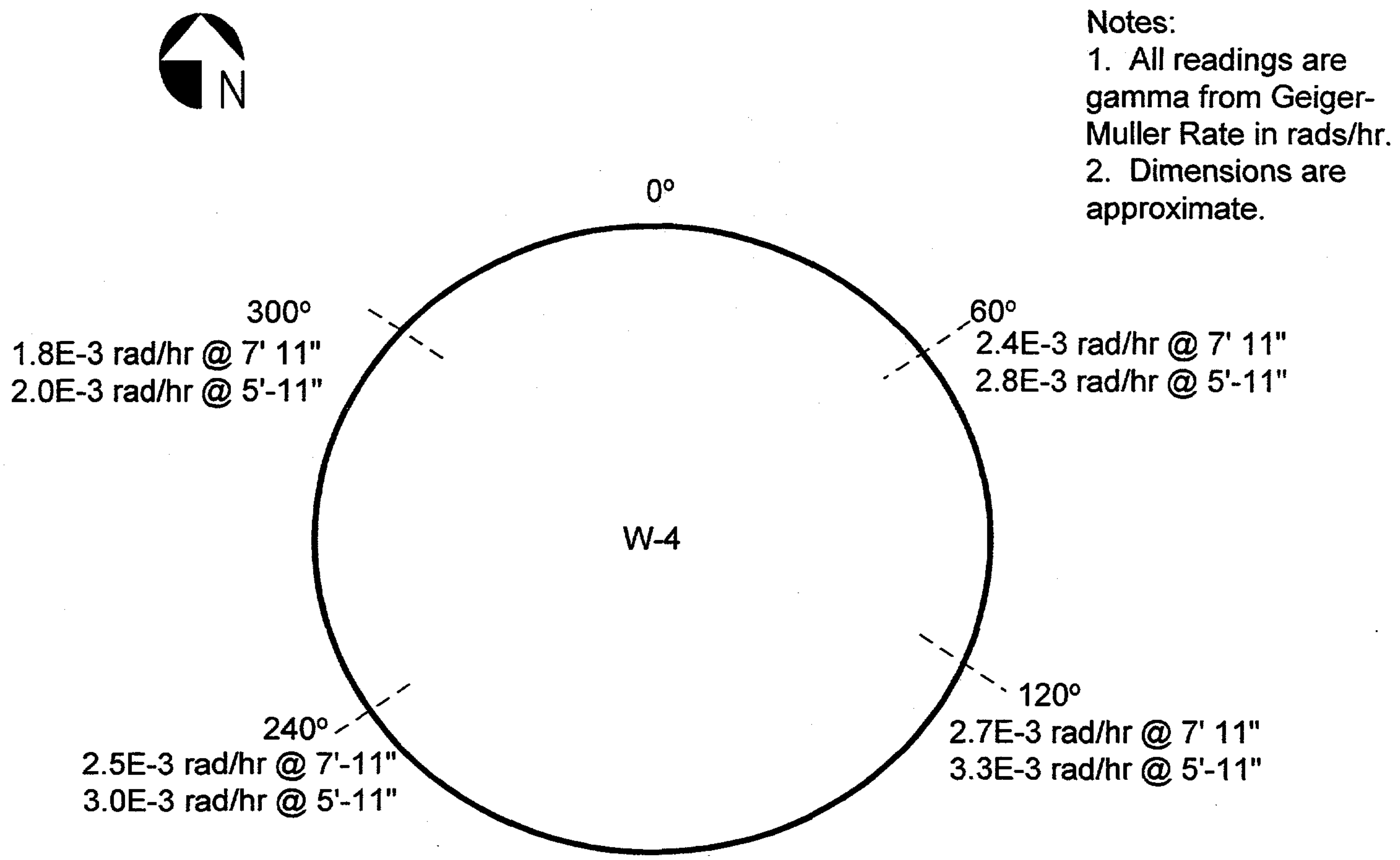
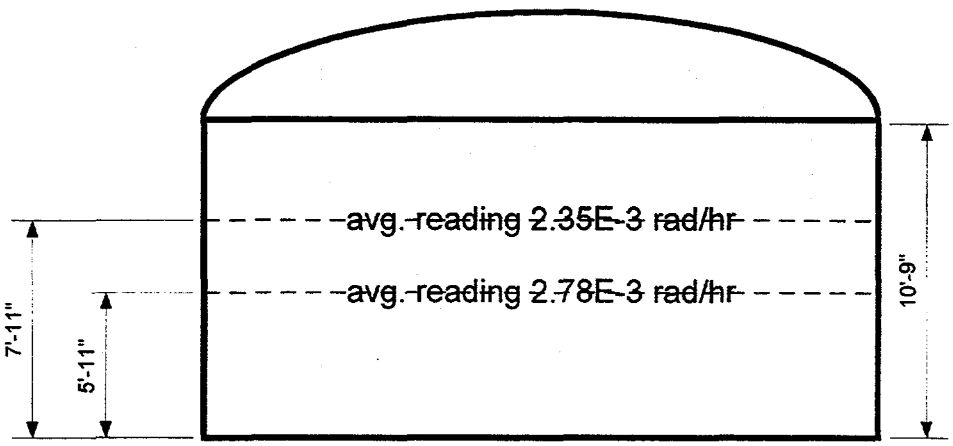


Fig. 6-8. W-4 baseline survey of beta with characterization end effector (10/22/97).

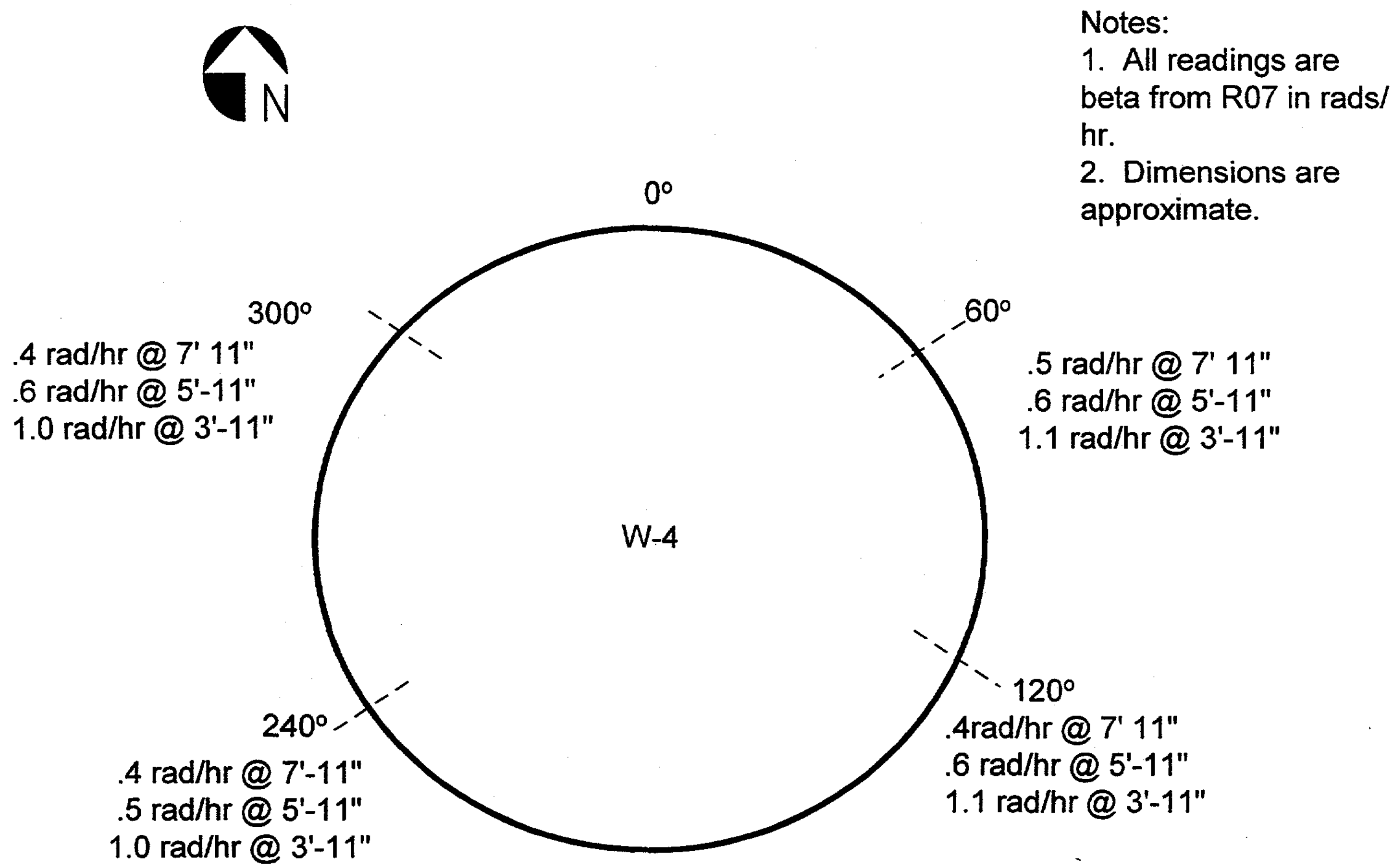


Plan View of Tank

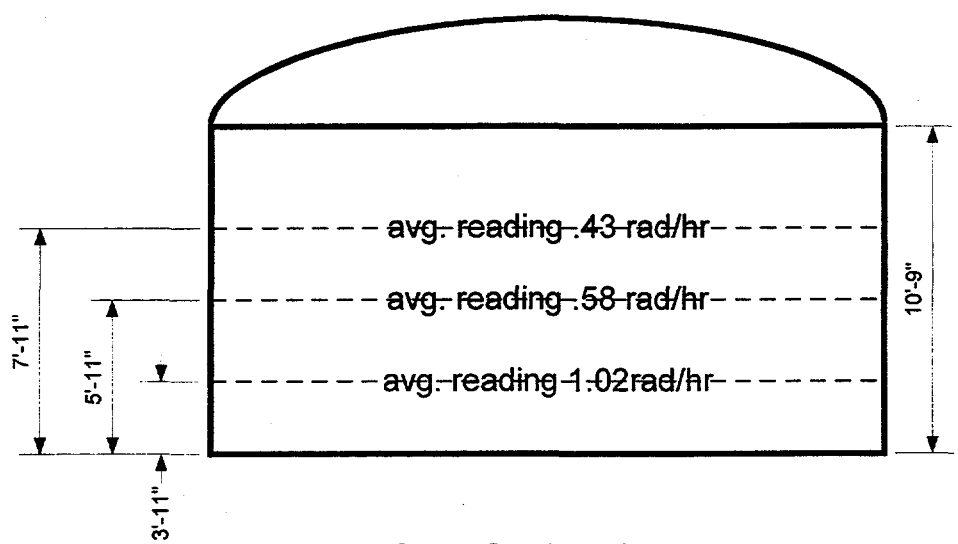


Cross Section of Tank

Fig. 6-9. W-4 baseline survey of gamma with characterization end effector (10/22/97).



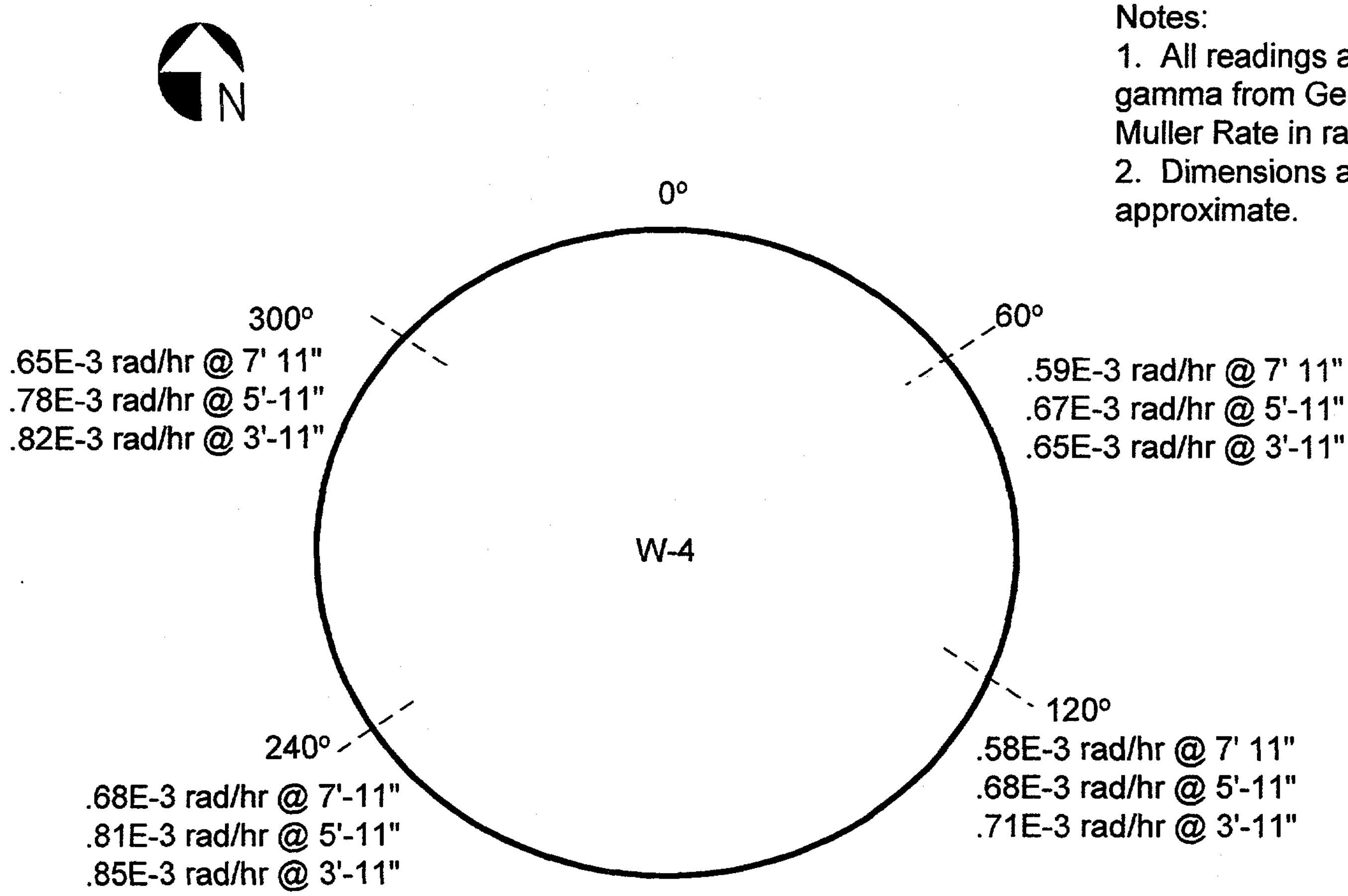
Plan View of Tank



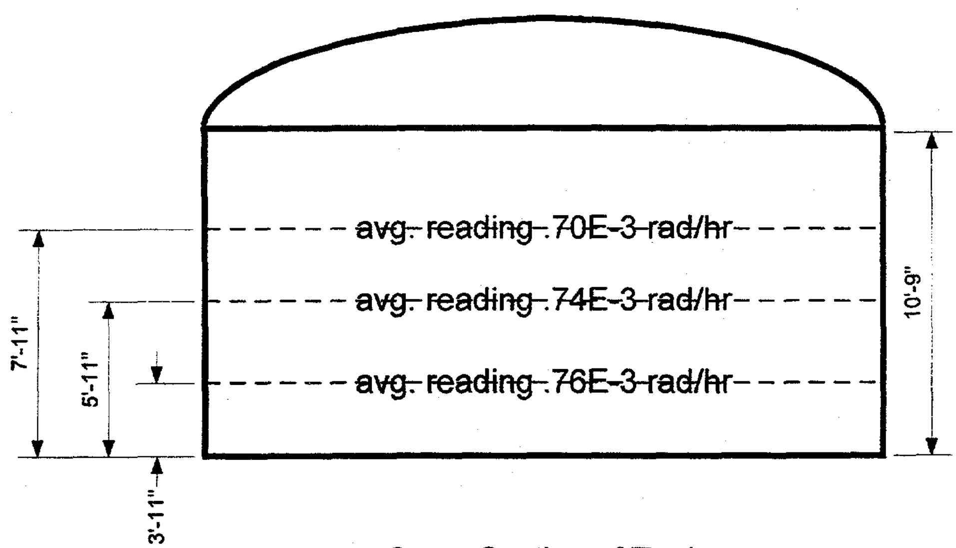
Cross Section of Tank

Fig. 6-10. W-4 post-cleaning survey of beta with characterization end effector (2/19/98).

Notes:
1. All readings are gamma from Geiger-Muller Rate in rads/hr.
2. Dimensions are approximate.



Plan View of Tank



Cross Section of Tank

Fig. 6-11. W-4 post-cleaning survey of gamma with characterization end effector (2/19/98).

7. MAINTENANCE

Maintenance was performed on all of the systems throughout NTF operations. Tables in this section indicate the types of maintenance required for each system and the location of the system during the activity.

7.1 ROV SYSTEM MAINTENANCE

7.1.1 ROV Maintenance

7.1.1.1 Primary Maintenance Issues in Tank W-3

The ROV currently operating in the GAAT is, in effect, a prototype system. One of the goals of the TS has been to test the limits of each of the technologies used, and because of its versatility, the ROV has been tested far beyond the original scope planned for it. In addition to deploying the CSEE and CEE, the ROV has proved to be the only system capable of deploying such tools as the Jaws-of-Life, a mobile-hydraulic shear, and a wall-coring end effector for sampling the Gunite tank walls. The ROV has been used on numerous occasions to rescue the MLDUA by retrieving and handing off end effectors that were either out of the arm's reach or not in the proper orientation for the MLDUA to pick up. The ROV has also been successful at its "expected" chores, which include plowing, picking up debris, and sluicing. On-site operators have taken to calling the system "the beast" because it is such a powerful workhorse. However, such heavy-duty testing of a first-generation system has resulted in numerous breakdowns and has brought many design flaws to light. The primary maintenance problems and their planned or implemented solutions are as follows.

- **Leaking or damaged hydraulic hoses, electrical cables, and connectors.** This has been the most persistent problem with the ROV system. The ROV design contains numerous hoses and cables routed from the tether termination point to the track manifolds, plow, and manipulator. Many of the connectors used are 45° and 90° connectors that are subject to damage or loosening when the vehicle is folded during retractions and deployments. It is also during these operations that the hoses are sometimes pinched. Fixes on the current system have been limited to controlling hose routing with wire ties, daily inspections of all hoses, and weekly tightening of all connectors. Attempts to find swivel connectors compatible with the present system have been unsuccessful. The "real fix," which will be implemented on the next ROV system, is to get rid of the nest of hoses and use manifolds for routing the hydraulic fluid. In addition, electrical cables will be routed to areas where they are less prone to damage. For example, the wrist camera cable will be routed inside the Schilling manipulator, rather than clamped to the outside of the housing as it is in the current system.

- **Unreliable operation of the TMADS door.** The TMADS door was hydraulically actuated and would occasionally fail without opening or closing on command. These difficulties were traced to a counterbalance valve system that was difficult to keep balanced properly and that leaked across the ports on one of the valves used. When the hydraulic valve that controlled the latch failed, it was discovered that there was no way to reach the cylinder once the system was contaminated without cutting a hole in the frame. A hole was cut, and a bolt-on panel was added in case the need should arise to access the panel again in the future. Test equipment was purchased to periodically check and adjust or balance pressure on the valves controlling the door opening and closing. The door has worked satisfactorily since these changes; however, a request was made to RedZone Robotics, Inc. (the manufacturer) to make the door on the next system electrically actuated rather than hydraulic.

- **Body Camera.** Loose pins in the body camera connector were traced to inadequate crimping or soldering performed at the Redzone facility. Lockheed Martin Energy Research (LMER) electricians repaired the pin connections in February 1997, when the vehicle was received from Redzone. Pan & Tilt motor mounting screws also loosened frequently, making the camera unit prone to damage during deployments and retractions. The mounting screws vibrated loose during normal tank operations, and the mounting holes frequently became stripped and had to be retapped.

Note: the preceding items are not an all-inclusive list of the maintenance problems found and corrected to date. However, the system lead believes that no "showstoppers" have been found. Many design improvements will be incorporated in the next system that should make it even more reliable.

7.1.1.2 Specific Maintenance Operations in Tank W-3

During June 1997, the ROV system was disconnected from the TTCTF and moved to the NTF. The system was positioned over the north riser of tank W-3 and was powered up for the first time on June 12 using the suitcase controller. During the next four months the vehicle was deployed and retracted from W-3 a total of 24 times. In all, the system logged approximately 150 hours of tank operations and was deployed in the tank on 27 workdays.

The specific maintenance activities undertaken during the tank W-3 campaign are shown in Table 7-1.

Table 7-1. ROV W-3 maintenance operations

Activity	Frequency (days)
Add oil to reservoir	2 (13-gal total)
Replace 12 in. bag	3
Replace glove	6
Replace hydraulic filters	1
Replace 20 in. bag	5

The ROV completed its first full deployment into tank W-3 on August 1, 1997. While the system completed 6 hours of operation and performed very well overall, hydraulic leaks were found to be an issue. Hydraulic leaks continued to be the most consistent failure of the system—rarely a full shift went by without a leak springing out somewhere. The most common failure point was at the 90° fittings to the track drive manifolds. The connectors loosened during normal operations and had to be tightened weekly.

On August 6, the ROV was used to take a bulk sludge sample from tank W-3. At this time the Titan III manipulator wrist rotate joint began to perform erratically, occasionally shaking back and forth for no apparent reason. After a few minutes, the problem would clear itself and operations would continue. However, the problem worsened over the ensuing weeks. After ruling out several other possibilities, consultation with Schilling Development Corp. indicated that the problem was most likely tied to a damaged slave controller cable.

The relief valve for the manipulator (located on the azimuth) was damaged during a retraction of the vehicle from the tank. This valve was easily replaced while the vehicle was stored in TMADS. Both vehicle-mounted cameras also sustained abuse during deployments and retractions. The body camera mounting bracket bent, and the mounting screws vibrated loose on several occasions. These screws were coated with threadlocker and were tightened down. The wrist camera-mounting bracket also loosened and was retightened in the containment bezel. The power and signal cable for the wrist camera was cut and had to be spliced back together in the containment bezel. This was an extremely difficult operation to perform through the glove ports. An in-line connector will be added at the tether termination during the next maintenance tent activity so that in the future the entire cable can be replaced if damaged. In addition, a request was made to RedZone to route the wrist camera cable inside the housing of the Titan III manipulator for their second-generation ROV system.

On September 15, the ROV deployed the FCEE, which had been designed to vacuum sludge out of the tank without adding water to the interior of the tank. During these vacuuming operations, the ROV suffered yet another hydraulic leak—a steady stream was visible coming from the left track manifold while the vehicle was being retracted. Two pipefitters were called in to fix the leak; however, they did not have sufficient access though the TMADS glove ports to actually replace the damaged hose and fittings. Further inspection revealed that the Schilling hydraulic supply line was also damaged. Several other minor maintenance items that could not be accomplished in TMADS had also been stacking up in the queue; therefore, a decision was made to erect the on-platform maintenance tent. The tent was erected, moved into place, and secured to the platform by September 19. An inner lining was built inside the tent to protect it from contamination and to mate it to the TMADS. Once equipment was received for operating airline respirators inside the tent, one of the storage compartment panels was removed and the vehicle was driven out of TMADS onto a maintenance table that had been installed in the tent. This was done on September 26. An engine hoist had also been installed in the tent so that the vehicle could be lifted onto jack stands as necessary for repairing/replacing hoses and fittings and for replacing the vehicle's tracks.

While in the tent, all the hydraulic lines on the vehicle were inspected and replaced if necessary. The plow blade and squeegee were replaced, and the wrist camera cable was respliced. The wrist camera lights had been loosening and were retightened. The plow blade limit switch was repositioned. An attempt was made to replace the pan and tilt unit on the body camera; however, the unit supplied from the camera vendor had a different connector from that supplied by RedZone. As with many other parts on the vehicle, RedZone had modified off-the-shelf equipment before installing it on the ROV. A jumper cable was ordered to mate the new pan and tilt with the vehicle's tether. In the meantime, the pan and tilt unit was reinstalled on the ROV. New azimuth limits were set for the Schilling manipulator to keep it from putting undue stress on the hydraulic lines. The hoses were wire-tied so that they would not interfere with the frame opening and closing. All these limits were tested.

On October 13, the vehicle was reinstalled in TMADS. To get it back in the confinement compartment, the azimuth limits on the Schilling were overridden, and, as a result, the right track-pressure hose was damaged and had to be replaced through the glove ports on TMADS.

The ROV was deployed into tank W-3 for the final time on October 17. It was used to perform a final plowing and scraping of the tank floor and to pick up any remaining visible debris and place it in the debris bucket. In the process, the shoulder bolt that secured the frame cylinder to the front cross link on the ROV fell out onto the ground. The ROV operator was able to use the tracks to fold the vehicle up for a retraction from the tank, and also managed to grab the displaced bolt with the manipulator while exiting the floor. There was no indication that the bolt or its threads had been damaged in any way. The bolt passed through the front cross link and rod of the frame cylinder before threading into the underside of the Schilling azimuth. As such, it could not be secured with a nut. The millwrights had been requested to apply threadlocker to all bolts and tighten them down during the maintenance tent activities. However, there was no specific documentation to prove that this particular bolt had indeed been tightened. In the future, drawings will be used and each bolt in the system will be initialed to verify that it has been tightened. A similar method will be used to verify that all hydraulic hoses and fitting have been inspected and tightened. A summary of ROV system maintenance is shown in Table 7-2.

Table 7-2. ROV system maintenance summary

Maintenance activity	Operations location
Repair TMADS door	W-3
Repair TMADS door latch	W-3
Remove TMADS door drain plug	W-3
Caulk TMADS fiberglass reinforced plastic (FRP) panels	W-3
Replace TMADS drain plug	W-3
Tighten TMADS door cylinder fitting	W-3
Repair/replace TMADS door cylinder	W-3
Repair ROV arm (wrist roll)	W-3
Replace mini master	W-3
Tightened loose hydraulic fitting	W-3
Replace relief valve	W-3
Replace damaged hydraulics	W-3
Replace damaged hose on right drive motor	W-3
Repair ROV squeegee	W-3
Replace oil reservoir lamp indicator	Post W-3/Pre W-4
Replace ROV plow blade	Post W-3/Pre W-4
Replace vehicle tracks	Post W-3/Pre W-4
Swap servo valves	Post W-3/Pre W-4
Replace hydraulic hose	Post W-3/Pre W-4
Replace bolt in frame	W-4
Troubleshoot/repair left track	W-4
Replaced damaged hydraulic fitting	W-4

7.1.1.3 Specific Maintenance Operations in Tank W-4[7]

On November 17, 1997, the ROV system move to tank W-4 was completed. The shoulder bolt that had fallen out of the frame cylinder in tank W-3 was replaced. Loctite and lock washers were used on the new shoulder bolt to prevent it from coming loose again. A minor hydraulic leak on the vehicle was also repaired at this time.

Although the ROV system was essentially in position and ready to go at this point, it could not actually be deployed into the tank for full-scale operations until the MLDUA had succeeded in lowering the supernatant level and clearing off a landing pad for the vehicle. This delay was necessary because the ROV's tether was not watertight.

The ROV was first fully deployed into tank W-4 on December 9, 1997, to begin plowing. However, once the vehicle landed it became apparent that the left track was not operating properly. The track did not turn at full speed and would occasionally stall out completely. The problem was eventually traced to a broken wire in the servo valve. The vehicle was retracted, and once the proper equipment was staged and the pipefitters were available, the faulty servo valve was replaced. This delicate maintenance activity was completed through the containment bezel glove ports with the vehicle suspended over the riser opening. The MLDUA had continued scarifying while the repair was completed; therefore, the extra water in the tank produced by scarifying had to be removed before the ROV could reenter the tank.

Finally, on December 16, 1997, full-scale operation of the ROV began. The ROV system was deployed and retracted from W-3 a total of 12 times and logged approximately 128 hours of tank operation. The specific activities undertaken during the tank W-4 campaign are shown in Table 7-3.

Table 7-3. ROV W-4 maintenance operations

Maintenance activity	Frequency (days)
Add oil to reservoir	1
Repair wrist camera lights	1
Replace 12 in. bag	Estimated 6
Replace glove	4
Replace hydraulic filters	1
Replace 20 in. bag	Estimated 5
Take oil sample	1
Replace track servo valve	1
Tighten wrist camera mount	2
Replace bolt	2
Replace hydraulic fitting	1
Tighten body camera pan & tilt mount	2

A shovel with a handle modified so that the manipulator could easily grasp it was deployed into the tank on February 16, and the ROV was used to shovel sludge into 5-gal buckets. During these operations, it is possible that the manipulator's shoulder had lain on the upraised plow forcefully enough to damage the plow lift mechanism. The vehicle was retracted and inspected in TMADS, but with the vehicle folded, an exact determination of the damage was not possible. Because tank cleanup operations had already been completed to the satisfaction of the regulators, a decision was made to inspect and repair the plow once the ROV system had been relocated to the STF maintenance tent. Routine maintenance and inspection activities had already been planned before deployment of the system in tank W-6.

Since the ROV system was not scheduled to be deployed in tank W-6 at the STF until the MLDUA had cleaned a one-fourth of the W-6 tank and moved to its second location, the ROV was the last system to be disconnected from W-4 and moved from the NTF. The ROV system also had to wait until maintenance activities on the WD&C system were completed in the STF maintenance tent before it could be moved to that location. While waiting for the move, some maintenance activities were completed on the containment bezel. A new black and white camera was mounted in the northeast corner of the bezel to provide the operators with another view during deployments and retractions. Retractable lanyards were also added to allow tools and parts to be secured when work was conducted over an open riser. New gaskets were placed on the THS interface panels, and an inner seal was welded onto the 20 in. bag-in port to prevent water from leaking out when the decontamination spray ring was operated. These activities were completed, and the vehicle was stowed for movement to the STF on April 1, 1998.

In summary, the ROV system remains a valuable workhorse for performing remote, in-tank operations. Lessons learned from tank W-3 operations were incorporated where possible to minimize downtime and to increase efficiency on tank W-4. These changes appeared to be quite effective.

7.2 MLDUA SYSTEM MAINTENANCE[5]

Although the system was unavailable for a total of 16 days during the 17 weeks of operations in tank W-3, the operating crew was usually able to reschedule in-tank tasks so that the Houdini system could carry on in place of the MLDUA or so that other beneficial operations could be scheduled. The nature of the component failures is such that the downtime during future deployments is anticipated to be less than during this initial field operation.

The MLDUA has both a primary contamination prevention boot and a secondary boot. The primary boot was replaced once during operations and was partially replaced on two other occasions. The usual reason for replacing all or part of the primary boot was because of tears in the boot. The secondary boot was replaced four times. In addition to being replaced because of tears, the secondary boot was replaced when it had become either sufficiently contaminated to threaten contamination of the primary boot and risk internal contamination of the MLDUA or when oil leaks had dirtied the boot sufficiently to warrant replacement.

A small boot was used on the gripper end effector (GEE), which was also replaced four times. Two major oil leaks occurred during operations. A total of about 7 gal of fluid was added to the reservoir.

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

A more serious failure occurred when an O-ring seal failed in the wrist pitch joint. To access the wrist pitch hydraulics, the TRIC structure was removed from the riser and set aside. This provided sufficient clearance between the bottom of the vertical positioning mast (VPM) and the support platform so that the MLDUA lower joints could be deployed and supported on the platform. The arm covers were removed, and the O-ring problem was discovered. This failure happened twice. The first time a total of eight days were lost. The repair for the first incident involved simply replacing the damaged O-ring with a new one of identical dimensions. This repair lasted a couple of weeks before the same wrist pitch symptom was observed. The second time that this failure occurred the hydraulic fitting was modified and a larger O-ring was inserted to ensure an adequate seal. The lost time for this repair was about five days. The major reason for improvement in downtime was experience gained the first time in contamination control measures. The only other significant component failure occurred when the cable attached to the VPM encoder came off the spool. This was caused by interference with a camera cable that was attached to the umbilical. The camera cable was repositioned, and the encoder cable was repaired. This repair required the use of a bucket lift to access the VPM while in the vertical position. This event resulted in about one day of lost time.

The MLDUA system had no major operating problems in tank W-4. A minor operating problem developed in tank W-4 when the hydraulic oil cooler dropped off line twice during operations. This required an operator to open the front panel of the cooler to reset the cooler's computer.

This problem will be tracked in future tank operations. With the HPU placement being off the STF tank platforms, any needed cooler computer resets will be quicker and easier than for tank W-4 where the HPU was on the tank platform.

A hydraulic oil sample was taken on December 19 and sent to Analysis, Inc. for testing. The oil sample test results were satisfactory. During the maintenance period after tank W-4 operations, all oil filters were replaced. A summary of the MLDUA system maintenance is shown in Table 7-4.

Table 7-4. MLDUA system maintenance summary

Maintenance activity	Operations location
Replace fused disconnect	W-3
Troubleshoot hydraulic oil leak	W-3
Repair inner tube position sensor	W-3
Repair oil leak	W-3
Install resistor in voltage ref. circuit	W-3
Seal TRIC panels	W-3
Install temperature sensor in oil reservoir	Post W-3/Pre W-4
Replace primary boot	Post W-3/Pre W-4
Repair HPU oil leaks	Post W-3/Pre W-4
Install VPM air purge line	Post W-3/Pre W-4
Tighten fitting on VPM inner tube cable winch	Post W-3/Pre W-4
Troubleshoot HPU oil temperature sensor	Post W-3/Pre W-4
Replace HPU oil temperature sensor	Post W-3/Pre W-4

7.3 WD&C SYSTEM MAINTENANCE[8]

The WD&C system experienced a few operational problems during W-3 operations. The one problem that made the WD&C unavailable was the failure of the rupture disk mounted on the HMA mast. After the second failure (the first failure was caused by a process problem and the second by an installation error) the rupture disk was relocated to the FCE/CB located at the platform level. This provides easy access in the event of additional failures. After relocation of the rupture disk and selection of a different acceptable rupture disk, no additional rupture disk failures were experienced. While the rupture disk was being relocated, other in-tank operations were under way.

During W-4 operations, the HMS performed with only one failure that affected its availability for waste removal operations. That failure was the severing of the shoulder pitch load cell and damaging the CSEE signal cable at the mast head. The damage was caused by the cable restraints being broken off during operations and allowing the cables to get caught between the mast head and the storage tube during mast deployment and retraction. These cables were temporarily repaired at W-4 and were permanently repaired or replaced in the STF maintenance tent. The restraints have been replaced in a more secure manner.

Other incidental failures during W-4 operations were the cable/hose retainers along HMA arm sections and the hose/cable bundle and some damage to the CSEE signal cable at the base of the mast. The retainers were redesigned and installed during maintenance activities during the STF move. The hose/cable bundle has been sheathed with an outer cover eliminating the need for retainers on the bundle. The cause for the CSEE cable damage is unknown, and no changes have been made as a result. The elbow yaw limit switches began operating sporadically in W-4 and were replaced in the STF maintenance tent. The cause of the malfunction is unknown, and no changes were made to them.

Before operations on W-4, the waste discharge hose at the top of the mast was cut into 2 ft lengths and was visually examined for wear. No wear was detected, and a new hose was put in place. The jet pump was removed and visually inspected before and after use on W-4. The inspection revealed wear on the jet nozzle bodies but no additional wear on the pump throat. However, no noticeable reduction in pump performance was encountered. The jet nozzles were replaced before and after W-4 operations, in the STF maintenance tent. In the STF maintenance tent, the two HMA arm sections and both swivel joints were disassembled and visually inspected. No additional wear was detected inside the arm sections or in the swivel joints. The suction hose was removed and replaced with a longer hose for STF operations. No internal wear was detected; however; the hose-covering material seemed to have become softer, and minor mechanical damage was encountered about 1 ft from the end that connects to the CSEE. A summary of the WD&C system maintenance is shown in Table 7-5.

Table 7-5. WD&C system maintenance summary

Maintenance activity	Operations location
Replace HMA rupture disk	W-3
Repair HMA signal cables	W-3
Repair HMA shoulder pitch motor cable	W-3
Repair CSEE screen and high-pressure swivel	W-3
Repair CSEE signal cable	W-3
Replace high-pressure swivel and swivel shroud	W-3
Replace pump inlet hose	Post W-3/ Pre W-4
Replace HMA suction hose	W-4
Replace limit switch on HMA	W-4
Replace HMA cable and hose clamp	W-4
Repair HMA electrical cables	W-4

7.4 BOP MAINTENANCE[8]

7.4.1 High-Pressure Pump Skid L-01

The decontamination system operated 16 hours at W-4. A failure of the pressure control valve controller (PV-144) was encountered during this period, and the controller was replaced. The reason for the failure is assumed to be because of contaminants (dirt, particulates, oil, etc.) introduced into the micro solenoids in the controller. In-line 10-micron filters were added to the air line supplying the high-pressure controllers on all three high-pressure pumps to eliminate this problem. The high-pressure cutoff switch, PSH-140, failed and was replaced. The reason for the failure was unknown. The decontamination spray rings and hoses operated without failure.

7.4.2 High-Pressure Pump Skid L-02

The CSEE cutting jet high-pressure water supply system operated 40 hours during W-4 operations. No failures were encountered that significantly impacted operations. The controller for FV-131 experienced erratic operation during this period. The controller failed to vent air pressure on the FV-131 operator upon system depressurization in cold weather. It is assumed that the problem could be caused by moisture in the micro solenoids. The lock nut that retains the magnetic pickup for the flow meter (FQIR-130) vibrated loose and had to retightened. A high-pressure fitting connecting the high-pressure cutoff switch (PSH-130) cracked. The cause of this failure is not known. During periods of extended (>12 h) temperatures below freezing, the inlet pressure sensing lines froze. A step was added to the winterization guide to blow down this line to prevent startup difficulties. However, this could become an issue for extended operation in temperatures below 25°F.

The L-02 and L-03 pumps' crank shaft and bearings were inspected during the move to the STF. The L-02 bearings and shaft were in good condition. During this maintenance, it was discovered that the L-02 and L-03 flow meter turbine retainers had failed or were close to fatigue failure. The cause of this failure is not known; however, more frequent inspections will be performed to prevent this failure in the future.

7.4.3 High-Pressure Pump Skid L-03

The jet pump high-pressure water supply system operated 92 hours during W-4 operations. No failures were encountered that significantly affected operations. During periods of extended (>12 h) temperatures below freezing, the inlet pressure sensing lines froze. A step was added to the winterization guide to blow down this line to prevent startup difficulties. However, this could become an issue for extended operation in periods of temperatures below 25°F. The dump valve FV-120 was leaking water to the jet pump when in the dump position and was replaced. The new replacement valve had the same problem. It is assumed that the problem was a poorly designed valve, and it was replaced with the same style dump valve as L-02. The replacement valve has not yet been tested.

The L-02 and L-03 pumps' crankshaft and bearings were inspected during the move to the STF. One of the L-03 bearings was worn significantly and required replacement. All journal bearings were replaced, and the shaft was in good condition. During this maintenance, it was discovered that the L-02 and L-03 flow meter turbine retainers had failed or were close to fatigue failure. The cause of this failure is not known; however, more frequent inspections will be performed to prevent this failure in the future.

7.4.4 Water Supply Pump Skid L-04

The L-04 process water pump operated 202 hours without a failure that affected operations. The back-flush water flow meter (FQIR-102) and the outlet pressure transmitter failed and are being repaired or replaced during the maintenance activity during the STF move. The only time the L-04 skid was unavailable for operations was because of scheduled and unscheduled plant process water outages.

7.4.5 Air Compressor Skid

During W-4 operations, the compressor started leaking oil into the air supplied to the dryer and was taken out of service. Plant air was connected to the air dryer inlet and supplied compressed air to the operation for the rest of W-4 activities. A summary of BOP maintenance is shown in Table 7-6.

Table 7-6. BOP maintenance summary

Maintenance activity	Operations location
Replace high-pressure switch on L-01	W-3
Replace flow element on L-03	W-3
Repair hand valve HV-106	Post W-3/ Pre W-4
Replace DSR manifold rupture disk	W-4
Repair leaks on L-02	W-4
Troubleshoot and repair L-03 (tightened fitting)	W-4
Replace Tescom controller on L-01	W-4
Repair Envelco flow meter on L-02	W-4

8. ON-THE-JOB TRAINING DOCUMENTATION

NTF waste removal operations required operators for four specific systems:

1. the modified light duty utility arm (MDLUA),
2. balance of plant (BOP),
3. graphical user interface (GUI), and the
4. remotely operated vehicle (ROV)

Each of these systems has a system log in which the operator records daily activities and signs as the operator. The operating time for each individual operator was compiled and is listed in Tables 8-1 through 8-4. These values represent the amount of on-the-job (OJT) training each operator received during NTF operations. Values are given for W-3 operations, W-4 operations, and the total time for NTF operations.

Before becoming a fully qualified operator, the individual must complete the system training requirements. Each system has a training plan that requires trainees to read and understand required reading materials, pass written and/or oral exams, and perform certain tasks listed on the system qualification card. While operators are in training, they will log in several hours of OJT (see Tables 8-1 through 8-4).

Table 8-1. MLDUA individual hours of operation

Operator	Tank W-3 total (h)	Tank W-4 total (h)	NTF totals (h)
Barry Burks		8	8
Diedre Falter		1.25	1.25
Curtis Fitzgerald		1.25	1.25
Rick Glassell	130	150	280
Walter Glover	130	150	280
Steve Killough		42.5	42.5
Harold Toy		7.5	7.5

Table 8-2. BOP individual hours of operation

Operator	Tank W-3 total (h)	Tank W-4 total (h)	NTF totals (h)
Jim Blank	16	0	16
Eric Depew*	0	94	94
Curtis Fitzgerald	80	49	129
Walter Glover*	0	32	32
Rick Hobson	48	0	48
Dan Kington*	0	46	46
Pete Lloyd	40	24	64
John Randolph	88	48	136
Harold Toy	40	125	165

* Not a fully qualified operator.

Table 8-3. GUI system individual hours of operation

Operator	Tank W-3 total (h)	Tank W-4 total (h)	NTF totals (h)
Jim Blank	200	221	**421**
Curtis Fitzgerald	48	100	**148**
Dan Kington*	8	0	**8**
Pete Lloyd	64	16	**80**
John Randolph	128	41	**169**
Harold Toy	0	16	**16**

* Not a fully qualified operator.

Table 8-4. ROV individual hours of operation

Operator	Tank W-3 total (h)	Tank W-4 total (h)	NTF totals (h)
David Dunning	6	0	**6**
Diedre Falter	49	39	**88**
Curtis Fitzgerald	2	9	**11**
Walter Glover	6	7	**13**
Dan Kington	80	63	**143**
Dirk Van Hoesen	16	16	**32**
Harold Toy*	2	0	**2**

* Not a fully qualified operator.

As shown in the preceding table(s), several of the equipment operators logged in a substantial number of hours during the NTF TS. These operators gained invaluable experience by actually operating their systems in the less contaminated NTF environment before starting operations in the more contaminated STF.

9. WASTE RETRIEVAL SYSTEM COST SUMMARY

The site preparation, equipment development, and operating costs are provided in Table 9-1. Equipment development costs include the testing performed at the TTCTF. W-3 operations includes the transfer of the sludge from W-3 to W-4, and W-4 operations includes the transfer of the sludge from W-4 to W-9. These costs do not include final disposal of the sludge or transfer of supernate from tank to tank.

Table 9-1. Waste retrieval system cost summary

	Labor ($1000)	Materials ($1000)	Total ($1000)
Site preparation and equipment development –DOE EM50 Funding	5,260	5,791	11,051 12,000
W-3 operations (6/12/97 to 9/12/97)	1,448	102	1,550
W-4 operations (9/15/97 to 2/18/98)	1,978	152	2,130
Total	8,686	6,045	26,731

The average operating cost for W-3 operations over 61 working days was approximately $26,000. The average operating cost for W-4 operations over 54 working days was $39,000. W-4 operations included many double shifts, which added cost to an average day of operation. If the W-4 operating costs are averaged per shift (over 72 shifts), the average operating cost is $30,000 per operating shift.

The average operating cost per gal of sludge transferred is $282 per gal for W-3 and $113 per gal for W-4. The average operating cost per curie removed from each tank is $4,844 per curie for W-3 and $1,699 per curie from W-4.

10. OBSERVATIONS AND LESSONS LEARNED

Table 10-1. GAAT hot test lessons learned

ORNL GAAT lesson learned	Recommendation for STF operations
1. Installation work instructions did not include steps to ensure that the riser dimensions matched the drawings.	Technical lead confirm all as-built dimensions.
2. The craft were given directions from different individuals, which resulted in some confusion.	Designate a single point of contact for the craft to coordinate activities.
3. Insufficient electrical craft were assigned to the task of installation.	Ensure that all agreements are in place before installation and contingencies are reviewed.
4. The holes cut into the top of the tank domes were not sufficiently large enough for the riser sleeves.	Fabricate a gauge to ensure that riser openings are cut to a sufficient diameter.
5. Holes had to be cut into the platform grating to allow for hydraulic and electrical lines to be run through the platform to the cable trays underneath.	Ensure that installation work instructions cover all details of installation.
6. Operators were unable to view the ROV tether reel.	Incorporate lexan panel on TMADS enclosure.
7. The ROV was damaged several times because of the transition through the riser sleeve.	Make riser openings larger, and review ROV design.
8. The clear secondary boot on the arm allowed the operators to see the first signs of a hydraulic leak in the arm and prevented the fluid from leaking into the tank.	Incorporate a clear boot into arm design.
9. CSEE was unable to remove the last few inches of waste from the tanks because the acorn nut that held the screen in place prevented the CSEE from being placed any closer to the floor.	Design the end effector with final sludge removal in mind.
10. Camera elements tended to overheat, and camera performance degraded over time because of the heat.	Chose camera systems that can withstand camera light heat for longer periods of time.
11. The length of time for the deployment and retraction of the equipment is significant.	Incorporate greater radiation tolerance into the design, or establish around the clock shift coverage.
12. Mining operations worked best by fully submerging the CSEE in the sludge after it had been diluted with the CSEE cutting jets.	Incorporate this procedure into operator training.
13. Several pieces of debris left in the tank from previous operations clogged the CSEE screen.	Develop operations such that a means of removing debris from the screen is provided.
14. Wall cleaning was done “blind” because when the cutting jets on the CSEE were in action the mist created in the tank reduced visibility to near zero. To prevent any problems, the MLDUA was maneuvered	Include this procedure in time estimates for tank wall cleaning.

ORNL GAAT lesson learned	Recommendation for STF operations
through the proposed area to be cleaned to ensure that there were no obstructions (e.g., riser sleeves, cameras, other equipment) and that the coupling of the HMA hose and MLDUA would not bind the hose.	
15. Wall cleaning was done at a distance of approximately 8 to 10 in. Cleaning closer to the wall yielded no significant difference in the amount of material removed from the wall, and operating at this distance gave the operator sufficient confidence that the CSEE would not be driven into the wall.	Incorporate this instruction into operator training.
16. Several problems were experienced with the ROV TMADS door. The decision was made to leave the door open at all times except during transport between tanks.	Incorporate this procedure into operator training.
17. The ROV experienced multiple hydraulic leaks.	Incorporate equipment checks to ensure that hydraulic fittings are tight.
18. Using identical pumps for the CSEE cutting jet high-pressure pump and the jet pump high-pressure pump added flexibility to the operation when one pump was inoperable.	Design systems for flexibility between items where substitutions can be made.
19. Maintenance work in the tent enclosure was hot and tiresome, resulting in short stay times preceded and followed by long periods of donning and doffing of PPE.	Plan work on a rotating basis so that as one team is rotating out another is entering, resulting in greater on-task time.
20. The HMA hoist and cable could not be viewed.	Incorporate a lexan panel on the HMA hoist enclosure.

11. SUMMARY AND CONCLUSIONS

Table 11-1 summarizes the performance parameters for the waste retrieval equipment in both W3 and W-4 operations.

Table 11-1. Tanks W-3 and W-4 operations performance

Performance parameters	Optimum operating envelope for W-3	Optimum operating envelope for W-4
Number of operating shifts and days of operations	June 25 to September 19, 1997 61 working days	November 18, 1997, to February 16, 1998 72 shifts in 54 operating days
Initial inventory	340 Ci (5500 gal) in sludge 7.3 Ci in scale on wall 6.4 Ci in wall	916 Ci (13,500 gal) in sludge 327 Ci from W-3 sludge and scale 3.7 Ci in scale on wall 4.2 Ci in wall
Inventory transferred	320 Ci (5400 gal) in sludge 7.3 Ci in scale from wall	1250 Ci (18,800 gal) in sludge 3.7 Ci in scale from wall
Residual inventory	6 Ci (100 gal) in sludge 6.4 Ci in wall	6 Ci (100 gal) in sludge 4.2 Ci in wall
Overall operations scheduling rate	157 gal of sludge removed per shift worked 35 shifts to remove sludge	279 gal of sludge removed per shift worked 68 shifts to remove sludge
Actual operating times	7 h supernate transfer 21.1 h sluicing 28.1 h wall cleaning 4.6 h residual water removal	7 h supernate transfer 93.6 h sluicing 34.9 h wall cleaning 11.5 h residual water removal
Total water added	41,797 gal	92,337 gal
Total gallons of water added per gallons of sludge removed	7.6	4.9 (includes removal of diluted W-3 sludge)
Wall area to be cleaned	707 ft^2	707 ft^2
Time to clean tank walls	28.1 h of CSEE high-pressure water pump (HPWP) operating time 76.4 h time held by MLDUA 17 intervals	34.9 h of CSEE HPWP operating time 148 h time held by MLDUA 16 intervals
Water to clean tank walls	13,477 gal	10,618 gal
Wall-cleaning water pressure	6000 to 7000 psi	6000 to 7000 psi
Wall-cleaning traverse rate	0.25 to 0.50 in. per second or 0.15 ft^2 per minute of MLDUA hold time	0.25 in. per second or 0.08 ft^2 per minute of MLDUA hold time
Wall-cleaning water flow	8 gal per minute 19 gal per square foot	8 gallons per minute 15 gallons per square foot
Wall-cleaning standoff	Up to 18 in.	6 in.
Shifts actual sluicing occurred	2 supernate retrieval 12 sludge transfer 5 transfer of wall washing residues	20 sludge transfer 8 transfer of wall washing residues

Performance parameters	Optimum operating envelope for W-3	Optimum operating envelope for W-4
Jet pump operating time	1265 minutes for sludge transfer 277 minutes for wall washing water transfer	5615 minutes for sludge transfer 689 minutes for wall washing water
Jet pump motive fluid rate	9.5 to 10.5 gal per minute	9.5 to 10.5 gal per minute
Jet pump motive fluid pressure	6000 to 7100 psi	6000 to 7100 psi
Sludge retrieval rate (daily)	458 gal per day of actual sludge transfer operations	950 gal per day of actual sludge transfer operations
Sludge retrieval rate (instantaneous)	4.35 gal of sludge per minute of jet pump operating time	3.4 gal of sludge per minute of jet pump operating time
Average slurry pumping ratio, including all water added	37.4 gal per minute of jet pump operating time	17.7 gal per minute of jet pump operating time
Ratio water added for sluicing	4.44 gal of water per gallon of sludge retrieved	3.98 gal of water per gallon of sludge retrieved
Ratio water added at CSEE for sludge retrieval	0.55 gal of water per gallon of sludge retrieved	1.15 gal of water per gallon of sludge retrieved
Flush water added	2853 gal 94 events using flush water; 30 gal average per event 114 gal per day of sluicing activities	2574 gal 92 gal per day of sluicing activities
Decontamination water used (not counting spray wands)	1239 gal 20 gal per operating day	2574 gal 36 gal per operating shift
	ROV – 10 to 32 gpm at 500 to 2000 psi – avg 137 seconds and 45 gal per event	**ROV** – 9 to 30 gpm at 210 to 2410 psi – avg 157 seconds and 47 gal per event
	MLDUA – 11 to 17 gpm at 200 to 500 psi – avg 58 seconds and 272 gal	**MLDUA** – 10 to 19 gpm at 200 to 640 psi – avg 145 seconds and 32 gal
	HMS – 13 to 26 gpm at 1000 to 2000 psi – avg 122 seconds and 35 gal per event	**HMS** – 7 to 27 gpm at 230 to 2000 psi – avg 236 seconds and 61 gal per event

11.1 WATER USAGE

Figures 11-1 and 11-2 present the water usage for each operation for each tank, W-3 and W-4. The majority of the water used in each tank was for sludge transfer operations, followed by the water used for wall cleaning, flush water, and then decontamination water. Decontamination water used for each tank was less than 3% of the total water used in tank operations. Decontamination water averaged 20 gal per operating day in W-3, and 36 gal per operating day in W-4. The decontamination water required in STF tanks may increase because of the increased level of radioactive contamination and because the equipment is getting older.

Flush water used in W-3 averaged 123 gal per day of sluicing activity, and W-4 flush water averaged 130 gal per day. Figures 11-3 and 11-4 present the water usage per day of operations.

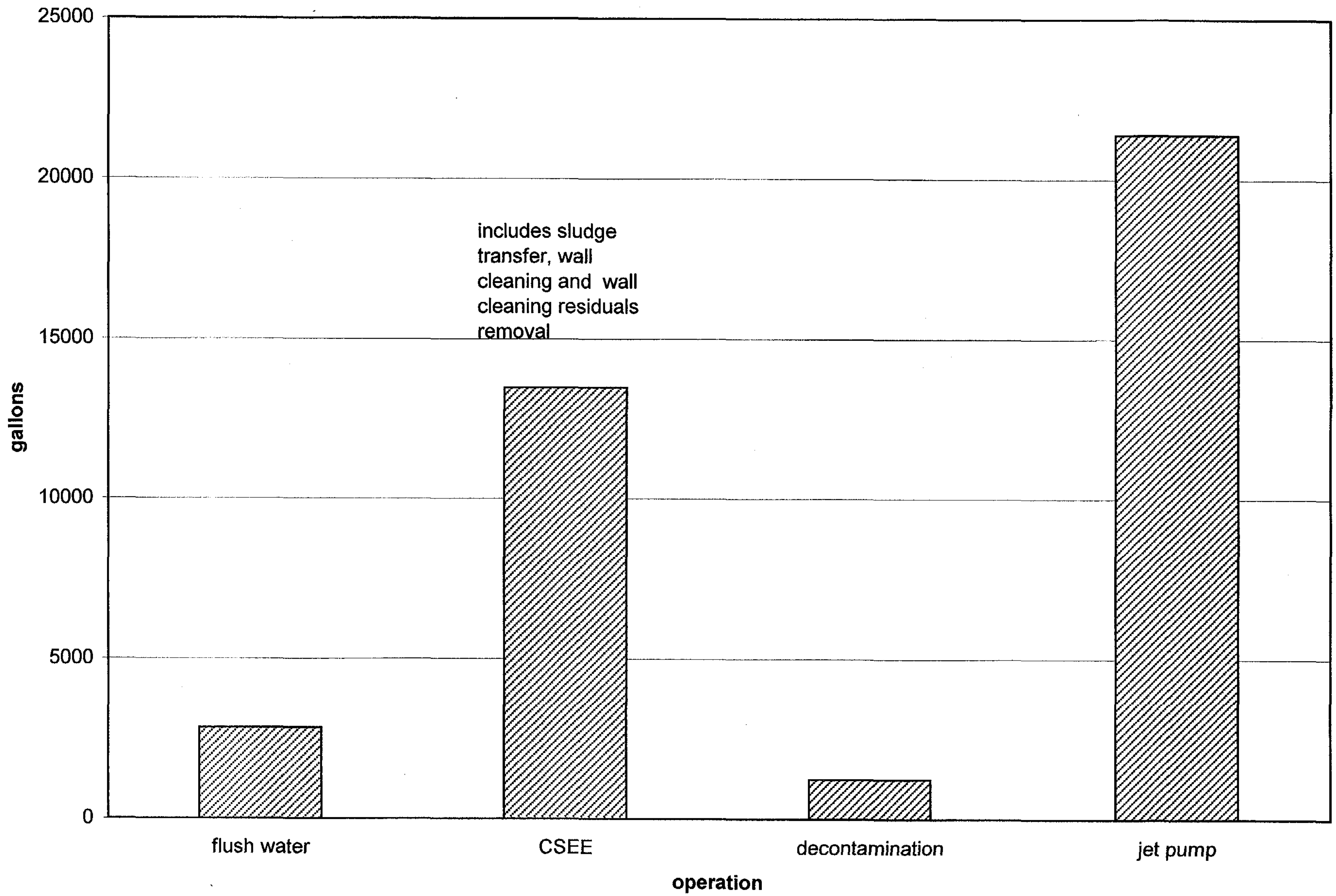


Fig. 11-1. W-3 water usage chart.

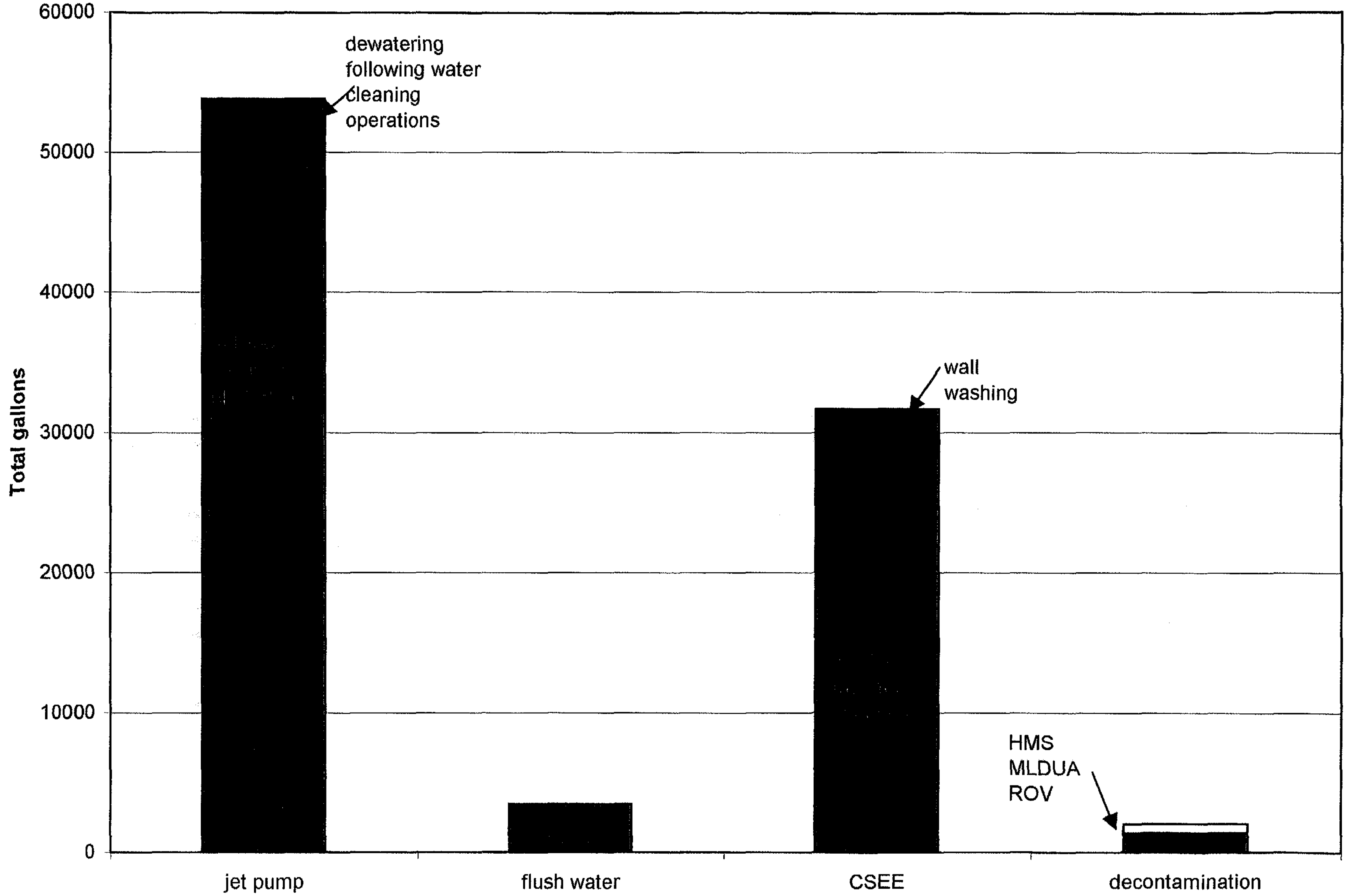


Fig. 11-2. W-4 water usage chart.

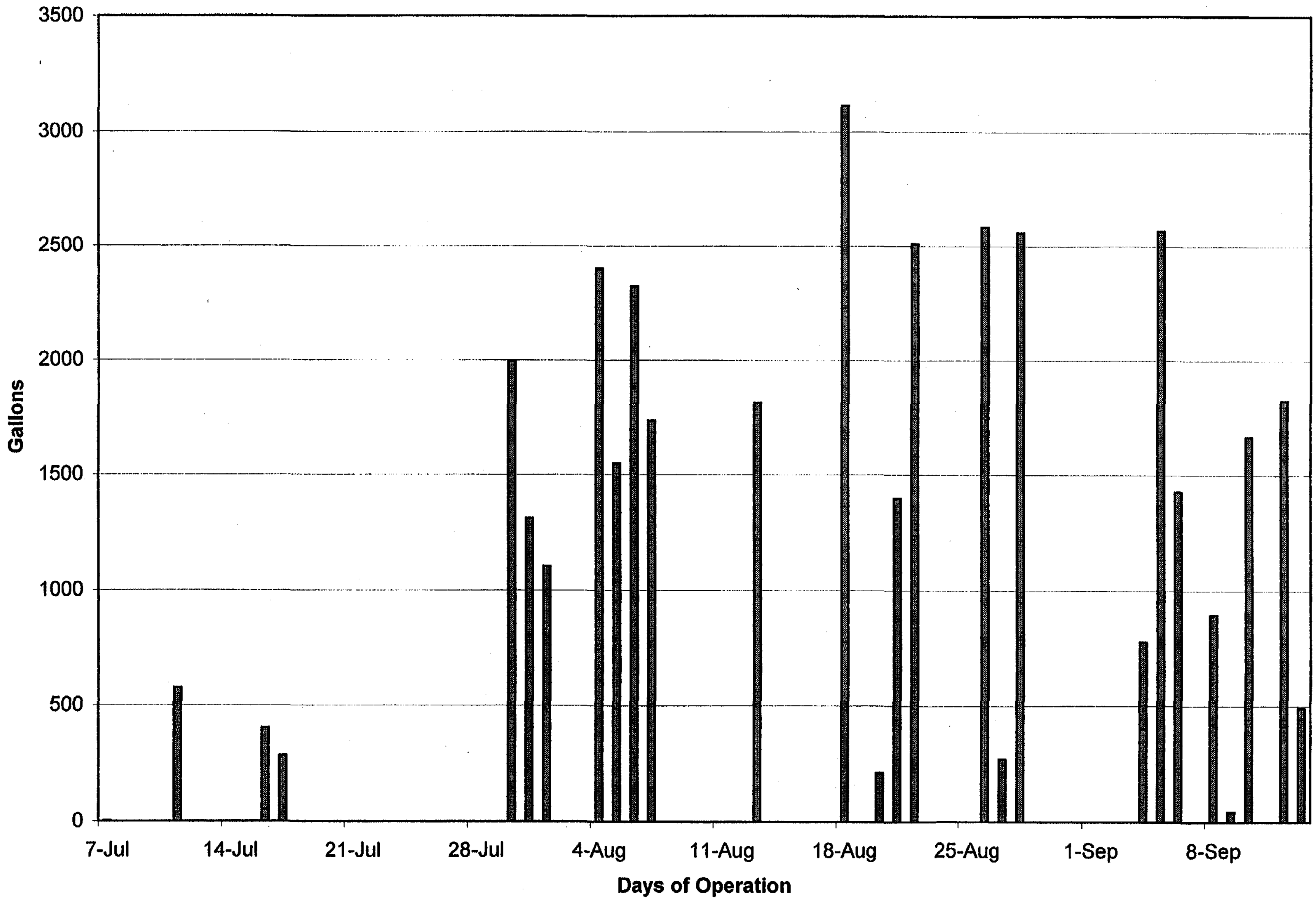


Fig. 11-3. Total water used in W-3 operations.

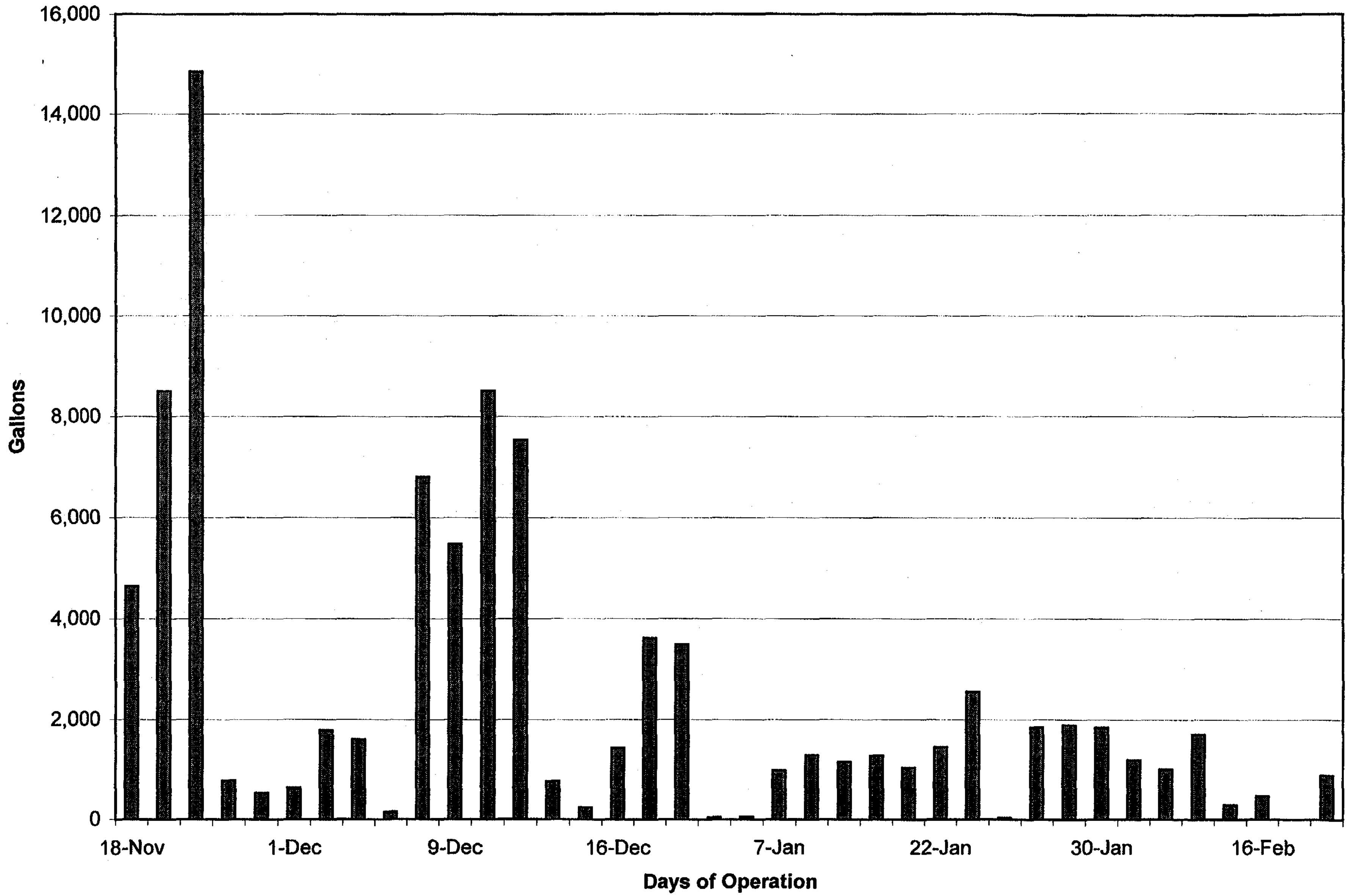


Fig. 11-4. Total water used in W-4 operations.

A learning curve is evident in water consumption during wall-cleaning activities from W-3 to W-4 operations. W-3 wall cleaning required 13,477 gal to clean 707 ft^2. W-4 wall cleaning required 10,618 gal for the same wall area. The number of wall-cleaning intervals, or shifts used to clean the tank walls, remained relatively constant at 17 intervals for W-3 and 16 intervals for W-4. However, the length of these intervals was evidently longer for W-4 operations since W-4 wall cleaning required 34.9 hours of CSEE high-pressure water pump operating time and W-3 wall cleaning required 28.1 hours. The time that the MLDUA held the CSEE specifically for wall-cleaning activities was considerably longer for W-4 operations, (148 hours) than for W-3 operations (76 hours).

Figure 11-5 presents the ratio of water used to sludge transferred. For W-4 operations, this can be evaluated in two different ways:

Tank W-4 contained an initial estimated volume of 13,500 gal of sludge. During W-3 operations, an additional 5,500 gal of sludge were transferred to W-4, for a final sludge volume of 19,000 gal. The sludge transferred from W-3 was a diluted stream when delivered to W-4 and was deposited on top of the initial W-4 sludge. In W-4 sludge transfer operations, the sludge layer from W-3 was found to be much easier to transfer from W-4 to W-9, probably because of being mobilized and diluted in W-3 operations. In tank W-4, underneath the W-3 sludge, the initial W-4 sludge was found to be much more compact than any other sludge encountered. The ratio of the water required to transfer this more dense sludge was greater than the ratio of the water required to transfer the W-3 sludge.

In evaluating the water required to transfer W-4 sludge, we can evaluate the ratio of 92,337 gal to the initial 13,500 gal in W-4 (6.8 gal of water added per gallons of sludge transferred), or the ratio of water added to the combined 19,000 gal (4.9 gal of water added per gallons of sludge transferred) (see Fig.11-5).

Using the maximum ratios of water required to perform the various operations,—sluicing, wall cleaning, decontamination and flushing,—the estimated maximum water usage for STF operations is shown in Figure 11-6 and Table 11-2.

11.2 RESIDUAL INVENTORY

Each tank, W-3 and W-4, has an estimated 0.50 in. of sludge (100 gal) remaining in the tank, most likely diluted by all the final tank-washing operations. Even if this sludge were not diluted, it is estimated to contain, at the most, 6 Ci in each tank.

Wall-washing operations with the CSEE are believed to have removed only the aluminum hydroxide scale that had built up on the walls. This scale has a density similar to the Gunite, and is estimated to have contained 7.3 Ci in tank W-3 and 3.7 Ci in tank W-4. It is believed that most of this scale (but not a significant part of the Gunite) was successfully removed in the wall-washing operations.

The core samples collected for each tank indicate that wall washing was not successful in removing much of the Gunite material. The tank walls are estimated to contain 6.4 Ci in tank W-3 and 4.2 Ci in tank W-4. More than 80% of the W-3 wall inventory was found in the first 0.13 in. of the tank wall, and more than 95% of the W-4 wall inventory was found in the first 0.063 in. of the tank wall.

11.3 PERFORMANCE ESTIMATE

Table 11-2 presents the estimated performance of the waste retrieval system for each tank and for the overall NTF operations.

Note: "W-3 and W-4" portrays the water used to transfer the combined sludge from both tanks.

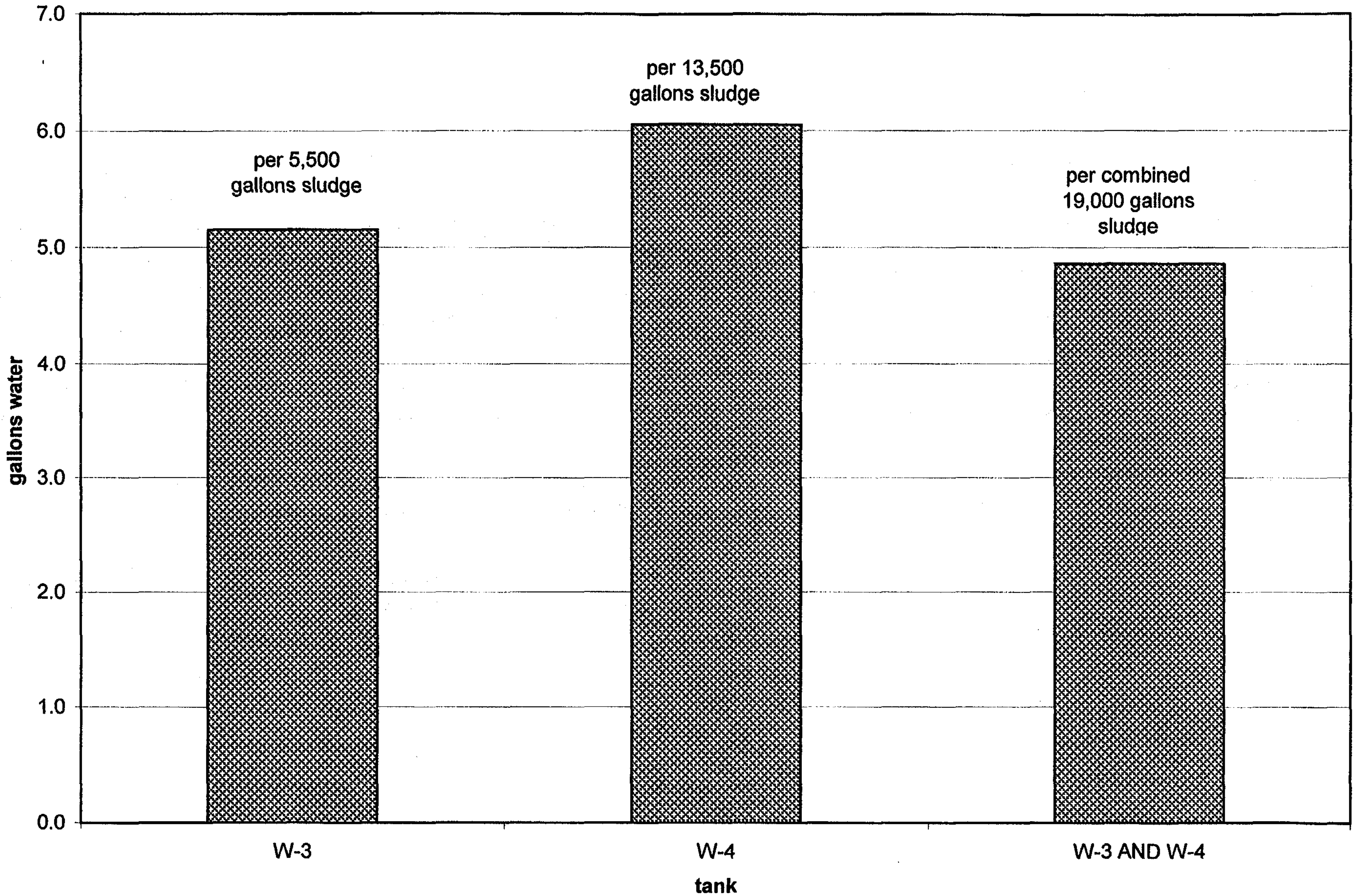


Fig. 11-5. Ratio of gallons water used per gallons sludge transferred.

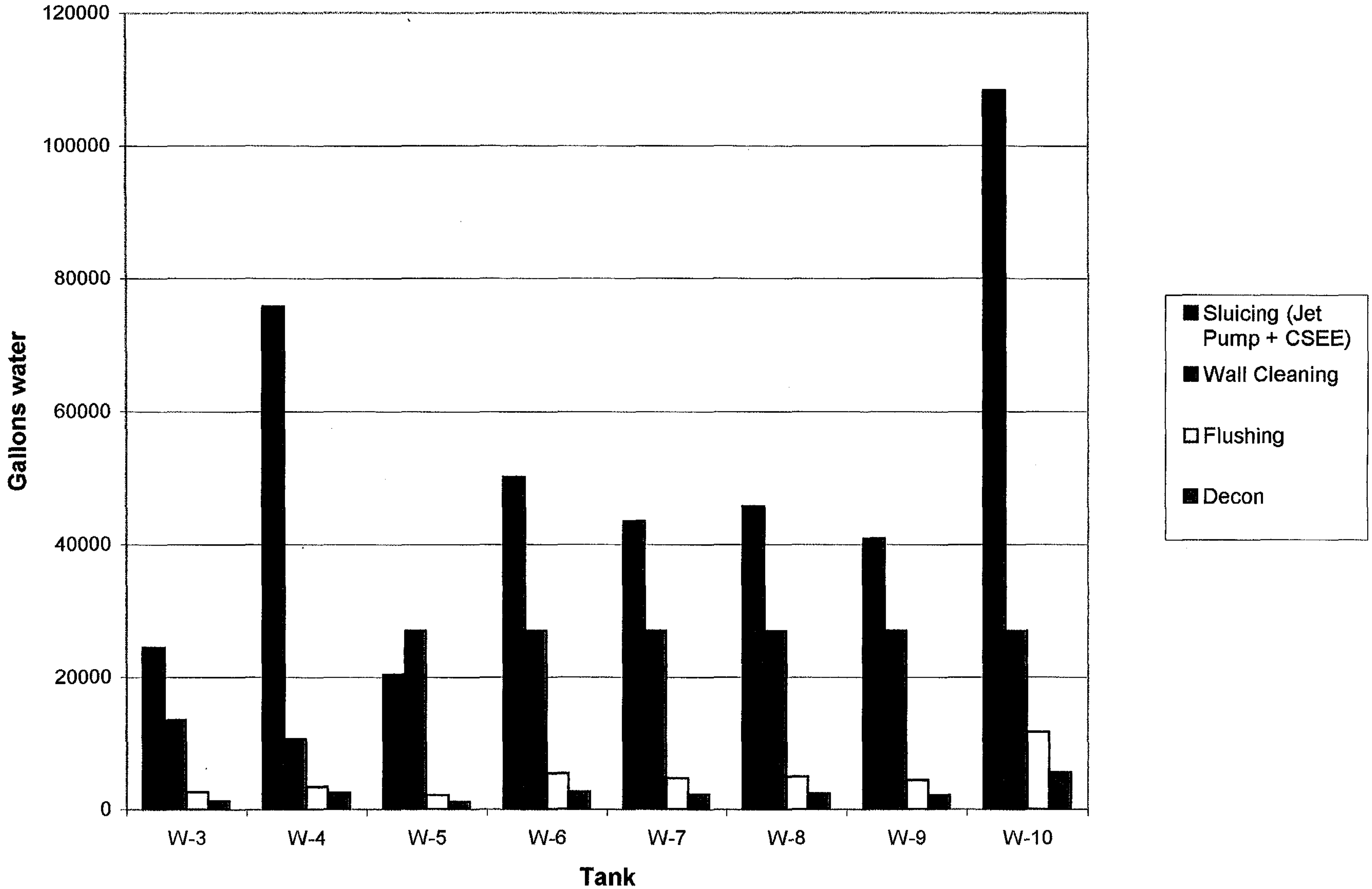


Fig. 11-6. Estimated maximum water usage for STF.

Table 11-2. Performance estimate

Parameter	W-3	W-4	Overall NTF
Initial inventory	340 Ci (5500 gal) in sludge 7.3 Ci in scale on wall 6.4 Ci in wall 353.7 Ci total	916 Ci (13,500 gal) in sludge 328 Ci from W-3 sludge and scale 3.7 Ci in scale on wall 4.2 Ci in wall 1251.9 Ci	916 + 340 = 1256 Ci 11 Ci in scale 10.6 Ci in wall 1277.6 Ci total
Residual inventory	5.9 Ci (100 gal) in sludge 6.4 Ci in wall 12.3 Ci total	6.7 Ci (100 gal) in sludge 4.2 Ci in wall 10.9 Ci total	12.6 Ci in sludge 10.6 Ci in wall 22.6 Ci total
Performance	12.3 / 353.7 = 3.5% residual, or 96.5% cleaning efficiency	10.9/1251.9 0.87% residual, or 99.13% cleaning efficiency	22.6/1277.6 1.7% residual, or 98.3% cleaning efficiency

11.4 CONCLUSIONS

The testing performed in the NTF verified that the waste retrieval equipment will be effective in removing waste from the larger STF tanks.

The phased approach used in the development and testing of the equipment, first as components, then as an integrated system in a cold test environment, and finally in a radioactive environment, has culminated in the following to provide a safe and effective waste retrieval system for the STF remedial action:

- a waste retrieval system design that is expected to be successful in waste retrieval operations in the STF,
- establishment of safe and effective operating parameters for the equipment,
- establishment of clear, concise procedures and practices,
  training of operators, and
- definition of preventive maintenance requirements for the equipment.

11.4.1 Equipment operation

The MLDUA and the ROV operated well individually and as a team in most activities. The MLDUA was used most successfully in wall-cleaning operations, mining hard heel waste in the tanks, and in holding the CSEE while the ROV pushed sludge in its direction. The ROV operated most effectively in pushing sludge to the MLDUA and CSEE, performing floor-cleaning operations, removing debris, and in deployment of coring and shearing tools. The HMS also was successful in most of its operations, being unavailable for operation only 1 day out of 54.

The main piece of equipment that can benefit by modification is the CSEE. This modification has been pursued in the design and testing of the GSEE. The GSEE was tested in tank W-4 but only with the existing high-pressure pumps at a maximum pressure of 7,000 psi. If wall-cleaning activities are to be performed, the GSEE will be required to operate at pressures higher than 7,000 psi to achieve better wall-cleaning results than the CSEE. To achieve scarification of the Gunite walls, a much higher pressure will be required. An ultrahigh-pressure pump (35,000 psi) is currently being evaluated to achieve better wall-cleaning results.

11.4.2 Tank Characterization

If tank characterization can be performed without intrusive techniques, and without requiring laboratory analysis, a large cost savings can be realized. Unfortunately, the data from the CEE was inconclusive in characterizing both tanks W-3 and W-4. The most successful tank characterization technology used was the coring tool, followed by laboratory analysis of the core samples. Although the coring tool was successful in retrieving core samples from the tank walls, many samples were dropped and were not retrieved successfully. This technology will require further design and modification to reduce the time required to collect viable core samples.

REFERENCES

[1] C. S. Hanskat, *Preliminary Report, Gunite and Associated Tanks Operable Unit (GAAT) Evaluation of Dome and Wall Strength Under Current Loading,* May 1995.

[2] M. A. Johnson, *Draft Sludge Volume Estimates for GAAT Tanks W-3 through W-10,* October 1997.

[3] MACTEC, *Evaluation of Phase I and Phase II Sampling and Analysis Data for the Gunite and Associated Tanks at Oak Ridge National Laboratory, Oak Ridge, Tennessee*, ORNL/ER-365, Lockheed Martin Energy Research Corporation, Oak Ridge National Laboratory, March 1996.

[4] D. D. Falter and B. L. Burks, *Houdini Remotely Operated Vehicle System Performance Assessment for Tank W-3 Waste Removal Operations,* ORNL/M-6535, TPG-0398-01, April 1998.

[5] B. L. Burks, R. L. Glassell, and W. Glover. *Draft Performance Assessment for Operation of Modified Light Duty Utility Arm in Oak Ridge National Laboratory Tank W-3,* October 1997.

[6] S. M. Killough, *The Characterization End Effector and its Findings in the North Tank Farm.* March 1998

[7] D. D. Falter, *Performance Assessment for Remotely Operated Vehicle in Tank W-4 at Oak Ridge National Laboratory.* May 1998.

[8] J. Blank, *Draft HMS Tank W-4 Report.* May 1998

APPENDIX A

CORE SAMPLE DATA

Figure A-1
Core Sample W-3003
Location: 240 degrees, 6 feet off floor in cleaned area

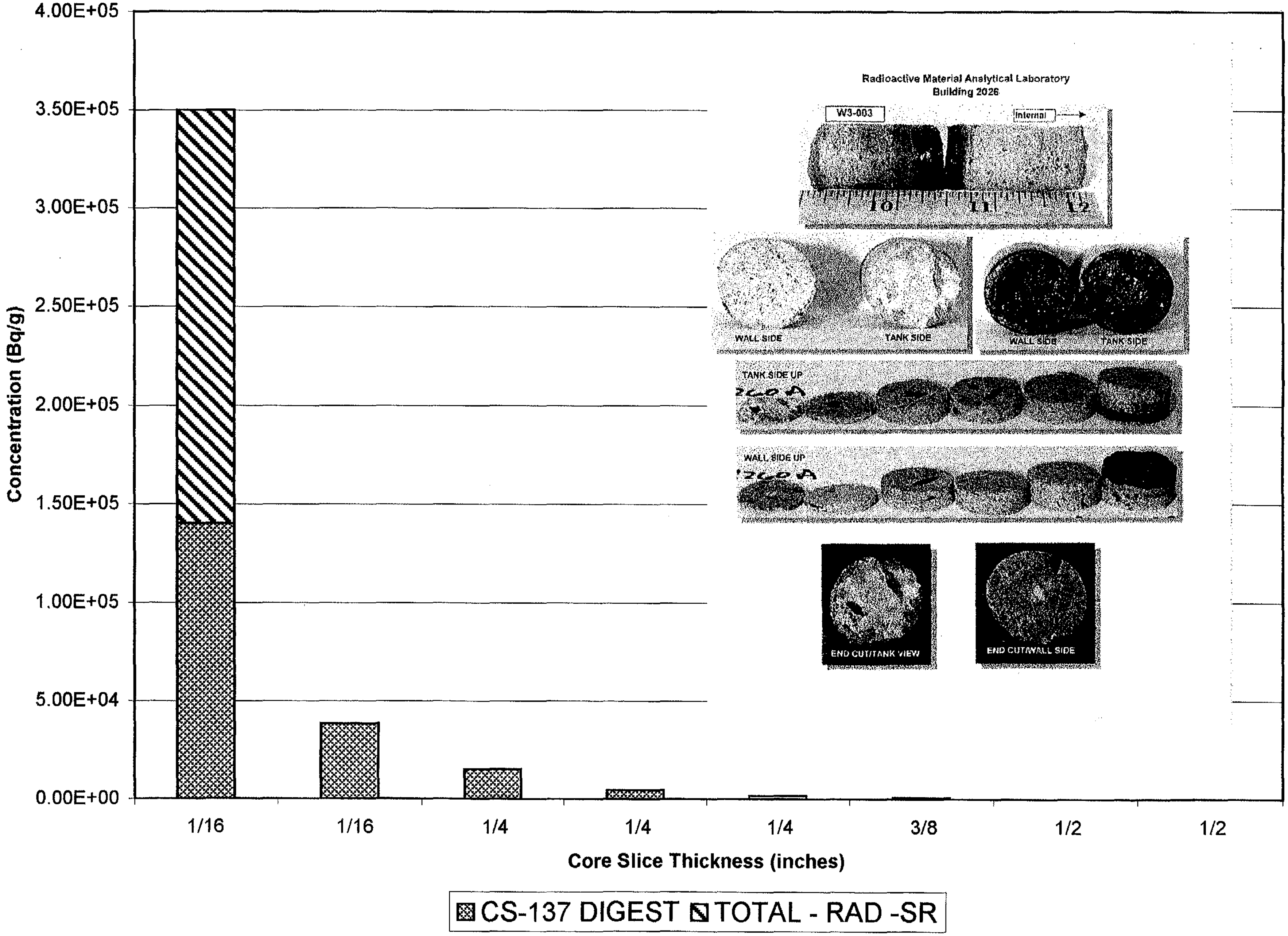
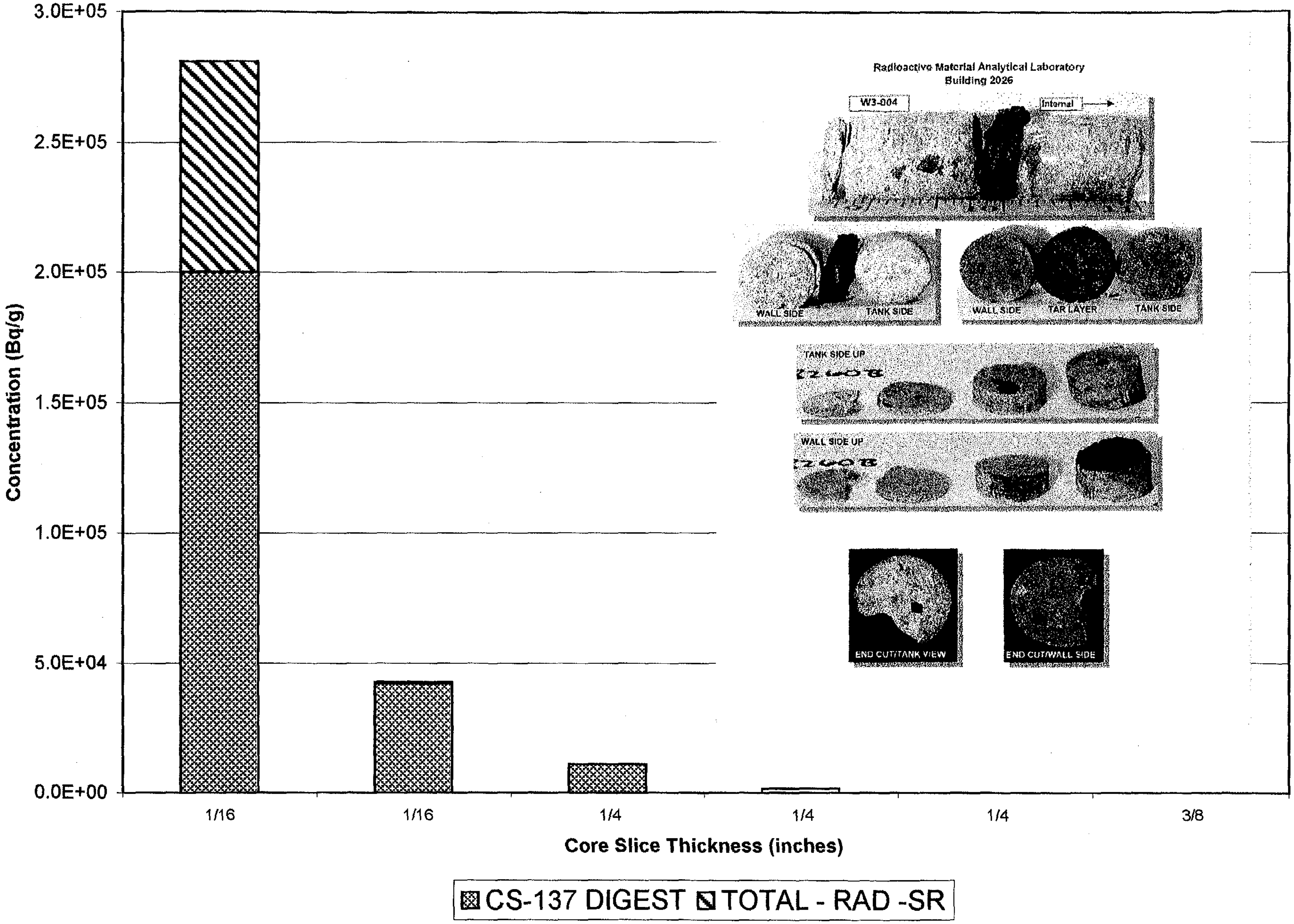


Figure A-2

Core Sample W-3004

Location: 300 degrees, 3 feet off floor



This sample was a loose piece from the wall, collected below an area that was cleaned at 3000 psi

Figure A-3
Core Sample W-3005
Location: 1 1/2" to left of 240 degrees, 4 feet off floor at uncleaned area nest to Core Sample W-3003

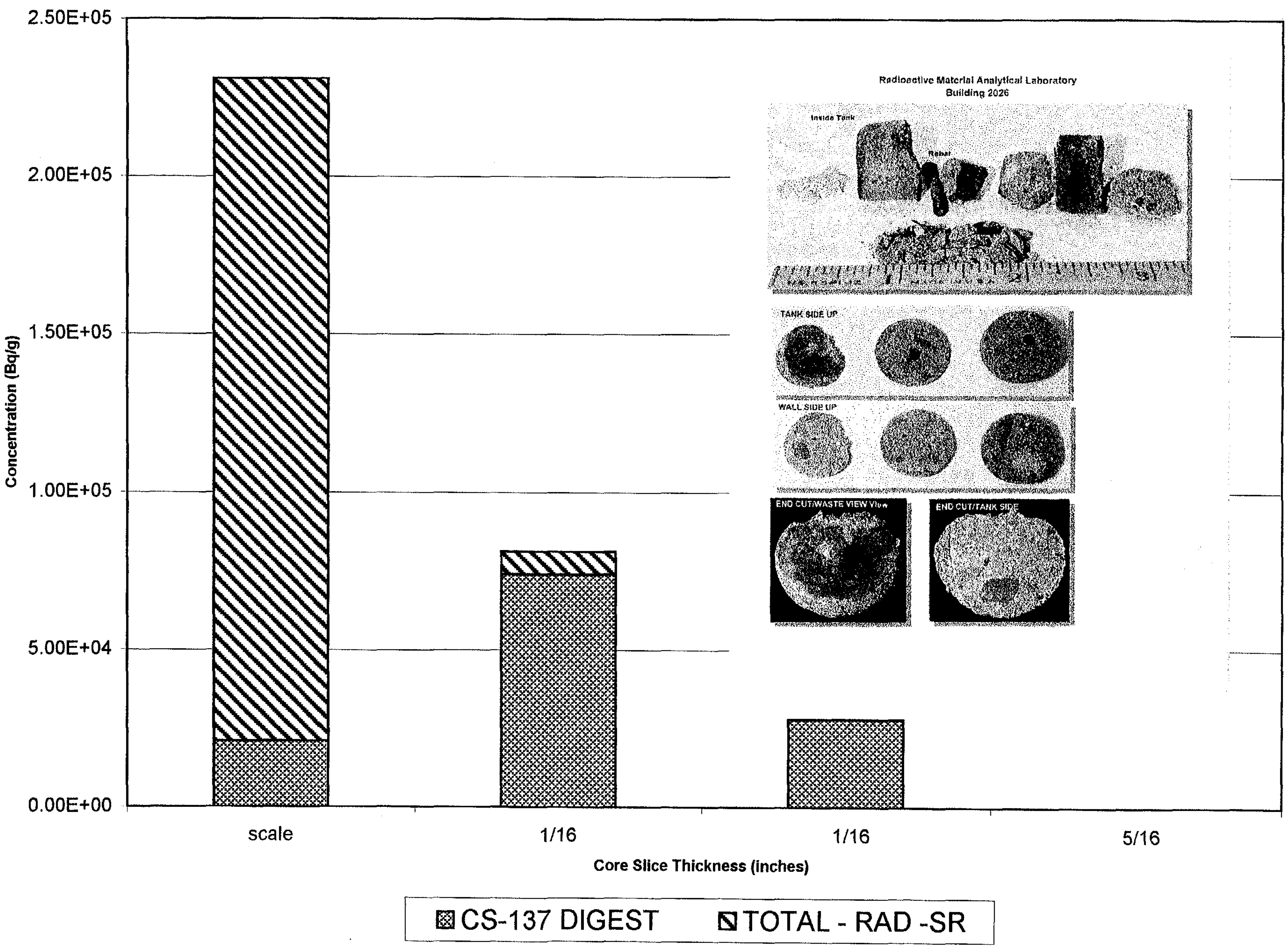
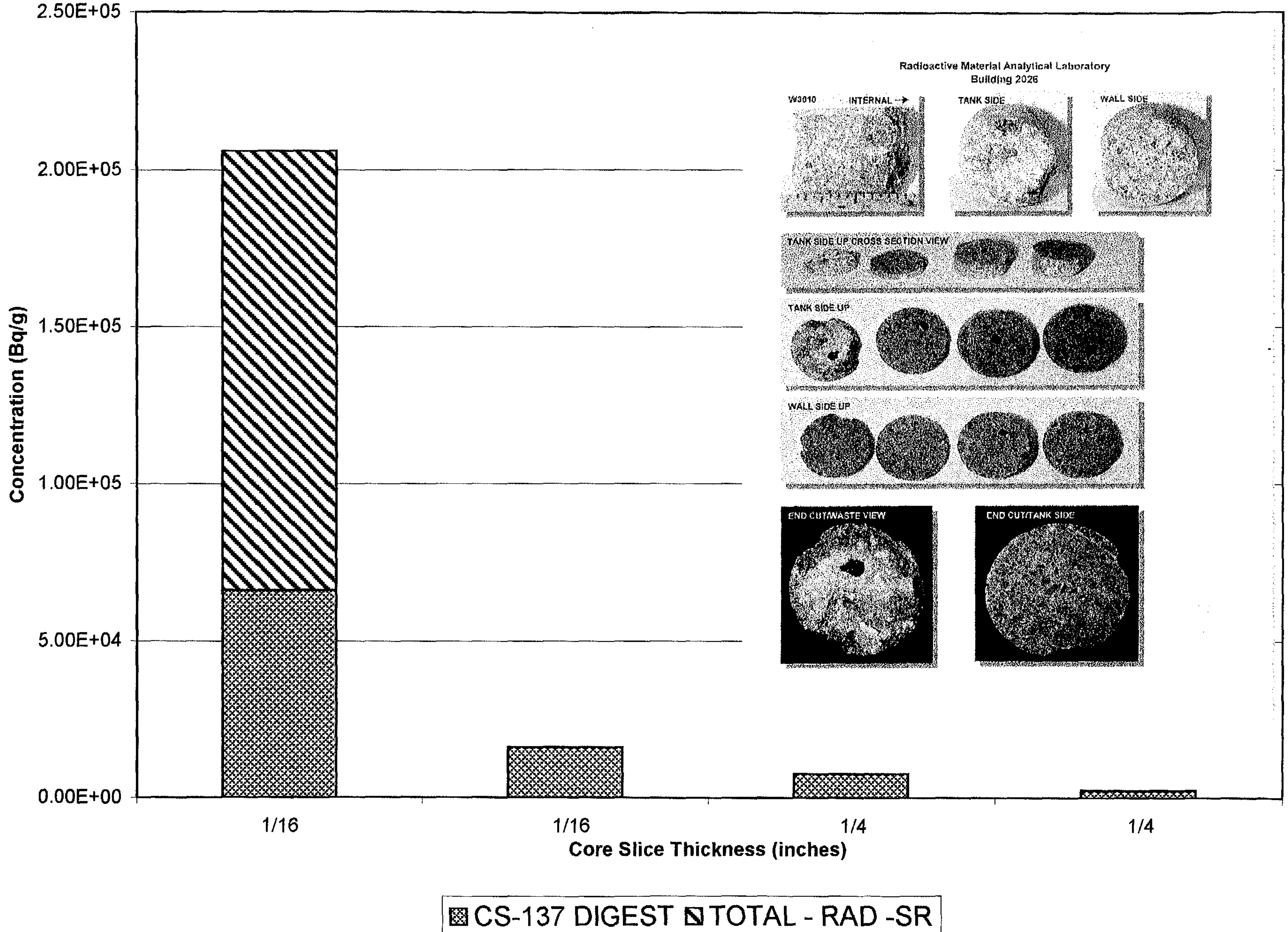


Figure A-4
Core Sample W-3010
Location: 300 degrees, 6 feet off floor in cleaned area



Core sample from cleaned area of wall

Figure A-5
Core Sample W-3012
Location: 135 degrees, 1 foot off floor

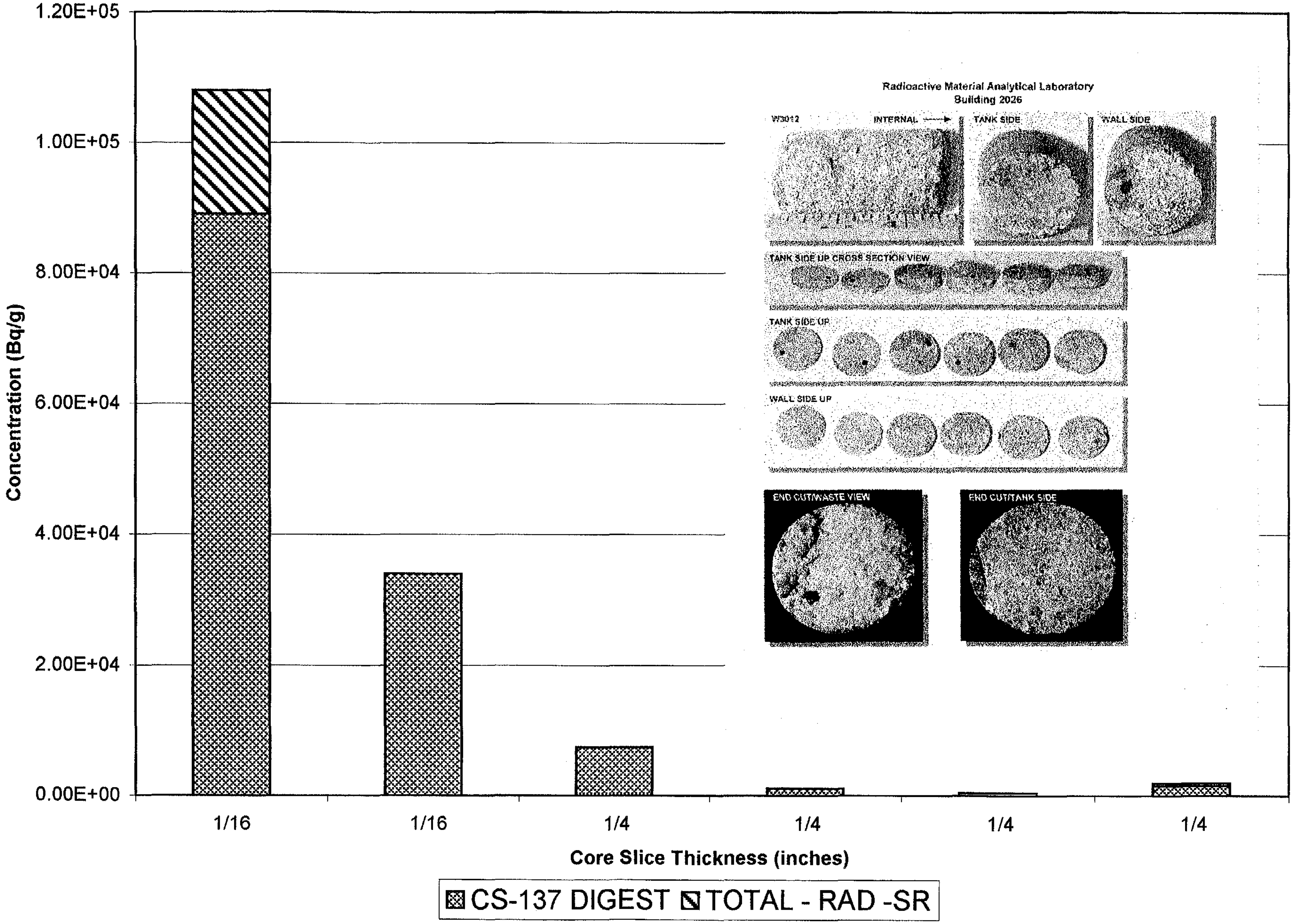


Figure A-6
Core Sample W-3014
Location: 230 degrees, 6 feet off floor in cleaned area

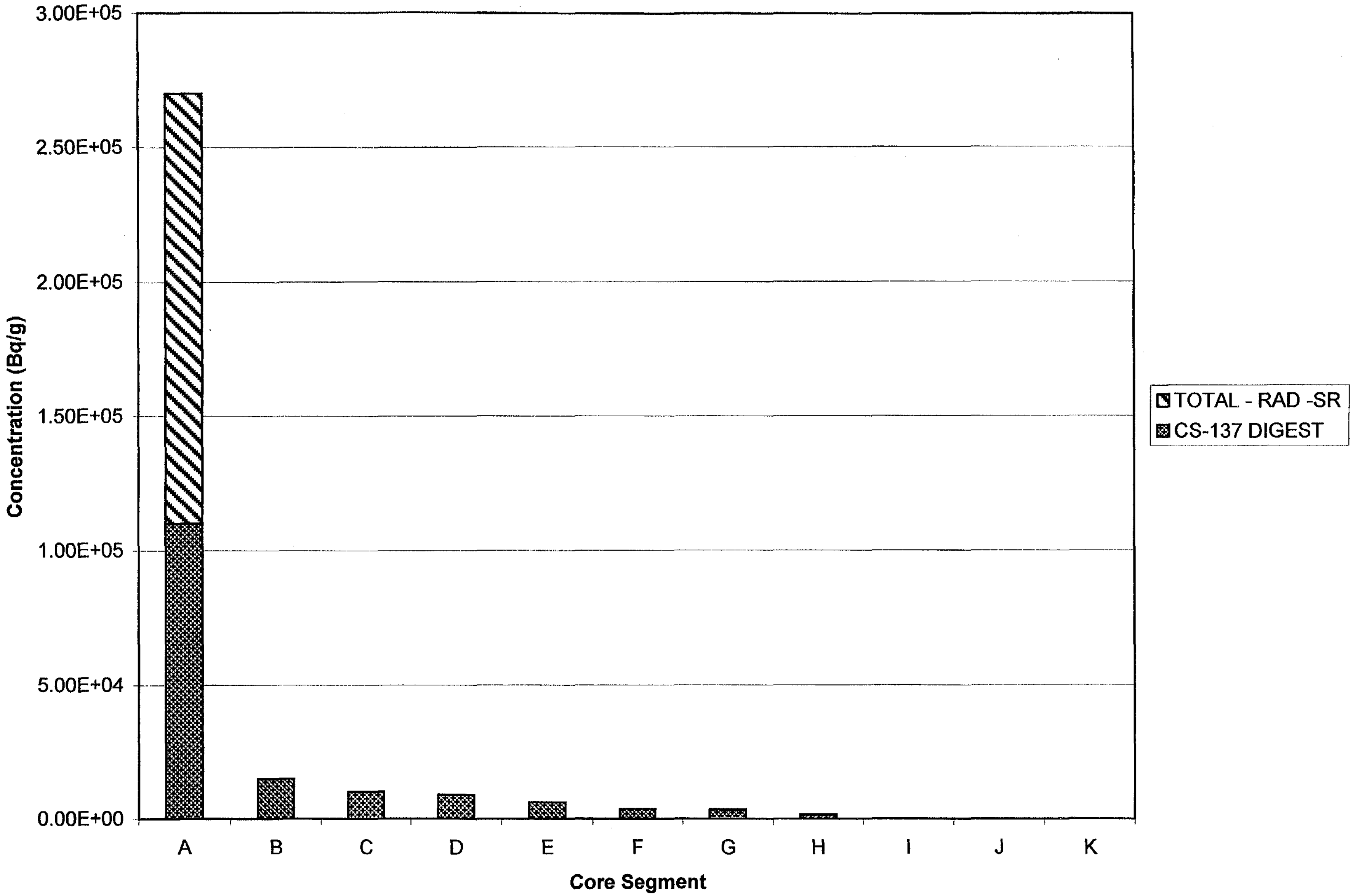


Figure A-7
Core Sample W-3015
Location: 290 degrees, 4 feet off floor in cleaned area

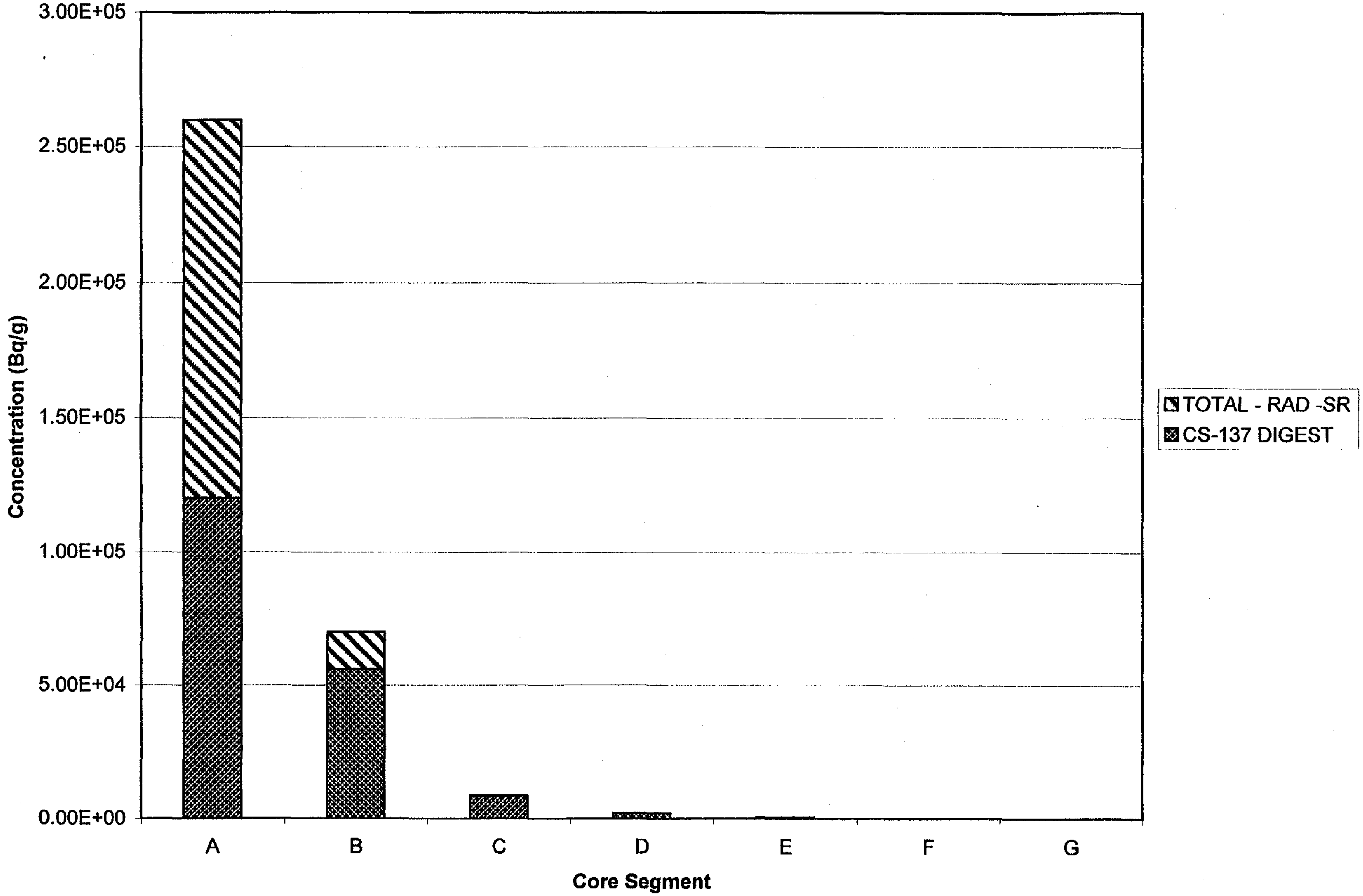


Figure A-8
Core Sample W-3016
Location: 290 degrees at wall haunch area

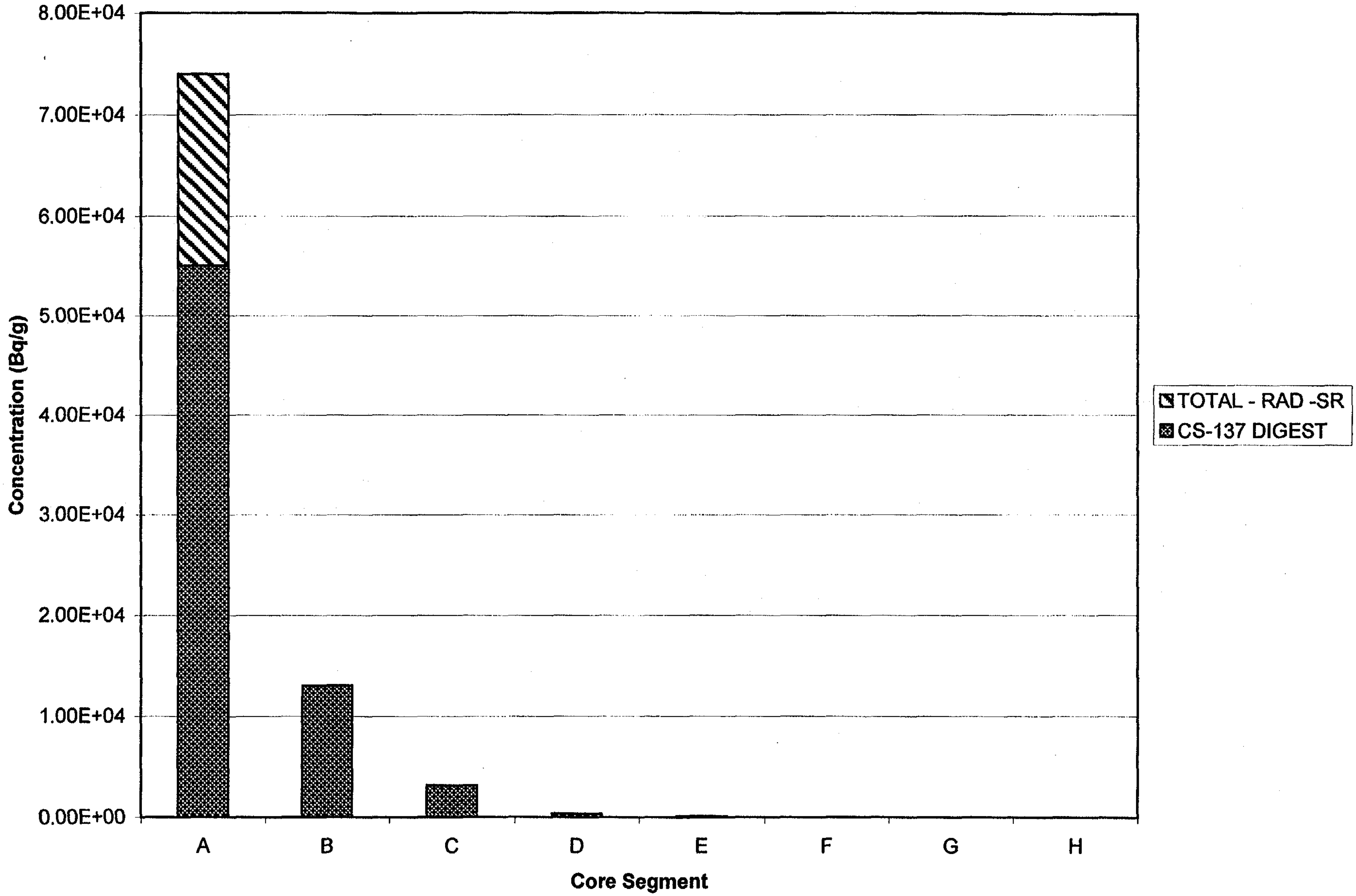


Figure A-9
Core Sample W-3018
Location: 120 degrees, 6 feet off floor in uncleaned area

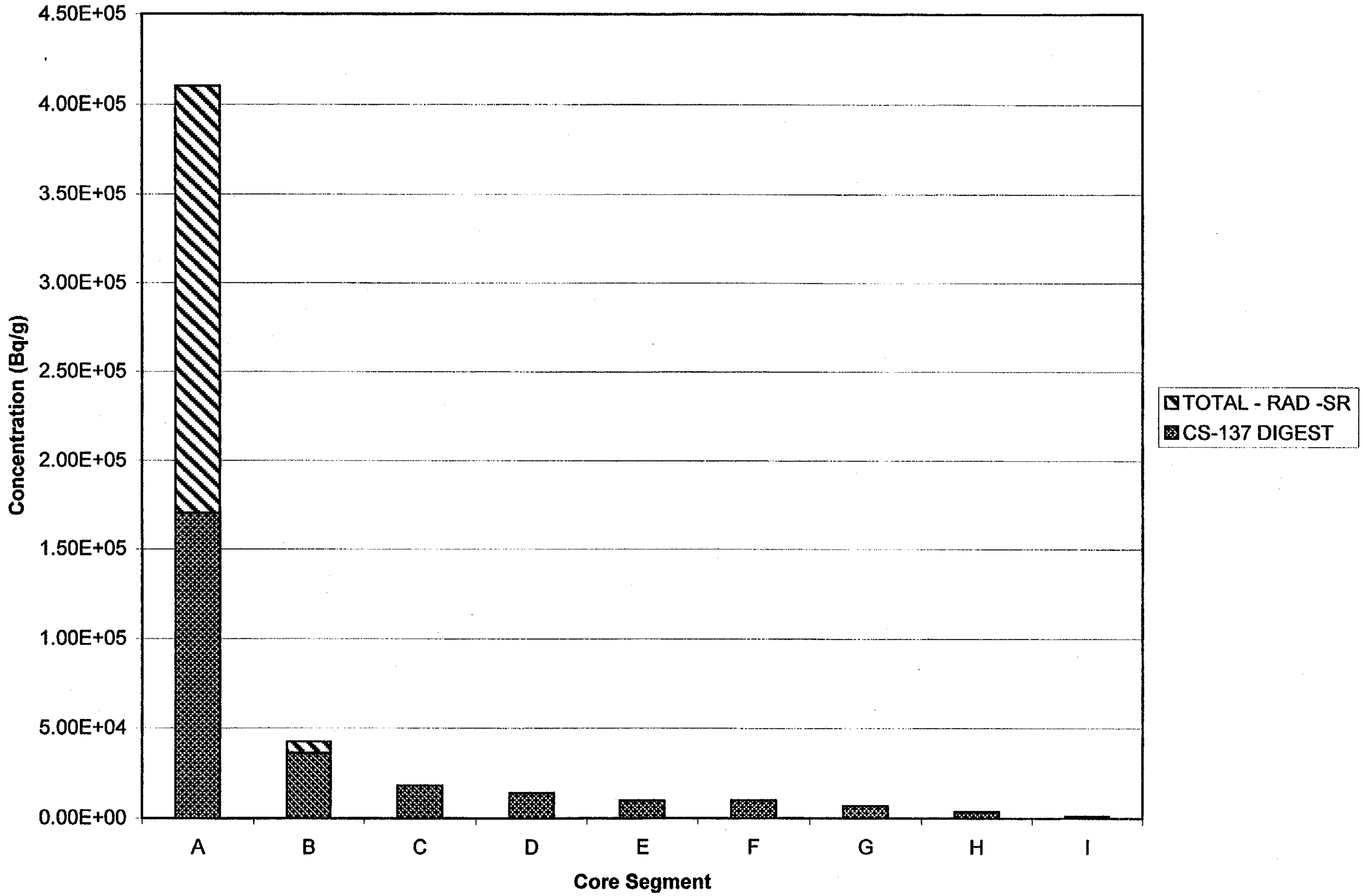


Figure A-10
Core Sample W-3019

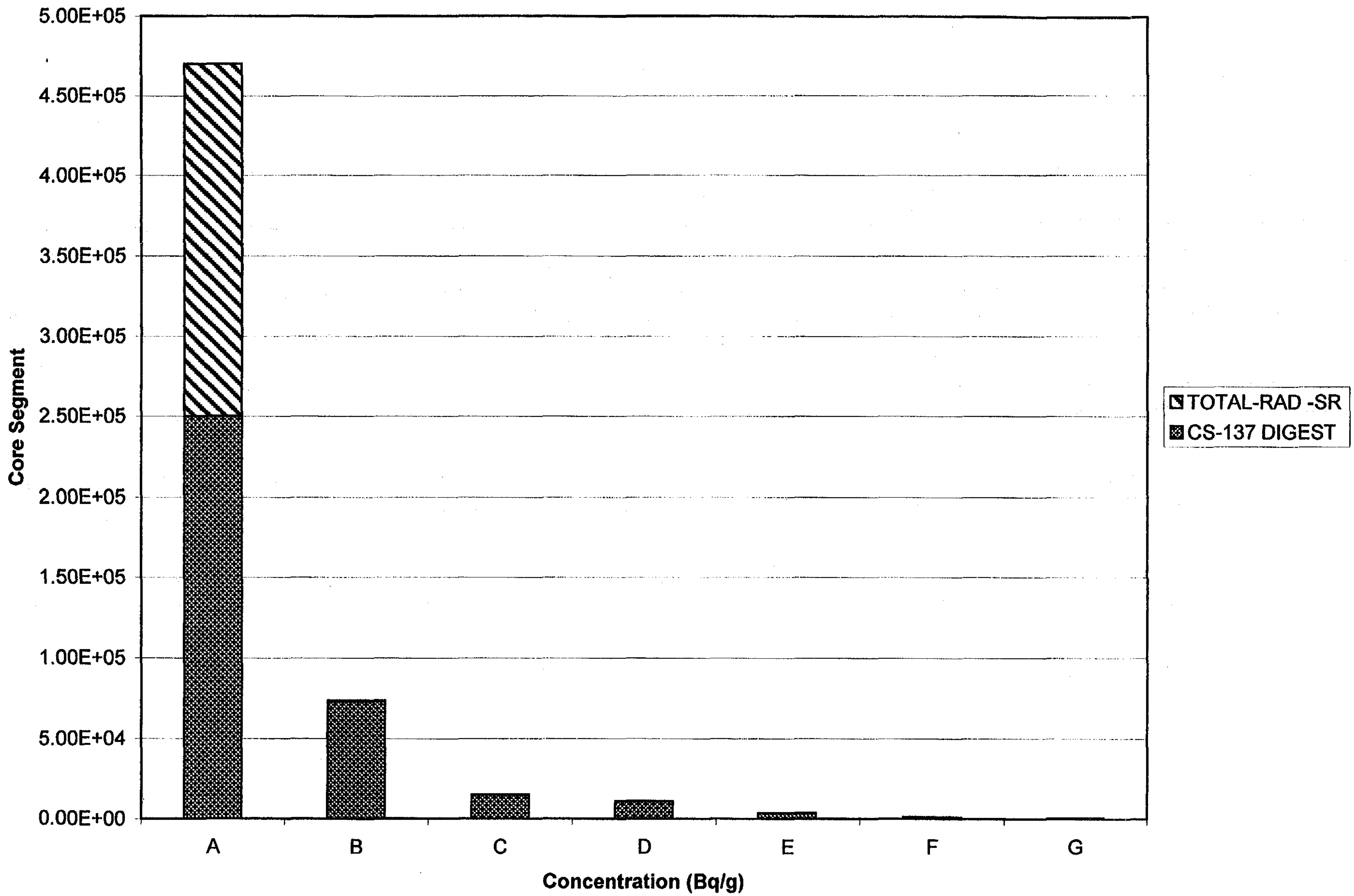
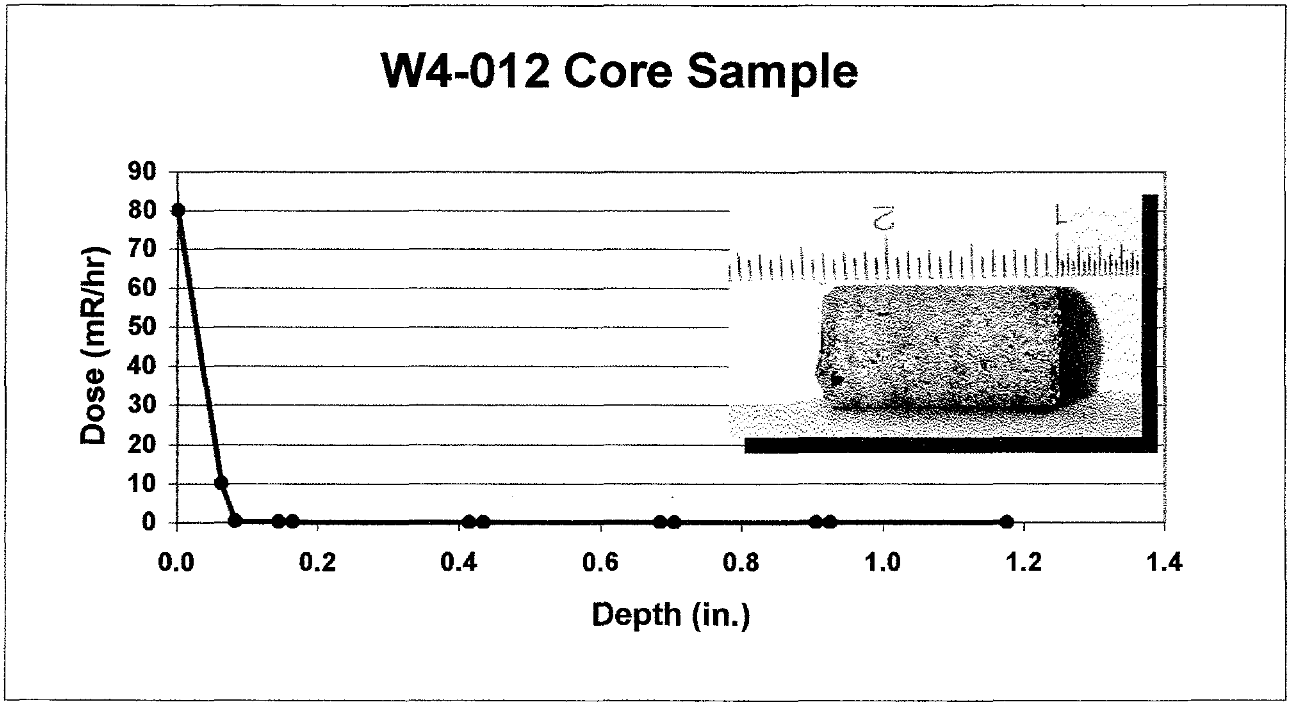


Figure A-11
Core Sample W4-012

W4-012 Core slices (cleaned area) **8668A**

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	β+γ (mR/hr)	β+γ (% dose)	β+γ (cpm)	β+γ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	0.8653	0.0000	17000	80.0	88.30%	1200000	87.86%	4.0	4.42%
A-2		0.0625		10.0	11.04%	150000	10.98%	0.4	0.39%
B-1	1.5714	0.0825	3700	0.4	0.44%	9000	0.66%	0.0	0.00%
B-2		0.1450		0.1	0.11%	2900	0.21%	0.0	0.00%
C-1	4.0891	0.1650	620	0.1	0.11%	1800	0.13%	0.0	0.00%
C-2		0.4150		0.0	0.00%	500	0.04%	0.0	0.00%
D-1	4.2112	0.4350	55	0.0	0.00%	310	0.02%	0.0	0.00%
D-2		0.6850		0.0	0.00%	150	0.01%	0.0	0.00%
E-1	4.2357	0.7050	11	0.0	0.00%	270	0.02%	0.0	0.00%
E-2		0.9050		0.0	0.00%	320	0.02%	0.0	0.00%
F-1	4.6828	0.9250	2	0.0	0.00%	260	0.02%	0.0	0.00%
F-2		1.1750		0.0	0.00%	350	0.03%	0.0	0.00%
				90.6	100.00%	1365860	100.00%	4.4	4.80%

Note: The cpm data on slice (A-1) for the β+γ measurement were calculated due to off-scale readings.



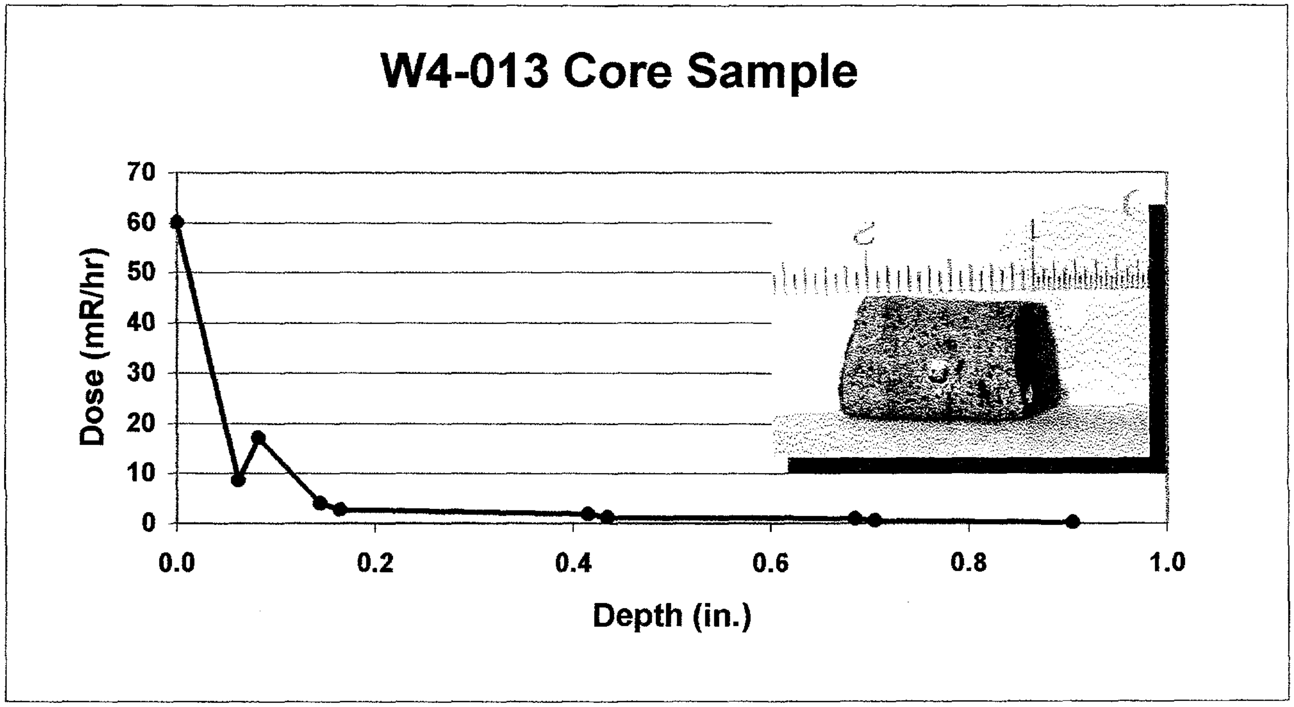
Ref: J. Keller, Data from Radioactive Materials Laboratory

Figure A-12
Core Sample W4-013

Dose Data for W4-013 Core slices (cleaned area) 8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	0.9821	0.0000	34000	60.0	62.14%	847059	61.16%	3.4	3.52%
A-2		0.0625		8.5	8.80%	120000	8.66%	0.4	0.36%
B-1	1.2166	0.0825	32000	17.0	17.61%	250000	18.05%	0.8	0.83%
B-2		0.1450		3.9	4.04%	65000	4.69%	0.3	0.26%
C-1	4.3398	0.1650	11000	2.7	2.80%	42000	3.03%	0.3	0.26%
C-2		0.4150		1.8	1.86%	20000	1.44%	0.3	0.26%
D-1	4.0166	0.4350	5300	1.2	1.24%	18000	1.30%	0.1	0.10%
D-2		0.6850		0.9	0.88%	12000	0.87%	0.2	0.16%
E-1	4.8330	0.7050	2200	0.5	0.47%	8000	0.58%	0.0	0.00%
E-2		0.9050		0.2	0.16%	3000	0.22%	0.0	0.00%
				96.6	100.00%	1385059	100.00%	5.6	5.75%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



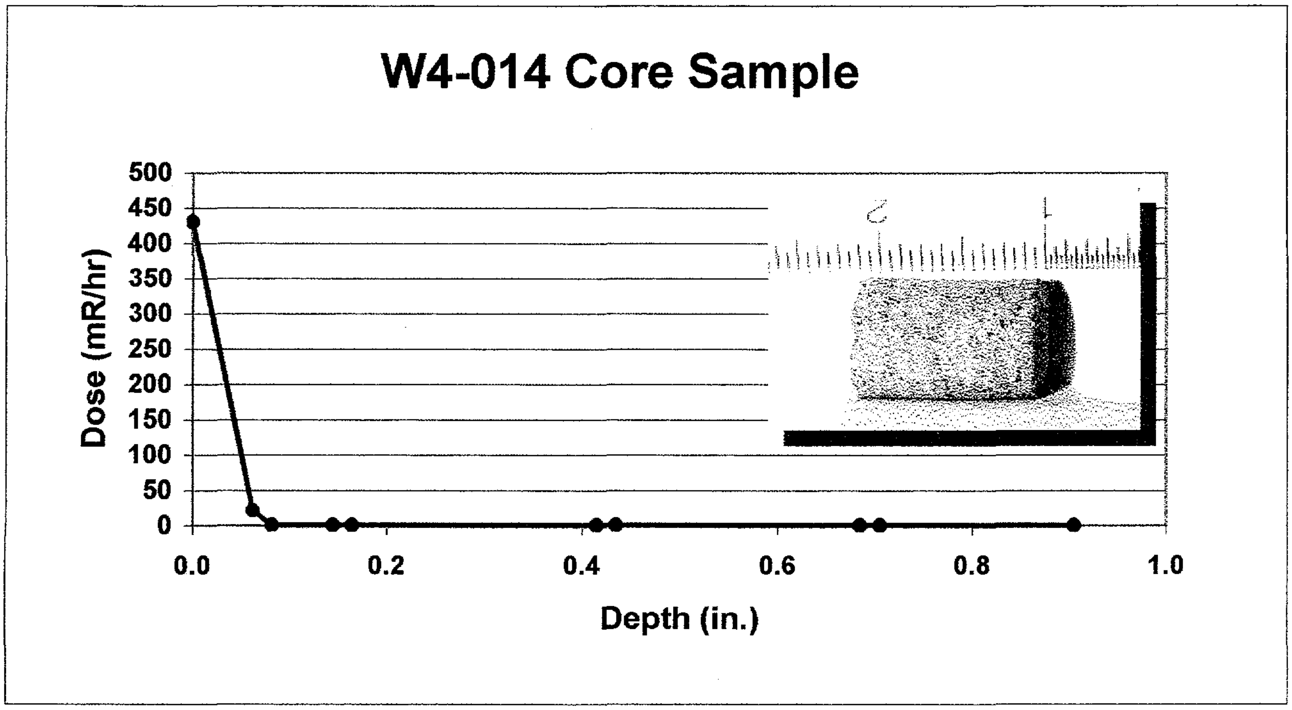
Ref: J. Keller, Data from Radioactive Materials Laboratory

Figure A-13
Core Sample W4-014

Dose Data for W4-014 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	β+γ (mR/hr)	β+γ (% dose)	β+γ (cpm)	β+γ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.4715	0.0000	33000	430.0	95.24%	5323810	95.10%	24.0	5.32%
A-2		0.0625		21.0	4.65%	260000	4.64%	0.7	0.16%
B-1	1.1983	0.0825	1800	0.3	0.06%	3500	0.06%	0.0	0.00%
B-2		0.1450		0.2	0.03%	2500	0.04%	0.0	0.00%
C-1	4.5469	0.1650	440	0.1	0.02%	2200	0.04%	0.0	0.00%
C-2		0.4150		0.0	0.00%	950	0.02%	0.0	0.00%
D-1	4.5138	0.4350	120	0.0	0.00%	1800	0.03%	0.0	0.00%
D-2		0.6850		0.0	0.00%	1100	0.02%	0.0	0.00%
E-1	4.6483	0.7050	47	0.0	0.00%	650	0.01%	0.0	0.00%
E-2		0.9050		0.0	0.00%	1400	0.03%	0.0	0.00%
				451.5	100.00%	5597910	100.00%	24.7	5.47%



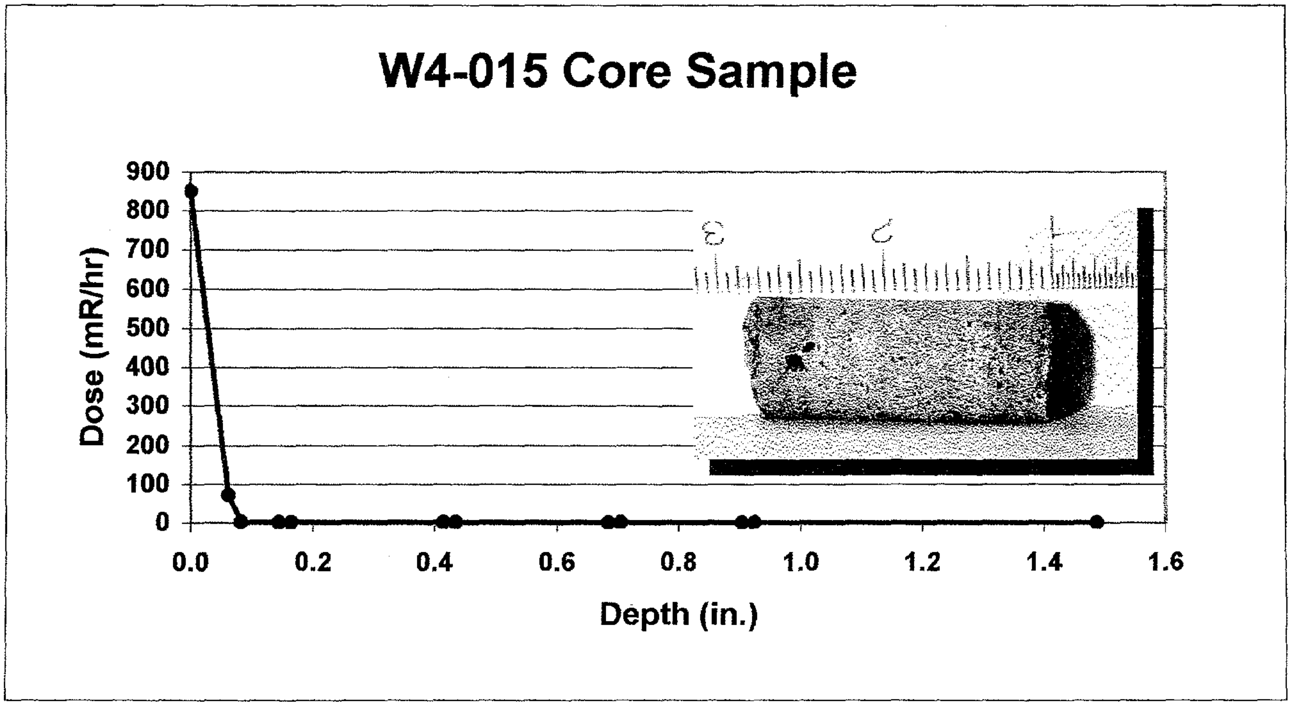
Ref: J. Keller, Data from Radioactive Materials Laboratory

Figure A-14
Core Sample W4-015

Dose Data for W4-015 Core slices (cleaned area) **8668A**

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	β+γ (mR/hr)	β+γ (% dose)	β+γ (cpm)	β+γ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.3160	0.0000	61000	850.0	92.25%	9350000	92.15%	47.0	5.10%
A-2		0.0625		70.0	7.60%	770000	7.59%	2.1	0.23%
B-1	1.7296	0.0825	5600	1.0	0.11%	11000	0.11%	0.0	0.00%
B-2		0.1450		0.3	0.03%	7000	0.07%	0.0	0.00%
C-1	4.3623	0.1650	440	0.1	0.01%	3100	0.03%	0.0	0.00%
C-2		0.4150		0.0	0.00%	850	0.01%	0.0	0.00%
D-1	4.2538	0.4350	51	0.0	0.00%	850	0.01%	0.0	0.00%
D-2		0.6850		0.0	0.00%	750	0.01%	0.0	0.00%
E-1	4.2435	0.7050	22	0.0	0.00%	750	0.01%	0.0	0.00%
E-2		0.9050		0.0	0.00%	500	0.00%	0.0	0.00%
F-1	9.5188	0.9250	6	0.0	0.00%	500	0.00%	0.0	0.00%
F-2		1.4875		0.0	0.00%	700	0.01%	0.0	0.00%
				921.4	100.00%	10146000	100.00%	49.1	5.33%

Note: The cpm data on slice (A-1) for the β+γ measurement were calculated due to off-scale readings.



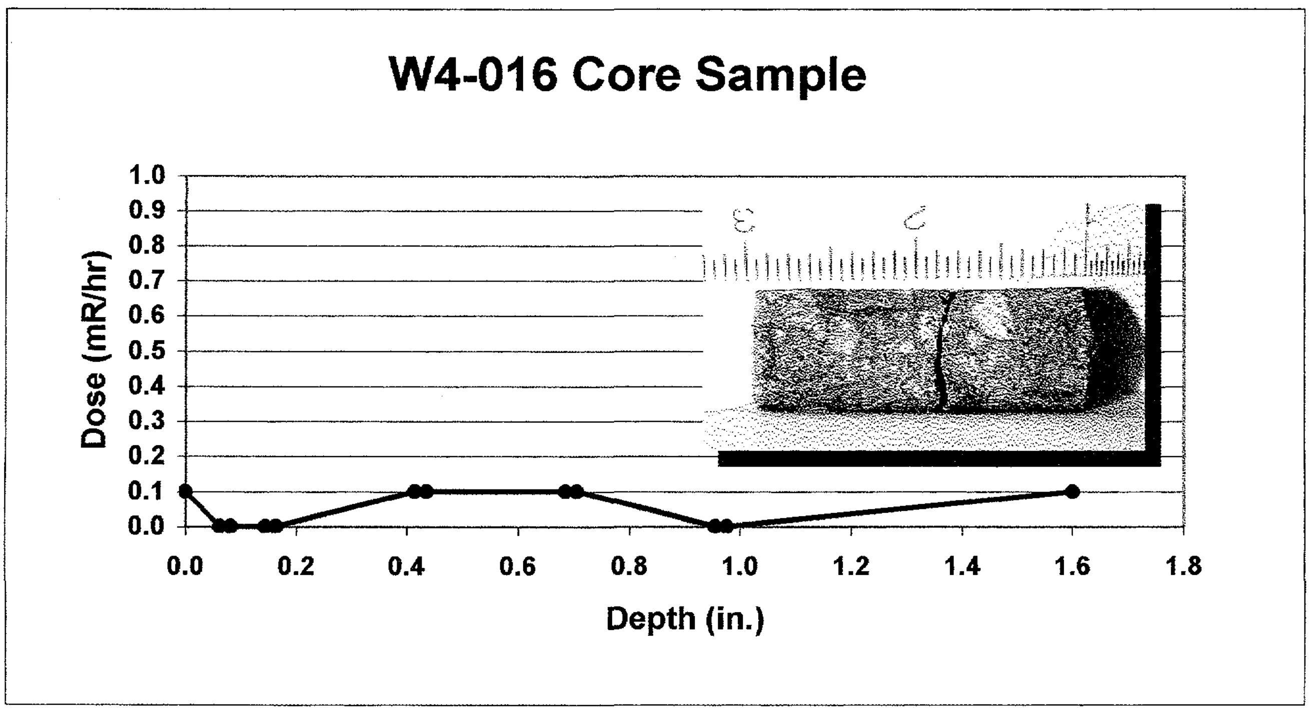
Ref: J. Keller, Data from Radioactive Materials Laboratory

Figure A-15
Core Sample W4-016

Dose Data for W4-016 Core slices (cleaned area) **8668A**

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	0.8079	0.0000	85	0.1	16.67%	2000	14.81%	0.0	0.00%
A-2		0.0625		0.0	0.00%	600	4.44%	0.0	0.00%
B-1	0.9001	0.0825	45	0.0	0.00%	410	3.04%	0.0	0.00%
B-2		0.1450		0.0	0.00%	290	2.15%	0.0	0.00%
C-1	4.8891	0.1650	33	0.0	0.00%	1100	8.15%	0.0	0.00%
C-2		0.4150		0.1	16.67%	900	6.67%	0.0	0.00%
D-1	5.2399	0.4350	22	0.1	16.67%	1500	11.11%	0.0	0.00%
D-2		0.6850		0.1	16.67%	2500	18.52%	0.0	0.00%
E-1	4.3221	0.7050	16	0.1	16.67%	1200	8.89%	0.0	0.00%
E-2		0.9550		0.0	0.00%	550	4.07%	0.0	0.00%
F-1	11.5223	0.9750	8	0.0	0.00%	750	5.56%	0.0	0.00%
F-2		1.6000		0.1	16.67%	1700	12.59%	0.0	0.00%
				0.6	100.00%	13500	100.00%	0.0	0.00%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



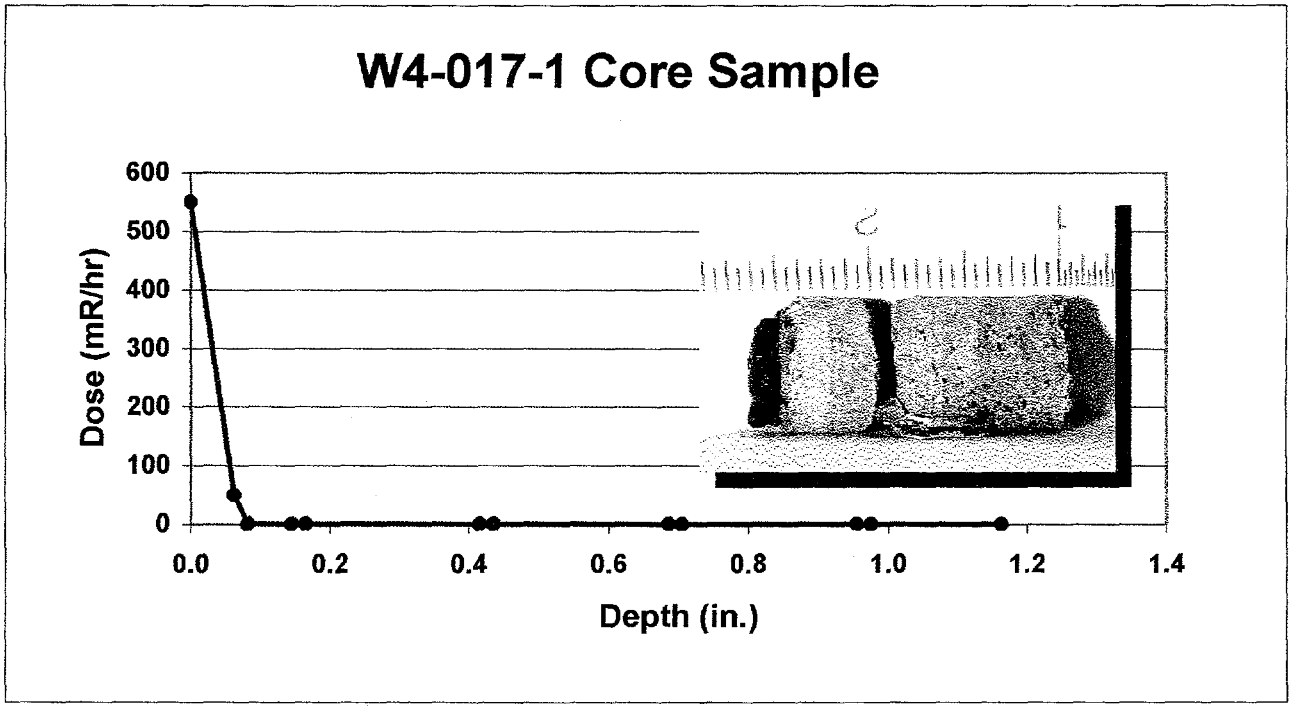
Ref: J. Keller, Data from Radioactive Materials Laboratory

Figure A-16
Core Sample W4-017-1

Dose Data for W4-017-1 Core slices (cleaned area) 8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	β+γ (mR/hr)	β+γ (% dose)	β+γ (cpm)	β+γ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.5486	0.0000	130000	550.0	91.75%	5387755	91.44%	31.0	5.17%
A-2		0.0625		49.0	8.17%	480000	8.15%	2.2	0.37%
B-1	1.6561	0.0825	1900	0.3	0.05%	6000	0.10%	0.0	0.00%
B-2		0.1450		0.2	0.03%	3200	0.05%	0.0	0.00%
C-1	4.6095	0.1650	330	0.0	0.00%	1700	0.03%	0.0	0.00%
C-2		0.4150		0.0	0.00%	750	0.01%	0.0	0.00%
D-1	5.3734	0.4350	49	0.0	0.00%	500	0.01%	0.0	0.00%
D-2		0.6850		0.0	0.00%	750	0.01%	0.0	0.00%
E-1	4.3546	0.7050	25	0.0	0.00%	750	0.01%	0.0	0.00%
E-2		0.9550		0.0	0.00%	460	0.01%	0.0	0.00%
F-1	3.2814	0.9750	18	0.0	0.00%	550	0.01%	0.0	0.00%
F-2		1.1625		0.0	0.00%	10000	0.17%	0.0	0.00%
				599.5	100.00%	5892415	100.00%	33.2	5.54%

Note: The cpm data on slice (A-1) for the β+γ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

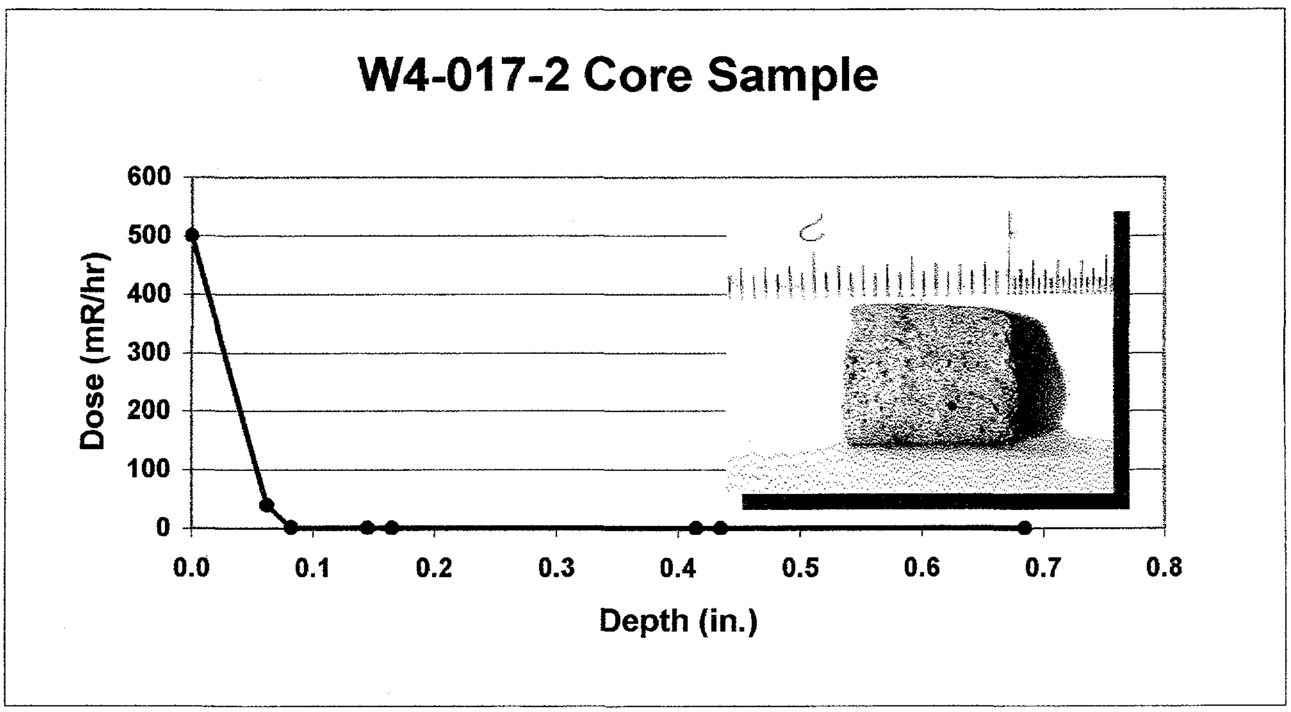
Figure A-17
Core Sample W4-017-2

Dose Data for W4-017-2 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.5872	0.0000	230000	500.0	92.58%	5128205	92.44%	30.0	5.56%
A-2		0.0625		39.0	7.22%	400000	7.21%	3.1	0.57%
B-1	1.5739	0.0825	3300	0.7	0.13%	10000	0.18%	0.0	0.00%
B-2		0.1450		0.1	0.02%	2300	0.04%	0.0	0.00%
C-1	4.0682	0.1650	360	0.1	0.02%	2000	0.04%	0.0	0.00%
C-2		0.4150		0.0	0.00%	1000	0.02%	0.0	0.00%
D-1	4.8750	0.4350	91	0.0	0.00%	1100	0.02%	0.0	0.00%
D-2		0.6850		0.2	0.03%	2800	0.05%	0.0	0.00%
				540.1	100.00%	5547405	100.00%	33.1	6.13%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

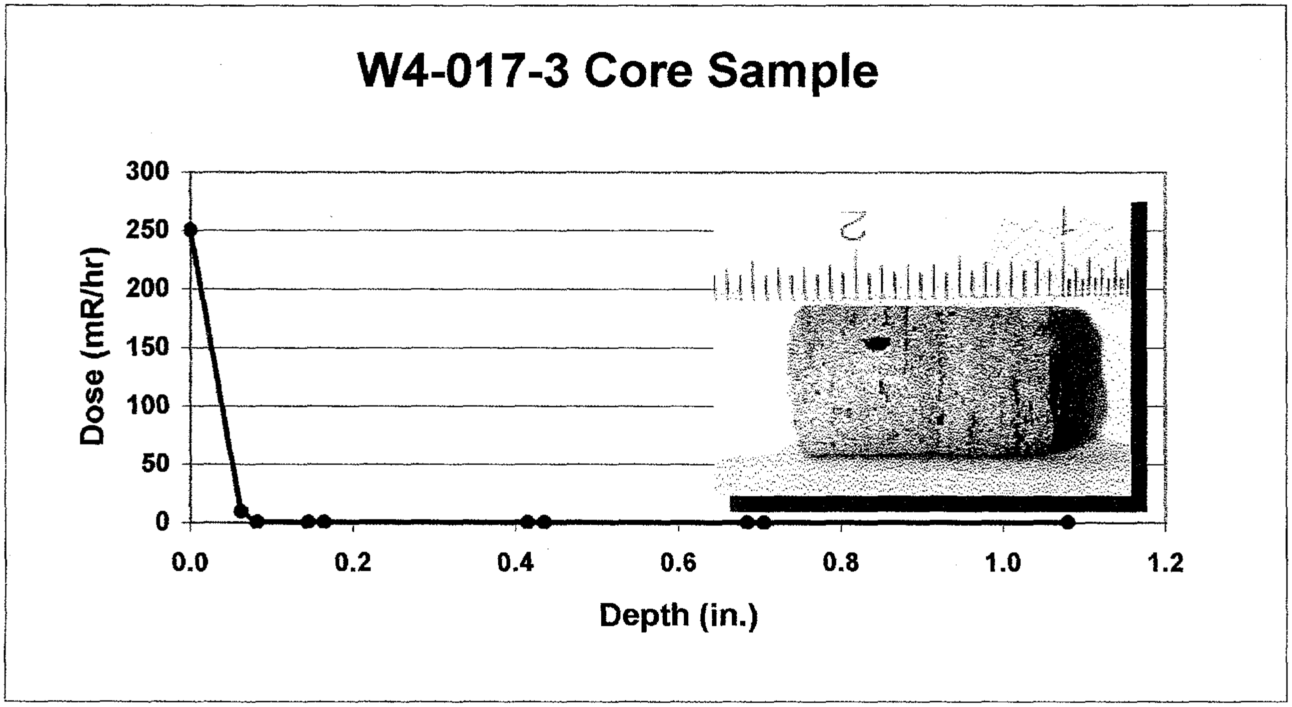
Figure A-18
Core Sample W4-017-3

Dose Data for W4-017-3 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.7612	0.0000	110000	250.0	96.12%	3684211	96.12%	12.0	4.61%
A-2		0.0625		9.5	3.65%	140000	3.65%	1.2	0.46%
B-1	1.0919	0.0825	1400	0.1	0.04%	2000	0.05%	0.0	0.00%
B-2		0.1450		0.1	0.04%	1800	0.05%	0.0	0.00%
C-1	3.8985	0.1650	350	0.1	0.04%	1200	0.03%	0.0	0.00%
C-2		0.4150		0.0	0.00%	750	0.02%	0.0	0.00%
D-1	5.6941	0.4350	61	0.0	0.00%	850	0.02%	0.0	0.00%
D-2		0.6850		0.0	0.00%	650	0.02%	0.0	0.00%
E-1	7.2699	0.7050	59	0.0	0.00%	800	0.02%	0.0	0.00%
E-2		1.0800		0.3	0.12%	750	0.02%	0.0	0.00%
				260.1	100.00%	3833011	100.00%	13.2	5.07%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

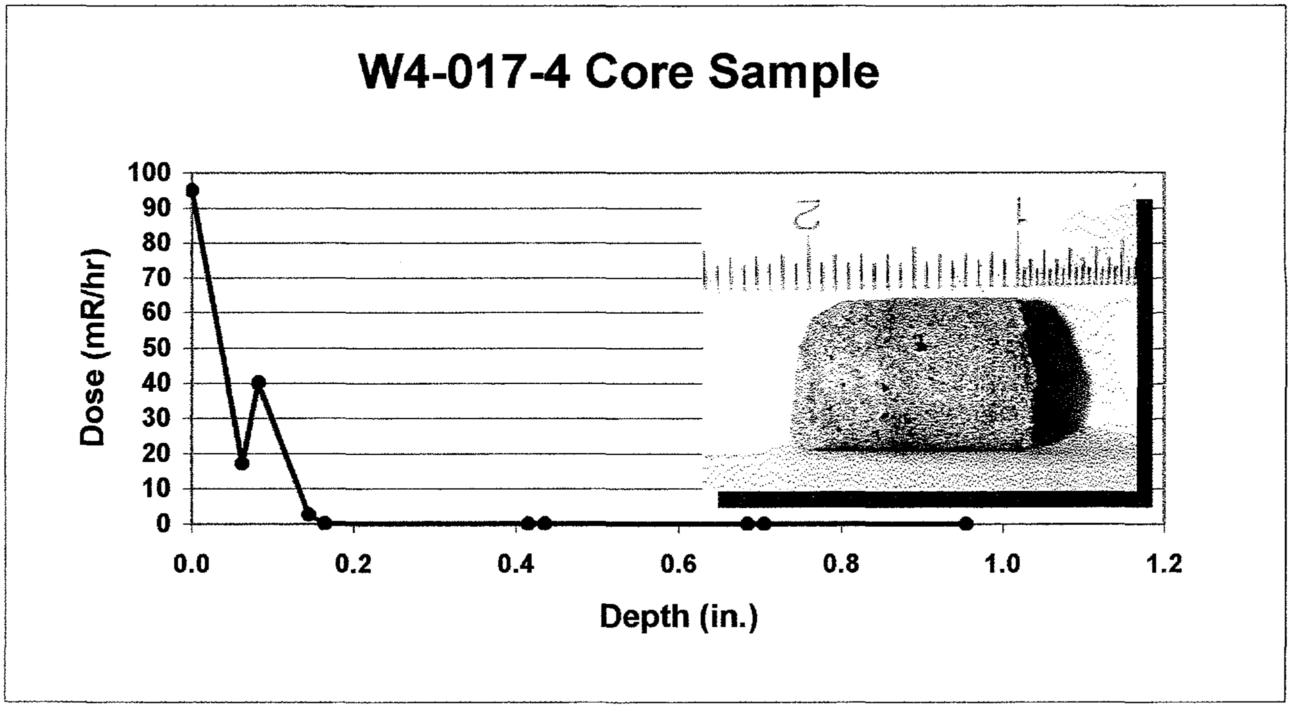
Figure A-19
Core Sample W4-017-4

Dose Data for W4-017-4 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	β+γ (mR/hr)	β+γ (% dose)	β+γ (cpm)	β+γ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	0.5828	0.0000	100000	95.0	61.49%	1285294	57.35%	4.5	2.91%
A-2		0.0625		17.0	11.00%	230000	10.26%	1.0	0.61%
B-1	1.7972	0.0825	17000	40.0	25.89%	420000	18.74%	2.1	1.36%
B-2		0.1450		2.5	1.62%	300000	13.39%	0.2	0.10%
C-1	4.2652	0.1650	440	0.0	0.00%	2000	0.09%	0.0	0.00%
C-2		0.4150		0.0	0.00%	850	0.04%	0.0	0.00%
D-1	4.6942	0.4350	71	0.0	0.00%	1100	0.05%	0.0	0.00%
D-2		0.6850		0.0	0.00%	430	0.02%	0.0	0.00%
E-1	3.2687	0.7050	32	0.0	0.00%	500	0.02%	0.0	0.00%
E-2		0.9550		0.0	0.00%	850	0.04%	0.0	0.00%
				154.5	100.00%	2241024	100.00%	7.7	4.98%

Note: The cpm data on slice (A-1) for the β+γ measurement were calculated due to off-scale readings.



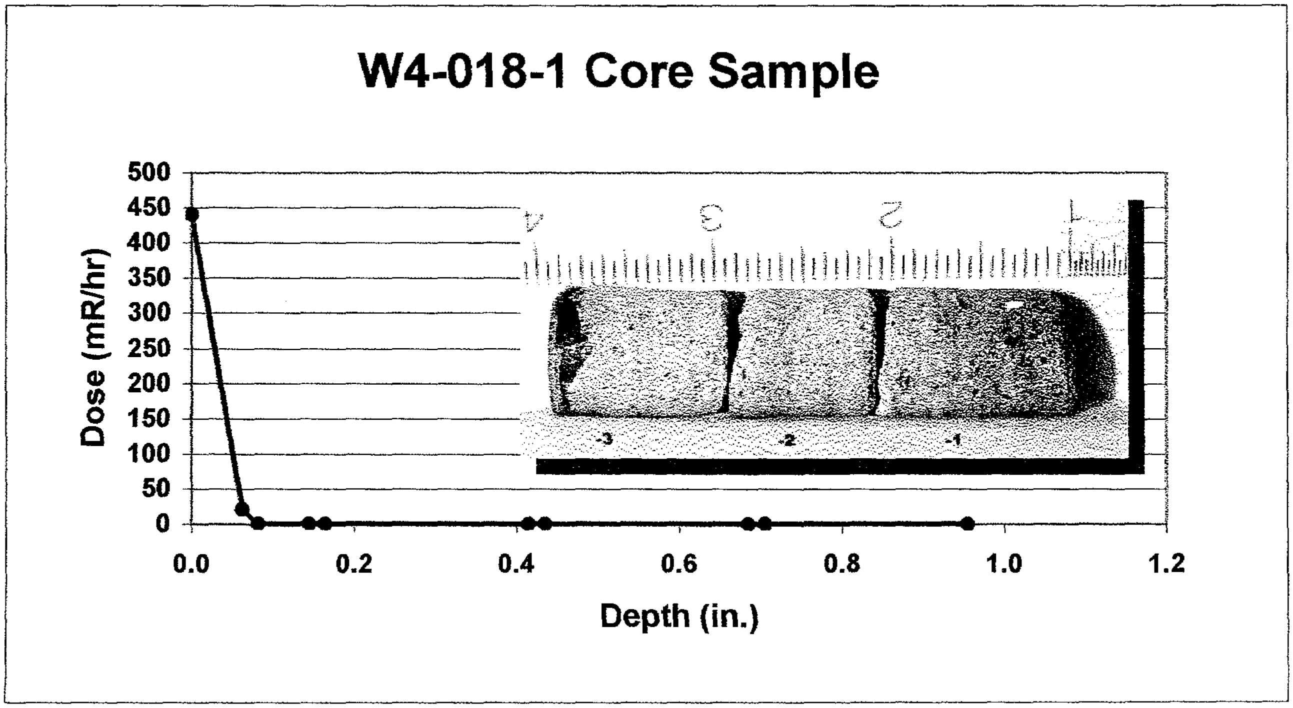
Ref: J. Keller, Data from Radioactive Materials Laboratory

Figure A-20
Core Sample W-018-1

Dose Data for W4-018-1 Core slices (cleaned area) 8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	2.0271	0.0000	58000	440.0	95.34%	6194175	95.19%	26.0	5.63%
A-2		0.0625		20.6	4.46%	290000	4.46%	1.5	0.33%
B-1	1.2328	0.0825	2800	0.4	0.08%	5000	0.08%	0.0	0.00%
B-2		0.1450		0.2	0.03%	3800	0.06%	0.0	0.00%
C-1	4.1466	0.1650	800	0.2	0.03%	3100	0.05%	0.0	0.00%
C-2		0.4150		0.0	0.00%	1300	0.02%	0.0	0.00%
D-1	4.5562	0.4350	120	0.0	0.00%	900	0.01%	0.0	0.00%
D-2		0.6850		0.0	0.00%	600	0.01%	0.0	0.00%
E-1	2.5690	0.7050	260	0.0	0.00%	800	0.01%	0.0	0.00%
E-2		0.9550		0.3	0.05%	7500	0.12%	0.0	0.00%
				461.5	100.00%	6507175	100.00%	27.5	5.96%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

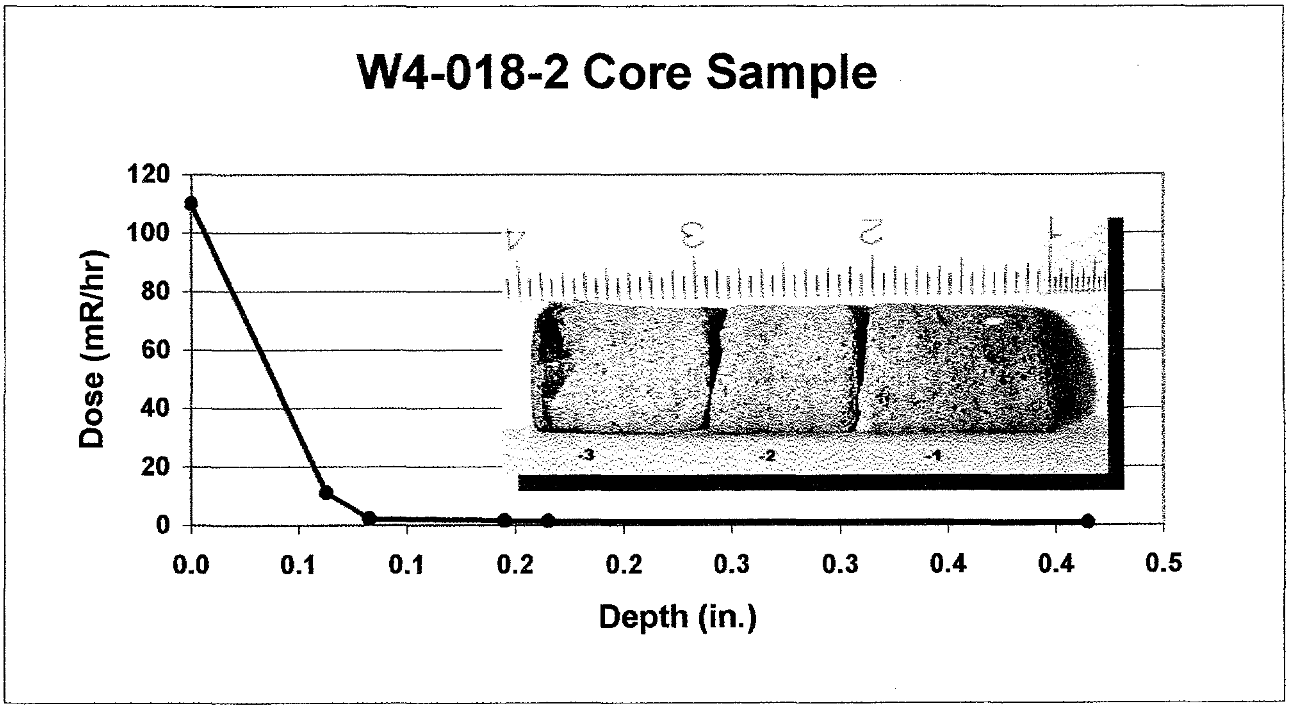
Figure A-21
Core Sample W-018-2

Dose Data for W4-018-2 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	β+γ (mR/hr)	β+γ (% dose)	β+γ (cpm)	β+γ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.4129	0.0000	42000	110.0	86.65%	1500000	86.71%	5.5	4.33%
A-2		0.0625		11.0	8.66%	150000	8.67%	0.6	0.43%
B-1	2.2665	0.0825	10000	2.1	1.65%	30000	1.73%	0.1	0.08%
B-2		0.1450		1.6	1.26%	20000	1.16%	0.1	0.08%
C-1	6.6550	0.1650	4400	1.4	1.10%	20000	1.16%	0.1	0.08%
C-2		0.4150		0.9	0.67%	10000	0.58%	0.0	0.00%
				127.0	100.00%	1730000	100.00%	6.4	5.00%

Note: The cpm data on slice (A-1) for the β+γ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

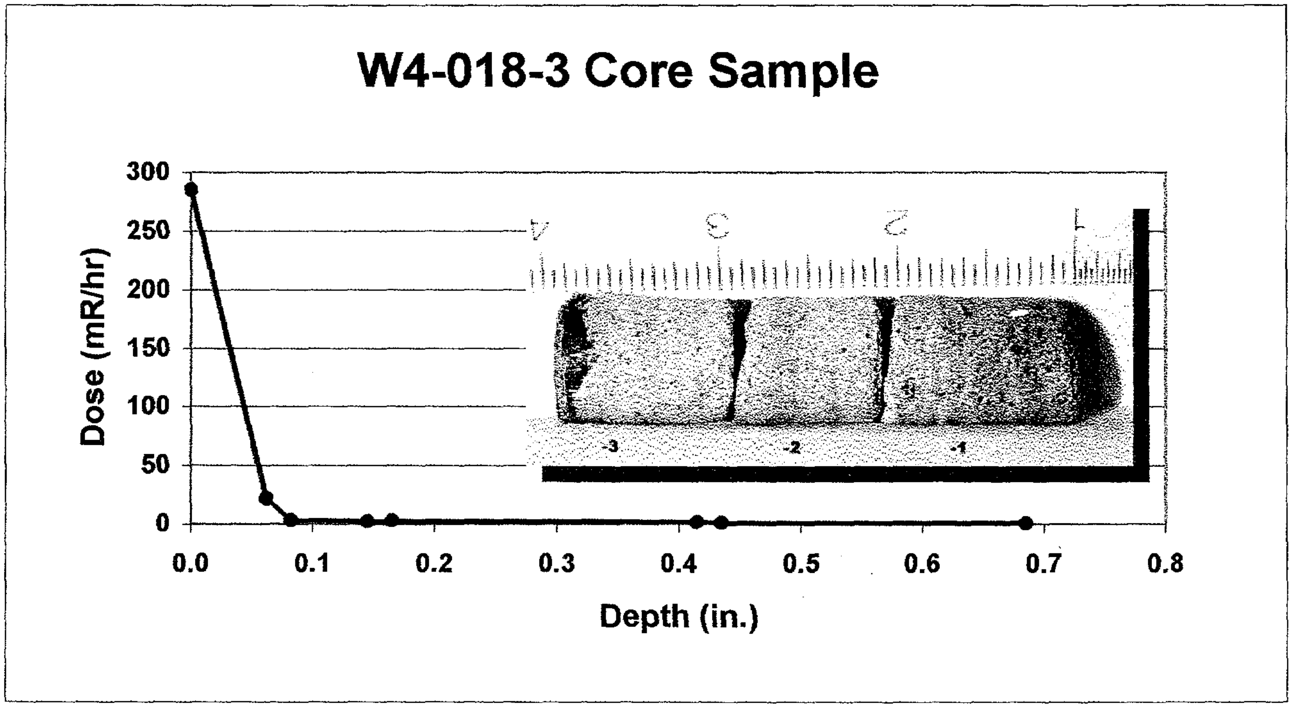
Figure A-22
Core Sample W4-018-3

Dose Data for W4-018-3 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.6725	0.0000	66000	285.0	89.75%	3497727	89.46%	16.0	5.04%
A-2		0.0625		22.0	6.93%	270000	6.91%	1.1	0.35%
B-1	1.7194	0.0825	19000	3.2	1.01%	41000	1.05%	0.1	0.03%
B-2		0.1450		2.2	0.69%	31000	0.79%	0.2	0.05%
C-1	4.671	0.1650	8900	2.5	0.79%	31000	0.79%	0.2	0.06%
C-2		0.4150		1.5	0.47%	20000	0.51%	0.2	0.05%
D-1	5.6876	0.4350	2600	0.9	0.27%	14000	0.36%	0.0	0.00%
D-2		0.6850		0.3	0.09%	5000	0.13%	0.0	0.00%
				317.6	100.00%	3909727	100.00%	17.7	5.57%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

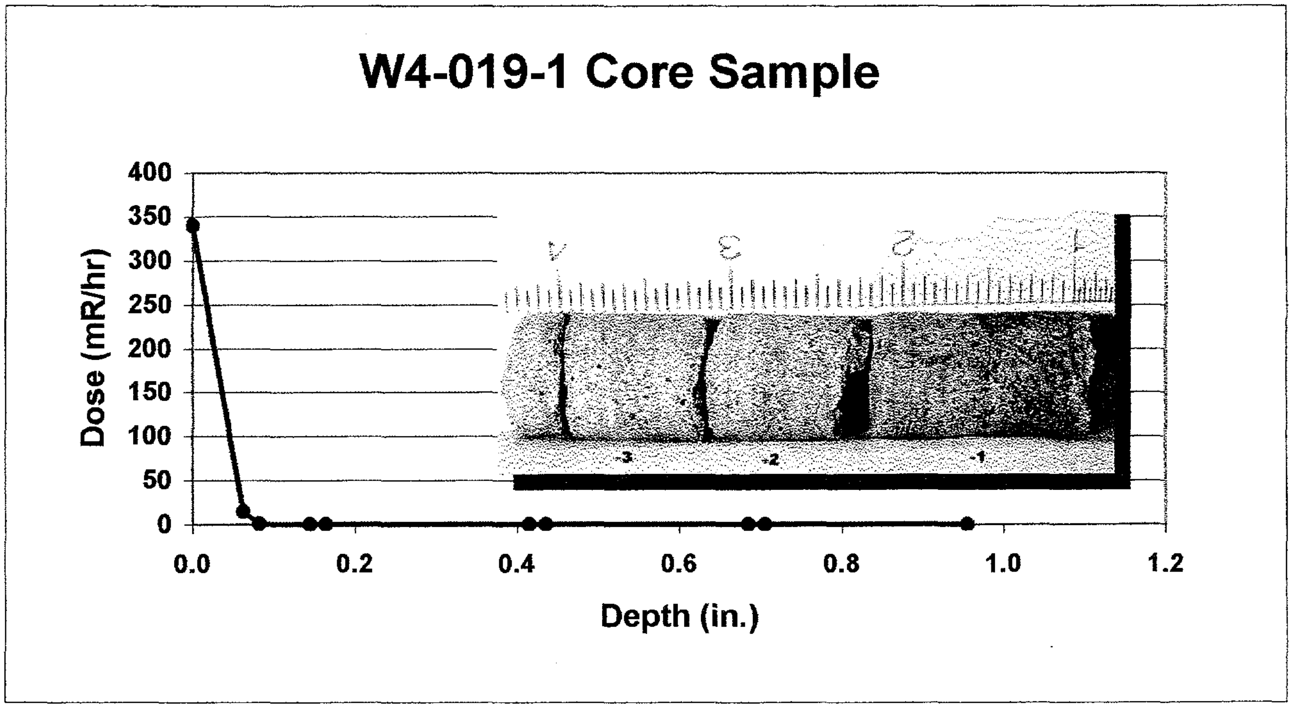
Figure A-23
Core Sample W4-019-1

Dose Data for W4-019-1 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	2.7862	0.0000	52000	340.0	95.57%	3986207	95.29%	18.0	5.06%
A-2		0.0625		14.5	4.08%	170000	4.06%	1.1	0.31%
B-1	1.9124	0.0825	2300	0.4	0.11%	6500	0.16%	0.0	0.00%
B-2		0.1450		0.2	0.06%	3700	0.09%	0.0	0.00%
C-1	5.4824	0.1650	330	0.2	0.06%	3000	0.07%	0.0	0.00%
C-2		0.4150		0.1	0.03%	2400	0.06%	0.0	0.00%
D-1	4.5450	0.4350	83	0.1	0.03%	2000	0.05%	0.0	0.00%
D-2		0.6850		0.0	0.00%	1500	0.04%	0.0	0.00%
E-1	4.2389	0.7050	100	0.0	0.00%	1500	0.04%	0.0	0.00%
E-2		0.9550		0.3	0.07%	6500	0.16%	0.0	0.00%
				355.8	100.00%	4183307	100.00%	19.1	5.37%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

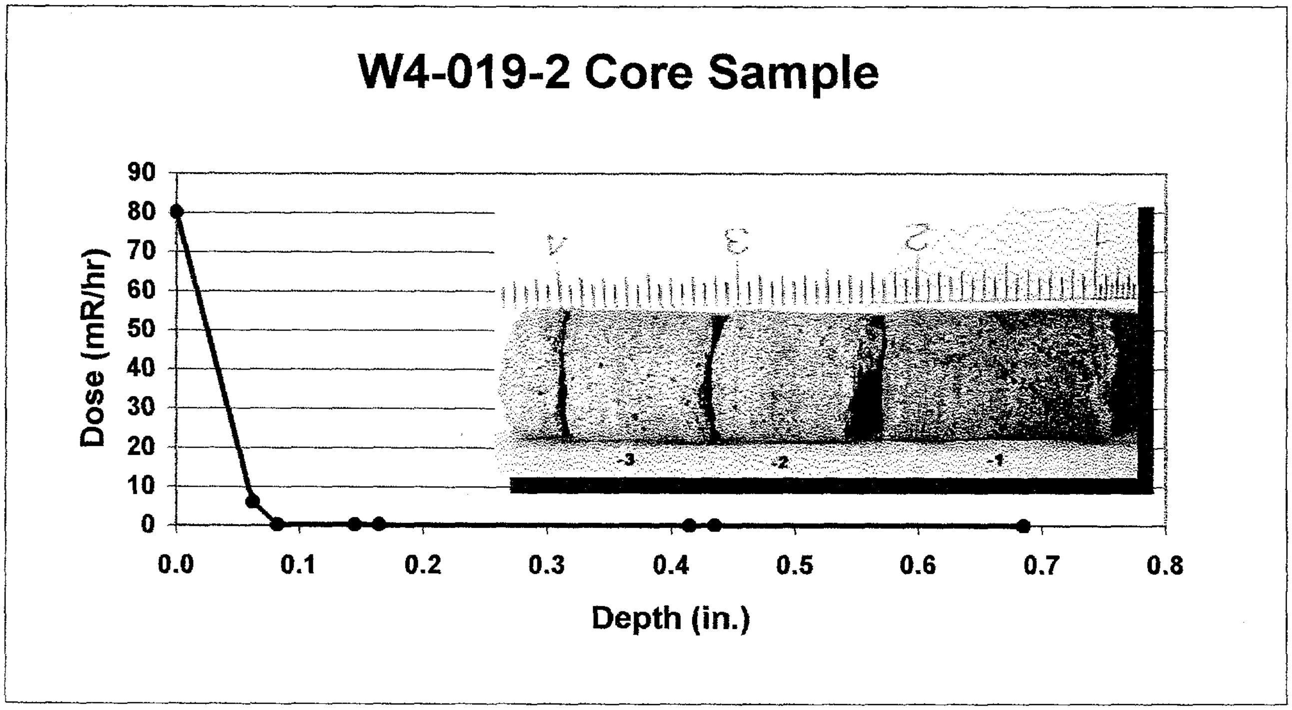
Figure A-24
Core Sample W4-019-2

Dose Data for W4-019-2 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	β+γ (mR/hr)	β+γ (% dose)	β+γ (cpm)	β+γ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.9582	0.0000	36000	80.0	92.59%	1133333	92.18%	4.6	5.32%
A-2		0.0625		6.0	6.94%	85000	6.91%	0.6	0.64%
B-1	1.1250	0.0825	1900	0.2	0.23%	3900	0.32%	0.0	0.00%
B-2		0.1450		0.1	0.12%	2400	0.20%	0.0	0.00%
C-1	4.4219	0.1650	430	0.1	0.12%	2500	0.20%	0.0	0.00%
C-2		0.4150		0.0	0.00%	850	0.07%	0.0	0.00%
D-1	3.7838	0.4350	77	0.0	0.00%	700	0.06%	0.0	0.00%
D-2		0.6850		0.0	0.00%	750	0.06%	0.0	0.00%
				86.4	100.00%	1229433	100.00%	5.2	5.96%

Note: The cpm data on slice (A-1) for the β+γ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

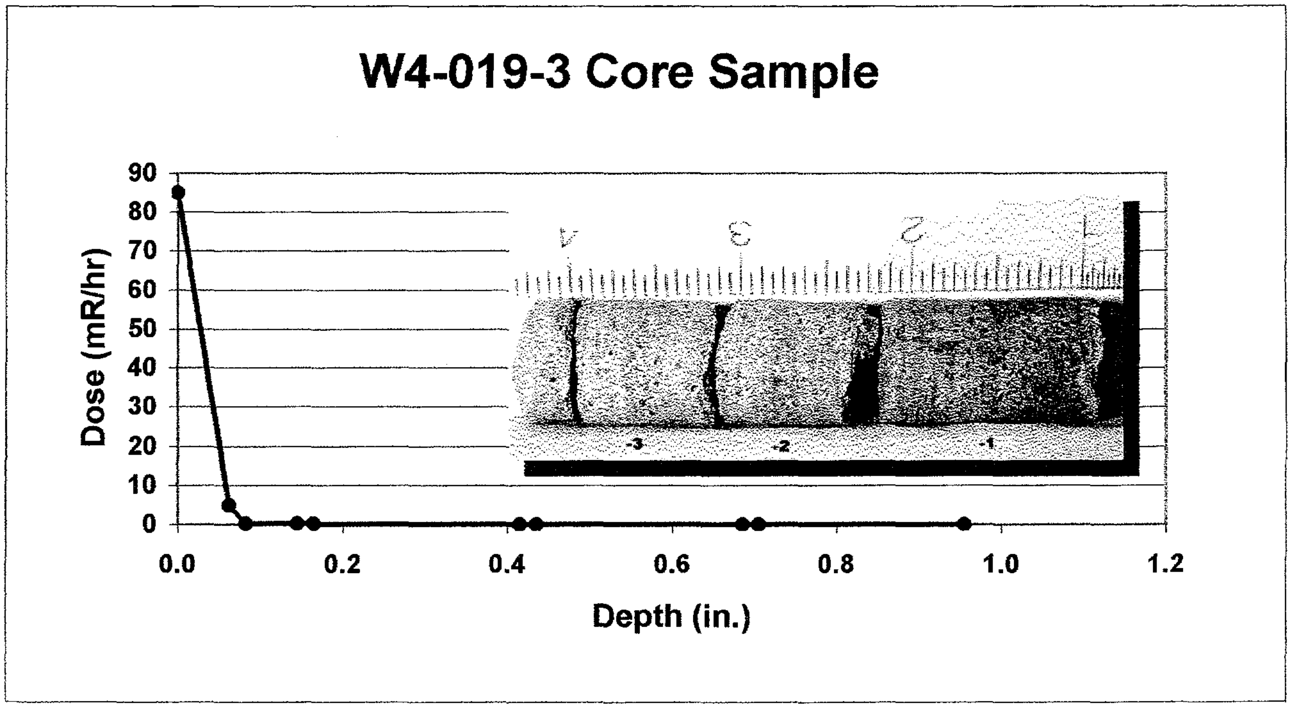
Figure A-25
Core Sample W4-019-3

Dose Data for W4-019-3 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	2.2994	0.0000	29000	85.0	94.24%	1127551	93.69%	4.7	5.21%
A-2		0.0625		4.9	5.43%	65000	5.40%	0.5	0.50%
B-1	1.5589	0.0825	1600	0.1	0.11%	3300	0.27%	0.0	0.00%
B-2		0.1450		0.1	0.11%	1600	0.13%	0.0	0.00%
C-1	4.6153	0.1650	210	0.1	0.11%	1600	0.13%	0.0	0.00%
C-2		0.4150		0.0	0.00%	950	0.08%	0.0	0.00%
D-1	3.1224	0.4350	100	0.0	0.00%	850	0.07%	0.0	0.00%
D-2		0.6850		0.0	0.00%	1900	0.16%	0.0	0.00%
E-1	4.5203	0.7050	31	0.0	0.00%	250	0.02%	0.0	0.00%
E-2		0.9550		0.0	0.00%	500	0.04%	0.0	0.00%
				90.2	100.00%	1203501	100.00%	5.2	5.71%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radioactive Materials Laboratory

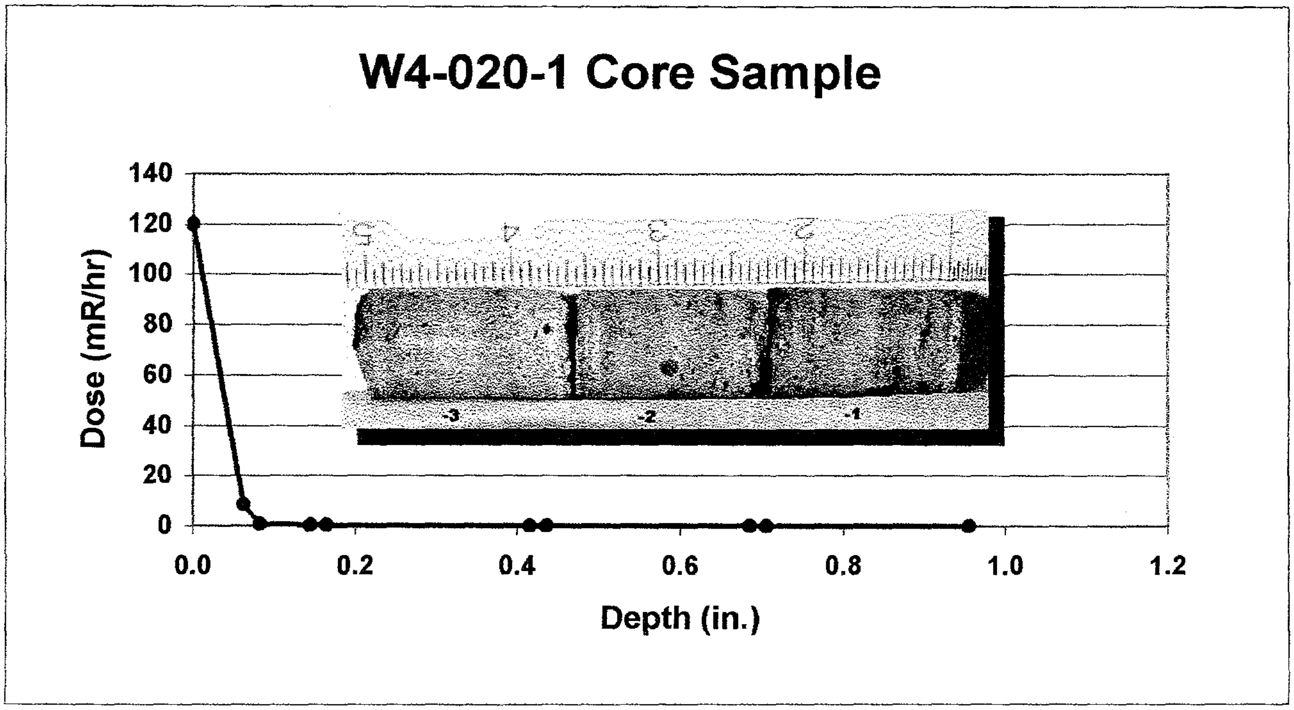
Figure A-26
Core Sample W4-020-1

Dose Data for W4-020-1 Core slices (cleaned area)

8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.9490	0.0000	38000	120.0	92.31%	1411765	91.79%	5.6	4.28%
A-2		0.0625		8.5	6.54%	100000	6.50%	0.5	0.38%
B-1	1.6057	0.0825	4200	0.8	0.58%	12000	0.78%	0.0	0.00%
B-2		0.1450		0.3	0.19%	6000	0.39%	0.0	0.00%
C-1	5.6466	0.1650	540	0.2	0.15%	3500	0.23%	0.0	0.00%
C-2		0.4150		0.1	0.08%	750	0.05%	0.0	0.00%
D-1	4.8002	0.4350	79	0.1	0.08%	390	0.03%	0.0	0.00%
D-2		0.6850		0.0	0.00%	240	0.02%	0.0	0.00%
E-1	5.3839	0.7050	50	0.0	0.00%	320	0.02%	0.0	0.00%
E-2		0.9550		0.1	0.08%	3100	0.20%	0.0	0.00%
				130.0	100.00%	1538065	100.00%	6.1	4.66%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



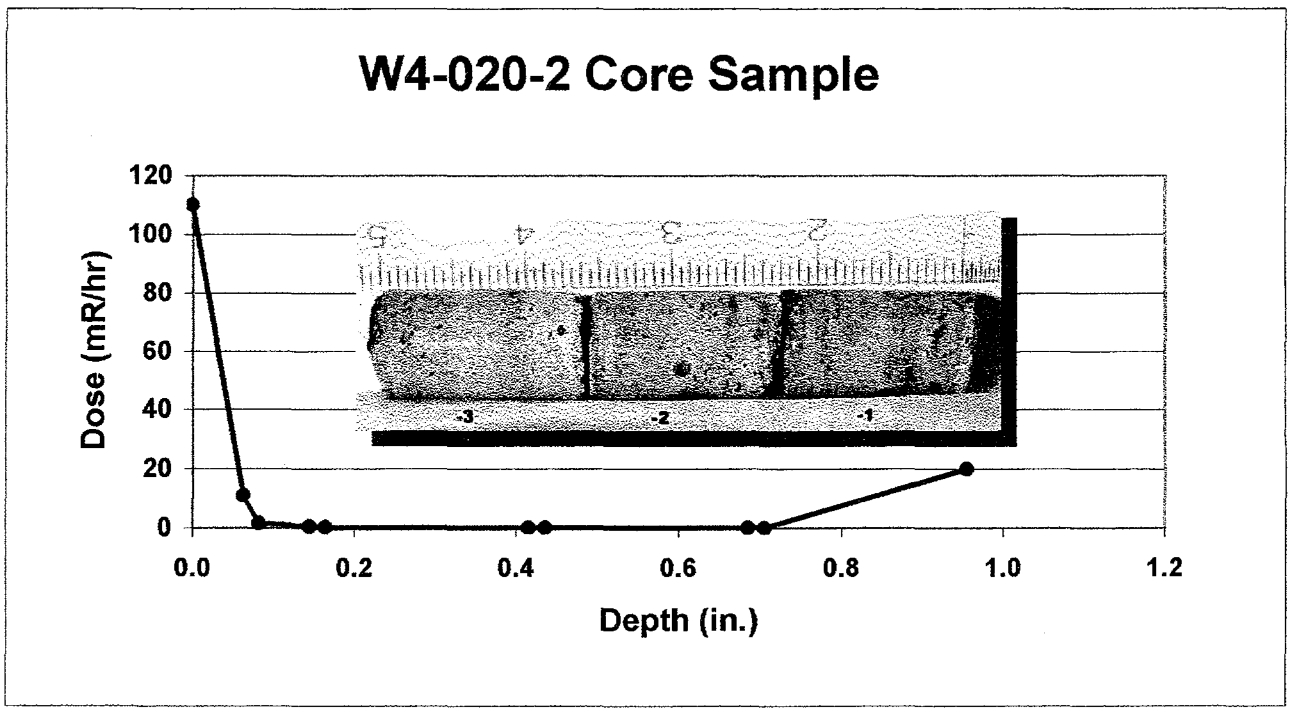
Ref: J. Keller, Data from Radioactive Materials Laboratory

Figure A-27
Core Sample W4-020-2

Dose Data for W4-020-2 Core slices (cleaned area) 8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	β+γ (mR/hr)	β+γ (% dose)	β+γ (cpm)	β+γ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.8102	0.0000	63000	110.0	76.74%	1500000	86.53%	6.0	4.19%
A-2		0.0625		11.0	7.67%	150000	8.65%	0.7	0.49%
B-1	1.5549	0.0825	6900	1.6	1.12%	24000	1.38%	0.0	0.00%
B-2		0.1450		0.4	0.28%	8000	0.46%	0.0	0.00%
C-1	4.9640	0.1650	700	0.2	0.10%	3200	0.18%	0.0	0.00%
C-2		0.4150		0.1	0.07%	1100	0.06%	0.0	0.00%
D-1	5.7201	0.4350	87	0.1	0.07%	700	0.04%	0.0	0.00%
D-2		0.6850		0.0	0.00%	700	0.04%	0.0	0.00%
E-1	5.1442	0.7050	100	0.0	0.00%	750	0.04%	0.0	0.00%
E-2		0.9550		20.0	13.95%	45000	2.60%	0.0	0.00%
				143.4	100.00%	1733450	100.00%	6.7	4.67%

Note: The cpm data on slice (A-1) for the β+γ measurement were calculated due to off-scale readings.



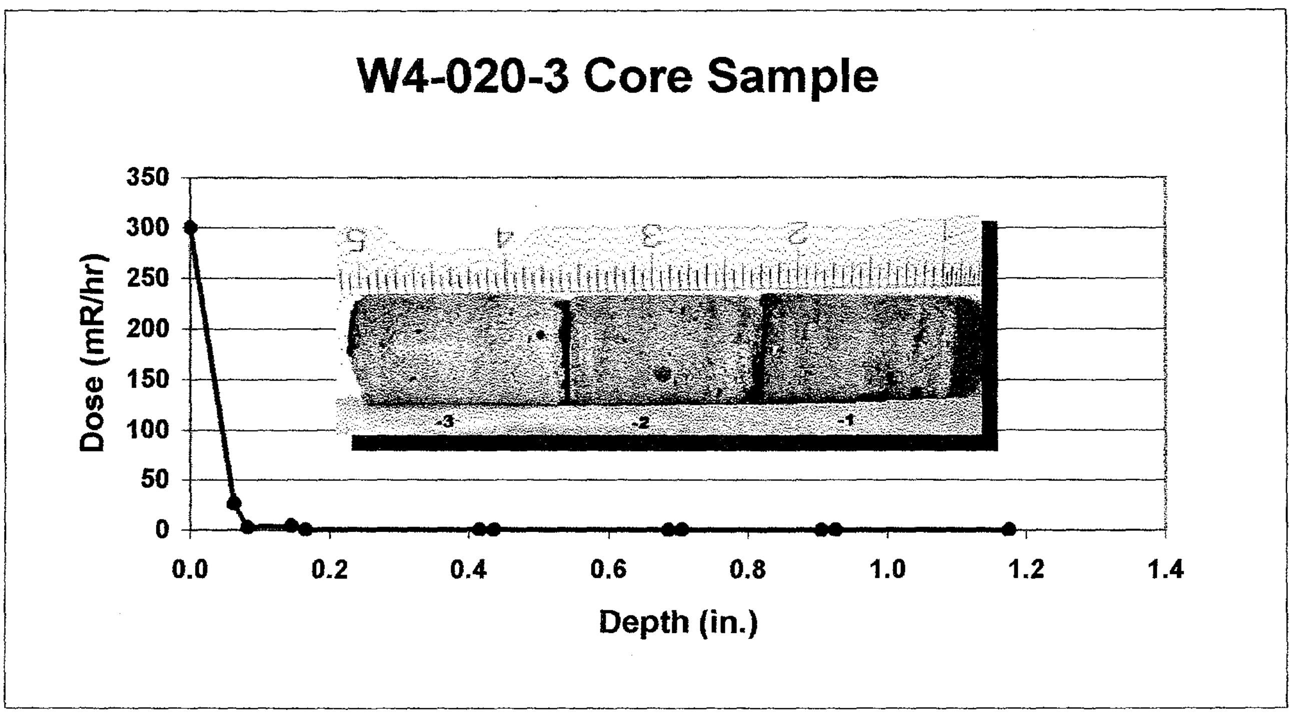
Ref: J. Keller, Data from Radiological Laboratory

Figure A-28
Core Sample W-020-3

W4-020-3 Core slices (cleaned area) 8668A

Slice	Weight (g)	Depth (in.)	^{137}Cs (Bq/g)	$\beta+\gamma$ (mR/hr)	$\beta+\gamma$ (% dose)	$\beta+\gamma$ (cpm)	$\beta+\gamma$ (% cpm)	γ (mR/hr)	γ/total (%)
blank		na		<0.1	na	120	na	na	na
A-1	1.6144	0.0000	67000	300.0	90.08%	3461538	90.66%	17.0	5.10%
A-2		0.0625		26.0	7.81%	300000	7.86%	1.2	0.36%
B-1	1.5410	0.0825	11000	2.8	0.84%	39000	1.02%	0.0	0.00%
B-2		0.1450		4.0	1.20%	7000	0.18%	0.0	0.00%
C-1	5.3271	0.1650	920	0.3	0.08%	5000	0.13%	0.0	0.00%
C-2		0.4150		0.0	0.00%	1100	0.03%	0.0	0.00%
D-1	4.3332	0.4350	100	0.0	0.00%	700	0.02%	0.0	0.00%
D-2		0.6850		0.0	0.00%	380	0.01%	0.0	0.00%
E-1	4.0938	0.7050	43	0.0	0.00%	350	0.01%	0.0	0.00%
E-2		0.9050		0.0	0.00%	200	0.01%	0.0	0.00%
F-1	3.4697	0.9250	28	0.0	0.00%	190	0.00%	0.0	0.00%
F-2		1.1750		0.0	0.00%	2800	0.07%	0.0	0.00%
				333.1	100.00%	3818258	100.00%	18.2	5.46%

Note: The cpm data on slice (A-1) for the $\beta+\gamma$ measurement were calculated due to off-scale readings.



Ref: J. Keller, Data from Radiological Materials Laboratory

INTERNAL DISTRIBUTION

1. D.H. Boling, Bldg. 7078-B, MS 6402
2. D.C. Haley, Bldg. 7601, MS 6304
3. J.N. Herndon, Bldg. 7601, MS 6305
4. B.E. Lewis, Bldg. 7601, MS 6306
5. A.P. Malinauskas, Bldg. 1000, MS 6296
6. T.E. Myrick, Bldg. 1000, MS 6296
7. K.E. Plummer, Bldg. 7601, 6306
8. S.L. Schrock, Bldg. 7601, MS 6304

9-38. D. Van Hoesen, Bldg. 1000, MS 6338

39. H.R. Yook, Bldg. 7601, MS 6304
40. Central Research Library, Bldg. 4500N, MS 6285
41. ORNL Laboratory Records - RC, Bldg. 4500N, MS 6285

42-43. ORNL Laboratory Records - OSTI, Bldg. 4500N, MS 6285

EXTERNAL DISTRIBUTION

44. S. Bailey, Pacific Northwest National Laboratory,
P.O. Box 999, KS-08, Richland, WA 99352
45. G. Boyd, US Department of Energy, Office of Science and Technology, EM-50
1000 Independence Ave., SW, Washington, DC 20585
46. T. Brouns, Pacific Northwest National Laboratory,
P.O. Box 999, K9-91, Richland, WA 99352

47-56. B. Burks, The Providence Group, P.O. Box 23408, Knoxville, TN 37933-1408

57. B. Carteret, Pacific Northwest National Laboratory,
P.O. Box 999, K9-91, Richland, WA 99352
58. C. Christensen, LITCO, P.O. Box 1625, 3211, Idaho Falls, ID 83415-3710

59-63. J. DeGregory, US Department of Energy,
19901 Germantown Road, Germantown, MD 20874-1290

64. D. Green, DOE Oak Ridge Operations Office, P.O. Box 2001, Oak Ridge, TN 37831
65. J.A. Frey, US Department of Energy Richland,
825 Jadwin Ave., Rm. 1622, Richland, WA 99352
66. P. Gibbons, NHC ,P.O. Box 1300, H6-12, Richland, WA 99352-1300
67. T. Gutmann, P.O. Box A, Bldg. 704S, Aiken, SC 29802

68-72. F.B. Hazen, Robotics Home Office, 576 East End Ave., Pittsburgh, PA 15221

73. R.M. Hollen, Los Alamos National Laboratory,
P.O. Box 1663, MS J580, Los Alamos, NM 87545
74. J. Honeyman, LMHC, P.O. Box 1500, G3-21, Richland, WA 99352
75. V.J. Kothari, FETC, P.O. Box 880, Morgantown, WV 26057-0880
76. K. Kwok, Sandia National Laboratories,
MS 1003, P.O. Box 5800, Albuquerque, NM 87185-1003

77. C. Louie, U.S. Department of Energy Richland
P.O. Box 550, B4-55, Richland, WA 99352
78. R. Mendoza, 3250 Port of Benton Blvd., Richland, WA 99352
79. C. Mims, DOE Oak Ridge Operations Office, P.O. Box 2001, Oak Ridge, TN 37831
80. J. Moore, DOE Oak Ridge Operations Office, P.O. Box 2001, Oak Ridge, TN 37831
81. J. Morin, Westinghouse Savannah River Company, SRTC Bldg. 103H, Aiken, SC 29801
82. J. Noble-Dial, DOE Oak Ridge Operations Office, P.O. Box 2001, Oak Ridge, TN 37831
83. J. Powell, DOE Oak Ridge Operations Office, P.O. Box 2001, Oak Ridge, TN 37831
84. M. Rinker, Pacific Northwest National Laboratory,
P.O. Box 999, K5-22, Richland, WA 99352
85-90. V. Rule, XL Associates, Inc., 677 Emory Valley Road, Suite C, Oak Ridge, TN 37830
91. E. Saldivar, Westinghouse Savannah River Company,
Bldg. 742-4G, Rm. 1, Aiken, SC 29801
92. L. Stebbins, FERMCO, Fluor Daniel Fernald, Fernald Technology Programs
P.O. Box 358704, MS-50, 7400 Willey Rd, Cincinnati, OH 45253-8704
93. T. Stewart, Pacific Northwest National Laboratory,
P.O. Box 999, K9-69, Richland, WA 99352
94. S. Tibrea, Westinghouse Savannah River Company,
Savannah River Technology Center, Bldg. 773-A, D-1132, Aiken, South Carolina 29808
95. J.H. Valentine, LITCO, P.O. Box 1625, 3211, Idaho Falls, ID 83415-3100
96. D. Wadsworth, Idaho National Engineering & Environmental Laboratory
P.O. Box 1625, MS 2220, Idaho Falls, ID 83415-2220
97. J.S. Walker, DOE-HQ, US Department of Energy,
19901 Germantown Road, Germantown, MD 20874
98. L. Yarbrough, DOE Albuquerque Operations Office,
P.O. Box 5400, Albuquerque, NM 87185-5400
99. J. Yount, Pacific Northwest National Laboratory,
P.O. Box 999, H6-12, Richland, WA 99352