U.S. Department of Energy
Office of Health, Safety, and Security
Office of Corporate Safety Programs

Type A Accident Investigation Report

THE JULY 27, 2007
TANK 241-S-102 WASTE SPILL
AT
THE HANFORD TANK FARMS

Volume 2

September 2007

Disclaimer

This report is an independent product of the Type A Accident Investigation Board appointed by Glenn Podonsky, Chief Health, Safety and Security Officer, Office of Health, Safety, and Security (HS-1)

The Board was appointed to perform a Type A Investigation of this accident and to prepare an investigation report in accordance with DOE 225.1A, *Accident Investigations*.

The discussion of facts, as determined by the Board, and the views expressed in the report do not assume, and are not intended to establish, the existence of any duty at law on the part of the U.S. Government, its employees or agents, contractors, their employees or agents, or subcontractors at any tier, or any other party.

This report neither determines nor implies any legal liability.

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VOLUME II

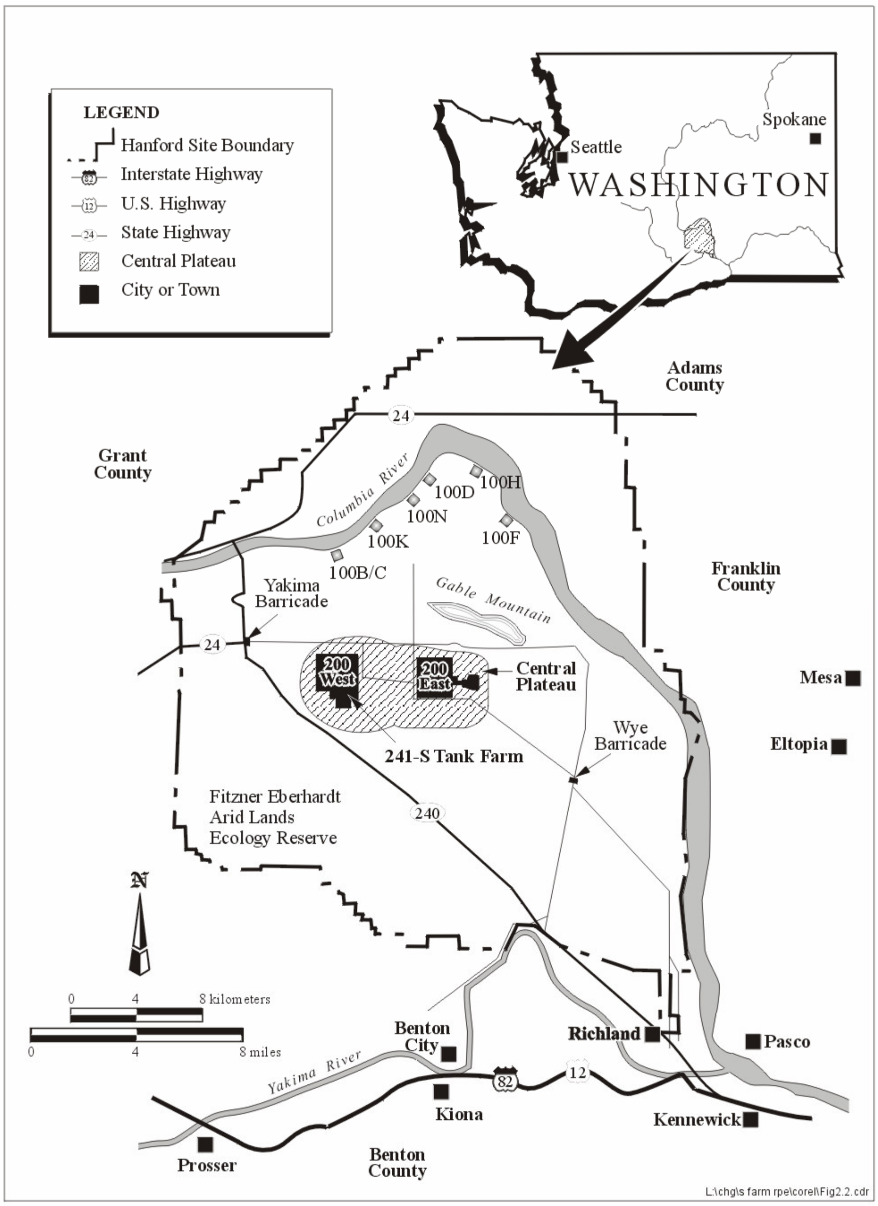
Acronyms

AMH	AdvanceMed Hanford
CH2M HILL	CH2M HILL Hanford Group, Inc.
DOE	United States Department of Energy
DSA	Documented Safety Analysis
EAL	Emergency Action Level
EM	Emergency Management
ENG	Engineering Design
EPHA	emergency planning hazards assessment
IH	Industrial Hygiene
JON	Judgment of Needs
MBDD	Material Balance Discrepancy Data
MS	Management System
ORP	Department of Energy’s Office of River Protection
PISA	Potentially Inadequate Safety Analysis
RPP	River Protection Project
SST	single shell tank
TSR	Technical Safety Requirements
USQ	Unreviewed Safety Question
WC	Work Control
WHA	Work Site Hazards Analysis

APPENDIX C

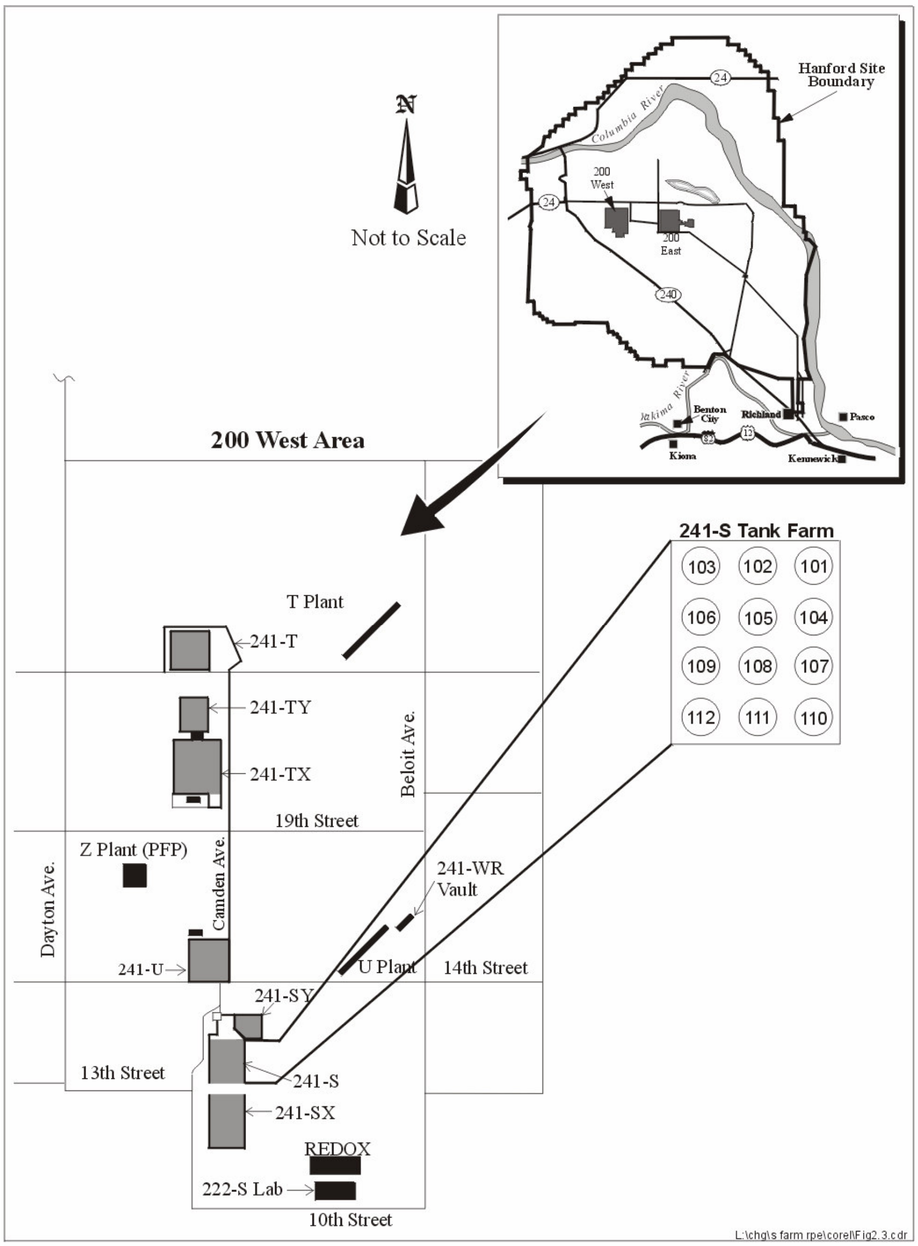
Facility Description

The contractor activities at the River Protection Project (RPP) are managed by the Department of Energy's (DOE) Office of River Protection. The project mission includes storage, retrieval, immobilization, and disposal of high-level radioactive waste currently stored in 177 underground tanks located in the 200 East and 200 West areas of the U.S. DOE Hanford Site, as seen in the figure below. These tanks consist of 149 single-shell tanks (SST), constructed between 1943 and 1964, and 28 newer, double-shell tanks (DST). The SSTs and DSTs contain a variety of solid and liquid wastes resulting from several decades of nuclear fuel reprocessing and radionuclide recovery processes conducted at the Hanford Site. The contractor for waste storage and retrieval is CH2M HILL Hanford Group.



The S Tank Farm

The S Tank Farm is located in the southern portion of the Hanford Site 200 West Area, near the Reduction–Oxidation (REDOX) Plant. The S Tank Farm contains 12 single-shell tanks (SST), each with a 2,869,000-liter (758,000-gallon) capacity; waste transfer lines; leak detection systems; and tank ancillary equipment. The SSTs are 23 meters (75 feet) in diameter. The S Farm SSTs are approximately 11.4 meters (37.3 feet) tall from base to dome. The tanks are covered with soil from the apex of the dome to ground surface, which is approximately 2.5 meters (8.0 feet) thick at the S Tank Farm. All of the tanks have dish-shaped bottoms. Information and data regarding the S Tank Farm facility description are taken from historical tank content estimates (WHC-SD-WM-ER-352).



The S Tank Farm SSTs are treatment, storage, and disposal units operating under interim status pending closure. Following waste retrieval, the S Tank Farm will be closed in accordance with "Closure and Post-Closure" (WAC 173-303-610), under the Washington State "Hazardous Waste Management Act" (HWMA) and Hanford Federal Facility Agreement and Consent Order (HFFACO), Milestone M-45-00.

Tank S-102

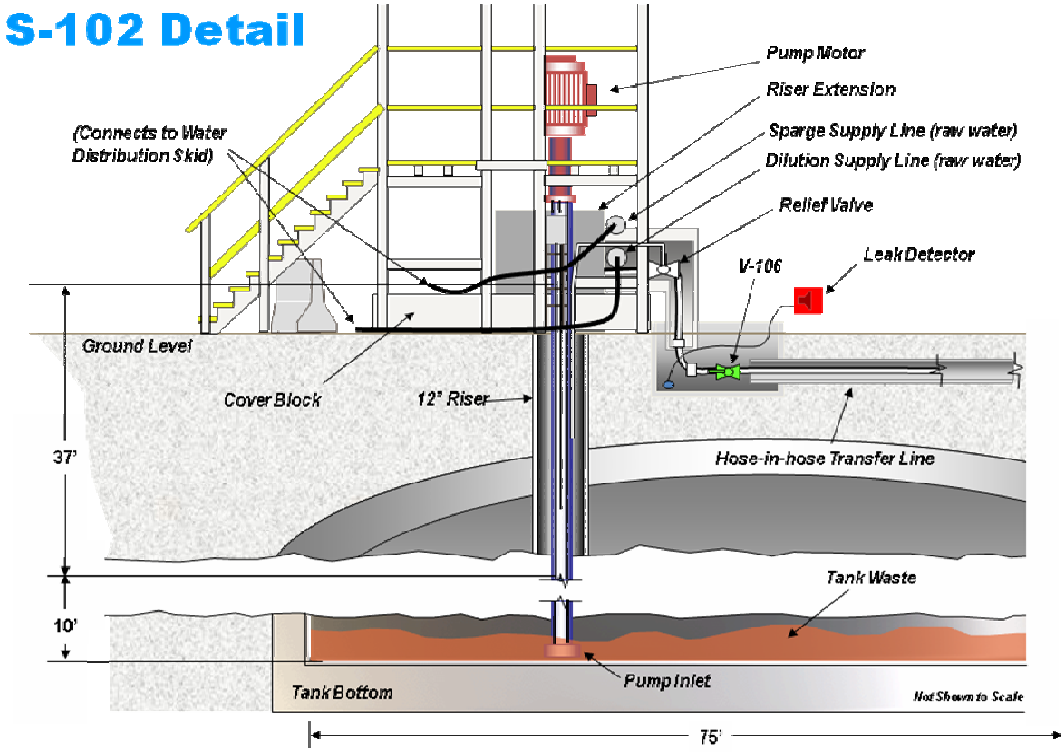
Between 1953 and 1955, Tank S-102 received REDOX high-level waste from S Plant and from Tank S-101. This was the last waste addition to Tank S-102 until the fourth quarter of 1973, when waste additions restarted and continued intermittently until the second quarter of 1979. Between 1973 and 1976, large, intermittent transfers of waste were added to the tank because Tank S-102 was the 242-S evaporator feed tank. Frequent transfers were made to Tank S-102 from other tanks during this period, including REDOX high-level waste, B Plant high-level waste, B Plant low-level waste, REDOX low-level waste, Plutonium-Uranium Extraction (PUREX) Plant low-level waste, Battelle Northwest Laboratory waste, evaporator bottoms, and terminal liquor. After 1976, Tank S-102 received mostly evaporator bottoms and evaporator feed from several other tanks in the tank farms.

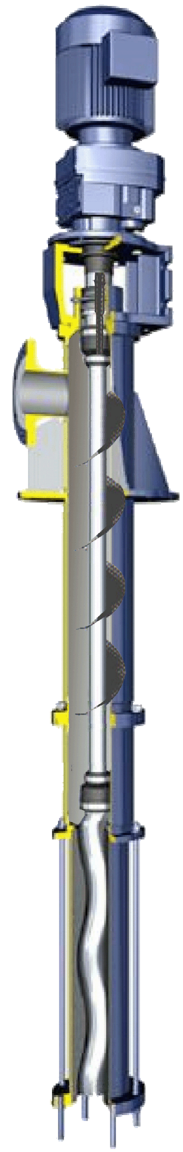
Tank S-102 was removed from service in 1980 and was partially isolated in 1982. Salt-well liquor waste was transferred from Tank S-102 to AW-106 during the fourth quarter of 1992 as part of the interim-stabilization process. The tank remained relatively undisturbed until interim stabilization efforts started in 2001, which involved removal of pumpable liquids from the SSTs in accordance with legally binding agreements with the State of Washington.

The solid-salt waste composition in Tank S-102 was determined by liquid grab and core samples taken in 1995 and 1998 and by monitoring data. The upper two-thirds of the waste was predominantly sodium-nitrate salt. The lower third contained lower-solubility salts (such as sodium fluoride phosphate) and metal-oxide sludge. Less soluble sulfate, carbonate and oxalate salts were present in higher concentration in the lower layers of the tank. Metal oxides included aluminum hydroxide, iron oxide, and manganese oxide. Silica was also present. Laboratory testing of Tank S-102 samples indicated that about 80 percent of the waste could be dissolved with water. Camera inspection of the waste during waste retrieval showed it resembled thick mud that appeared to harden with time.

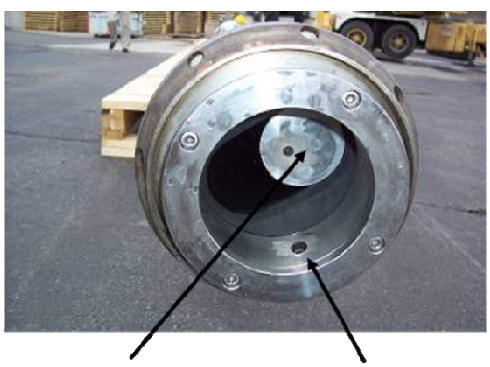
Tank S-102 Waste Removal System

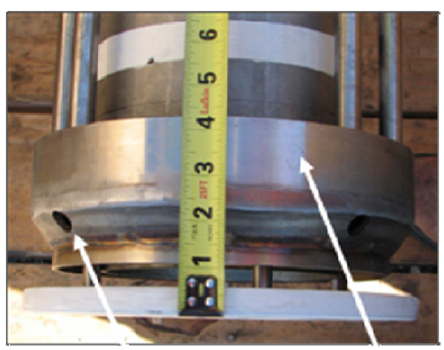
The waste in Tank S-102 is a phosphate-laden sludge with a dense gummy consistency that must be mobilized and suspended as slurry in order to be pumped out of the tank. The waste removal pump is mounted on top of Tank S-102 and extends into the tank through a 12-inch riser down to near, or at, the bottom of Tank S-102, as shown in the figure below. The pump is a reversible, positive displacement, progressive cavity type pump that is driven by a reversible, variable speed, 480-VAC motor located above the tank riser extension on a platform.





Dilution water is supplied to the pump inlet and is used to aid in the retrieval process by diluting the slurry to the appropriate specific gravity conducive to waste transfer. The dilution water is supplied from the Water Distribution Skid above Tank S-102 and is directed inside the pump suction. The dilution water and sparge water nozzles located on the pump suction are shown in the photographs below.





The discharge of the waste removal pump is directed up the riser and exits the enclosure above the tank. A pump discharge isolation valve in this line isolates the pump from the line connected to Tank SY-102, which is a double-shell tank. Upstream of the discharge valve, a relief valve protects the discharge line and the pump from overpressure if the pump is inadvertently started with the discharge valve closed.

APPENDIX D

Accident Chronology

This timeline starts in October 2003 and ends Saturday, July 28, 2007. Except where annotated as log entries, all times are approximate.

October 2003

October 17, 2003, S-112 procurement design review comment identifies potential backflow to dilution line during reverse pump operation. Comment resolution concludes that water flow could be used to prevent backflow.

December 2003

90 percent design reviews conducted for the S-112 Seepex pump installation.

May 2004

90 percent design review conducted for the Tank S-102 Seepex pump installation.

December 2004

Tank S-102 retrieval begins with Seepex Pump 1. Subsequently, the use of the Seepex pump was halted. A Gorman-Rupp pump was installed, used for retrieval, and eventually failed. Seepex Pump 1 was reinstalled with the addition of high-pressure mixers to enhance slurry transfer. After several months of retrieval operations, Seepex Pump 1 in Tank S-102 failed (March 2007).

March 2005

CH2M HILL issued PAAA Enforcement Action 2005-01 related to four incidents involving contamination, training, and management issues. One incident occurred in S-112 retrieval operations.

March 2007

Seepex Pump 1 failed.

July 12, 2007

Installation of Seepex Pump 2 initiated and delayed due to dowel-pin configuration.

July 17, 2007

Installation of Seepex Pump 2 completed.

July 24, 2007

Tank waste transfer initiated from Tank S-102 to Tank SY-102.

July 25, 2007

10:24 A.M. – 08:18 P.M. – Tank waste transfer ends with approximately 60,000 gallons transferred.

Thursday – July 26, 2007

7:30 A.M. – Started day shift.

9:55 A.M. – Started S-102 retrieval pump. Pump shut down on high discharge pressure due to discharge valve (V-106) being closed.

10:00 A.M. – OE-1 reports valve lineup discrepancy to OD. OD briefs OE and operating crew on this event with the expectation reinforced that specific actions required by the procedure (e.g., Valve V-106 is open) are reported instead of more general statements such as "all prerequisites are completed."

10:30 A.M. – NCO-1 opened V-106 per procedure TO-420-905.

10:32 A.M. – NCO-3 re-starts transfer pump, based on direction from OE-1.

11:57 A.M. – OD briefs workers and writes "PER CH2M-PER-2007-1299."

3:11 P.M. – Operator discontinues transfer in accordance with TO-420-905, step 5.8.2, to clear blockage; process engineer contacted for concurrence prior to execution.

3:27 P.M. – NCO-3 runs transfer pump in reverse using "stop auto reverse" feature; then resumes transfer.

6:22 P.M.– Retrieval pump stops due to ground fault alarm on Variable Frequency Drive (VFD).

9:45 P.M. – NCO-2 flushes transfer line to SY-102 per operating procedure TO-420-905.

10:00 P.M. – E-2, M-1, and EE-1 complete troubleshoot of VFD and associated electrical system. No problem/cause determined. VFD ground fault alarm cleared.

10:13 P.M. – NCO-9 restarts transfer pump in reverse.

10:30 P.M. – NCO-9 immediately shuts down transfer pump when motor current increased rapidly to 75 amps (Normal is about 10 to 15 amps).

10:30 P.M. – NCO-9 attempts twice to operate transfer pump in reverse. Attempts are unsuccessful.

10:45 P.M. – OE-2 calls out work crew (E-1, MW-1) to manually rotate pump in reverse per routine work package.

11:30 P.M. – Work crew arrives and is briefed by ML-1.

Friday – July 27, 2007

00:00 A.M. – E-1, MW-1, HPT-4, OE-2, ML-1, and EE-1 enter S Farm and make four attempts to manually rotate pump in reverse, followed each time by attempts to operate the pump electrically. Lock Out/Tag Out with Authorized Worker Tag (AWT) used to isolate pump motor during manual rotations. Initial manual rotations observed from outside fence by EE-1.

01:30 A.M. – Work crew plugs motor supply cord into receptacle.

01:30 A.M. – NCO-9 in OCT runs pump two times at 45 HZ for 105 seconds each time.

02:05 A.M. – All personnel exit S Farm with manual pump rotation package complete.

02:08 A.M. – Field NCO-8 meets HPT-4 at the S Farm Change Trailer.

02:10 A.M. – NCO-9 runs pump in reverse from OCT for about 105 seconds. (No one is stationed in the farm.)

02:10 A.M. – Tank waste spills into ground around Riser 7.

02:10 A.M. – HPT-4 in S Farm Change Trailer observes increase in the Ludlum Frisker background from 100 to 400 counts per minute (cpm) for less than a minute before settling at 200 cpm.

02:15 A.M. – HPT-4 and NCO-8 enter S Farm via S Change Trailer to perform post-transfer surveys and NCO-8 to perform shutdown valve line-up.

02:20 A.M. – HPT-4 detects 200 mR/hr (closed window) at 10 to 12 feet from riser extension enclosure and notifies OE-2 in OCT of high radiation reading or bad instrument. OE-2 notifies SM-2 of possible high reading.

02:20 A.M. – HPT-4 and NCO-8 exit farm and NCO-7 obtains second RO-20 from 2704-HV

02:40 A.M. – HPT-4 and NCO-8 re-enter tank farm.

02:40 A.M. – NCO-8 notices a darkened area or shadow on north side of pump pit. NCO-8 makes radio report to OE-2 that "this farm is stinky."

02:40 A.M. – HPT-4 confirms radiation levels with second set of instrumentation; notifies OE-2 in OCT and RM-1. 100 mR/hr (closed window) both sides; west side 100 mR/hr (closed window) at 6 feet from pump box. CO personnel stationed at SX, S, and SY Change Trailers to prevent personnel entry into High Radiation Area (HRA).

02:40 A.M. – OE-2 notifies SM-2 of HRA conditions at S-02B valve pit; personnel evacuated from area; transfer secured; personnel instructed to not enter S complex. No active leak detectors in alarm; material balance discrepancies within specifications.

02:40 A.M. – HPT-4 notifies RM-1 of anomalous radiological conditions (elevated general area dose rates) at Tank S-102.

02:40 A.M. – Log Entry – OE-2 reports SM-2 HRA condition around S-A valve pit; personnel evacuated from area; transfer secured and personnel instructed not to enter S Complex. TF-AOP-006, *Response to High Radiation Area*, initial actions complete. RadCon on call performed dose investigation. No active leak detector and MBD is within specifications (see S-102 pump procedure MBD note, swing shift 7/26/07). NOTE: SM-2 does not dial 911 per procedure AOP-006.

02:43 A.M. – OE-2 contacts OD and reports HRA around pump.

02:45 A.M. – CO RadCon Support Manager initiates cell phone contact with OE-2.

- Verifies that S-Complex Tank Farm is controlled and is to continue being controlled as a HRA with no access allowed.
- Verifies that OE-2 has communicated known conditions and control of S-Complex Tank Farm.
- Instructs OE-2 that no entries into the S-Complex Tank Farm be made until her arrival to develop an entry plan with appropriate controls.

02:51 A.M. – RM-1 initiates phone conversation with OD and discusses instructions and controls from 0243 conversation with OE-2.

03:27 A.M. – CO RadCon Support Manager initiates cell phone conversation with SM-2.

- Verifies that S-Complex Tank Farm is controlled as an HRA.
- Verifies that OE-2 has communicated conditions to SM-2.
- Receives information that WFO SM has entered into TF-AOP-006, *Response to High Radiation*, and is taking actions as listed.

03:30 A.M. – S Farm OE-2 contacts OD and requests permission to call in NCOs for support. Permission given.

03:32 A.M. – S Farm NCO-7 contacts OD: "Have not had a break, please get additional operator support here."

03:42 A.M. – OD contacts SM-2 and requests NCO support; informed that they were responding to problem in WFO (WFO HPT responded).

03:45 A.M. – RM-1 contacts Senior On-Call Manager.

03:45 A.M. – OD contacts CO S Farm Project Director.

03:49 A.M. – RM-1 initiates cell phone conversation with HPT supporting Tank S-102 Retrieval Operations. Provides instructions to:

- Begin immediate habitability surveys outside of S-Complex to include:
  - grab air sampling for radioactive material;
  - radiation dose rates; and
  - contamination surveys.
- Discusses wind speed and direction with HPT. Verifies no wind detected or noted at this time.

03:59 A.M. – OE-2 notifies NCO-7, NCO-8, NCO-9 that S-Complex access control will be performed using key control.

04:00 A.M. – Senior On-Call Manager contacts SM-2.

04:00 A.M. – RM-1 and OD start planning investigative survey.

04:09 A.M. – Grab air sampling begun at west side of S Farm between 242-S and SX-Change Trailer.

04:00 – 05:00 A.M. – Performed RadCon investigative surveys at tank farm fence line (readings <0.5 mR/hr, closed window). Sampling includes dose rates, air sampling, and a discussion that no apparent wind noted from any direction.

04:10 A.M. – SM-2 discusses ongoing actions with Senior On-Call Manager. Senior On-Call Manager directs that a "send page" on HRA discovery at Tank S-102 be issued. SM-2 directed to call FR.

04:10 A.M. – RM-1 arrives at S Farm Complex.

04:15 A.M. – Senior On-Call Manager contacts C Farm Project Director.

04:15 A.M. – Log Entry – COSM notified ORP FR of Tank S-102 HRA and completed send page.

04:22 A.M. – CO RadCon Support Manager arrives at Shift Office, and SFOD arrives at S Farm.

04:22 A.M. – RadCon Program Director contacts RadCon Count Room support HPTs. Requests they travel to 2704 HV for potentially needed sample counting support.

04:27 A.M. – RadCon Programs Director contacts CO RadCon Support Manager and offers support for event.

04:28 A.M. – First page notification sent by WFO Shift Manager stating "Elevated Dose Rate @ S-102 pit results in HRA. No abnormalities during S-102 transfer."

04:50 A.M. – Senior On Call Manager contacts Acting Company President to discuss the event and reports that Senior Management in Denver aware of event.

05:10 A.M. – RadCon Program Director arrives at event scene and contacts CO RadCon Support Manager and offers support for event.

05:14 A.M. – CO Radiological Control Director (Acting) contacts CO RadCon Support Manager and receives current status of radiological conditions and activities.

05:15 A.M. – CO Radiological Control Director (Acting) and RadCon Program Director arrive at S Farm Operations Lunchroom Trailer. They receive briefing from OD and CO RadCon Support Manager on event status. CO S Farm Operations Director states his belief that the transfer line has a slug of waste material, causing elevated dose rate readings.

05:43 A.M. – Night Shift SM-2 relieved by Day Shift SM-4.

05:43 A.M. – Day Shift SM-4 reviewed log and assumed duties.

05:57 A.M. – RadCon Program Director contacts CH2MHILL Safety, Health, and Quality Assurance Vice President to provide a brief and update. Restates OD's belief that the transfer line is plugged. They discuss establishing a conservative and defensive posture for re-entry until a plugged line is confirmed.

06:11 A.M. – OD attempts to contact C-Farm IH Manager and leaves message.

06:25 A.M. – First habitability air sample at the S Farm west fence line (from 04:10 A.M. to 06:25 A.M.) field-counted. No indication of airborne radioactivity. Second habitability air sample at same location started.

06:30 A.M. – Safety, Health, and Quality Assurance Vice President contacts Acting Company President.

06:55 A.M. – COSM reports using the tank farm cameras to monitor the S-102 pit area. No evidence of a leak. Still no active leak detectors. OD suspects a slug in the transfer line.

07:00 A.M. – FH Teamsters (FHT) start herbicide north and northwest of SY Farm (mixture of Prox, Overdrive, and MSO).

07:20 A.M. – Log Entry – CO RadCon Support Manager reports the initial HPT-4 readings at the S-02B valve pit were 200 mR/Hr beta-gamma at 8 feet on west side of valve pit. Investigative survey will be performed using RWP CO-T-101, Revision 009. Will start in SY Farm at the PPP then down the HIHTL to S-102. Turn back values established. PPE and dosimetry. Using RWP and AOP-006.

07:20 A.M. – CO RadCon Support Manager briefs the SM-4 on the proposed re-entry plan for S-Complex.

- Reports HPT dose rate readings of 200 mR/Hr at S-102.
- Instructs all personnel assigned duties in re-entry plan to use RWP COJ-101.
- Discusses re-entry plan objectives:
  - turn-back values;
  - survey requirements;
  - personal protective clothing and equipment; and
  - dosimetry requirements

07:30 A.M. – S-102 Operations Director and OE-1 views area of S-102 with binoculars; no indications of leak observed.

07:30 A.M. – Safety, Health, and Quality Assurance Vice President contacts ORP.

08:30 A.M. – Pre-entry briefing with work crew/

08:35 A.M. – TMR subcontractor reports smelling creosote-like odor in 242-S parking lot. IH surveys taken in general area are normal. Radiological surveys at head level (GM) were abnormally high (800 cpm; normal is less than 100).

09:45 – IH Sample survey in 242-S parking lot shows less than detectable VOC and ammonia. NOTE: These samples were not directly related to the spill response, but rather an unrelated report of unusual odor at this location.

09:45 A.M. - Log Entry – Report that pre-job complete for entry to SY and S Farm for investigative survey, 2 HPTs and 1 NCO. High Rad guard on station on SY Change Trailer. Authorized entry.

09:45 A.M. – HPT-4, FLS-1, and NCO-2 walk the transfer line from SY-102 Anti-Siphon Slurry Distributor (ASSD) to S-102.

10:07 A.M. – HPT-4, FLS-1, and NCO-2 report normal background radiation readings until S-A valve pit, 80 mR/hr at contact (direct); personnel approached closer and reported beta and gamma readings near the S-102 passive breather filter (near pump pit readings of approximately 15 R/hr (open window), 5 R/hr (closed window); observed wet, oily looking ground (highest reported readings 25 R/hr (shallow dose equivalent) 5 R/hr @ 30 cm). Tank S-102 Operations Director directs workers to take cover. Re-entry team take grab air sample and two lapel samples.

10:07 A.M. – Log Entry – S entry team backing out. Observed dark liquid around S-102 pump pit and breather filter. SM notified.

10:10 A.M. – Log Entry – Dispatched FOS to SY Change Trailer.

10:15 A.M. – FHT Fuel Driver checks levels on compressors, pumps, and generators at S Farm fence line at south end of S Farm Change Trailer parking lot. Driver is waved to MO-027 (told he was going to be detained for a little bit).

10:20 A.M. – Safety, Health, and Quality Assurance Vice President contacts ORP; notifies them that spill observed.

10:21 A.M. – Log Entry – There are nine people @ SY Change Trailer, eight @ MO-027, HVAC units, shut down. Local winds NE – SW, Stability Class D (eventually 11 people in SY Change trailer).

10:25 A.M. – FHT Fuel Driver parks his truck at the rear of MO-027.

10:30 A.M. – Truck driver takes cover in MO-027.

10:30 A.M. – FHT herbicide applicator hears Take Cover Alarm and returns to shop. At that time he was E-SE of SY Farm (siren sounded at 10:35)

10:32 A.M. – SM calls 911, requests a precautionary "take cover" in 200 West and a Hazmat response to SY Change Trailer.

10:35 A.M. – Sirens sound for the take cover.

10:53 A.M. – Event coordination team paged.

11:00 A.M. – ICP activated at MO368 WFO Shift Manager's office. IC checks met data; official notifications completed.

12:35 P.M. – ERDF personnel released to 2704 HV.

12:40 P.M. – S Tank Farm personnel released to 2704 HV.

12:50 P.M. – ORP Emergency Manager arrives at EOC.

~1:00–3:00 P.M. – HFD perform initial medical evaluation under AOP-12; seven people went to AHM.

1:26 P.M. – News release issued.

1:48 P.M. – ECC Notified Department of Ecology of spill.

2:25 P.M. – ONC categories vent as ORPS reportable.

3:15 P.M. – IC-1 lifts 'Take Cover'.

5:03–5:45 P.M. – Tank farm entry made to apply fixative.

Saturday 7/28/07

9:30 - 11:50 A.M. – Tank farm entry made to apply additional application.

END TIMELINE

APPENDIX E

Supporting Information – Industrial Hygiene and Medical Programs

Introduction

The July 27, 2007, accident resulted in the release of an estimated 85 gallons of tank waste, including suspended solids and vapors, in a short period of time from a ruptured dilution hose near the pump. At the time of the accident, workers were not present in the area of the spill. However, in the hours and days following the spill, a number of Hanford workers identified odors, experienced symptoms or health effects, or expressed concerns about their potential exposure to the waste chemicals from the spill.

The DOE Type A Investigation Board, in response to these worker concerns, established a chemical exposure and health effects sub-team to address the potential worker chemical exposures resulting from this accident. The sub-team consisted of two medical personnel, a toxicologist, and an industrial hygienist. The sub-team interviewed workers who had identified medical symptoms, reported odors, or both that were associated with the spill; reviewed procedures and accident events; evaluated the consequences of the spill; and investigated the reasons for the reported symptoms and health effects.

Considering the nature of the accident and the location of workers, the primary focus of the chemical exposure and health effects sub-team was to determine the degree to which vapors released during the accident could cause worker exposures and subsequent health effects. To systematically examine the potential impacts on workers, the sub-team evaluated four areas: (1) industrial hygiene practices associated with monitoring chemical vapors from Tank S-102 and industrial hygiene response to the spill event; (2) chemical and toxicological exposure hazards associated with the spill; (3) medical symptoms and potential acute and chronic health effects of the workers in the vicinity of the spill; and (4) adequacy of the medical response to this accident.

The following background information is important to an accurate understanding of the evaluation of the potential for exposures and health effects to workers.

- Vapor exposures and their potential health effects on workers have been a longstanding area of attention at the Hanford tank farms. Because of worker complaints, internal and external assessments and studies, and DOE and contractor initiatives, the potential for vapor exposures and the appropriate controls have been extensively evaluated in the past few years. As part of the site's efforts, Hanford Waste Tank industrial hygiene (IH) program staff has made substantial improvements and developed extensive information about the composition of the vapors in the tanks, the nature and magnitude of fugitive emissions, the potential health hazards to workers, and the application of controls to manage the vapor exposure risks to workers.
- For much of the past few years, workers in the tank farms were required to use respirators and chemical protective clothing. Extensive industrial hygiene monitoring and sampling of tank vapors in the S Tank Farms was conducted since the commencement of waste retrieval for Tank S-102 in December 2004. All results outside of vapor control zones (VCZ) were below 50 percent of exposure limits and 95 percent of the results were below detection limits

for the instruments. As a result, industrial hygiene eliminated the requirement for the use of chemical protective clothing and respirators, with the exception of specific work tasks involving the breach of a waste tank confinement or entry into vapor control zones. The technical basis for the current sampling and monitoring program for S-102 is well documented in the *Tank 241-S-102 Waste Retrieval Industrial Hygiene Monitoring Plan* and supporting interoffice memoranda.

- Most of the CH2M Hill efforts have focused on controlling vapor exposures to vapor that is released during normal operations through the tank breathing vents. The information obtained in the past few years is useful in evaluating the potential chemical exposures and health effects that were possible from the July 27 accident.

Industrial Hygiene Practices and Response

During the past few years, progress has been achieved in the procurement of instrumentation, and in the development, revision, and implementation of hygiene programs, including industrial hygiene procedures and training. Since the 2005 DOE Office of Independent Oversight review of tank farm operations, procedures have been developed and implemented for all of the primary industrial hygiene instrumentation. Additional instrumentation has been procured, including a state-of-the art portable gas chromatograph for field identification of chemical vapors. A training and qualification program for industrial hygiene technicians has been developed and implemented. This has resulted in increased knowledge for technicians, according to interviews, and in improved consistency and rigor in industrial hygiene instrument records.

The industrial hygiene sampling and monitoring program for normal waste tank operations is well defined in procedures, technical basis documents, and interoffice memoranda. For example, the 238 page *Industrial Hygiene Technical Basis* provides a mechanism by which the industrial hygiene professionals can make decisions and set controls to ensure worker protection from waste tank chemicals and vapors. At the time of the spill, a program for routine sampling of tank areas, breather filters, and workers had been established and was being implemented as planned, based on the 3-year duration of the S-102 waste retrieval campaign.

Immediately before the spill, operators and maintenance personnel were conducting pump operations and corrective maintenance on the S-102 pump. Work control documents in effect at the time of the spill included tank farm Operating Procedure TO-420-905, *Perform 241 S-102 Waste Retrieval Pumping*, and associated work permits (radiological, lockout/tagout, etc.), and corrective maintenance was being performed under verbal work control as described elsewhere in this report. At the time of the spill, two vapor control zones had been implemented for S-102 at the breather filter and near the Continuous Airborne Monitoring Control Panel, as defined in the Tank Vapor Information Sheet. Respiratory protection was not required for this activity. Chemical protection requirements for workers were defined in the work control documents.

Notwithstanding the improvements in industrial hygiene programs, the Accident Investigation Board identified three areas of concern in the CH2M Hill industrial hygiene program and the industrial hygiene aspects of the response to the accident. These concerns are discussed in the following paragraphs.

Insufficient Communication and Implementation of Established Requirements

Although the vapor-monitoring plan and requirements are well documented, some of the chemical hazard controls for workers that were in effect at the time of the spill were incorrect, difficult to locate, and/or not followed by workers. One problem was that the documents in the work package did not always accurately reflect current requirements. For example, revisions A and B of the tank farms Job Hazard Analysis accompanying the *S-102 Waste Retrieval Pumping* procedure had been replaced with a Worksite Hazard Analysis in October 2006 as part of changes that CH2M Hill made to the Job Hazard Analyses program. The Worksite Hazard Analyses is a tool used by workers to identify the hazards, controls, permits, and associated personal protective equipment (PPE) at a worksite, as defined in the CH2M Hill Job Hazard Analysis procedure. The Worksite Hazard Analysis in effect for operators at the time of the spill identified requirements for chemical hazard controls, including silver shield gloves, self-contained breathing apparatus (SCBA), rain suits, and industrial hygiene monitoring for flammable gases. However, these controls were not required by industrial hygiene and had not been removed from the Worksite Hazard Analysis at the time of the spill. As a result, the chemical PPE requirements at the time of the spill were indeterminate or were not followed. A contributing factor is that procedures for performing the hazard analysis apparently were not followed. Specifically, Step 3.1.2 of the *Waste Retrieval Pumping* procedure requires a walk down of the job and documentation of hazards and controls on the Worksite Hazard Analysis. However, there is no record of such a walk down, which may account for the considerable number of errors in the Worksite Hazard Analysis.

Insufficient Provisions for Coordination and Integration of Industrial Hygiene in Response to Abnormal Conditions

Industrial hygiene monitoring was well established and documented for routine tank work activities and in support of planned work. However, the potential chemical hazards associated with abnormal conditions were not sufficiently identified by operations personnel immediately following the spill and were not analyzed to facilitate an effective industrial hygiene response to some abnormal events (e.g., high radiation). A spill during pumping operations is a credible but unanticipated event at the tank farms. A spill is also one of the possible causes of a high radiation condition. Thus, the likelihood that chemical vapor hazards would coexist with radiation hazards is a foreseeable event that should be reflected in response procedures and in responses to the accident by health physics technicians, workers, and supervisors.

The existing industrial hygiene procedures or protocols are not sufficient for responding to the potential of chemical exposures resulting from spills or other unanticipated events identified in the Tank Farms Hazard Analysis and other safety basis documents. Industrial hygiene has developed procedures and protocols for responding to an unexpected odor event. However, the response to an odor event is generally straightforward and does not include more than routine measurements with two standard direct reading instruments for VOCs and ammonia. Although appropriate for odor events, this procedure is not sufficient for the credible range of abnormal events. Industrial Hygiene has also issued a procedure for responding to hazardous material leaks, spills, or personnel contamination. That procedure focuses more on personnel notification rather than recognition and evaluation of the hazard. Furthermore, the emergency response procedures, as described in Section 2.3, lack sufficient industrial hygiene guidance and monitoring protocols for responding to such events. As a result, industrial hygiene resources, including investigative staff and instrumentation, are not integrated into the response to abnormal events in a timely manner (except for reported odor issues). As discussed below, for this spill event industrial hygiene services were not directly involved in comprehensive sampling and monitoring until 13 hours after the event.

Because many abnormal events, such as a spill or tank vapor release, are brief and transitory, established monitoring protocols and pre-staging of instrumentation based on risk and probability will be necessary to provide adequate monitoring and sampling data. However, the Accident Investigation Board recognizes that, even with such plans in place, monitoring of potential worker exposures can be extremely difficult in many scenarios, particularly short duration events, because of the nature of the unanticipated event. In addition, the vast variety of chemicals in the tanks and headspaces creates significant challenges; each chemical could require different monitoring, sampling instrumentation, and protocols.

Insufficient Provisions for Timely and Relevant Industrial Hygiene Monitoring to Evaluate Exposures Following in Response to Abnormal Conditions

Largely because of the insufficient abnormal response procedures and coordination and integration issues discussed above, the industrial hygiene monitoring and sampling data collected during the period following the accident were not sufficient to provide an adequate estimate of worker exposures to the tank spill event. Although the spill was estimated to occur at approximately 2:10 A.M. on July 27, 2007, the first industrial hygiene monitoring conducted specifically because of the spill was performed at 3:30 P.M. (more than 13 hours after the spill). This monitoring was performed in support of the emergency response team's effort to establish respiratory protection requirements at the tank farm boundaries and was not focused on evaluating chemical exposures to workers or providing a basis for evaluating health effects. Monitoring conducted at this time was "habitability" monitoring, using direct reading instruments for VOCs and ammonia. Initial air samples (personal breathing zone) were first obtained inside the fence at 9:45 A.M. on July 29, 2007 (2 days following the event). As of September 5, 2007, there had been no collection or laboratory analysis of the spilled material for chemicals.

Unrelated to the spill, some industrial hygiene monitoring at the S Tank Farms was conducted at approximately 8:30 A.M. on July 27. The direct reading monitoring conducted at this time was performed outside the S-Area Farms and in response to a "creosote" odor identified by a subcontractor (TMR01) and unrelated to the S-102 pump operation. In response to the "creosote" odor, direct reading instruments for VOCs and ammonia were obtained at three locations outside the S-102 fence near the 242S evaporator. All readings indicated non-detectable concentrations of VOCs and ammonia.

For the specific circumstances of this accident, the period in which higher vapor concentrations were present was likely to be very short. Therefore, even a rapid deployment of industrial hygiene monitoring may not have provided sufficient specific and useful information about the type and quantity of chemicals in the area of the spill or in the breathing zone of workers in the area. Nevertheless, the accident revealed a number of weaknesses in industrial hygiene practices and response that need to be corrected and could be important in other accident scenarios,

Chemical and Toxilogical Exposures

This section examines the potential chemical and toxicological exposures, including the type and quantity of chemicals vapors in the tanks, the characteristics of the spill, dispersion after the spill, and the estimated airborne chemical consequences from the spill.

Hanford tank farm personnel have performed analyses of the chemicals in the tank over the past several years. In response to this accident, they performed additional analyses of the release during the accident, the subsequent dispersion of the chemicals in the atmosphere, and the exposure of individuals in the area, considering the distance from the spill, and the time and duration that they were present in the area. The Accident Investigation Board reviewed the work performed by industrial hygiene personnel to evaluate the credibility of the exposure model in determining estimates of chemical exposures.

Hanford Analysis of Chemicals in the Tanks

Chemicals in the Hanford Tanks, including S-102, have been extensively studied. The ongoing release of these chemicals through the breathing vents has also been extensively evaluated. Vapors from the tank headspace have been sampled periodically since the early 1990s, with the most recent chemical analysis of headspace vapors being conducted in 2002. In addition, headspace gases emanating from the S-102 tank breather filter and the portable exhaust (which is operated during waste retrieval operations) are routinely sampled by IH as part of their monitoring program. The contents include dissolved chemicals in an aqueous medium, precipitated chemicals in a sludge medium, and chemical vapors in the headspace above the surface of the liquid.

At the time of the spill, Hanford data shows that over 92 percent of the solid wastes had been removed from S-102, as well as all of the liquids, with the exception of the liquid residual from dilution and sluicing activities performed on the waste in the tank. The chemical waste assumed to be released during the spill consisted of some fraction of dissolved waste solids and the vapors associated with this material. Table 2 provides an estimate of the concentration of headspace gases in Tank S-102 at the time of the spill based on measurements from the S-102 exhauster and breather filter.

The toxicological effects of the chemicals have also been extensively studied, including a review by an independent panel. For many of the chemicals in the tanks, various occupational exposure limits (OEL) have been established by government agencies or industrial groups. Threshold limiting values (TLV) are one of the most commonly used types of OEL. Exposures below these values are unlikely to cause adverse impacts on human health. For many other chemicals present in the tanks, however, no widely accepted OELs have been established. When no such limits were found acceptable, a prior 2004 Hanford independent toxicological panel (ITP) recommended exposure limits for selected chemicals based on criteria such as animal experimentation data or results from similar chemicals. In the case of demonstrated human carcinogens, the approach recommended by the ITP was to limit exposures to as low as possible.

Table 2 shows a list of 18 chemicals that were most likely to be present in the S-102 headspace at the time of the spill; the highest concentrations of each that were detected, reported, or calculated; the OEL, and the ratio of the concentration of the chemical to the OEL. The table reveals that the maximum measured concentration is in the range of 10 percent of the OEL. Ammonia, nitrous oxide, and N-nitroso-dimethylamine (NDMA) exceeded the OEL.

Acute toxicity and potential carcinogenicity of these same chemicals is provided in Table 3. A description of the acute toxicological profile of each chemical is presented, as well any data on long term carcinogenicity resulting from exposure to these chemicals. Data on chronic toxicity is not shown because of the transient nature of the spill. In reviewing this material, it is important to understand that any type of toxic effect will be related to the degree of exposure and individual sensitivity. For each effect, there will be a dose-response relationship for acute effects. The data source is the Hazardous Substances Data Base of the National Library of Medicine.

CH2M Hill Analysis of the Spill and Subsequent Dispersion

It was determined that the accident resulted in the short-term release and spill of approximately 85 gallons of S-102 waste within a 20-foot-diameter zone outside the S-102 tank pump.

To develop an estimate of potential human exposure to chemicals in the spill 3 days following the spill event, the Industrial Hygiene group developed an “S-102 Waste Spill Chemical Dispersion Model.” This exposure model predicts the worst-case scenario for an assumed instantaneous release of two representative headspace chemical vapors that are likely to be in a release/spill as reflected in Table 2.

The two selected representative chemicals are ammonia, which is the chemical present at the highest concentration and which also was present at approximately 16 times the OEL, and N-dimethylnitrosamine (or NDMA), a potential carcinogen which was present at 9 times the OEL (see tables 2 and 3). There is general agreement among many regulatory agencies regarding the OEL for ammonia. But, because there is no established occupational exposure standard for N-dimethylnitrosamine, the data in tables 2 and 3 for the OEL for N-dimethylnitrosamine (i.e., 0.3 ppb) were developed at Hanford considering the ITP’s recommendations. This OEL for NDMA is also consistent with the occupational standard developed for NDMA by the German government. Ammonia is a strong irritant and a good indicator of the presence of other volatile chemicals. NDMA is a model for other volatiles that may not cause immediate symptoms, but may have long-term health consequences (e.g., cancers).

The data in Table 2 were taken from headspace exhaust analysis. The potential exposure to the spill involved chemicals trapped in the sediment of the tank. The assumption made in developing the model was that the headspace data could serve as a reasonable surrogate for the concentration of chemicals in the sediment. The procedure for developing the dispersion model, and the assumptions used in its establishment, are reported in a memo from M.L. Sable to T.J. Anderson et al., dated August 23, 2007.

The model predicts dispersion of both chemicals within a few minutes from the release. The suggested exposures derived from the model described in the August 23, 2007, memo, were shown in the August 3 memo. They suggest, for example, that for NDMA, a person 3 meters (approximately 10 feet) from the source 1 minute after the release would be exposed to 113 ppb, whereas at 5 minutes after the release, the exposure would be 0.9 ppb. The model suggests that the released vapors are rapidly diluted near the source, but residual vapors can be detected at some time and distance following the release. Thus, at 16 meters, (or about 50 feet) no NDMA would be detected at 1 minute, but 0.9 ppb would be detected at 5 minutes. At distances from 1 to 40 meters, 0.11 ppb would be detected at 10 minutes after the release. [Note: This model suggests that the material at the source is completely volatilized, which is a conservative approach. If there is residual material at the source, there would be continued release of vapors but for the same total quantity the peak vapor concentrations would be lower.] Figures 1 and 2 provide a graphical presentation of the maximum exposure distances from the spill at which a worker could potentially have exceeded the 8-hour Time Weighted Average concentration for both ammonia and NDMA.

Accident Investigation Board Analysis of Hanford Exposure Modeling

The Accident Investigation Board believes that the CH2M Hill Industrial Hygiene group analysis of the chemicals, source term, and dispersion is credible. There are a number of assumptions inherent in the analysis. However, several assumptions are conservative (e.g., the assumption of an instantaneous release when the actual release probably took over a minute). Other assumptions are credible and their uncertainties are reasonably well understood (e.g., the assumption that the chemicals in the release are adequately characterized by the existing analysis of tank chemicals) and that the two chemicals selected for dispersion modeling are adequate to bound the credible exposures.

Notwithstanding the uncertainties and assumptions, the Hanford analysis demonstrates that chemical exposures from the S-102 tank accident would be negligible beyond 25 to 30 meters, even in the worst-case scenario. This distance is well within the S Area tank farm fence. Only two individuals were within the time-weighted average exposure circles depicted in figures 1 and 2 shortly after the spill, as further discussed in the following section.

Medical Symptoms and Potential Acute and Chronic Health Effects for the Workers in the Vicinity of the Spill

Reported Chemical Exposures

As of September 1, 2007, a number of CH2M Hill, Fluor Hanford, and their subcontractors had reported to medical and indicated a possible exposure to tank vapors resulting from the spill. Some symptoms and complaints were reported within hours of the spill event, and others were reported several weeks following the spill. A number of these employees were interviewed by the Type A Investigation Board based on their complaints and symptoms and on their proximity to the event in time and distance (see Table 1). Other individuals may have come within the 200-meter radius, which was used by CH2M Hill as an administrative limit of possible exposure. However, these individuals were present for only brief time periods, were not inside the fenced perimeter of the S-Area tank farm, were present only after the spill plume had dissipated, or had no symptoms or complaints. The Board believes that the potential for these individuals to be exposed was very low.

In addition, a group of eight subcontracted workers indicated that they may have been exposed to hazardous chemical vapors resulting from the spill as a result of their environmental well-drilling pad preparations south of the West Tank Farm (see Figure 2). Two of these individuals reported odors or symptoms following the spill. However, upon reviewing the location of these workers following the spill, and their approximate time at this location (3 to 5 hours after the spill), their potential for exposure is also judged by the Investigation Board to be very low. Based on interviews, the workers were outside the 2W fence, in front of the laboratories and the REDOX building. That location was greater than a mile from the S-102 tank and (approximately) ½ mile from the herbicide application operation (which will be discussed later). Such a location would preclude any significant tank spill exposure from the tank vapors.

The Board interviewed 25 workers, 18 of who were involved directly or indirectly with activities following the spill and within a mile of the spill. Of these 18, 8 interviewees identified either odor or health symptoms or both. Table 1 provides a summary of the activities of several of these workers, and the symptoms and odors experienced, if any. In the course of their investigation into this spill, CH2M Hill identified additional workers, a number of whom to date have received or requested medical attention. The scope of this health effects investigation, however, has been limited to only those individuals who received a transcribed interview conducted by the Board. The following paragraphs provide additional discussions on complaints, odors, and symptoms, as well as an assessment of the medical response to this spill.

Complaints and Odors

The symptoms and complaints of the potentially exposed workers, including those interviewed by the Board, were diverse among the individuals who reported experiencing abnormalities. The symptoms included hoarseness, irritated breathing, coughing episodes to the point of vomiting, abdominal discomfort/nausea, irritated eyes, “burning” skin, and various smells (creosote, overwhelming tank farm smell, sweet almonds).

The timing of the reported symptoms also was quite varied. The earliest reported symptom was reported by CH36, approximately 1 to 2 hours post-leak and was described as abdominal discomfort, which was relieved by drinking two (12 oz) bottles of water, followed by coughing episodes to the point of vomiting which occurred a few days later. FH07 reported skin burning (limited to the right upper extremities and right side of the face). CH35 experienced a wave of nausea on the drive home approximately 6 to 7 hours post-event. CH16, who was outside the tank farm fence at all times post-spill awoke with a feeling of “breathing tubes burning” 12 hours after the spill that has continued (and even increased) 4 weeks later. FH100 reported symptoms of hoarseness and tingling of the hands (which he had experienced before); he was several hundred meters from S-102 at his closest approach.

The odors reported by CH35, who was 10 to 12 feet from the pump head when the radiation fields were being defined, were described as overwhelming and the worst “tank farm” smell ever experienced. CH36 who was 2 to 3 feet in front of CH35 experienced no such odor. TMR01 (who was in the parking lot by the evaporator) reported a creosote smell, but was not concerned because the wind was blowing (at the time of the smell perception) N to NW toward the S Tank Farm.

Most symptoms are in the category of possible exposure to an irritant toxicant: skin symptoms, respiratory irritation, and eye irritation. Ammonia is the primary irritant known to be a tank component, as previously discussed. However, immediate irritant effects, especially burning eyes or nasal passages, were not reported by the two individuals who were closest to the spill (CH35 and CH36). Skin symptoms reported by the FH07 were documented by the Hanford Fire Department (HFD) Emergency Medical Technician (EMT) (“…states that his right arm & right side of face itch…”). The evaluation occurred late in the afternoon of July 27. The pulmonary symptoms of one individual (CH16) close to the tank farm fence occurred almost 12 hours post-release. A second individual (CH12) stated that a cough occurred a few days after the event, occurring twice a day (morning and evening) to the point of vomiting; the symptoms were not reported until this individual was seen at the medical organization on August 22, 2007.

Objective Medical Findings

Three individuals had objective findings that were documented by health professionals. FH07 had a red eye, which was thoroughly evaluated by a Kadilec Emergency Department physician who noted injected vessels, no corneal abrasions, and no swelling of the membrane in front of the eye. No exam of the skin for irritation, which the individual reported when visiting the emergency department, is documented in that encounter. When evaluated by a toxicologist at

Harborview Medical Center in Seattle Washington, non-specific findings of nasal mucosal stranding, and a red eye were again noted. The diagnosis of trigeminal neuralgia (facial nerve irritation) was made on the bases of the headache pattern, facial wincing, and grabbing of the face, which was observed during the interview.

FH09 had documented normal liver function before the event, but elevated liver enzymes when evaluated after the event. CH35 who was inside the tank farm fence after the spill had slightly elevated liver enzymes documented before the spill, but was noted to be improved when measured after the spill event.

All other lab abnormalities reported relate to personal medical conditions (e.g., urinary tract infection), known physiological variants (e.g., Gilbert's Syndrome), or minor excursions of red cell mass.

Individuals who were onsite at the time of the "take cover" alarm were sequestered for approximately 3 hours in environments with limited ventilation and temperature control (promoting sweating) and in some cases without water. This environment may also have contributed to their symptoms.

Other Possible Chemical Exposures

On July 27, Fluor Hanford (FH) employees began applying approximately 2,400 gallons of herbicide. The application occurred from 7:30 A.M. to approximately 10:00 A.M., north and east of the tank farm (see figures 1 and 2). The Material Safety Data Sheets for the two herbicides, anti-foam agent, and methylated seed oil indicate they may be skin, eye, and respiratory irritants, and cause gastrointestinal symptoms on ingestion (see Table 4). The FH worker coordinating the spray team access and routing reported no adverse effects from the herbicide application activities.

The two, 45-foot-long booms used in this operation spray from a height of approximately 5 feet above ground. The uneven ground of the spray area causes the boom to tilt and causes an even greater height of spray.

FH07 filled the day tank at the northwest corner of the tank farm a little before 10:00 A.M. This activity would have placed him close to the herbicide application area. The distribution of the skin irritation (right upper extremity and right side of face) is not typical of an aerosolized exposure cloud, which should be symmetrical. However, partial shielding by position cannot be ruled out. In addition, for this individual, diesel fuel may be a skin irritant, especially with repeated exposures.

Radiological Exposures to the Spill

Radiological exposures to personnel during the S-102 event were well below any regulatory action or company administrative control levels; therefore, the resulting radiological health effects would be indistinguishable from those of other radiological workers. The two individuals with the greatest potential for exposure were the operator and HPT who discovered the unexpected high radiation levels during the waste transfer line walk down at 2:05 A.M. on July 27. These individuals' TLDs were pulled and read. The highest dose of 25 mrem shallow dose and 12 mrem deep dose were received by the Radiation Control Technician (RCT). Subsequent entries into the area required direct reading dosimeters, which were used for incremental dose tracking. Personnel located outside the S Tank Farm fenced area would have received lower external doses due to the further distance from the source and low measured perimeter dose rates at the S Tank Farm boundary. There were also no confirmed intakes of radioactive material. CH35 and CH36 had the highest potential for internal exposures and were, therefore, subjected to whole body counts and to both urine and fecal bioassay for the prevalent radionuclides in the S-102 waste tank (Sr-90, Cs-137, Pu-239). Samples were collected from these individuals on July 31, and all results were less than screening levels associated with an intake. No internal dose was assigned for this event based on bioassay results. Personnel and area air samples were also taken at various times and locations within and surrounding the S Tank Farm, with no measurable radioactivity above background detected.

Medical Emergency Response

Hanford Fire Department

The initial medical response commenced when an ambulance arrived at the S Change Trailer where the emergency medical technicians triaged individuals who may have been exposed. Other workers were sent to 2704 HV Building for triage. The “Patient Contact Information” form was used to document these encounters. In general, this form is used to document EMT evaluation for any event that does not have an injury or significant illness or ambulance transfer. This EMT-completed form, mandated by the State of Washington, is used for those categories.

The Patient Contact Information form has several key sections, including patient identification information; vital signs; a place for a narrative of the event; event/hazard description; method of decontamination; and level of provider, but lacks a block for objective physical findings and a place to note the time and location of the encounter. The Medical Officer/Paramedic who is in charge of training for Hanford Fire Department expects the EMT/paramedic record documentation to satisfy the standard SOAP (subjective-objective-analysis-plan) format, which was not evident on the form, with absence of objective findings notable. Only one out of five forms reviewed noted the time of the encounter.

It was found that the physician responsible for the EMT/Paramedic program had not been involved in any reviews for “6 months to a year.” The EMT/Paramedics are trauma oriented and have limited training or expertise in chemical exposure events. Procedures place the responsibility for reporting to Advanced Medical Hanford (AMH) on the employee and the manager.

Advanced Medical Hanford

Prior to this event, when an emergency event was categorized and the Emergency Operations Center was activated, medical personnel were expected to report. The level of expertise for personnel reporting for the event can be either a physician’s assistant or a physician.

The notification of the spill occurred via two mechanisms. The pager system was used for notification of the event occurrence, which was sent to all “on call” personnel, including the clinic manager for AMH. There is always a clinic manager on call for such events. In addition, the “take cover” alarm at approximately 10:20 A.M. was received by the nurse at the 200 West Medical Facility. These notifications were adequate to invoke a response by AMH, which included calling personnel to come to the AMH facility in Richland. When the Event Coordination Team (ECT) was activated, there was no discernable attempt to request medical expertise. Since the event, AMH notification and medical support to the ECT has been incorporated into procedures, so medical expertise can be more readily available. This process has been tested during drill activities.

Baseline laboratory testing and histories were obtained at the AMH Richland facility from people who were believed to have a potential for exposure, as required by AMH procedures. Not all individuals who had laboratory work completed have had the results reported to them, for example worker FH-100.

Referral to AMH was of a voluntary nature. FH07 refused, and then was sent to the Kadilec emergency room by his management, with instructions to follow up with AMH 3 days later (Monday, July 30th). Follow-up for potentially exposed individuals was also voluntary on the part of those individuals, as they reportedly were told to return if any other problems presented.

The emergency departments of local medical facilities in the area have been given emergency exposure protocols by AMH, and a generic approach for an exposure to an uncategorized/ unknown chemical. It is assumed these will be used by the emergency department physician when evaluating individuals from the site who report an exposure. Because there is not a requirement that visits to other medical providers are to be coordinated by the AMH, the employee is the only source from which to obtain the conditions of exposure and type(s) of possible toxicants. There is no evidence that the AMH emergency exposure protocols were utilized by the examining physician at the Kadilec Emergency Department.

Coordination Between Hanford Fire Department and Advanced Medical Hanford

There is interaction between HFD and AMH, but the integration is not well defined in procedures. It appears that if an issue is trauma related, or an illness requires ambulance transport, HFD addresses the situation, and physician medical control is through the receiving hospital. If there is a toxicant involved, without any immediate patient distress, the condition is assumed to be "occupational," and the individuals are referred to AMH. The communication to AMH appears to be a copy of the Patient Encounter Form, which the employee is instructed to present to AMH. The Medical Officer for the HFD, as noted above, believes that any chemical exposure with stable patients should go directly to AMH.

Conclusions

Industrial Hygiene

Improvements in industrial hygiene programs, instrumentation, training, and the development of sampling and monitoring technical bases are evident since the 2005 DOE Office of Oversight review. The chemical constituents of hazardous chemicals within the waste tanks (such as S-102) are well analyzed. Considerable monitoring and sampling data have been performed for S-102 during the current retrieval and transfer campaign, which began in December 2004. Monitoring data collected at the S-102 tank breather filter, portable exhaust, general areas, and for workers near the tank indicate that worker exposures for most routine activities are less than the detection limits of the instruments. However, opportunities for the anticipation, recognition, evaluation, and control of the July 27 accident were missed. With respect to responding to abnormal events, improvements in industrial hygiene are needed, particularly in the following areas:

- Improvements in the recognition by site workers, supervisors, and support personnel of the potential presence of chemical hazards associated with abnormal events and the importance of integrating industrial hygiene into procedures associated with these events.
- Improvements in industrial hygiene programs, training, and monitoring to anticipate a response to abnormal events other than odor responses.

Chemical Exposure Pathways

During the past 10 years, significant resources have been dedicated to the sampling, modeling, and understanding of the chemical constituents of the Hanford waste tanks. For Tank S-102, chemicals within the tank solids and supernatant were most recently sampled in 1994-1995, when the tank was filled, and prior to any transfer or retrieval operations. However, since CY 2004, when the current S-102 waste retrieval and transfer operations began, S-102 headspace gases have been sampled and the inventory of solids has been routinely adjusted to reflect changing chemical inventories. At the time of the accident, more than 92 percent of the tank contents had been removed, as well as all of the original tank supernatants.

Since there was no IH instrumentation to monitor or detect the spill release within the initial 12 hours following the spill, worker exposures can only be predicted or estimated based on the solid and vapor chemical contents of the tank and the nature of the spill. No sampling of the spilled tank material was conducted; however, the chemicals present in the spill can be estimated from historical data. Three days following the spill, the CH2M Hill Industrial Hygiene Group modeled the spill. A resultant calculation was performed based on two “marker” chemicals. Ammonia was selected based on the abundance of ammonia within the tank and its strong odor threshold, and NDMA was selected based on relative abundance with the tank headspace and low exposure threshold since NDMA is a suspect carcinogen. Worker exposures at the 8-hour Time-Weighted Hour threshold limits were projected (see figures 1 and 2). At 2 minutes following the spill, those workers within 20 feet of the spill location would have been subjected to ammonia at concentrations of up to the 8-hour TLV of 25 ppm. The effects of ammonia are more acute than chronic, and the ammonia odors and health symptoms could have been evident at this concentration. However, no such odors or symptoms were reported by workers near the spill.   8 minutes following the spill, only those workers within 100 feet of the spill could have been exposed to NDMA concentrations up to the 8-hour TLV of 0.3 ppb. The effects of NDMA are chronic and not acute, and would not have been evident. Additional evaluation of health effects is provided in the following section.

Medical Symptoms, Complaints, and Odors

The two individuals who entered the tank farm shortly after the leak event and came within 8 to10 feet of the leak (CH35, CH 36) may have been exposed to tank vapors, especially with the pooling/ground saturation that probably occurred, according to the accident scenario. The chemical concentrations were probably low, based on the dispersion model. The chemical vapor odors may still have been quite strong, as reported by CH35. The lack of smell perception by CH36 only a few feet away may have occurred because of his focused attention to the task of defining the 100 mrem radiation limit.

Other individuals, such as CH12, and CH16, who have reported symptoms, were on the west side of the tank farm outside the tank farm fence. The closest distance to the spill region from the S Area fence was estimated at 40 meters. Based on the dispersion modeling, the volume of distribution and dispersion would indicate that exposure to an individual outside the S Tank Farm boundary fence would be below OELs.

CH12 and CH16 were outside the S Tank Farm fence and west of the herbicide application area (north and east of the tank farm). Most of the herbicide spray would have been applied when FH07 was at the northwest corner of the tank farm fence. There is no sampling data for the herbicide application, so there is no definitive information relating to the time of herbicide air suspension, drift pattern, or concentration. A possible scenario would be herbicide application, aerosol drifting from east to west, and contamination of the individuals who reported symptoms. The sequestering and sheltering of workers following the spill in Building MO027, in a warm environment without ventilation and limited drinking water, may have exacerbated the possible exposure.

FH09 who had abnormal liver function tests post-event was approximately ¼ mile from S-l02, and the herbicide components do not pose a liver toxicity risk on contact exposure. This individual should have medical follow-up, since all possibilities of liver toxicity need to be explored.

It should be noted that an isolated trigeminal neuralgia is not known to be associated with an identified toxicant. A medical records review associated with this event (and subsequent to the event) indicated that the headache of FH07 was initially described as generalized or global. It is possible, and understandable, that a tension headache could occur because of concern about the possible adverse health effects related to the event.

The delayed appearance of symptoms is not usual for an irritant exposure. A response unique to an individual is also a possibility. A low level of exposure with minor respiratory track irritation, resultant coughing and persistence due to the exacerbation of respiratory tree irritation caused by the coughing itself, is a possibility.

Medical Emergency Response

Medical response to the hazardous, mixed-waste spill was generally provided in accordance with established procedures. However, a number of concerns and opportunities for improvement were identified by the Board, such as improved communications between the Hanford Fire Department and Advanced Medical Hanford, the need for improved training for EMTs with respect to chemical exposures that are not trauma related, and improved medical monitoring and accountability of individuals with health symptoms.

Overall Conclusion

The accident is very unlikely to have caused significant exposure to workers, in large part because of the limited quantities of spilled material, rapid dispersion of chemical vapors and because no individuals were present at the time of the release. Under other circumstances or accident scenarios, the results could have been more severe.

Table 1

Health Effects and Symptoms

July 27, 2007 S-102 Spill Event Type A Investigation

Code	Org	Work Shift or Hours	Activity at the Time of the Spill or Directly Following	Maximally Exposed Location	Est. Time of Possible Exposure	Symptoms	Smells
CH36	CH2M Hill	11:30 P.M. (7/26) – 8:00 A.M. (7/27)	First to identify high radiation area near S102 following the spill.	8–10 ft from spill	2:30 A.M.	Cough to the point of vomiting, two times per day. Delayed reporting of symptoms.	None
CH35	CH2M Hill	1130 P.M. (7/26) – 8:00 A.M. (7/27)	Operations support to HPT.	50–60 ft from spill (1st);10-12 ft from spill (2nd)	2:30 A.M. (1st) 3:15 A.M. (2nd)	Nausea on drive home at 8:30 A.M. Continued hoarseness.	Strong unpleasant odor (2nd entry)
FH07	FH	07:30 A.M. (7/27) – 3:00 P.M (7/27)	Filling diesel oil tanks outside of S-tank farm boundary. In MO27 after 10:30 A.M.	NW Perimeter of S-tank farm	9:50 A.M. – 10:30 A.M. (take cover).	Nasal, skin, eye, facial nerve.	None
CH16	CH2M Hill	11:30 A.M. (7/26) – 3:00 P.M. (7/27)	Operations Support (midnight shift). No entries after midnight. Controlled access at S102 Change Trailer.		S-tank farm boundary from 2:30 A.M.	Hoarseness and irritation of breathing tree noted at 2 P.M. next day.	None
CH12	CH2M Hill	11:30 P.M. (7/26) – 8:00 A.M. (7/27)	NCO for swing shift held over. Controlling access to S farm after high radiation event.	Moving between operating trailer and Change Trailer.	45-60 min after high radiation area identified.	Abdominal discomfort, nausea 3:00 A.M. – 4:00 A.M. Drank water then OK.	None
WCH02	CEM	5:30 A.M. (7/27) –3:00 P.M.(7/27)	Not onsite during spill event.	Directly west of evaporator; outside S area; ¼ mile	5:30 A.M. – 10:30 A.M.	Prickly skin, headache, metallic taste.	Chlorine or sweet smell. Two co-workers confirmed odors.
FH09	FH	07:30 A.M. (7/27) –3:00 P.M. (7/27)	Not onsite during spill event. Arrived 7 A.M..	NE outside S Farm	7:30 – 10:15 A.M.	Raspy voice, hand numbness.	
TMR01	TMR	11:30 P.M. (7/26) – 8:00 A.M. (7/27)	Not onsite during spill event. Arrived 7 A.M. at staging area near evaporator.		7 A.M.-10:20 A.M.	None	Creosote odor 7:30 A.M. – 830 A.M. in parking lot, south of evaporator.

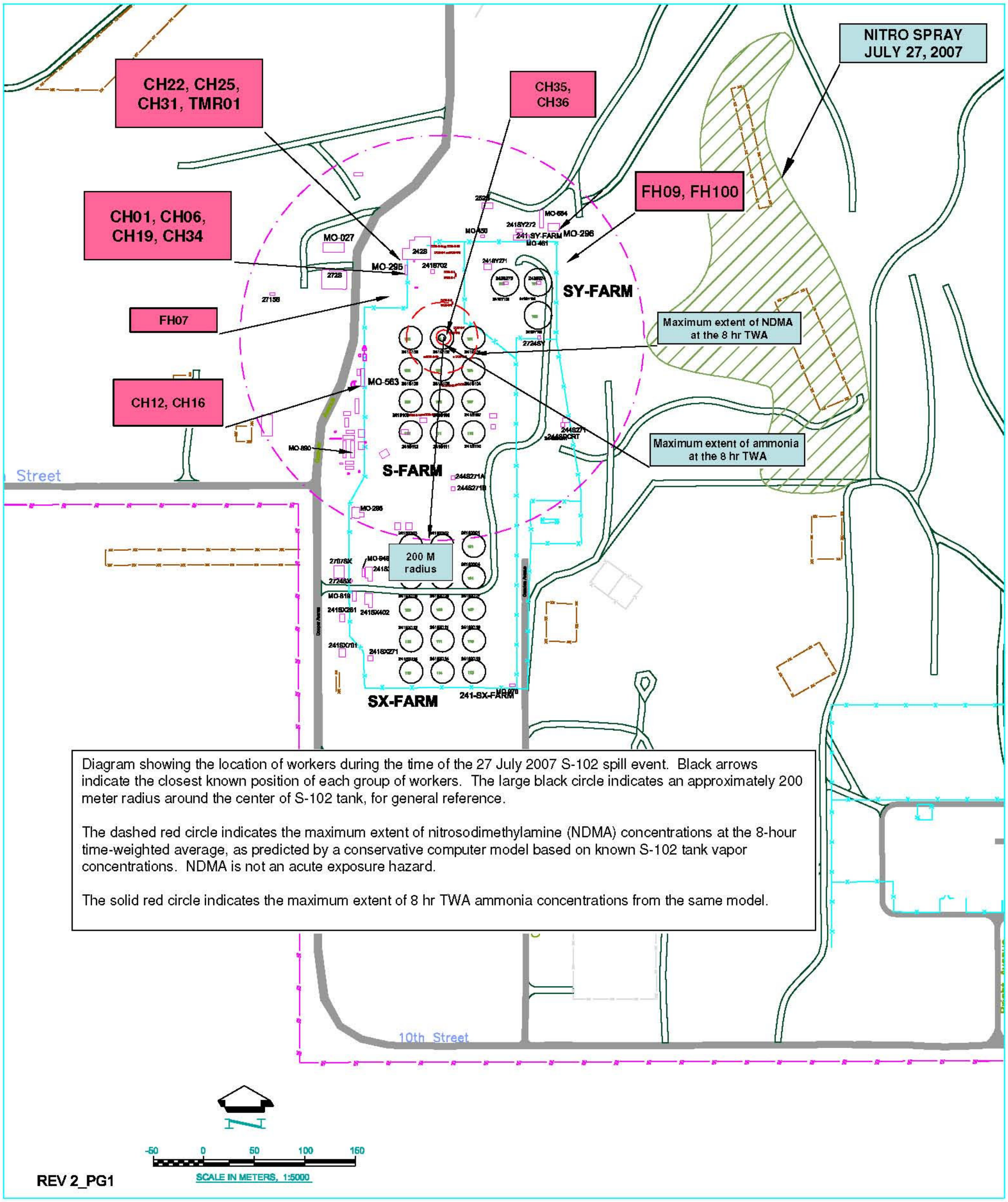
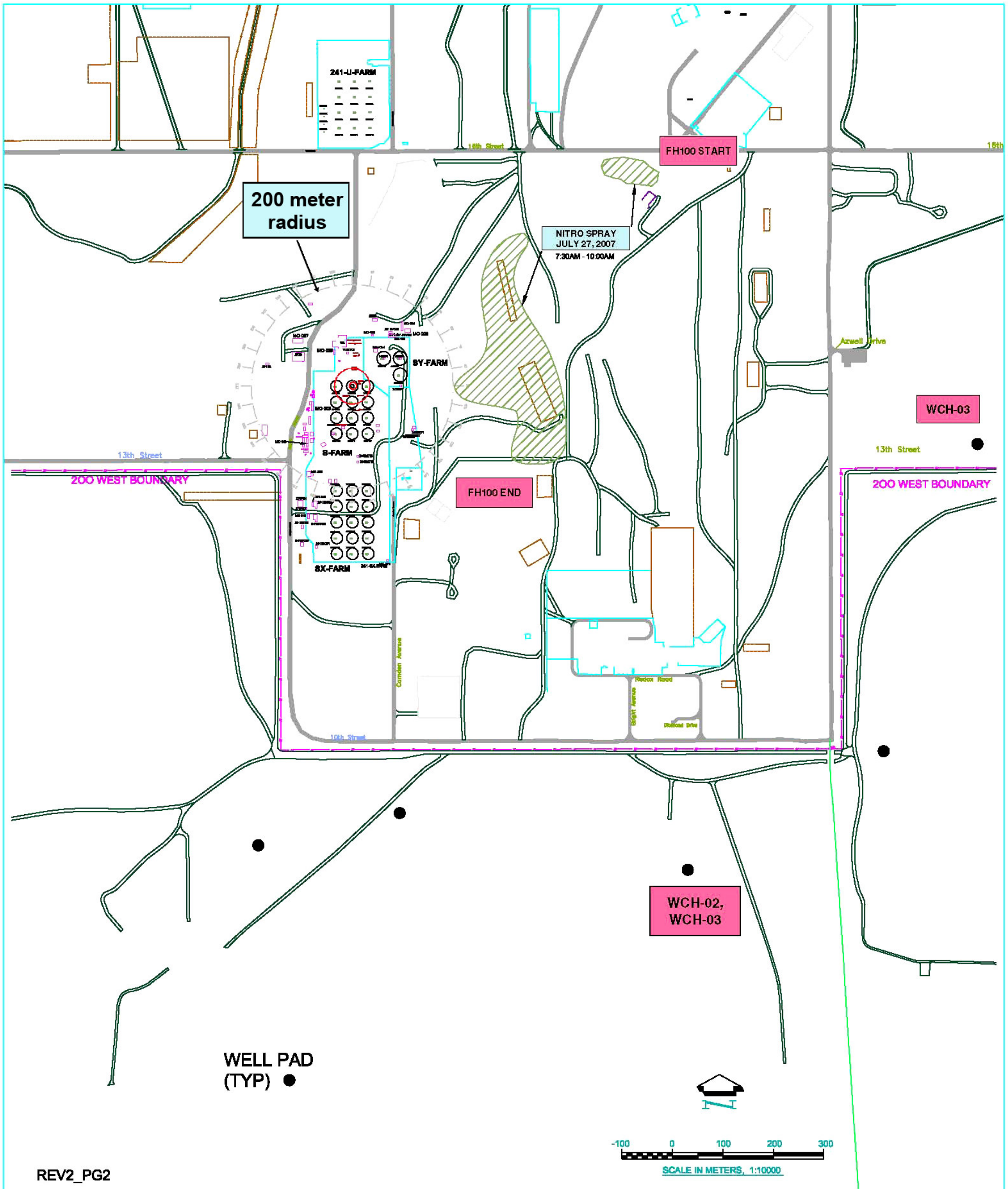


Diagram showing the location of workers during the time of the 27 July 2007 S-102 spill event. Black arrows indicate the closest known position of each group of workers. The large black circle indicates an approximately 200 meter radius around the center of S-102 tank, for general reference.

The dashed red circle indicates the maximum extent of nitrosodimethylamine (NDMA) concentrations at the 8-hour time-weighted average, as predicted by a conservative computer model based on known S-102 tank vapor concentrations. NDMA is not an acute exposure hazard.

The solid red circle indicates the maximum extent of 8 hr TWA ammonia concentrations from the same model.

S-102 Tank Spill Exposure
July 27, 2007
Figure 1 of 2



S-102 Tank Spill Exposure
July 27, 2007
Figure 2 of 2

Table 2

S-102 Headspace Gases Previously Detected in Tank S-102 Vapor Samples

Chemical	CAS #	Concentration	Units	OEL	Units	OEL Source	Max % OEL
1,4, Dioxane	123-91-1	0.012	ppm	20	ppm	ACGIH TLV	0.060
1- Butonol	71-36-3	0.87	ppm	20	ppm	ACGIH TLV	4.4
1-Proponol	71-23-3	0.017	ppm	200	ppm	ACGIH TLV	0.009
2-Proponol	67-63-0	0.022	ppm	200	ppm	ACGIH TLV	0.011
Acetaldehyde	75007-0	0.037	ppm	25	ppm	ACGIH CEILING	0.15
Acetone	67-64-1	0.024	ppm	500	ppm	ACGIH TLV	0.005
Acetonitrile	75-05-8	0.038	ppm	20	ppm	ACGIH TLV	0.19
Ammonia	6664-41-7	398.94	ppm	25	ppm	ACGIH TLV	1596
Butanal	123-72-8	0.031	ppm	25	ppm	ACGIH TLV	0.12
Ethanol	64-17-5	1.1	ppm	1000	ppm	ACGIH TLV	0.11
Methanol	67-56-1	1.8	ppm	200	ppm	ACGIH TLV	0.90
Nitrous Oxide	10024-97-2	86	ppm	50	ppm	ACGIH TLV	172
n-Nitrosodibutylamine	924-16-3	0.008	Ppb	4	Ppb	IH TECH BASIS	0.20
N-Nitrosodimethylamine (NDMA)	62-75-9	2.64	Ppb	0.3	Ppb	IH TECH BASIS	880
N-Nitrosomethylethylamine	10595-95-6	0.007	Ppb	0.3	Ppb	IH TECH BASIS	2.3
Tetrahydrofuran	109-99-9	0.015	ppm	200	ppm	ACGIH TLV	0.008
Toluene	108-88-3	0.092	ppm	50	ppm	ACGIH TLV	0.18
Xylenes	1330-20-7	0.007	ppm	100	ppm	ACGIH TLV	0.007

Table 3

Chemicals and Chemical Carcinogens Previously Detected in Tank S-102 Vapor Samples

Chemical	Acute Toxicity	Potential Carcinogenicity	Conc/ OEL
1,4-dioxane	Irritating to eyes, nose and throat from 0.1% to 3% vapor concentration; confusion, ataxia, drowsiness; convulsions at higher doses. Continued exposure can lead to pulmonary edema and renal and hepatic injury. Lethality has been observed at 470 ppm. Other workers were exposed to concentration as high as 1,600 ppm for 10 minutes, demonstrated acute irritation to eyes, but survived.	IARC Class 2B: probably carcinogenic to humans.	0.06
1-butanol	Irritation to mucous membranes, coughing; at 200 ppm; ocular effects, including corneal inflammation, possible keratitis, conjunctival edema. Reduced RBC above 200 ppm. CNS effects include headaches, giddiness, ataxia, confusion, delirium, etc.	IARC Class D: Not classifiable as a human carcinogen.	4.4
1-propanol	Mild CNS depression, drowsiness, headaches, ataxia, gastrointestinal pain, cramps, nausea and vomiting.	IARC Class A3: Confirmed animal carcinogen with unknown relevance to humans.	0.009
acetaldehyde	Eye irritation at 25 ppm for 15 min; respiratory irritation at 134 ppm for 30 min. At higher concentrations coughing, pulmonary edema, depressed respiratory rate, elevated blood pressure.	IARC Class 2B: probably carcinogenic to humans).	0.15
acetone	Emotional liability, exhilaration, tendency towards mania. Dipolopia, vertigo, flushing of face, rapid pulse, sweating. Nausea and vomiting, CNS depression. Hypotension, tachycardia, hypothermia.	IARC Class D: Not classifiable as a human carcinogen.	0.005
acetonitrile	Chest pain, tightness in chest, nausea, emesis, tachycardia, short, shallow respiration. Blood cyanide may be elevated.	IARC Class D: Not classifiable as a human carcinogen.	0.19
ammonia	Irritation to eyes and respiratory tract. High concentrations lead to conjunctivitis, laryngitis, and pulmonary edema or pneumonia.	Not reviewed for carcinogenicity by IARC or other agencies.	1596
butanal	Eye, nose, skin, and throat irritant.	Not reviewed for carcinogenicity by IARC or other agencies.	0.12
ethanol	Vapors irritate eye at 0.7-1%. NOEL at 0.25%.	IARC Class A4: Not classifiable as a human carcinogen.	0.11
methanol	Headaches, dizziness, eye irritation, blurred vision, GI distress.	Not reviewed for carcinogenicity by IARC or other agencies.	0.90
nitrous oxide	General anesthetic. Increasing CNS depression leading to loss of consciousness between 20% and 80%.	IARC Class A4: Not classifiable as a human carcinogen.	172
N-nitrosodibutylamine	ND	IARC Class 2B: probably carcinogenic to humans.)	0.2
N- nitrosodimethylamine	ND	IARC Class 2B: probably carcinogenic to humans.	880

Chemical	Acute Toxicity	Potential Carcinogenicity	Conc/ OEL
N-nitrosomethyl-ethylamineylamine	ND	IARC Class 2B: probably carcinogenic to humans.	2.3
tetrahydrofuran	Occipital headaches. Human lethal dose estimated at 50-500 mg/kg.	IARC Class A3: Confirmed animal carcinogen with unknown relevance to humans.	0.008
toluene	CNS depression	ACGIH: Not classifiable as a human carcinogen.	0.18
xylenes	CNS depression	ACGIH: Not classifiable as a human carcinogen.	0.18

Table 4

Potential Acute Toxic Effects of Chemicals Reported in Herbicide Sprays

Chemical	Acute toxic effects
Na diflufenzopyr	– No toxic effects reported in humans. – In acute studies in rats the LD50 (median lethal oral dose) ranged from 3-5 gm/kg.
Dimethylamine salts of dicamba (3,6-dichloro-o-anisic acid)	– Irritating to eyes, skin, and mucous membranes. Severe eye injury may occur after handling very fine material. Inhalation exposure may occur in the vicinity of spraying. – Loss of appetite and weight, vomiting, depression, muscular weakness. – Mean LD50 in three mammalian species was 1.6 gm/kg.
Bromoxynil octanoate	– Mild skin and eye irritant and sensitizer. – Excessive perspiration, thirst, fever, emesis, myalgia. LD50 in three mammalian species averaged 257 mg/kg.
1,2,4-trimethylbenzene	– CNS depressant; respiratory irritant. – TLV = 25 ppm
Diethlene glycol	– CNS depressant. Liver and kidney lesions following oral administration may be severe. (Using diethylene glycol monoethyl ether as a surrogate: NOEL for systemic effects = 200 ppm; NOEL respiratory irritation = 16 ppm)
Atrizine	– Possible human carcinogen. – Cramps, hematological effects, ataxia, hypothermia, GI effects, CNS depression, etc. LC50 in rats = 1750 ppm.
Dimethylpolysiloxane	– Neither sensitizing nor irritating.

APPENDIX F

Supporting Information — Engineering Design

Background

CH2M HILL developed plans to retrieve waste in tank S-102 to satisfy Milestone M-45-05A of the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement). The goal of this retrieval was transfer and safe storage (in tank SY-102) of 99 percent of the S-102 tank contents by volume and the bulk of the mobile, long-lived radioisotopes from the tank. In May, 2002, the schedule for completing this retrieval was mid FY-06. On August 2, 2002, ORP redirected CH2MHill's focus for this retrieval from technology development to mission acceleration. In response, CH2M Hill developed a revised *Mission Acceleration Baseline Change Request* (RPP-03-004 R0), dated March 31, 2003. This baseline accelerated the planned retrieval of 26 tanks in the period 2003 through 2005. (As of this report, tanks S-112, C-103, C-106, and C-201-204 had been retrieved, with S-102 [92 percent], C-108 [89 percent], and C-109 [85percent] partially retrieved.) Tank S-102's retrieval date was accelerated from mid-FY-06 to the 9-month period from October 1, 2003, to June 3, 2004.

The waste retrieval system has two functions: (1) waste mobilization and (2) waste transfer. Waste transfer was accomplished using one of two types of retrieval pumps, described below.

Waste mobilization used water at various pressures to dissolve the soluble salts in tank S-102 and to mobilize soluble and insoluble components. This had the capability to direct a relatively forceful, solid stream of water to the waste surface of the tank (known as sluicing). In addition, a high-pressure mixer originally was located approximately 11 feet from the suction of the operating retrieval pump (Retrieval Pump #3), but the mixer had been removed at the time of the accident. The demonstrated effective radius of this high-pressure mixer system was approximately 3 feet. Finally, dilution or sparging of the waste, using low-pressure raw water or air injected in the immediate vicinity of the pump suction, was available.

Waste Transfer Equipment

Waste Retrieval Pump

The current S-102 pump, Retrieval Pump #3, a revised design from the original Seepex pump (i.e., Retrieval Pump #1), is a vertical, progressive-cavity-style, line-shaft-driven pump with the motor located outside the tank. It was designed and built by Seepex to be capable of transferring a dissolved salt cake solution with up to 30 percent solids content and a specific gravity within the range of 1 and 1.45 up the vertical column. The pump design point is 80 gpm at 251 psig as measured at the pump discharge, and it was designed to convey the waste at a range of flows from 40 to 80 gpm with the use of a variable frequency drive. The pump manufacturer believes the pump is capable of a minimum of 750 psi shut-off head, but potentially capable of a higher pressure. With materials denser or more viscous than water, these pressures could be even more elevated.

The pump is equipped with integral dedicated lines for waste dilution, column flushing, and sparging of the waste near the pump inlet. The discharge piping is equipped with a pressure relief valve that discharges back into the tank. The pump column assembly extends approximately 45 feet into the tank from the riser extension assembly enclosure baseplate. The riser extension enclosure houses the pump discharge flange connection, the discharge pressure relief valve, and connections to the dilution, flushing, and sparger water connections, and is designed to contain and gravity-drain any leakage from the pump or connections inside the riser extension enclosure back to the tank. The pump was designed to be capable of operation in reverse flow. Below the pump inlet is a foot device, which is a metal ring approximately ½ inch thick, approximately 10 inches in diameter with a hole approximately 5¼ inches in diameter in its center. The pump is placed is with this inlet essentially on or very close to the tank bottom. The pump driver consists of a 480-volt, 30 horsepower motor with a variable frequency drive (VFD) connected to the pump through a gearbox.

Routine functional testing was completed at the manufacturer's facility. All testing was performed with water and without the use of a simulant fluid.

Evolution of Retrieval Pump Design

In September of 2002, a strategy was developed for using a progressive cavity pump for retrieval in Tank S-112. This was followed by a design review meeting that considered the usage of the Seepex pump. Later, in April of 2003, a design review meeting addressed the usage of the Seepex pump in Tank S-102.

The Seepex pump design, as currently installed in Tank S-102, evolved from operational experience with earlier vintage pumps in tanks S-112 and S-102. The initial Seepex pump in Tank S-112 operated relatively well; however, the waste was more readily soluble than the waste found in the Tank S-102. The first version of the Seepex pump in Tank S-102 (Retrieval Pump #1) was identical in configuration, except that the dilution flow-rate was increased from 20 gpm to 40 gpm, largely due to the different character of the waste. Usage of the initial design was suspended because of plugging of the inlet strainer, which occurred after only approximately 7 percent of the tank was retrieved, when retrieval efficiency sharply declined.

Next, a centrifugal pump (Retrieval Pump #2), was installed in riser 7 to remove waste from the upper waste surface, rather than from the bottom of the tank. This pump worked well until about 45 percent of the waste had been removed, when it too failed.

The Seepex pump (Retrieval Pump #1) was then reactivated. CH2MHILL had previous success mobilizing salt waste in Tank S-112 using ultra-high pressure water jets (32,000 psig), so a high-pressure mixer system was installed in an available tank riser (R2) located 3 feet away. This mixer was used to clean the suction screen of the retrieval pump when it became fouled. This pump with mixer combination removed 92 percent of the waste before the pump failed. The pump would not rotate, and repeated efforts to rotate it manually were unsuccessful. Direction was given to increase the force to attempt to free the pump, as had been done in the past. The pump rotor and motor were later observed to be mechanically disconnected. The weakest link in the pump shaft was the universal joints, so CH2MHILL has postulated that one of these was damaged by manually over-torquing the rotor, and that it subsequently failed during normal operation.

Based on lessons learned from Tank S-112 and Retrieval Pump #1, enhanced features were implemented on a newly designed Seepex pump (Retrieval Pump #3). In July of 2007, a Hazard Evaluation Workshop was held to evaluate the key differences in the redesigned Seepex pump. Key differences between the old and new pump included an adjustable height feature, an air/water sparge capability outside of the pump intake (sparge ring), improved solids suspension equipment in the riser column above the pump (with auger-like blades inside), and reconfiguration of the dilution line to an integral nozzle discharging at a 45-degree downward angle in the foot of the pump. Retrieval Pump #3 was installed in Riser R7, located approximately 11 feet from the previously installed high-pressure mixer, which had been removed. A decision was made to operate Retrieval Pump # 3 without reinstalling another high-pressure mixer in proximity to the pump, because the only riser in proximity to this pump was used by a thermocouple tree that would have to have been removed or modified to accept a new high-pressure mixer.

The accident occurred following the initial series of waste transfers to SY-102 with Retrieval Pump #3, as detailed in the "Accident Chronology" in Appendix D

Waste Transfer Support Systems

The Raw Water (RW) system provided the source of water for all support systems for the second 241-S-102 Seepex waste transfer pump (Retrieval Pump # 3).

The dilution system was used to aid in the retrieval process by diluting the slurry to the appropriate specific gravity conducive to waste transfer. Additionally, the dilution water supply of at least 20 gpm was specified to prevent waste hardening during the waste transfer. Raw water is supplied to a skid outlet connected to a 1½-inch hose through a strainer and isolation valve to the S-102 retrieval riser extension enclosure. Inside the riser extension enclosure, the dilution water is supplied to another 1½-inch hose that connected to a 1-inch hard pipe. The hard pipe delivers RW to the pump suction through a nozzle located inside the foot cavity.

The sparging system was intended to aid in the retrieval process by dislodging sludge material and putting it into suspension for induction into the pump suction. This was to be accomplished by spraying the RW from multiple nozzles on the outside of the pump foot. Sparging was through a 1½-inch hose connected through isolation valves to the S-102 riser extension enclosure. Inside the riser extension enclosure, the sparging water is supplied to another 1½-inch hose connected to a ¾-inch hard pipe that delivers RW to eight nozzles located outside the pump foot. The sparging system also has the capability of using compressed air.

The retrieval pump discharge inside the riser extension enclosure is connected through a hose to the valve pit, where there are provisions for a flushwater connection; pressure, temperature, and flow sensors; and a leak detection sensor. The pump and discharge piping and hoses are protected by a relief valve (PRV-102) that relieves back into the tank.

Flush water for the discharge path is provided by connecting an exterior 1½-inch hose. The pump discharge hose is connected to the double-wall, 2-inch transfer hose.

All of the 1½-inch hoses for S-102 were purchased in 2004. The hose vendor estimated that the useful life for the hoses was 5 years. The hoses had a rated working pressure of 175 psig with a burst pressure of 700 psig. Specific identification of the hoses in question was not possible prior to their retrieval.

Chronology of Pump Operations Leading to Probable Hose Failure and Release of Up to 85 Gallons of Radioactive Waste from Tank S-102 onto the Soil

The Accident Chronology contains a description of what occurred during this event. However, this section provides an expanded discussion of the events that occurred immediately prior to the release of radioactive waste onto the ground.

The level of waste in the tank at the time of the incident was approximately 18 inches.

- Beginning on Tuesday, July 24, 2007, waste transfer operations from Tank S-102 to SY-102 resumed until Thursday, July 26, 2007 at 6:22 P.M. (day and swing shifts only).
- Thursday, July 26, 2007, 6:22 P.M. – The VFD motor tripped on ground fault. From this time until 9:15 P.M., no flushes of either the pump or the transfer line between the tanks were performed. Approximately 100 to 120 gallons of material from tank S-102 remained in the pump column and in the pump itself. During this period, this material had the opportunity to settle and harden—phenomena which could immobilize the pump. At 9:45 P.M., a raw water flush of the transfer line from S-102 to SY-102 was completed, leaving approximately 100 to 120 gallons of a mixture of cleaner flush water and any residual waste that had settled in the line in the approximately 3 hours the line was stagnant. After the first two unsuccessful attempts to electrically rotate the pump in reverse, four attempts to manually rotate the pump in reverse were combined with four attempts to subsequently electrically bump the pump in reverse at approximately midnight. The final manual attempt appeared to free the pump.
- 1:30 A.M. – Pump was started and ran successfully in reverse for 105 seconds at 60 gpm or less. This first reverse run could have moved as much as 85 gallons downward through the pump and back toward Tank S-102.
- 2:01AM – Pump was started and ran successfully in reverse a second time for 105 seconds at 60 gpm or less.
- 2:10 A.M. – Final pump run was started in reverse. At approximately 85 seconds into the run, visible indications of fluid discharge into the tank were observed with the video camera. At this point, the Field Works Supervisor declared the pump to be free of waste, and at approximately 105 seconds the pump shut down on the automatic timer.

It appears from the data that the rupture of the dilution water supply hose occurred at some point during the period from 20 seconds into the final run until the end, with the most likely time being at the 20-second point, where a step change registered by the pump discharge pressure transducer and motor current meter occurred. The Board concluded that what happened during these final seconds was the development of a pressure pulse large enough to lift the pump, rupture the dilution hose, and release a mixture of tank waste and dilution water in the pump platform area. The exact amount released could not be determined from the pump data, but it was estimated to be 85 gallons or less.

Point of Release

On July 27, 2007, before a contamination fixative was applied to minimize airborne dispersal, photographs were taken of the pump head and surrounding areas. When these were compared with photographs of these areas from Wednesday, July 25, 2007, the indications of the physical areas affected by the liquid release and of solids dispersal from the release point could be clearly seen.

These indications included splatter on the stairs and framework on the north side of the pump head and on a concrete vehicle barrier (primarily on its south face) that was located northwest of the pump head, approximately 15 feet away; wetted ground around the pump head area; and what appeared to be granular solids that were entrained in the liquid release. The release appeared to have originated in the 1½- inch dilution water supply hose at a location near a gap between a concrete vehicle barrier and the pump pit wall. The splatter range, pattern, and volume indications support this as the release point, and seem to suggest that the release was initially at a higher pressure, consistent with a depressurizing volume. The photographs also suggest this point of release by a puddle that collected in a cavity that was formed by the dilution water supply hose where it touched the pump pit wall on its northeast and northwest corners.

The photographs clearly show a "bathtub ring" on the inside of this cavity several inches deep along the top of the hose and on the north face of the pump pit wall. If the leak had been from any other location downhill from this location, this puddle could not have formed.

Pump Movement

When the pump was installed in the tank, metal foil sealing tape was applied to a small gap between the pump and the riser extension enclosure around the pump head. During physical inspections of the pump area after the event, it was observed that this tape had been pulled apart circumferentially, approximately along the line of the gap, as an apparent result of motion of the pump.

Release Timing

Three, 105-second reverse pump runs were performed. During the first two of these runs, several personnel were at the pump head, and given the pattern of the release indications described above, had the release occurred during the period these workers were in the pump vicinity, they would have observed (and likely felt) the effects of the release. Therefore, it was concluded that the actual release occurred during the third pump run. In addition, a momentary increase in background radiation was observed in the S Tank Farm Change Trailer by the Health Physics Technician at approximately 2:10 A.M. This is consistent with the timing of the third successful reverse run.

Acceptability of Manual Torquing to 280 ft-lb during Reverse Flow Attempts

To determine the maximum manually applied torque allowed to be applied at the top of the second S-102 pump (Retrieval Pump #3) motor shaft in the event it became stuck, Seepex performed a calculation for CH2M Hill of the maximum permissible torque for the weak links of the pump. This calculation was based on the ultimate strength of the Type 316 stainless steel coupling material and a safety factor of 2.5. This resulted in a maximum permitted manually applied torque of 169 ft-lb. In a subsequent informal calculation by CH2M engineering, it was determined that up to 280 ft-lb was to be permitted (a safety factor of 1.5 over ultimate). The Board concluded that 280 ft-lb was sufficient to result in plastic deformation of the coupling, potentially adversely affecting pump operation. At the time the manual reverse torquing was applied in an attempt to rotate the pump in reverse at approximately midnight on Friday, July 27, 2007, it was decided that since the pump was not functional in its immobile condition, the high torque (280 ft-lb) would be applied.

Safety Basis Context

The Board reviewed the primary safety basis documents (DSA and TSRs and Bases) to determine the safety basis context of this event. This review sought to determine (1) if the hazards associated with the actual occurrence of this event (as opposed to the hazards associated with responding to and dealing with the event) and (2) the appropriate controls for these hazards had been adequately identified. The following sections outline the observations of this review:

DSA Hazards and Accident Analyses

Chapter 3 of the DSA addressed the hazards and accident analyses. This chapter identified the events with the potential to exceed evaluation guidelines or accident exposure limits for onsite workers. It analyzed these events, and identified the safety functions required to prevent or mitigate these events. The following sections address each of these functions:

Accident Selection

Several representative accidents (or sub-sets) were identified in DSA Section 3.3.2.3.1 that enveloped this event. These included *Waste Transfer Leak* (Group 33) and its sub-sets, which encompassed all waste transfer-related leaks. It entailed two representative break types: fine spray leaks and large pipe breaks into a pit, which included release of waste onto the soil surface. These were very close to the break scenario that occurred and appeared to be enveloping. Sub-sets of these accidents were Scenario 33D, *Waste Transfer Leak due to Misroute*, and Subcategory 33C, *Waste Transfer onto Soil Surface or into Atmosphere*. Scenario 33D included waste transfer into non-waste transfer systems connected to the transfer system, such as raw water and dilution systems, which was the scenario applicable to this event.

The descriptions and analyses of the scenarios presented appear to be clear, complete, and adequate to describe and envelope the event.

Summary of Safety-Significant SSCs and TSRs

DSA Section 3.3.2.4.13.4 identified and explained in detail the various safety significant (SS) preventative and mitigative controls (SSC) and Technical Safety Requirements (TSR) that were applicable to the hazards and each of the accident event scenarios that had been identified. For the variation of Event Scenario 33D involving waste transfer into non-waste transfer systems, such as raw water systems, controls that "involved backflow prevention" were required to be applied.

Such non-waste transfer systems were defined as those that were "physically connected" to transfer system structures. Physically connected is defined in Section 3.3.2.4.13.6 as "…any piping that is part of or *connected to the transfer route"* [emphasis added]; and "transfer route" was described in Section 4.4.6.2 as: "A planned waste transfer route consists of the piping, structures, and tanks that are along the transfer path." These DSA definitions and descriptions clearly enveloped the dilution water line (raw water) that was "physically connected" to the inlet foot of the transfer pump, through which material being pumped passed whenever the pump was operated, regardless of the direction.

This section described three types of engineered controls that could be applied to achieve the safety function of physically isolating the waste transfer system from the non-waste transfer system piping — safety significant double valve isolation, backflow preventers, or service water pressure detection systems. The double isolation valves option was described as accomplishing two safety functions — (1) "to maintain structural integrity for waste transfer system conditions (e.g., pressure, temperature) and (2) to prevent, or limit to an inconsequential volume the misroute (i.e., leakage) of waste into physically disconnected [as a result of the valves being closed] piping." These valves were required to be capable of withstanding the conditions that could occur in the waste transfer route, as well as providing backflow prevention. Additionally, this section stated that backflow preventers and service water pressure detection systems were the controls selected as safety significant SSCs specifically to address backflow scenarios in non-waste transfer systems physically connected to the waste transfer system.

The description of the detailed event scenarios included an event type that described the actual event that occurred, waste transfer from a planned waste transfer route path into a physically connected non-waste transfer system. It also described the type of engineered controls that were to be applied to prevent such transfer, backflow preventers or service water pressure detection systems, and it defined the classification (safety significant) and some of the design requirements (capable of withstanding waste conditions, such as pressure and temperature) that were to be applied to these controls.

The descriptions of the hazard location, hazard, type and hazard conditions that might exist as detailed in this DSA section enveloped the actual event type and conditions. The required types of engineered controls that were to be applied for the event scenarios were clear, complete, and adequate to have prevented the event that occurred, had they been properly applied. The TSR controls developed in this DSA section directly reflected these requirements.

DSA-Identified Safety Structures, Systems, and Components

DSA Chapter 4 identifies and describes the safety SSCs that were required to perform the preventative or mitigative functions described in Chapter 3 to prevent accident events and to ensure that, should they occur, their consequences would be mitigated to below evaluation guidelines or exposure limits. This chapter described again, but in greater detail, the engineered controls that were to be in place to prevent backflow of material from waste transfer systems into physically connected non-waste transfer systems, as follows.

Backflow Preventers (BPs)

Backflow preventers were identified as a safety significant component that was to be used to perform the function of physically disconnecting the waste transfer system from non-waste transfer systems.

Double Isolation Valves

Double isolation valves were also identified as safety significant components that were acceptable to physically disconnect piping. This section of the DSA went beyond the Chapter 3 requirements regarding the structural integrity of the valves. The valves were required to meet ASME Code B31.3, *Process Piping,* or equivalent, which in Paragraph 302, "Design Criteria," states the required pressure-temperature ratings, stress criteria, design allowances, and minimum design values, with permissible variations of these factors that safety significant isolation valves must meet. Implicit in these statements was that piping connecting such double isolation valves to the waste transfer route must also be designed to the same standards. These same requirements would be implied for all such isolation devices that might be used to ensure the integrity of these devices for all credible events that would require their safety functions to be performed.

Service Water Pressure Detection Systems

Service water pressure detection systems were described as acceptable SSCs to physically disconnect a waste transfer system from non-waste transfer systems. (The terms service water and raw water are used interchangeably in descriptions of this installation and in other documents, including safety basis documents.) These systems consist of two isolation valves in series, with a pressure switch between the valves. If waste flows past the first valve, the pressure switch will actuate an alarm to notify operators so that the transfer pump can be manually shut down, or in some installations, the pressure switch automatically shuts down the transfer pump.

The descriptions in this DSA section of the safety SSCs that were required to perform the preventative or mitigative functions described in Chapter 3 were complete and adequate, and described in detail the required types of engineered controls that were to be applied for the event scenarios. Such controls would have been adequate to prevent the accident, had they been properly applied.

TSR Review

TSR Limiting Condition of Operation (LCO) 3.1.2 stated that "One of the backflow prevention systems listed below shall be provided: a. An OPERABLE service water pressure detection system…OR b. An OPERABLE backflow preventer." The TSR-stated that **applicability** of this LCO was to "**non-waste** transfer systems (e.g., service water, raw water, dilution systems) that are **physically connected** to an **active waste** transfer pump not under administrative lock." These requirements directly implemented the DSA-identified engineered controls to prevent backflow of wastes from a waste transfer route into non-waste transfer systems, such as raw water or dilution systems.

The Board concluded that this TSR LCO was adequate to have prevented the event had it been followed as required. CH2M Hill personnel initially did not consider this TSR to have been violated, but later declared a violation of the LCO and notified DOE accordingly.

Safety Bases Context Conclusions

The following conclusions were made regarding the safety bases context of this event:

- Backflow of wastes from a waste transfer route into non-waste transfer systems is an accident clearly identified and analyzed in the safety bases.
- Prevention of such an event by isolation of the waste transfer route from the non-waste transfer systems is a safety function for which safety-significant engineered controls are required by the safety bases.
- Acceptable alternative engineered controls identified in the safety bases for performing this isolation function are double isolation valves, backflow preventers, or service water pressure detection systems. The safety bases indicate that one of these alternatives must be provided at each location where such isolation is required for connection of non-waste transfer systems to the waste transfer route.
- The safety bases documents have adequate general and detailed direction regarding the requirements for providing isolation devices between waste transfer routes and non-waste transfer systems to ensure that such connections reasonably could have been identified and engineered controls could have been designed to prevent this event.

Engineering Failures Contributing to the Accident

Technical Factors

Absence of Safety Significant Isolation Devices

A direct technical cause for the event was that an isolation device, such as a backflow preventer, had not been installed between the dilution water system (service water), which was a non-waste transfer system, and the waste transfer route, as required by the DSA and the TSRs. (The sparging water system [also service water], which also met the DSA definition of a non-waste transfer system "physically connected" to the waste transfer route was not protected by such an isolation device, although this absence of protection did not result in any actual failure.). In translating these DSA and TSR requirements, all engineering and safety bases personnel contacted recognized that the sparge and dilution lines were attached to the pump at its suction. They (with one exception discussed later) did not consider these attachment points to be within the "waste transfer route" since they were not on the normal pump discharge, which was pressurized during waste transfers. They did not recognize that the pump suction side could be pressurized, as well, during pump reverse operation.

Absence of Sparging

The transfer evolution was begun in spite of the absence of sparging due to plugging of the sparge line. The sparging feature had been added to this design evolution of the pump to break up and diffuse the sludge before it entered the pump suction to minimize the potential that the pump would mechanically stall. Such pump stalling had been a problem in the previous iteration of this pump's design in Tank S-112, where the sludge appeared to be more mobile than in Tank S-102. The Seepex pump sparging capability was included in the design but was considered plugged and not available during this event. The criteria for sparging for S-102 operation were not specified in the operating requirements.

Qualification and Classification of Primary Confinement

A contributing technical cause for the event was that the hoses within the potentially affected pressure barriers were not qualified for the pressures to which they might be subjected. The direct cause of this absence of adequate qualification was, as with the absence of backflow preventers, general non-recognition that these hoses could become pressurized from the waste pump. These hoses include those that ran from the auxiliary raw water skid isolation valves to the hard through-wall connections on the outside of the pump riser extension enclosure (one of which was the point of failure for this event), as well as the hoses inside the pump riser extension enclosure required to accommodate differential movement between the pump and the box. Such qualification, had this condition been recognized, should have included, as a minimum, (1) classification of the hoses inside the pressure boundary of the appropriate isolation device as SS, with the commensurate quality, inspection, testing, and so on; with controls being applied, and (2) having ratings commensurate with the credible pressures, temperatures, and other conditions to which they might be subjected.

Programmatic Factors

One of the major programmatic contributors to this event was ineffective oversight of CH2M Hill's subcontractors. The Board reviewed of all applicable CH2M Hill programs and procedures. They identified that, although there were generic requirements for the subcontractor's oversight and even some specific instructions on how to review calculations and test procedures generated by a subcontractor, there was neither a dedicated procedure that detailed the requirements for oversight, review and approval of the subcontractor's preformed design, nor specific details in the CH2M Hill procedures that collectively could have provided this guidance.

Interviews of the CH2M Hill's project and engineering management indicated that a corporate procedure TFC-ENG-DESIGN-P-17, *Design Verification*, was used for review and approval of design of application of the Seepex pumps performed by the subcontractor (DMJM Holmes and Narver) during the 30 percent, 60 percent, and 90 percent Design Review for the S-112 Waste Retrieval Project (December 2002). Additionally, the interviews provided information that in addition to these reviews, there were weekly reviews. However, for the S-102 Waste Retrieval Project there was only a 90 percent design review. The Board's review of this procedure and the records of both the S-112 and S-102 90 percent reviews identified the following.

- The Design Requirements Compliance Matrix (DRCM) instructions (provided in TFC-ENG-DESIGN-P-17) required that the matrix, as a minimum, must document the applicable project requirements; the design assumptions/DSA assumptions; project technical assumptions that would impact design; the necessary actions to avoid, mitigate, or eliminate the technical assumptions; and how the technical assumptions were verified.
- The DRCM for the first S-102 Seepex pump installation was generated by the subcontractor (DMJMH+N), but was not reviewed by CH2M Hill.

The Board's review of DRCM revealed that the DRCM did not identify two critical requirements.

1. The DRCM did not identify potential for backflow/pressurization of the Raw Water System during a reverse flow evolution and credited the existed backflow prevention system

241-S-102 WRS, controlled by CH2M Hill and located outside of the tank farm boundary (item 3.3.1.3.b); thus, it did not require verification.

2. The DRCM (item 3.2.1.5.a) did not specify a procedurally required minimum flow of 20 gpm. The reason for the minimum flow rate is to preclude precipitation or hardening of waste in the transfer lines.

The 90 percent design review for the S-102 Seepex pump (RPP-16298) did not include review of the DRCM. The 90 percent design review for the earlier S-112 Seepex pump installation (RPP-16404) included review of the DRCM.

- The scope section credited a very extensive design review process that the S-112 Seepex pump installation went through. Due to the perceived similarity between the S-102 the S-112 projects, CH2M Hill applied a graded approach for the design review for S-102. This review did not consider additional controls or design features for the thicker consistency and less soluble consistency of the waste in S-102 for the first Seepex pump in S-102. As described above, additional features were added for the second S-102 pump.
- The S-102 pump "Design Review Strategy" identified that the DRCM was "informational only"; therefore, it was not reviewed.

Organizational Factors

CH2M Hill Procedure Compliance with the Design Review Process

One organizational factor that had a significant role in this event was the failure of the Contractor's organization to properly respond when a concern was formally raised in the review and comment process for the original transfer pump design. One comment submitted stated that the dilution water hose connected to the pump suction could be pressurized whenever the pump was operated in the reverse direction, which was the apparent primary failure mechanism for this event. The response provided was that the water pressure could be provided from the service water system, which did not resolve the concern. No record was found of subsequent disposition or acceptance of the response, but the lack of design features to address this concern shows that it was never adequately resolved. Although there were procedural requirements in place at the time that should have caused such a comment to be properly resolved, in this case, the organization failed to accomplish what the procedures required.

Failure of USQ Process to Detect Inadequacy with Respect to the Safety Bases

Each time the new transfer pumps were installed in both Tank S-102 and Tank S-112, the equipment change underwent the USQ process, as required by 10 CFR 830, which is intended to identify any aspect of the change that could be outside the current approved safety basis. Each of these USQ evaluations was a missed opportunity to identify that the dilution water and sparging water connections to the pump did not meet the DSA requirements with respect to isolation devices. In each of these cases, the organization failed to accomplish what the USQ process required.

APPENDIX G

Supporting Information — Work Planning and Control

Introduction

The work control processes associated with this accident were reviewed against the core functions of integrated safety management. Several work activities were conducted prior to and during this event, including troubleshooting of the variable frequency drive, operations and maintenance activities to free the clogged Seepex pump (manual pump rotation combined with electrical pump bumping), waste retrieval pumping operations prior to the event, and radiological controls associated with retrieval operations and during the event response. The Board placed special attention on reviewing activities that were important to the accident. However, it was also necessary to sample the performance of other activities supporting waste retrieval to fully understand the implementation of the integrated safety management core functions. To support that effort the functional areas of operations, maintenance and radiological controls were evaluated separately in relation to the core functions.

Operations Core Function Review

The CH2M Hill organization is divided into three primary field sections: Waste Feed Operations (WFO), Closure Operations (CO), and Analytical Technical Services. The accident at the S-102 Tank was under the responsibility of Closure Operations. However, on back shifts the WFO shift manager typically is in charge of both WFO and CO crews, and in this case was in charge of the shift.

Define the Scope of Work

The primary procedure in effect during the event was TO-420-905, Rev. C-24, dated July 26, 2007, "*Perform 241-S-102 Waste Retrieval Pumping*." The procedure adequately defines the scope for normal operation. However, the operators were recovering from a clogged pump by alternately jogging the pump and attempting to manually rotate the pump. This waste retrieval pumping procedure did not define the scope of this work by either reference to a maintenance instruction or within the procedure itself.

Analyze the Hazards

The S-102 waste retrieval pumping procedure requires that workers performing this procedure walk down the job and document hazards and controls in the Worksite Hazard Analysis. The Worksite Hazard Analysis had not been performed or updated since 2006. This was a missed opportunity in potentially identifying hazards and controls and in identifying and reviewing radiological and industrial hygiene controls (also discussed in this report). In addition, inadequate lighting at the S Tank Farm had been previously identified and evaluated. Management decided to proceed with operations and to request additional funding from DOE to bring the condition into compliance.

Recent software changes associated with waste transfer pump low flow and low pressure resulted in no audible or visual alarm when the transfer pump shut down following the VFD "ground fault." This deficiency is also similar to one listed in a letter from the DOE Office of Price-Anderson Enforcement to CH2M Hill Hanford Group, Inc., "Preliminary Notice of Violation and

Proposed Civil Penalty - $316,250," dated March 10, 2005, which indicates a weakness in the CH2M Hill corrective action management system.

Develop and Implement Hazard Controls

Process Memo, P.M.-CO-07-005, dated July 25, 2007, "Startup and Operation of New SEEPEX Pump-Revised," inappropriately contained operating instructions that should be included in the operating procedure in accordance with Section 2.2 of the tank farm *Conduct of Operations Manual*. The process memo included instructions for flushing, pump rotation checks, sparging, radiation surveys, and methods to shut down the pump normally and when operating in the recirculation mode. Precautions were included for running in auto reverse and in forward with limits on flow rates for prevention of plugging. Instructions are further given for shutting down the pump with auto reverse, if increasing the dilution flow, using the air sparge process of stirring the waste with the Remote Water Distribution Device (RWDD).

The importance of turning the Seepex pump in the reverse direction to prevent waste material clogging was well known and understood by management. Despite this understanding, the S-102, Waste Transfer Retrieval Procedure was not changed to address this off-normal condition by providing time limits and actions to take to ensure the waste was removed from the pump or at least kept in suspension in a timely manner. It is noted in DOE Order 5480.19, *Conduct of Operations Requirements for DOE Facilities*, that procedures should be developed for all anticipated operations, evolutions, tests, and abnormal or emergency situations. When the Seepex pump shut down on the VFD "ground fault" on July 26, 2007, the pump apparently became clogged with hardened waste because of the time it took to sequentially clear the fault and set up maintenance for manually rotating the pump.

The Operations Director stated that a readiness activity conducted for restarting S-102 waste retrieval operations identified the need for an air powered "jacking motor" to turn the S-102 waste transfer pump in the reverse direction upon loss of electrical power. Procurement of an air motor was in progress, but the need was determined to be a "post-restart" item. The Board determined that inability to move the S-102 waste transfer pump in either direction in a timely manner following the VFD fault was a contributing cause to the event.

The controls developed for TO-420-905 were inadequate in that Checklist 2, "Pre-Transfer Valve Alignment," Section B, specifies that the expected position of valve POR60-RW-V-308 (sparger isolation valve) is "closed." However, Section 5.4, "Operate the Dilution/Sparger Line," does not address subsequently opening this valve to initiate sparge operations.

A review of TO-420-905 indicated extensive use of the word "ensure" as an action verb. Interviews with qualified supervisors and operators revealed that the understanding of the word "ensure" is inconsistent.

Perform Work within Controls

Waste retrieval operations from Tank S-102 to Tank SY-102 using the new Seepex pump began on Tuesday, July 24, 2007. On July 26, 2007, at about 10:00 A.M., during start of retrieval operations with the newly installed S-102 waste transfer pump, the operations procedure was not properly performed, and the positive displacement Seepex pump was started with Discharge Valve V-106 shut.

Step 5.3.27 of TO-420-905 is identified as being associated with Administrative Control 5.12, “Administrative Lock Controls,” and requires that the time that the Administrative Lock Condition is removed is recorded on Data Sheet #1. However, Data Sheet #1 records for July 26 and 27, 2007, do not include the time that the administrative lock condition was removed for troubleshooting the variable frequency drive or for “bumping” the pump nine times, and it appears that the Administrative Control was not met.

The Training Plan for S-102 retrievals contains sub-certification training classes for each of the specialty equipment (high pressure dissolvers, sluicer rotary vipers). This plan also required attendance at Training Activity # T07026, “Briefing on Changes to S-102 Retrieval Operations,” for all personnel previously qualified on S-102 operations and high pressure water jetting. This training included pump modifications to sparge and dilution aspects plus pump internals to keep the pump from plugging up with high density materials. The Board reviewed attendance records for this training and confirmed that the affected operations engineer and two of three NCOs had completed the training. However, a key NCO involved in the event had not completed the required training.

The Board also had difficulty determining whether the tank farm operators and other staff were effectively trained and qualified to perform their tasks. Discussions regarding how a supervisor might know who is a qualified operator indicate that this is a “problem”. In one case, a supervisor indicated that he always had to call a specialist from Training Department to determine whether an operator was qualified. He would gather information regarding the OJT, JPMs, and classes the individual had completed and would go to the specialist to find out the qualification status. The Board determined that a controlled list of position qualifications should be available to supervisors and individuals in order to verify qualification status.

A review of Closure Operations Shift Manager and Control Trailer NCO logs indicated that recording TSR-related Administrative Lock (Admin Lock) conditions (Administrative Control 5.12) was not properly performed. As an example, Procedure TO-420-905, Section 5.3, required the NCO to obtain Shift Manager’s permission to remove the Admin Lock and required the NCO to record the time that the Admin Lock was removed on Data Sheet #1. Section 5.8 required the NCO to notify the Shift Manager when the Admin Lock was re-established and record the time on Data Sheet #1. Data Sheet #1 records for July 26 and 27, 2007, do not include the time that the Admin Lock was removed and re-established, which was especially important when troubleshooting the VFD and electrically bumping the Waste Transfer Pump.

Procedure TFC-OPS-OPER-C-17, Rev A-9 March 26, 2007, Section 4.1, “Operating Logbooks Process,” requires maintenance of continuous logbooks at the Closure Operations Shift Office and the Tank Monitor and Control System Central Facility; but not at the S-tank farm Operations Control Trailer or the S-tank farm Operations and Supervisor Trailer. As a result the Board had a difficult time establishing the events, and the chronology of events, that occurred prior to and following the spill event. DOE Order 5480.19 states that the following information should be recorded in at least one log, although any one log might not contain all these items: facility mode or condition changes (e.g., shutdown, operations, run, startup, refueling); abnormal facility configurations; status changes to safety-related and other major facility equipment; occurrence of any reportable events; out-of-specification chemistry or process results; and shift reliefs. Most of this information is not included in the compilation of logs, checklists, and data sheets associated with S Tank Farm operations.

Maintenance Core Function Review

The key activities reviewed in maintenance were the troubleshooting of the VFD and the manual rotation of the Seepex pump.

Define the Scope of Work

In response to the S-102 waste transfer pump stopping, a Field Work Supervisor (FWS) and an electrician were called to the S Tank Farm to investigate the cause of the "ground fault" indication on the VFD. Troubleshooting of the VFD was conducted under an "Instrument Technician Standing Minor Work Instruction," verbal directions, and an "Authorized Worker Single Point Lockout/Tagout" form. Although the maintenance activity did not involve an instrument technician, an "Instrument Technician Standing Minor Work Instruction" was used to control the work. With the exception of titles, all craft standing Minor Work Instructions are essentially identical.

The stated scope of the "Instrument Technician Standing Minor Work Instruction" is limited to a requirement to document work directions; however, the instruction included a number of additional requirements not encompassed by the stated work scope; that is, developing a troubleshooting plan and Work-Site Hazards Analysis (WHA), documenting approvals, and documenting results of maintenance testing. No documented troubleshooting plan was developed. The completed work record indicated that the directed work scope was to troubleshoot the VFD for the "ground fault" and to use an "Authorized Worker Lockout/Tagout" to measure resistance phase to phase. This definition of scope is incomplete in that it does not include the expectation to measure phase to ground resistance.

The same FWS involved in VFD troubleshooting called out a different electrician and a millwright to support the manual pump rotation activity, which also was conducted under an "Instrument Technician Standing Minor Work Instruction," verbal directions, and the requirements for an "Authorized Worker Single Point Lockout/Tagout Without Written Authorization."

There is no operating or maintenance procedure that defines the scope, hazards, controls and coordination required for this activity. The work record indicated the directed work scope was to rotate the pump by hand, not to exceed 280 ft-lb, and to use the pump electrical plug as the disconnect means ("Authorized Worker Lockout/Tagout"). Again, a documented troubleshooting plan was not developed. The adequacy of the verbal direction was not assessed, since it is not otherwise documented.

Analyze the Hazards

Troubleshooting the VFD was performed in a non-radiological area that does not require an RWP. The Minor Work Instruction requires the FWS to ensure the development of a WHA prior to performing field work, unless the hazards for the task are general or a WHA can be reused if the hazards are identical to those previously assessed. The electrical hazard was addressed by the "Authorized Worker Single Point Lockout/Tagout" and the added requirement on the form for a "zero electrical energy check." The FWS determined that the remaining hazards were adequately addressed by the standing "Tank Farms General Industrial Safety Hazards Analysis."

Given the maintenance staff's previous experience with similar evolutions, the FWS determined that the hazards of manually rotating the Seepex pump were already defined in the standing

RWP referenced in the Minor Work Instruction, the standing "Tank Farms General Industrial Safety Hazards Analysis," and the requirements for the "Authorized Worker Single Point Lockout/Tagout Without Written Authority." The parent "Tank Farm Contractor Work Control" procedure defines Minor Work as: "Work requiring routine repetitive tasks or work orders and may be accomplished using verbal direction without a Work Site Hazard Analysis…." Listed examples of routine tasks that don't require a Work Site Hazard Analysis include "Single craft tasks in frequently visited areas". The conclusion of the FWS that a new Work Site Hazard Analysis was not needed is supported by historical records documenting multiple Work Orders (WO) for manually rotating Seepex pumps and an earlier "Tank Farm Job Hazard Analysis" developed for an earlier manual pump rotation that would not expire until November 3, 2007. Coordination between the maintenance and operations staff was defined by verbal direction, and the FWS considered the activity a repetitive,-routine task that did not require additional analysis.

Develop and Implement Hazard Controls

The "Authorized Worker Single Point Lockout/Tagout" form required turning the VFD power supply off, applying the lock and tag, and performing a zero electrical energy check. The general safety hazard analysis includes controls typical for routine low stress work and low hazard environments that are not normally covered in work instructions or technical procedures.

The Minor Work Instruction used to troubleshoot the VFD specified that if troubleshooting was required, a troubleshooting plan with specified attributes would need to be developed. A documented troubleshooting plan for this maintenance activity was not developed.

A maintenance document was not developed for manually rotating the Seepex pump to describe the required calibrated torque wrench, the correct drive extension, special socket, and the 280 ft-lb torque limit. Informal training on the hardware and torque specification had been provided previously to two of the three millwrights, but not to the millwright assigned to perform the task on July 27, 2007.

Based on craft jurisdiction, an electrician was required to disconnect and maintain control over the electrical plug, in support of the millwright's safety while manually rotating the pump shaft, followed by reconnecting the pump electrical plug after the millwright and his tools were clear to support operating the waste transfer pump electrically, in reverse. The Lockout/Tagout Program allows an "Authorized Worker Single Point Lockout/Tagout without Written Authorization" if three conditions are met.

1. The equipment is supplied electrical power by a plug and cord.
2. Exposure to the hazards of unexpected energization or startup of the equipment is controlled by unplugging the equipment from the energy source.
3. The plug is within arm's reach and line of sight of all employees involved in the servicing and maintenance, or all employee(s) performing servicing and maintenance on the equipment will apply their authorized worker locks and danger tags to the plug.

On July 17, 2007, a Maintenance Manager had stated in an email to Project Engineering that the Maintenance staff was not prepared to manually rotate the new Seepex pump without some additional information, including any provided special tooling and torque limits. On July 19, 2007, a Project Engineer indicated the torque limit was 280 ft-lb, which reportedly provided an equipment protection factor of 1.5 and that a special socket had been provided. On July 24, 2007, Engineering sent an email to the Maintenance Manager documenting the results of a telephone discussion that confirmed Maintenance had been provided the requested information and tooling to manually rotate the Seepex pump.

On July 27, 2007, a pre-job briefing was held by the FWS with the operations engineer, an electrical engineer, the electrician, and the millwright to discuss the planned activities and associated hazards and controls. The maintenance team assigned to perform the task initially was not aware of the special hardware and torque specification requirements associated with manually rotating the Seepex pump, and were prepared to manually rotate the pump with a pipe wrench until the Electrical Engineer, who was at the jobsite by chance, informed them that he believed torque specifications had been developed.

Perform Work within Controls

The Minor Work Instruction used for VFD troubleshooting requires the FWS to ensure documentation of the approval of the work on the work record and to document any maintenance testing in the work record. Shift Manager approval of the work was not recorded in the work record as required, but was recorded by the Shift Manager on the bottom of the July 26, 2007, Plan of the Day. The FWS accompanied the electrician to the work site where the lockout/tagout was implemented and resistance readings were taken. Phase-to-ground resistance readings ranged from 8 to 30 megohms, while phase-to-phase resistance readings read approximately 8 ohms. These readings were recorded on the back of the “Authorized Worker Single Point Lockout/Tagout” form, not in the work record, as required. Taking phase-to-ground readings was outside task directions as recorded in the work record. No components were replaced; the cables were re-landed, the Lockout/Tagout was cleared, the VFD equipment was energized, and the previously locked-in indication did not reappear. The troubleshooting activities failed to identify the cause of the earlier “ground fault.”

Interviews conducted by the Board indicated that a VFD “ground fault” can be caused by an actual ground fault condition or a “drifting” output card. Output card problems have previously been experienced at the S Tank Farm with VFDs on both S-102 and S-112, and the output card in the S-112 VFD had been cannibalized and was in the S-102 VFD at the time of the event. The Board was informed that the unreliability of VFDs was well known, and a replacement VFD for the S-102 pump had been procured and was scheduled to be installed the week following the event. The decision to begin retrieval operations with an unreliable VFD directly contributed to the event because the VFD fault that occurred at 7:27 P.M. stopped the S-102 waste transfer pump and made the pump electrically inoperable and, therefore, unable to operate in reverse to clear the waste material that later solidified.

On July 26, 2007, at about 2200 hours, troubleshooting of the VFD was completed with no problem or cause for the ground fault identified. Following troubleshooting, an attempt was made to start the S-102 Waste Transfer Pump in the reverse direction to clear the pump of waste sludge; however, the pump was manually shut down within a few seconds by the operator on observation of high motor current. A total of six unsuccessful attempts were made to electrically “bump” the pump in the reverse direction, and a decision was then made to attempt to manually rotate the pump shaft in the reverse direction.

The Minor Work Instruction used for manual rotation of the Seepex pump requires the FWS to obtain and document in the work record the approval of the Radiological Control Organization and of the Shift Manager to perform the work. Shift Manager and Radiological Control

Organization approval of the work was not recorded in the work record as required, but was recorded on the bottom of the July 26,2007 Plan of the Day.

Operations procedural controls and procedural compliance for rotating the pump manually and intermittently "bumping" the pump electrically were also not adequate. TO-420-905, "Perform 241-S-102 Waste Retrieval Pumping," does not contain procedural steps for momentarily bumping the waste retrieval pump. On July 27, 2007, the sequence of manually rotating and then attempting to electrically bump the S-102 waste transfer pump was conducted several times. This activity was complex, required close coordination, and involved significant personal safety risk, especially to prevent electrically energizing the motor when operating tools were attached to the motor shaft and workers were in the immediate vicinity.

After a delay to locate the required socket and tools to engage the pump motor shaft, the FWS accompanied the electrician, millwright, and operating engineer to the work site, where the electrician opened the pump power disconnect, pulled the electrical plug and attached the lockout/tagout. At least three unsuccessful attempts were then made to break the pump loose by attempting manual rotation while limiting torque to less than or equal to 280 ft-lbs, followed by electrical bumping in the reverse direction. Interviews indicated that during this activity, the criteria allowing use of an "Authorized Worker Single Source Lockout/Tagout Without Written Authorization" were not always met; specifically, the electrical plug was not always within arm's reach and line of sight of all employees involved in operating the ratchet on top of the pump and all employee(s) performing this activity had not applied their authorized worker locks and danger tags to the plug.

The pump shaft appeared to break free on the fourth manual rotation attempt, which was followed by a successful electrical run in the reverse direction that stopped only after the automatic timeout. The maintenance staff remained at the pump for a successful second electrical run to verify that the pump power cord insulation was not being damaged by rubbing against the riser extension box. The maintenance staff had left the tank farm prior to the decision by Operation's to run the Seepex pump in the reverse direction one more time, which appears to have caused the waste spill.

The actual work record for this activity for these activities was made as a labeled late entry on July 30, 2007 and incorrectly indicates the work was performed on July 27, 2007. These deficiencies indicate an inattention to detail and informality not consistent with Conduct of Operations expectations. Further, it is not clear that the late entry would have been documented, had the spill event not occurred.

The Board determined that the work control documentation associated with troubleshooting the VFD was not in noncompliance with the requirements of the Minor Work Instruction.

Radiation Protection Controls Core Function Review

Activities reviewed in this section are the methods used for waste leak identification and performing radiological work as part of abnormal events.

Define the Scope of Work

The primary procedure in effect during the event, TO-420-905, Rev C-24, dated July 26, 2007, "Perform 241-S-102 Waste Retrieval Pumping," defined radiological survey requirements as part of waste transfer controls; however, this procedure and the abnormal operating procedures did not adequately define the scope of permitted radiological work conducted during the event. Radiological work permits used during the event also did not contain adequate work scope definition sufficient to permit hazard analysis and development of appropriate safety controls.

Analyze the Hazards

The S-102 waste retrieval pumping procedure lacked a documented technical basis, including data quality objectives associated with radiological criteria of 75 mrem and 100 mrem used as trigger levels for response actions.

Radiological hazards associated with potential waste transfer leaks, including the purpose and objectives of the radiological surveys being used as waste transfer controls, were not sufficiently analyzed. There is no formal mechanism to ensure that subject matter experts (SME) responsible for procedure reviews understand whether radiological surveys required by TFC-ESHQ-R-ADM-P01, Rev. 6, are to be used to implement TSR requirements for leak detection, and if they are not, how any differences in objectives would be addressed. As such, the S-102 waste retrieval pumping procedure lacked a documented technical basis including data quality objectives associated with the radiological criteria of 75 mrem and 100 mrem as trigger levels for response actions.

Inadequate hazard analysis was also noted during the S-102 event response. An entry into the S-farm High Radiation Area at approximately 10:00 A.M. to conduct a survey to further investigate high radiation conditions was planned and authorized using an informal entry plan rather than the formal procedure for Radiological Control investigative surveys defined in TF-OPS-025. TF-OPS-025 establishes specific requirements associated with tank farm investigative surveys, including hazard analysis and work authorization requirements. The informal entry plan failed to address a number of important elements of TF-OPS-025 including the investigative survey request process, development of a WHA in support of meeting Industrial Hygiene monitoring requirements, Senior Supervisory watch and ALARA/RadCon Management oversight, post-job review requirements, and so on.

Develop and Implement Hazard Controls

Inadequate recognition that a waste leak was the source of the high radiation readings delayed response actions for several hours and significantly increased the number of potentially impacted personnel. There were several controls in place intended to ensure proper recognition of waste transfer leaks, including radiological surveys. Weaknesses in design and/or implementation of these controls resulted in a prolonged delay in discovery of the leakage of waste material near S-102.

The principal TSR Administrative Control for leak detection at S-farm is MBDD; however, tank farm TSRs also require that when MBDD is not possible or insufficient, the primary TSR control for leak detection is a radiological survey. However, incomplete procedural guidance associated with radiological surveys, radiological criteria, and necessary response actions and weak implementation of survey protocols rendered this control ineffective in ensuring prompt detection of the spill. Specifically, TFC-ESHQ_RP_ADM-P01, Rev. 6, “Radiological Monitoring During Waste Transfers and Waste Pump Maintenance Activities,” defines expectations for radiological monitoring in support of waste transfers including instructions for radiological control personnel responsible for development and review of operations procedures involving waste transfers. This procedure is intended to implement RadCon Manual and 10 CFR

835 requirements for radiological monitoring, as well as applicable TSR administrative controls for radiological surveys.

The operations procedure for S-102 transfers was TO-420-905, Rev. C-24, "Perform 241-S-102 Waste Retrieval Pumping." A number of radiological control problems with content and implementation of the procedure were evident, contributing to weaknesses in the S-102 event response. It was noted that while radiological surveys were not a specific TSR control because of material balance capability at S-102, similar radiological control weaknesses existed in procedures for other tank farm transfer locations where there is no material balance capability (i.e., where radiological monitoring is the principal administrative leak detection control). The Board compared the operations procedures for waste transfer used at S-102, where material balance is the TSR control, and at C-109, where radiological monitoring is the TSR control, and found no difference in the rigor, technical basis, quality, or clarity of how radiological surveys are to be used as an indicator of waste leaks. The C-109 procedure contained even less detail than S-102 and contained verbiage concerning the purpose of radiological surveys that casts doubts on whether the procedure authors and reviewers were aware of the TSR requirements associated with leak detection.

A lack of rigor in ensuring adequate technical basis and proper flow-down of radiological requirements resulted in operations procedure TO-420-905 containing inadequate instructions for performing, evaluating, and acting upon abnormal radiation readings. Specific deficiencies include the following.

- According to TFC-ESHQ_RP_ADM-P01, Rev. 6, a dose rate more than double the baseline and greater than 5mrem/hr represents indication of a potential release from a transfer line and requires notification of the Shift Manager/OE and execution of TF-ERP-05, Radiological Release at the direction of the Shift Manager. However, this criterion has not been followed or used during development of the operations procedure, nor is it considered suitable criteria by tank farm operations or RadCon personnel. Despite this discrepancy in a formal procedure requirement used to implement TSR controls, no issue for corrective action has been raised, nor has there been any action to review or revise these values. Higher dose rate action levels are contained in the operations procedure (75 and 100 mrem) but according to radiological engineering, these values have no documented technical basis associated with leakage, as expected by TFC-ESHQ_RP_ADM-P01. Instead, they are based on the posting criteria for a high radiation area and not considered by radiological engineering to be sufficient indicators for presuming a transfer leak.
- TO-420-905 contains insufficient instructions for dose rate monitoring for evaluation of potential waste transfer leaks, and the data quality objectives associated with use of dose rate action levels specified in the procedure do not have a documented technical basis.
- TO-420-905 Step 5.7.3 states: "Confirm no pooling of waste" and "If pooling is found," execute TF-ERP-005, "Radiological Release." However, the term "pooling" is not defined and may not be a sufficient or sole indicator of a leak, especially if only visual indications are to be used. Further instructions on how one is expected to "Confirm no pooling of waste" are not provided, nor are there any time constraints listed. The use of the term "confirm no pooling" implies a presumption that pooling is not likely, which was consistent with the mindset of most response personnel who postulated a slug of waste in the line. However, this

presumption contradicts the intent of a dose rate action level to be used as a leak indicator, as shown in TFC-SHQ_RP_ADM-P01, Section 4.7, and TSR Administrative Control 5.11.

- Neither TFC-ESHQ-RP-ADM-P01 or TO-420-905 contain clear requirements for beta (open window) readings as a mechanism to evaluate possible breaches in the waste transfer system. While dose rate monitoring is specified in both, neither procedure defines whether the measurements to be taken are deep dose (gamma only) or both deep and shallow dose (beta-gamma). Since beta particles would not be detected through transfer line shielding, presence of beta radiation during a dose rate survey should be a clear indicator of the presence material outside the containment structure. Data sheet 5 in TO-420-905 provides for only one type of dose rate reading per survey evolution and does not specify gamma only or beta-gamma.
- When securing a waste transfer TO-420-905, Step 5.8.17, requires a final radiological survey to be performed per Data Sheet 5, but does not involve the step 5.7.3 if high radiation is detected.

Conduct of Operations expectations were not clearly delineated in the Abnormal Operating Procedures (AOP), including linkage and/or reference to existing procedures and processes that must be followed or acceptable conditions for deviation.

Perform Work within Controls

As part of the S-102 response, several radiological control activities were not planned or performed in accordance with existing tank farm procedures and formality/Conduct of Operations expectations, including use and development of radiological work permits; conduct of health physics investigative surveys radiological surveys; and recordkeeping and related actions. The use and consideration of AOPs as standalone procedures without regard to other required tank farm procedures and protocols resulted in potentially unsafe working conditions, missed opportunities to engage appropriate safety disciplines in the response, and inadequate or unclear PPE specification during response actions. Specific areas of concern include the following.

- HPT did not follow TF-RC-003 RO-20 operating instructions for performing both open- and closed-window dose rate measurements. Review of tank farm radiological survey reports indicates this to be common and accepted practice and not an isolated case. CH2M Hill RadCon management has not enforced expectations and requirements for Health Physics Technicians (HPT) to take and document both gamma and beta-gamma measurements when performing routine radiation surveys, resulting in a normal HPT practice of recording only closed-window gamma exposure rates. Many routine radiological survey reports indicating N/A for beta measurements were approved by RadCon management, indicating management acceptance of this practice
- Section 5.7 of TO-420-905 includes actions to be taken if transfer route dose rate readings indicate higher than 75 mR/hr at 30 cm, but those actions were not performed and completed when that condition was identified and reported on July 27, 2007, opting instead for execution of the generic AOP-005, “Response to High Radiation.” Visual observation of the waste spill was not accomplished in a timely manner because of inadequate lighting (a previously identified deficiency) conditions at the S Tank Farm and the inability to survey the entire waste spill area with a remotely controlled camera.

- Although members of the operating crew noticed a change in background radiation from 200 cpm to 400 cpm and back to 200 cpm in a short period of time, as well as simultaneous updating of the PCM-1B due to a change in background radiation level, they did not consider those indications could be related to a waste spill.
- A report by an experienced Nuclear Chemical Operator that the area was “very stinky” did not prompt the supervisor or operating crew to consider that condition could be related to a waste spill.
- The supervisor and operating crew inappropriately used Material Balance Discrepancy Data (MBDD) to conclude a waste spill had not occurred. MBDD is intended to detect large volume waste leaks (several hundred gallons) rather than the relatively small volume involved in this waste spill.
- The supervisor, operating crew, and responders incorrectly believed that an above ground, unmonitored (not detected by the Transfer Leak Detection System) waste leak was not a credible event; therefore, they did not aggressively pursue that possibility when investigating the high radiation level condition.
- Upon discovery of a high radiation area at approximately 2:05 A.M. on July 27, 2007, the HPT and NCO exited S farm to retrieve another survey meter to verify the initial readings. However, the re-entry was performed under the same RWP, which is not valid for High Radiation Area entries. Neither worker recognized the voiding of the original RWP, the need to request supervisory direction, and utilize a more restrictive RWP during re-entry. While the desire to verify the readings was acceptable, there was no apparent reason to believe the instrument readings were invalid, and the workers subjected themselves to measured high radiation levels and unknown conditions using a routine low risk RWP.
- An entry into the S-farm High Radiation Area at approximately 10:00 A.M. to conduct a survey to further investigate the high radiation conditions were planned and authorized using an informal entry plan rather than the formal procedure for Radiological Control investigative surveys defined in TF-OPS-025. TF-OPS-025 establishes specific requirements associated with tank farm investigative surveys including hazard analysis and work authorization requirements. The informal entry plan failed to address a number of important elements of TF-OPS-025 including the investigative survey request process, development of a WHA in support of meeting Industrial Hygiene monitoring requirements, Senior Supervisory watch and ALARA/RadCon Management oversight, post-job review requirements, and so on.

The entry plan also defined radiological control requirements and referenced RWP COJ-101 for dose tracking purposes. The meaning of this is unclear and the entry plan failed to meet Radcon Manual requirements for an RWP (e.g., no worker signature indicating understanding) Neither the entry plan nor RWP contained the specific PPE requirements for the entry. For example, the entry plan PPE requirement stated “one full set of anti-c’s,” with no further clarification as to the composition of the outer gloves normally worn when donning “a single set.” The RWP referenced Special Instruction 6; however, Special Instruction 6 contained no details relevant to outer glove requirements. TF-OPS-025 requires use of silver shield gloves if the potential exists for encountering tank waste. Neither this control nor any warning about encountering tank waste was contained in the entry plan or RWP.

- Subsequent entries into the S-farm to apply fixative to the spill continued to utilize informal entry plans and RWP COJ-101, with similar deficiencies noted above. In addition, RWP COJ-101 authorizes only "HPT Investigative Surveys"; therefore, its use for fixative application is inappropriate and not within the authorized work scope and hazard analysis. During one of the entries, a photograph shows an HPT taking a swipe on a chair splattered with tank waste wearing only latex outer gloves rather than the required silver shield gloves.
- Radiological Survey Reports associated with the S102 event response contained a variety of errors and inconsistencies and did not meet the requirements of TFC-ESHQ-RP-ADM-P-09 for radiological survey records. Examples include inaccurate/incomplete association of the survey record to the specific work package or technical procedure controlling the work, use of N/A for beta dose rates and air samples, survey start and stop times extending for more than a single shift without explanation, inaccurate denotation of the purpose of the survey, failure to include complete information on air samples (including type of air sample and air sample log numbers for breathing zone samples), failure to include maps denoting survey locations, and incomplete review signatures.

Work Control, Provide Feedback and Improvement

Lessons learned from the previous damage to the original Seepex pump, including procurement of an air motor to turn a stopped pump versus by hand and special tools and torque limits for turning the pump by hand, if needed, were not implemented effectively.

A readiness review considered the use of the air motor to be a "post-restart" item, and maintenance indicated that they were ready to support pump (manual) rotation when needed — the tools were available, the staff was briefed, and that Engineering had provided the torque limits. Controls to implement these lessons were not effectively established nor implemented.

Several of the deficiencies identified during conduct of this DOE Type A Accident Investigation are very similar to non-compliant conditions included in the PAAA Enforcement Action issued on March 10, 2005.

Work Control Process Summary

The analysis of work control process in regard to operations, maintenance, and radiological control has shown many areas that require attention. CH2M Hill has not implemented an effective method for identifying tank farm small quantity waste leaks. There is inadequate flow down of radiological control requirements during abnormal conditions. There were many examples of radiological Conduct of Operations deficiencies that were evident during the S-102 response to abnormal operating conditions. CH2M HILL management lacks an adequate Conduct of Operations Program for closure operations that fulfills the commitments in the safety basis. CH2M HILL lacks fully effective administrative controls for transfer controls for waste transfer pump bump and administrative lock controls.

APPENDIX H

Supporting Information — Emergency Management

Introduction

The tank farm emergency planning hazards assessment (EPHA) consequence analyses and emergency action levels (EAL) have been developed utilizing the event scenarios contained in the respective Documented Safety Analysis (DSA). In the DSA, high-probability, low-consequence events are identified as having only minor onsite impact on personnel and the environment, and were not analyzed. Correspondingly, the EPHA does not postulate and analyze events covering the full range of possible initiators and severity levels as recommended in the *Emergency Management Guide*, DOE Guide 151.1. Specifically, the July 27, 2007, spill represents the lower end of the consequence spectrum, and EPHA consequence analyses have not been performed. As a result an EAL was not developed that would provide for the prompt recognition and predetermined protective actions for an event of this type.

Extensive studies have been performed on chemical effects for releases from the tank farms. Due to multiple chemicals contained in the waste, sum-of-the-fraction calculations (conservative approach) were used to determine protective action guides that would result in the declaration of an operational emergency (alert, site area emergency, general emergency). The sum-of-the-fraction calculations were also used to determine protective action distances for each of the identified release scenarios. Protective action distances provided in the EALs were determined by comparing dose consequence distances from both the radiological and chemical calculations. The worst-case distance for either radiological or chemical consequences was used for each operational emergency level and protective action distance in the EALs. However, the EAL tables do not indicate whether the results were determined from the radiological isotopes or the chemical constituents. An extensive understanding of the DSA and EPHA would be required to know which material presents the greater hazards to workers and responders for each of the identified release scenarios.

Two EALs were evaluated for applicability to this event. The first involves an observed liquid spray and, the second, a pool. An EAL that pertains to an unobserved spray leak has not been developed, even though the waste may be carried substantial distances through the air. The tank farm EPHA did not consider this type of accident scenario. Assumptions used for consequence assessment analyses in the EPHA and for EAL development are not adequately documented. Through interviews it was determined that the EAL pertaining to the pool release scenario was developed assuming a hard surface with a pool depth of 1.3-inches, which equates to 256 gallons of waste over a 20-foot-diameter circle. The July 27, 2007 release resulted in a pool, with size estimates ranging from approximately 8 feet to 18 feet in diameter by facility personnel that had pooled in some areas close to the pump. Because the spray was not observed, and the pool area was estimated to be less that a 20-foot-diameter circle, the thresholds for implementing these EALs were not met. The congestion of equipment in the area and soil conditions make the determination of pool size, used as the EAL threshold, impractical.

The Board found that the EPHA and EALs do not adequately address releases of mixed waste at the tank farms. Additionally, assumptions used for EPHA analyses are not adequately documented and EALs do not identify whether the protective action distances are based on radiological or chemical hazards. [JON ER-1]

Plans, Procedures & Checklists

The Hanford site has detailed emergency response and event response plans and procedures that are applicable to the event that occurred on July 27, 2007. The site-wide emergency plan is supported by detailed emergency plan implementing procedures (EPIP). The EPIPs include position specific checklists for all key positions in the incident command structure (ICS) and emergency operation center (EOC). EPIPs adequately address event categorization and classification, incident command, EOC operations, worker notifications, and use of sirens. The EPIP for incident command also provides for using the ICS for abnormal events not meeting the threshold for an emergency. An EPIP is also in place for establishing an event coordination team (ECT) for non-emergency events that do not require activation of the full EOC team. These procedures and the ICS framework facilitate a graded response to events on the Hanford Site.

The building emergency plan (RPP 27869) for the tank farms is supported by emergency response procedures (ERP) and abnormal operating procedures (AOP). These documents describe planning and response activities for analyzed events at the tank farms. The ERPs provide specific steps to be taken to implement actions required by EPIPs. Two of these procedures, TF-ERP-001, *Take Cover/Personnel Accountability/Evacuation*, and TF-ERP-005, *Radiological Release*, were applicable to the event that occurred.

AOPs provide required actions for response to events that do not meet EAL thresholds for operational emergencies. Of the 19 AOPs, the following are directly applicable to the July 27 event:

- TF-AOP-003, *Response to Elevated Airborne Radioactivity*;
- TF-AOP-006, *Response to High Radiation*;
- TF-AOP- 011, *Response to Radiological/Hazardous Material Leaks, Spills and/or Personnel Contamination*; and
- TF-AOP-015, *Response to Odors/Unexpected Changes to Vapor Conditions*

The Hanford Patrol Operations Center (POC) is the point of contact for all events on the Hanford Site. They provide security, access controls, and much of the site communication used for emergency response. The POC receives all 911 calls, provides initial notifications, operates crash phones for emergency notifications to workers within facilities, and activates emergency warnings sirens. The POC has quick reaction checklists for the 911 operator's use that prescribes required notifications and actions for declared emergencies and protective actions, such as take cover and facility evacuation. These checklists are an effective aid to the 911 operator in making proper and timely notifications.

Although procedures and checklists used to respond to the July 27, 2007, abnormal event are generally comprehensive and provided for integrated response, the following weaknesses were noted.

- The abnormal operating procedure (AOP-006) used for responding to high radiation areas (HRA) requires the cause of the HRA to be determined. However, it does not adequately address the potential for airborne releases. The procedure does not require that the cause of the HRA be conservatively assumed to be a release until determined otherwise or that air samples (radiological or chemical.) be taken. This conservative approach would address the potential for airborne hazards as well as the high radiation area. Air samples for radioactivity were taken at the fence perimeter at approximately 4:30 A.M. No industrial hygiene air sample was taken close to the spill area until the leak was discovered, hours later.

- Clear limits on what responses are allowed by an AOP/ERP have not been determined. An informal entry/re-entry plan, concurred on by the RadCon Manager and Building Emergency Director, was used in lieu of established work control processes, such as a radiological work permit.
- The POC has quick reaction checklists for declared emergencies and protective actions but not for abnormal events or operational emergencies not further classified. The AOP for responding to a high radiation area required a call to 911, but did not specify what actions were expected as a result of that call. Additionally, there is no formal training for patrol officers who receive 911 calls on these types of events.
- The crash phone announcements contained in the quick reaction checklists were specifically written for emergencies. The announcement read from the checklist for this event, categorized as an abnormal event, stated that there was an emergency, causing some confusion as to the significance of the event on the part of workers receiving the message.

The Board found that the plans and procedures implemented for the July 27, 2007, abnormal event response provided for an integrated response by the incident command team and ECT and POC. However, some procedure weaknesses were noted related to identification and communication of hazards.

Event Response

Event Recognition

A number of weaknesses contributed to the failure to recognize the accident as a hazardous waste spill. One of the most significant was the mindset of the personnel involved that the high radiation reading was caused by a slug of waste in the transfer line. The first indication of a potential hazardous waste spill was when a Health Physics Technician (HPT) noted that the personnel contamination monitoring instrument (frisker) in a Change Trailer indicated approximately double the normal background rate. After a few seconds the counts dropped back to normal background. A second indicator was a gamma reading of 200 mr/hr approximately 8 feet from the valve pit that was observed by the HPT and nuclear chemical operator (NCO) who entered the tank farm at approximately 2:20 A.M. to perform after-transfer radiation surveys and the shutdown valve lineup. The NCO also noticed a darkened area on ground (lighting was poor) and communicated to the operating engineer that “this farm is stinky.” The HPT, thinking he may have a defective instrument, got another instrument to verify the high radiation levels. The HPT did not take open-window beta-gamma readings, which would have made it obvious that there was spill of radioactive material.

The NCO and HPT evacuated the area and established proper access controls for the high radiation area. The Closure Operations RadCon Manager and the Waste Feed Operations Shift Manager were notified. The Shift Manager implemented AOP-006, *Response to High Radiation Area,* and at approximately 2:40 A.M. made a log entry that he was performing actions specified by the procedure and noted that initial actions were complete. However, he had not made a call to 911 as the initial actions of the procedure required. Since he would not have requested assistance, and there is no quick reaction checklist for 911 officers to dictate actions and notifications for a high radiation area, it cannot be determined what effect, if any, the 911 call would have made to event response and recognition. Additionally, as stated previously, the procedure requires that the source of the high radiation be determined, but it does not require that precautionary actions for a spill be taken until it is established that no spill has occurred.

The Shift Manager verified that there were no leak detector alarms and no discrepancy in Material Balance Data. Numerous CH2M Hill managers were notified from 2:20 A.M. until 6:30 A.M., and the U.S. Department of Energy, Office of River Protection (ORP) Facility Representative was contacted at 4:15 A.M. During this same period of time airborne radioactivity, surface contamination, and radiation surveys were performed along the tank farm fence line. No abnormal levels of radiation were detected. Industrial Hygiene air samples were not taken during this period.

At 10:07 A.M. an investigative survey identified that a spill had occurred and was the cause of the previously discovered high radiation readings. The shift manager, now acting as the Building Emergency Director (BED), implemented AOP-011, *Response to Radiological/Hazardous Material Leaks, Spills and/or Personnel Contamination*. The BED contacted a Shift Manager from a nearby evaporator facility and dispatched him to the SY Change Trailer at the S-Complex. The BED then received a call from an NCO in the SY Change Trailer who briefed him on conditions at the scene, including local wind direction, to establish safe approach routes. At 10:32 A.M., the BED called 911 to report the spill, which was routed to the Hanford Fire Department (HFD) and the occurrence notification center (ONC). The HFD Battalion Chief assumed the role of incident commander in accordance with site procedures. The BED requested that the POC initiate a take cover notification for the 200 West and adjacent areas. ERPs, EPIPs, and checklists were then used to guide proper response activities in the field. The ONC contacted the Richland Operations Office (RL) emergency duty officer (EDO) and at 10:52 A.M. the EDO activated the ECT.

The Board found that event recognition was not timely as a result of procedure content and use.

Categorization/Classification

The decision to categorize the tank farm release as an abnormal event was made by the ONC in consultation with the BED, and later the ECT. The categorization was based on the two EALs developed for the facility that are in turn based on the EPHA consequence analyses. The first EAL pertains to a waste transfer spray leak (or pool leak with splash or splatter) that produces an aerosol spray (or significant splash or splatter) of waste; however, visual confirmation of the spray (or significant splash or splatter) being released is required to meet the expectations of this EAL. The second EAL pertains to a waste transfer surface pool leak (without spray, splash, or splatter) that results in liquid waste leaking from a waste transfer line with a pooled surface area of at least 20 feet in diameter. Therefore, because the spray release from the tank farm event was not visually confirmed at the time of the release, and the pool area was less than 20 feet in diameter, the decision to not categorize the tank farm release as an operational emergency is consistent with the EALs as currently written.

Generic EALs, used to categorize unforeseen events that have not been analyzed, could have been used to categorize this event as an emergency, but the site classification procedure requires that generic EALs should be used only when an EAL event category is not available. Since EALs did address the upper bounds for the waste leaks accident scenarios, generic EALs were not used. However, the response actions to this event would not have been substantially different, based on the prompt implementation of the ICS and involvement of the ECT.

The Board found that the event categorization was consistent with site procedures and EALs.

Notifications & Communications

Upon receiving the 911 call and a request for take cover notification, the POC entered the applicable quick reaction checklist and activated the alerting siren for take cover for the 200W area. Crash phones were activated at 10:38 A.M. for the affected area only, and a pre-approved message was read instructing personnel to take cover, close doors and windows, and secure ventilation systems. Although categorized as an abnormal event, the initial message, read verbatim, stated that there was an emergency in the 200 West Area. This was corrected in a second crash phone message that went out to all areas at 11:28 A.M. The POC received numerous calls from people outside the affected area wanting to know about the event and whether they were required to take cover. At the recommendation of the ECT crash phone coordinator, all messages after the initial one went out to all areas.

The BED made timely notifications of the abnormal event to offsite agencies in accordance with site procedures. An update notification was faxed to inform them when no contamination was detected at the facility boundary, and the take cover was lifted. The ONC called the DOE Headquarters Watch Office and faxed a prompt notification form within an hour of the event categorization. Although these reports provided an adequate summary of the event description, they did not indicate that the leak had occurred approximately 8 hours before the discovery time noted on the forms.

The ECT was notified by pager at 10:52 A.M.. Although required by the ECT procedure (RLEP 2.4), neither the RL nor ORP Emergency Managers were notified when the ECT was initially activated. Although the ECT was promptly activated and staffed by experienced personnel, it was not until 12:30 P.M. that people in the ECT found out that the spill actually occurred at 2:10 A.M. The RL Emergency Manager was informed of the event by the Site Security Director, and he arrived at the EOC at the same time other ECT members were responding. The ORP Emergency Manager was notified at approximately 12:15 P.M., and he arrived at the EOC at 12:50 P.M. As a result of the delay in notification, the ORP emergency manager did not get briefed on the event until shortly before 1:00 P.M.

A news release was issued at 1:26 P.M. on Friday and, as required, it was reviewed and approved by the ORP Emergency Manager. The ORP Emergency Manager also provided recorded verbal information to a local news station. The news release contained some inaccuracies; such as the leak was believed to have been started and stopped on late Thursday, and that it was discovered by environmental monitoring.

The Board found that notifications and communications were generally timely and effective at activating response organizations, and warning workers and the public of potential hazards.

Incident Command

The Incident Command Team demonstrated an effective capability for initial and ongoing response to the event. Staffing the incident command post (ICP) and ECT was accomplished in a timely manner by individuals assigned on the duty roster. Incident Command Team members used their position-specific checklists to guide them in performing their assigned functions, and the ECT provided support and additional expertise.

Initial event actions were led by the Senior Shift Manager serving as the BED. Upon receiving information that the high radiation area was the result of a spill, the BED called 911, requested a take cover siren and crash phone message for the affected area, and established an ICP. Once 911 was called, the HFD Battalion Chief responded to the tank farm from a safe upwind direction to access the event scene. After receiving a briefing at the SY Change Trailer (MO-296), the Battalion Chief reported to the ICP and assumed the role of Incident Commander.

An Incident Command Team was established in accordance with the applicable EPIP. The principles of ICS and the Hanford EPIPs allow for a graded approach. In accordance with these procedures, the IC ensured key ICS positions were staffed and implemented the same ICS procedure checklists as he would have used for an emergency response. An appropriate set of priorities was established to ensure personnel safety and to mitigate the potential hazards of the waste spill. Although checklists include reminders for personnel manning the ICP to prepare and retain logs and forms in order to maintain a record of activities, most of these checklists and log forms were not available after the event either because they were not filled out or they were disposed of following the event.

The ECT, a subset of the EOC team, provided assistance and support to the IC. For example the ECT assisted the IC by assembling a team to perform radiological field monitoring and assumed responsibility for providing updates to personnel who had been instructed to take cover.

The Board found that incident command was effectively implemented.

Protective Actions

Protective actions to prevent worker exposure to hazardous chemicals and high radiation doses included evacuation of the immediate area, issuing a take cover order, and establishing access controls. Considering the quantity and constituents of the hazardous waste release, these actions fulfilled their purpose. However, some weaknesses were identified in the implementation of protective actions.

The response to the high radiation area included evacuating the immediate area and establishing positive controls to ensure personnel could not enter the S-farm complex. Personnel were stationed at the three entrances in the change trailers until lock and key control could be established. Once lock and key controls were established and prior to the discovery of the leak, workers were free to move around (including eating and drinking) outside the tank farm fence. When the leak was discovered, personnel who had been free to move around outside the fence for 7 hours were instructed to take cover, where they stayed for approximately 2.5 hours.

Additionally, the HFD Battalion Chief arrived at the SY Change Trailer (MO-296) to assess the situation as the take cover siren sounded. Although the IC decided it was safe for him to leave the SY trailer to report to the ICP, 9 workers were left in the SY trailer for approximately 2.5 hours under the take cover order, as mentioned above. Under a take cover order, workers are instructed to close doors and windows and secure ventilation. As a result, workers were sheltered in a trailer for an extended time without ventilation on a day when outside temperatures exceeded 90 degrees Fahrenheit. More significantly, responders place themselves at risk by entering and leaving an area where the hazards are not fully characterized.

Subcontractors working outside the S Tank Farm fence took cover in their vehicles when the siren sounded. These people had general employee training that included instructions to take cover inside the nearest building, but because they were not near a building they were not sure of what to do or what direction they should head to find a building nearby. They called their Flour Hanford supervisor who in turn contacted 911 and later the ICP to determine where they should go to take cover. These people waited several hours before being told they could leave the area. During this time they observed several Hanford Patrol vehicles pass by on a nearby road. Hanford Patrol officers did not stop to help them or to tell them to take cover in a building.

Although take cover was ordered for the 200W area and three adjacent facilities, access controls were established only for the 200W area. No positive controls were established to prevent people from entering the adjacent facilities from the north and east.

The Board found that processes for protective action decision-making and communication were effective; however, some weaknesses in implementation would add unnecessary risk to workers and responders for events with more severe consequences

Consequence Assessment

Consequence assessment functions were performed by the EOC radiological assessor when the assessor reported to the EOC for the ECT activation. Microshield, a modeling tool used for determining stand-off distances, was used to determine approximate source terms from the open- and closed-window readings obtained by the RCTs after the tank farm event was classified an abnormal event. The results of the Microshield modeling estimated 5 Ci of Cs^{137} and 1.5 Ci of Sr^{90} as the worst-case source-term. HotSpot modeling was not performed to verify if protective action distances were exceeded because radiological field monitoring data had already confirmed that readings at the fence line of the tank farm were not above background readings. However, field monitoring or modeling chemical constituent releases from the tank farm waste was not considered in implementing the consequence assessment functions.

The Site Emergency Director requested a radiological assessor to report to the EOC for support on performing radiological modeling, but did not consider requesting an industrial hygiene assessor for support on modeling the chemical constituents contained in the tank farm waste. Modeling of chemical materials was not performed until Monday, July 30, 2007. Modeling was conducted after the event, due to gaps in monitoring data, in order to estimate potential near-field dose exposures. Concentrations of ammonia and N-nitrosodimethylamine (NDMA) were the chemical constituents modeled. These are representative of the worst-case gases that can be emitted from the tanks. Consequence assessment modeling of the headspace gases is more conservative than modeling pool releases; therefore, modeling for only the gaseous releases is justifiable as these would produce the worst-case results. Ammonia and NDMA were modeled assuming 100 percent instantaneous volatilization and the modeling indicates that the release resulted in negligible exposures at 25 meters to 30 meters beyond from the S-102 tank, even in the worst case scenario (see the Health Effects section of this report).

The modeling of the headspace gases indicated that protective action guide values were not exceeded at a distance that would have required classifying the event as an operational emergency; however, ammonia and NDMA are not listed among the chemical constituents analyzed in the EPHA. In addition, because the EPHA does not mention or describe a release of the gases, consequence assessment modeling in the EOC was less likely to have been performed even if an industrial hygiene assessor had been requested to report to the EOC. The industrial hygiene assessor only has a listing of the chemicals used in the EPHA for reference in performing consequence assessment modeling and, unless the assessor had a thorough understanding of the tank farms and the potential for a release of the headspace gases, consequences of a release of the gases would not be considered.

The Board found that consequence assessment activities were appropriately conservative and provided further validation of field monitoring data.

APPENDIX I

Supporting Information — Management Systems

CH2M Hill Oversight Roles

Senior management was interviewed concerning their understanding of the management systems related to the accident. They stated that the current contract had been in effect since October 1, 2006, and had removed the requirement to retrieve 26 tanks in 5 years that had been in the previous contract. They agreed the initial DOE contractual requirement imposed significant schedule and budget pressure for tank retrieval. As noted elsewhere in this report, this requirement was not met, and only seven tanks have been retrieved.

The current contract provided incentives for completing waste retrieval of Tank S-102 by September 30, 2008. An incentive fee to complete retrieval operations by March 31, 2007 was not earned. They considered that the current contract was much more achievable, and the schedule and budget for this was adequate.

Senior management was not familiar with the scope and extent of the testing that was performed on the S-112 and S-102 pumps, although other CH2M staff members were. Senior management stated its expectation that all new retrieval technology would be tested using simulant in the ORP Cold Test Facility.

Senior management stated, based on lessons learned from this accident, that oversight and engineering capabilities were not as effective as they expected and outlined immediate actions being taken to increase these capabilities. In addition, they stated that staff recognition of the potential for spread of radioactive contamination during retrieval activities needed improvement and was being re-emphasized. Finally, they stated that continuous monitoring of selected hazardous chemicals during retrievals appeared appropriate and that systems to achieve this were being developed and implemented.

DOE Oversight Roles

The Department of Energy redirected the contractor in 2002 to focus the waste retrieval program for tanks S-112 and S-102 from technology demonstration to rapid mission acceleration. Twenty six tanks were scheduled for retrieval in 5 years, with no validation from experience that this schedule was realistic. The resulting overly aggressive retrieval schedule was a contributing factor to incomplete reviews of the changes in the designs for the Seepex retrieval pumps for S-102.

In addition, testing of the design of retrieval systems for S-102 was inadequate for the modified character of the waste in the tank, as discussed earlier in the report. The change in pump design and the inadequate testing program were not reviewed or identified by ORP or DOE, due to a lack of engineering expertise, inadequate staff, and overemphasis by ORP management on meeting an unrealistic schedule at the time the schedule was prepared in late 2002. ORP management in 2007 was not familiar with the limited nature of testing of the Seepex pump and high pressure mixer installations.

The engineering of the Seepex pump installations was performed during the period from late 2002 through early 2003. At that time, a small review team at the ORP was reviewing and approving the first Documented Safety Analysis (DSA). The S-112 and S-102 retrieval pump designs were not reviewed by ORP at the time due to limited staff. The backflow prevention criteria in the DSA approved by ORP were adequate. However, ORP did not identify the deficiency in the design, nor did it identify that some portions of the systems physically connected to the tanks were not conservatively classified as safety significant when they should have been.

In the 5 years since the design was completed, engineering and nuclear safety oversight by the ORP of CH2M Hill engineering has been very limited. In the last 2 years, division supervision has been diverted to other temporary assignments for extended periods. In this period, management commitment to engineering and nuclear safety oversight appears to have been a low priority, such that insufficient resources were provided to this activity. However, ORP oversight of operational safety in this period was evident and directly contributed to deliberate reduction in retrieval to ensure adequate safety was achieved or, in some cases, restored. Retrieval schedules were extensively revised in late 2006 to permit much slower retrieval, and are now considered realistic by both ORP and CH2M Hill.

Throughout the period 2002 through 2007, the Facility Representative Program has been adequately staffed, and has provided adequate oversight of operational activities. In addition, senior ORP management has aggressively required improved CH2M Hill operational performance. This was evident from ORP responses to a series of occurrences in radiological protection, industrial safety and hygiene, and weaknesses in the integrated safety management system. ORP and, more broadly, DOE, have taken significant action to ensure these operational deficiencies were identified and corrected, in the period from August 2002 through 2006.

Lessons Learned from Previous Events

CH2M Hill was issued a "Preliminary Notice of Violation and Proposed Civil Penalty," dated March 10, 2005, totaling $316,250, which identified several deficiencies that are very similar to potential issues currently being evaluated by the DOE Accident Investigation Board. Specifically, those shown below.

"Preliminary Notice of Violation and Proposed Civil Penalty," dated March 10, 2005	Issues currently being evaluated by the DOE Accident Investigation Board
Requirement that one of three backflow prevention systems be provided when non-waste transfer systems are physically connected to an active waste transfer pump.	Same condition identified now and resulted in a TSR violation.
Failure to position a valve to the correct position while performing an operations procedure.	Transfer Pump Discharge Valve left in closed position when the pump was started.
Failure to formally report equipment reliability issues.	VFD known to be unreliable directly resulted in the inability to operate the pump in the reverse direction to clear waste material from the pump due to a ground fault.
Software verification and validation shall ensure that software adequately and correctly performs all intended functions. Contrary to that requirement modifications to software associated with the low flow interlock was not adequately tested nor verified. As a result automatic shutdown of the transfer pump on low flow conditions did not occur.	Recent software changes associated with low flow resulted in the transfer pump tripping on a fault with no audible or visual alarm function.
One of the operators involved in the accident had not completed the system walk down portion of the training.	One of the operators had not completed the delta change training for S-102 operations, and the millwright had not received training specific to the newly installed pump.)

The Board concluded that the corrective action plan implemented following Preliminary Notice of Violation and Proposed Civil Penalty dated March 10, 2005, was ineffective.

CH2M Hill notified DOE of a Potentially Inadequate Safety Analysis (PISA) on September 27, 2005. The issue prompting the notification was the accumulation of waste material in the air line of the tank C-200 vacuum retrieval system, which represented a scenario that was not bounded by the Documented Safety Analysis (DSA).

The declaration of this PISA, combined with the conclusions on this accident investigation regarding the adequacy of the DSA supporting waste retrieval from tank S-102, indicates that CH2M Hill has not developed and implemented corrective action plans that prevent similar events from happening again.

The Board concluded that the CH2M Hill's corrective action plans implemented following Preliminary Notice of Violation and Proposed Civil Penalty dated March 10, 2005, and the PISA declared on September 27, 2005 were ineffective.

Role of Quality Assurance

CH2M Hill accomplished quality assurance in a small organization independent of the line project organization, reporting to the Vice President for Safety, Health, and Quality, with direct reporting for significant concerns to the President. The organization had changed its Director at least five times since 2002, but the scope and functions of the organization had remained relatively stable. Changes were initiated in 2003 and continued to the present to improve surveillance processes for construction activities. These functions included quality assurance manual revisions, audits and surveillances of procurements, surveillances of operations (including retrievals), and audits and surveillances of vendor quality assurance programs. In addition, corrective action programs were managed within the quality assurance organization.

A review of audits and surveillances performed in the period of pump design and procurement was conducted. Personnel stated that the procurement of the Seepex pumps for S-112 and S-102 had been pursued as a design-build project, with an aggressive schedule. Quality assurance personnel stated that their audit focus was on ensuring that components identified in the DSA as containing pressurized waste were procured consistent with the quality requirements in effect at the time. These personnel recalled that the pump vendor's (DMGM, Holmes & Narver) quality-related documentation had not initially met CH2M Hill's acceptance criteria, but these deficiencies were corrected. A record of a supplier audit completed in September, 2004 by Fluor Hanford personnel for CH2M Hill substantiated this observation. Finally, quality assurance personnel participated in the pump design review process discussed elsewhere in this report. The engineering for the third Seepex pump was performed by COGEMA/AREVA. Their quality assurance program was also not directly audited by CH2M Hill, but indirectly, through Fluor-Hanford. The Board noted that none of the quality assurance audits and surveillances that were conducted identified any of the broad programmatic issues identified in this report.

The arrangement whereby quality assurance oversight of the pump vendor and designers was performed by Fluor-Hanford introduced the possibility of confusion in responsibility for effective quality assurance. However, both ORP and CH2M Hill recognized their direct responsibility for quality assurance, notwithstanding Fluor's involvement.

Finally, ORP routinely reviewed changes to the approved CH2M Hill QA Program and identified deficiencies in CH2M Hill QA Program implementation through its surveillances and review of CH2M reports. ORP quality assurance reviews did not identify any of the broad programmatic issues identified in this report.

APPENDIX J

Barrier Analysis, Change Analysis, and Event and Causal Factors Chart

Causal Factor Analysis

Barrier Analysis

Barrier analysis is based on the premise that hazards are associated with all tasks. A barrier is any management or physical means used to control, prevent, or impede the hazard from reaching the target (i.e., persons or objects that a hazard may damage, injure, or harm). The results of the barrier analysis are integrated into the Events and Causal Factors Chart to support the development of causal factors. The Board's complete Barrier Analysis of physical and management barriers that did not perform as intended and thereby contributed to the accident can be found at the end of this Appendix.

Change Analysis

Change analysis examines planned or unplanned changes that caused undesirable results related to the accident. This process analyzes the difference between what is normal, or expected, and what actually occurred before the accident. The results of the change analysis conducted by the Board are integrated into the events and causal factors chart to support the development of causal factors. The Board's Change Analysis, which reinforces the Barrier Analysis, can be found at the end of this Appendix.

Causal Factors Analyzed

The Events and Causal Factors Analysis is a systematic process that uses methods to determine Causal Factors of an accident. Causal Factors are the significant events and conditions that produced or contributed to the Direct Cause, the Contributing Causes, and the Root Causes of the accident. This investigation followed the processes described in the DOE Workbook *Conducting Accident Investigations*, Revision 2, where the direct, contributing, and root causes are defined as follows.

- The direct cause is the immediate event or condition that caused the accident.
- Root causes are causal factors that, if corrected, would prevent recurrence of the same or similar accidents.
- Contributing causes are events or conditions that collectively with other causes increased the likelihood of an accident but that individually did not cause the accident. Appendix D contains the Board's Events and Causal Factors Analysis. Other contributing factors are identified in appendices B and C.

Direct Cause

The direct cause of the July 27, 2007, accident was leakage of high level waste from the retrieval pump system in S-102, most likely from a failed dilution hose.

Root Cause

The root cause was the failure to implement the DSA requirement to provide backflow prevention as prescribed in TSR LCO 3.1.2.

Contributing Causes

- The design process failed to recognize and mitigate the back pressurization hazard resulting from the direct connection of the dilution and sparge lines to the waste system.
- Management failed to apply lessons learned from previous contamination and vapor exposure incidents.
- The physical confinement for radioactive materials was not classified as safety significant.
- Incorporation of requirements to implementing procedures was inadequate.
- Response procedures were not developed for expected abnormal events.
- Management and personnel did not conservatively treat the High Radiation Area as a potential leak until it could be proven otherwise.
- Management allowed informal work activities.
- Management failed to follow procedure steps.
- Workers failed to follow procedural steps.
- Equipment failed.
- Hazards analysis was not performed or not complete.
- Workers were not wearing necessary personal protective equipment (PPE) for the work being performed.
- Industrial hygiene monitoring/sampling was not performed.
- Abnormal operating procedures were inadequate
- Operating procedures were inadequate
- An event was not analyzed in Emergency Planning Hazard Assessment (EPHA).
- Schedule pressure resulted in inadequate performance of a safety function.

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Barrier Analysis Worksheet

HAZARD			TARGET	
	What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
1.	Post Transfer Shutdown Radiological Survey	The barrier was effective in identifying a high radiation condition; it was ineffective in identifying a chemical leak spill.	The survey was not performed as prescribed by instrument operating procedure; no open window (beta) reading was taken. Management accepted routine HPT practice of closed window only readings by approving incomplete Radiological Survey reports.	The leak condition was not identified until approximately 8 hours after the high radiation condition was identified. The number of people potentially affected and/or exposed to radiation and chemical hazards was significantly increased.
2.	Tank Farm Operations Procedure Instructions for Response to Abnormal Radiation Levels	The barrier was not effective in ensuring timely evaluation and assessment of potential waste leaks associated with abnormal radiation levels.	Inadequate incorporation of radiological requirements associated with purpose and criteria for dose rate surveys. Vague and incomplete procedural instructions Lack of formal technical basis associated with dose rate action levels. No association of potential chemical leak concurrent with radiological exposure	The leak condition was not identified until approximately 8 hours after the high radiation condition was identified. The number of people potentially affected and/or exposed to radiation and chemical hazards was significantly increased.
3.	Corporate procedures for RWP use and Tank Farm operating procedure for Radiological Control Investigative Surveys	These barriers were not effective in ensuring effective controls during response activities and proper integration of appropriate management and safety disciplines in response planning.	Procedures not followed in favor of informal plans and protocols.	Personnel had the potential for exposure to radiological and chemical hazards for which specified controls were not clearly defined and/or adequate. Involvement of industrial hygiene personnel was delayed as no WHA was developed and procedure not followed.
4.	Pump piping system pressure boundary	The barrier was effective until the last cycle of reverse operation, when it failed and a leak occurred.	The plugged suction end of the pump allowed pressure buildup beyond the rating of the weakest component (the hose).	The leak is a direct result of the failure of the pressure boundary.
5.	Engineering design review process for S-112 Seepex pump installation	The process identified a potential backflow path during pump clearing operations with the pump operated in reverse. Resolution of this comment was inadequate. It implied that the dilution supply pressure would be adequate to prevent backflow, but did not provide for backflow prevention nor use material with sufficient pressure rating for maximum pump discharge (suction, in reverse) pressure.	The plugged suction end of the pump allowed pressure buildup beyond the supply pressure of the dilution water. Backflow and over-pressurization of the dilution line occurred.	The dilution line (hose) failed and the spill occurred.

	HAZARD		TARGET	
	What were the barriers?	**How did each barrier perform?**	**Why did the barrier fail?**	**How did the barrier affect the accident?**
6.	Abnormal operating procedures (AOP-005)	The barrier was not effective. It was initially effective in securing tank farm access, but the 911 call was not made as required. ▪ The AOP was misinterpreted as taking the place of other required tank farm procedures and protocols. ▪ AOP is not conservative in assuming spill until proven otherwise.	▪Shift manger chose not call 911, believing that no assistance would be required. ▪The AOP was used incorrectly as a standalone procedure without regard to other required tank farm procedures and protocols (e.g., RWP, investigative surveys). ▪ Personnel did not consider a leak as a credible cause of the HRA.	While the number of acute individual exposures was limited, failure to make the 911 call delayed application of additional resources and potentially increased the number of people onsite during the event prior to declaration of a leak.
7.	Operations data sheet provided only one space for survey values.	The barrier was ineffective in that it reinforced routine practice of taking only closed-window readings.	Personnel did not understand the basic reason for conducting the post-transfer survey was to check for leaks and the open-window reading would show beta radiation indicative of a leak.	Discovery of spill condition was delayed by approximately 8 hours.
8.	Operations procedures do not provide detail actions to respond to unplanned pump stoppage.	The barrier was ineffective; ad hoc pump troubleshooting was conducted under verbal direction of OE.	No action was taken to prevent pump from plugging during electrical troubleshooting. Personnel were not fully prepared for manual rotation (e.g., torque limit not initially known, delay in obtaining correct equipment).	Extended electrical troubleshooting activity may have contributed to pump plugging.
9.	Design Safety Analysis requirements for adequate approved procedures, control of configuration, and work control processes were not fully implemented — incomplete flow-down. DSA defense-in-depth controls not fully implemented.	The barrier was ineffective in the following. ▪ Credible operating conditions, both normal and off-normal were not fully identified and mitigated in the design. ▪ Formal design review of Seepex pump installations were not conducted at intermediate steps and at the completion of the subcontract design.	Pump installation was not recognized or treated as a new configuration. Schedule pressure likely contributed to the abbreviated reviews and testing.	▪ Back flow prevention not provided. ▪ Inadequate mixing may have contributed to pump plugging. ▪ Allowed a 'near miss' of personnel exposure to a spray of high level waste.
10.	New pump configuration was tested with water, which does not exhibit many of the troublesome features of the high level waste slurries. Testing with simulated waste to evaluate effectiveness of incremental improvements (e.g., sparge, modified inlet, shaft auger section) was not performed.	The barrier was ineffective in that: ▪ Effectiveness of sparge ring was not demonstrated. ▪ Performance of high level mixers at greater distance from the pump suction was not verified. ▪ Clearing pump suction by reverse rotation was not demonstrated.	Pump installation was not recognized or treated as a new configuration. Schedule pressure likely contributed to the abbreviated reviews and testing.	▪ Inadequate mixing may have contributed to pump plugging.

HAZARD			TARGET	
	What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
11.	Hazardous Operability (HAZOPS) review did not identify backflow to dilution lines as a hazard. (Thirty-one other hazards were identified and mitigated.)	The HAZOPS review was effective in identifying 31 potential hazard scenarios. It was ineffective in identifying back pressurization of dilution lines during reverse operation of the pump.	Personnel assumed that any backflow through the pump suction drains to an atmospheric tank. Possibility of plugging the pump section was not considered credible. The tank depth being great enough to preclude siphons reinforced this mindset.	The dilution line (hose) failed and the spill occurred.
12.	Management control systems	Failed to identify broad programmatic issues, including lack of procedural implementation; inconsistent application of personnel qualification; lack of rigor in engineering configuration control; and failure to achieve permanent corrective action.	Internal and external assessments failed to identify the broad programmatic deficiencies identified in this report.	Personnel and management involved in the accident failed to follow procedures in several instances, and personnel were assigned to tasks for which their training and qualifications were not current. The conditions are nearly identical to findings address for S-tank farm in the 2005 PAAA Enforcement Action. Engineering changes to installed alarms also contributed to the accident.

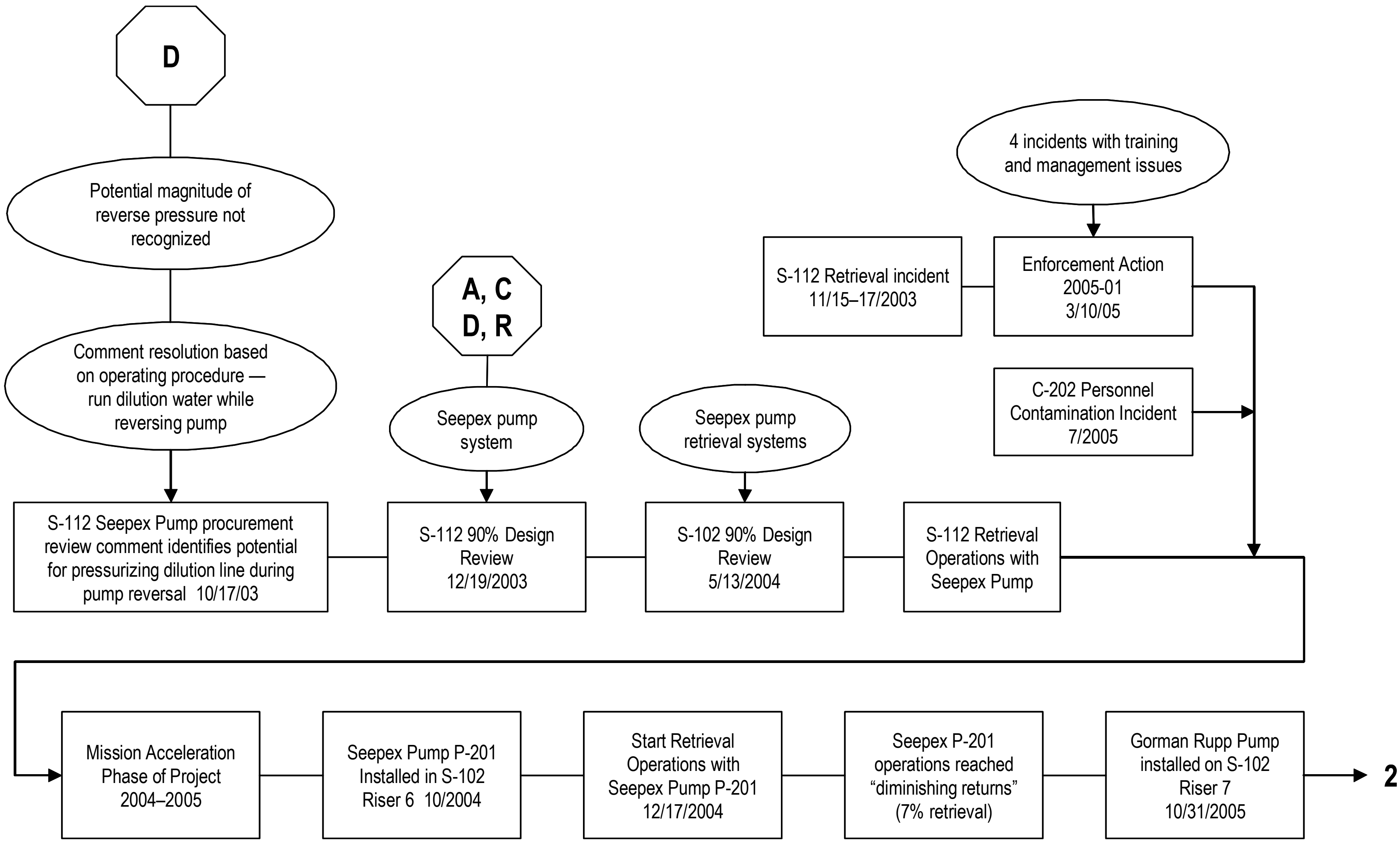
Change Analysis Worksheet

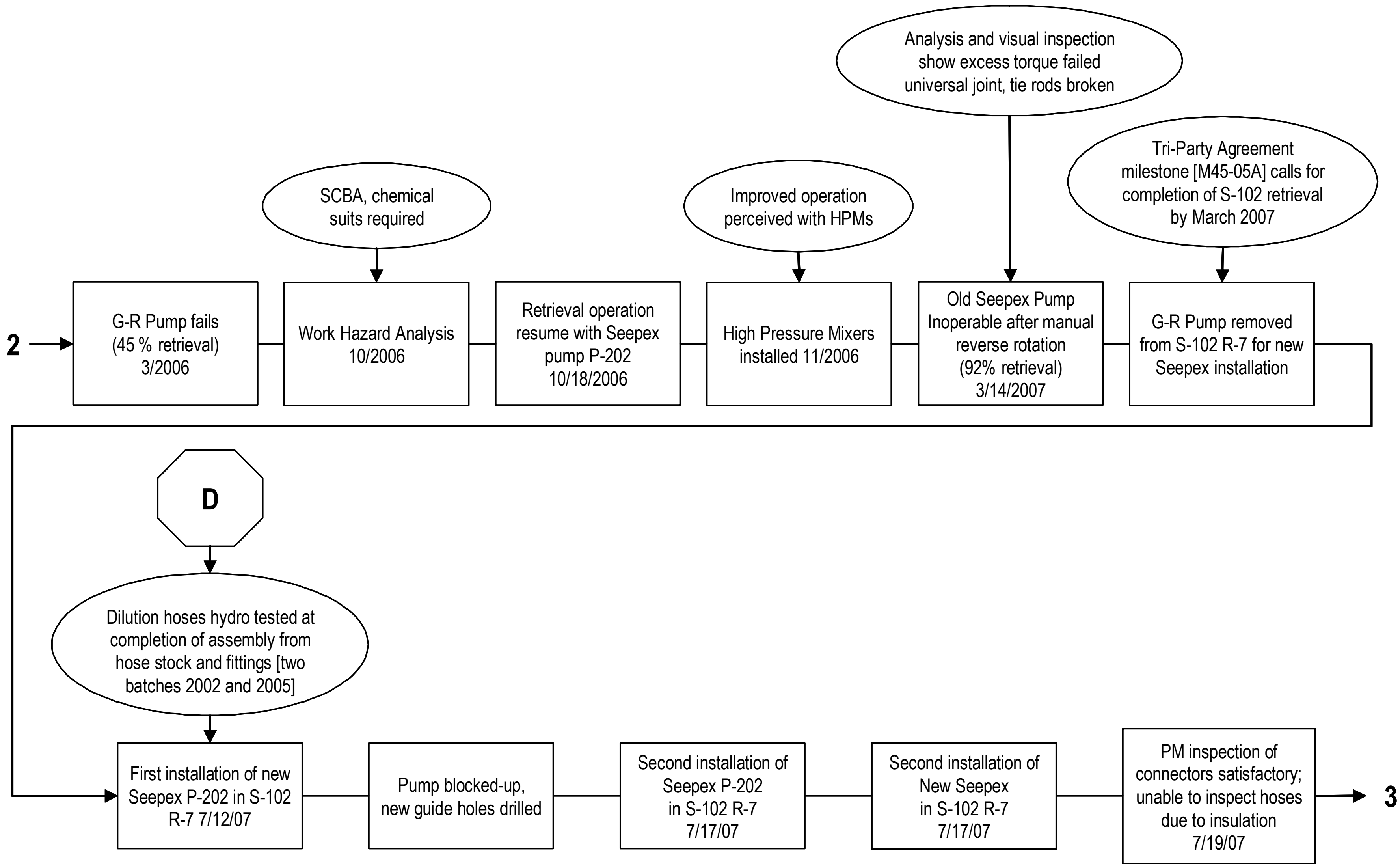
	Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
1.	Pump stopped running without a PLC alarm.	An alarm would be generated to alert operators of an unplanned pump shutdown.	Simple shutoff of the pump did not trigger any alarm logic.	Operators did not discover the pump shutdown condition for approximately 10 minutes.
2.	Low-flow interlock eliminated; alarm function set for low flow AND low dilution water flow (<10 gpm).	Alarm functions would be provided for relevant process conditions; in this case, including unplanned pump shut off.	Simple shutoff of the pump did not trigger any alarm logic.	Operators did not discover the pump shutdown condition for about 10 minutes.
3.	Pump remained in shutdown condition for several hours before solids could be flushed from the pump column.	Pump flushed prior to shutdown (as occurs with the normal shutdown and automatic reverse sequence) or alternate flushing means provided when pump inoperable.	Solids settled, plugging the pump suction and prevented restart of the pump; troubleshooting efforts were then needed.	Efforts to clear the pump eventually resulted in the spill.
4.	High pressure mixer not located near pump suction.	At least one mixer located near the pump suction to provide localized mixing as in the previous Seepex installation in S-102.	Mixer keeps solids suspended, demonstrated successfully in previous installation.	Build up of a cylindrical wall of solids around the pump suction may have contributed to the pump plugging.
5.	Pump sparge line plugged during or shortly after installation.	Sparge is available for use to provided localized mixing.	Sparge intended to provide mixings of solids into a slurry at the pump suction. Capability to blow clear settled solids at pump base is not available.	Build up of a cylindrical wall of solids around the pump suction may have contributed to the pump plugging. Ability to clear solids reduced.
6.	Beta dose rate measurements (open window) not taken. Practice of taking only closed-window readings had become routine despite procedural requirement.	Open- and closed-window readings normally taken to assess potential for beta radiation.	An incomplete evaluation of changes in radiological conditions was conducted.	Presence of beta radiation indicates a loss of containment since beta particles do not penetrate the transfer line shielding. Caused delay in recognizing spill.
7.	Troubleshooting plugged pump done under verbal direction of expert.	Troubleshooting procedure written with limits and controls.	Troubleshooting would be more organized, hazards and controls better evaluated, and needs for additional assistance would be identified.	A more thoughtful approach might have prevented the spill.
8.	No IH personnel or area monitoring in place during the spill event	IH personnel and area monitoring conducted.	No direct data on air borne chemical exposures were available for response personnel.	Assessing potential exposure and explaining effects to symptomatic individuals is more difficult.
9.	Tank farm lighting is inadequate for backshift operations. Deficiency known based on startup review.	Adequate permanent lighting available for all shifts worked.	Personnel may have been able to see the spill pool.	Recognition of the spill condition was delayed, and the number of potentially affected/exposed personnel was increased.

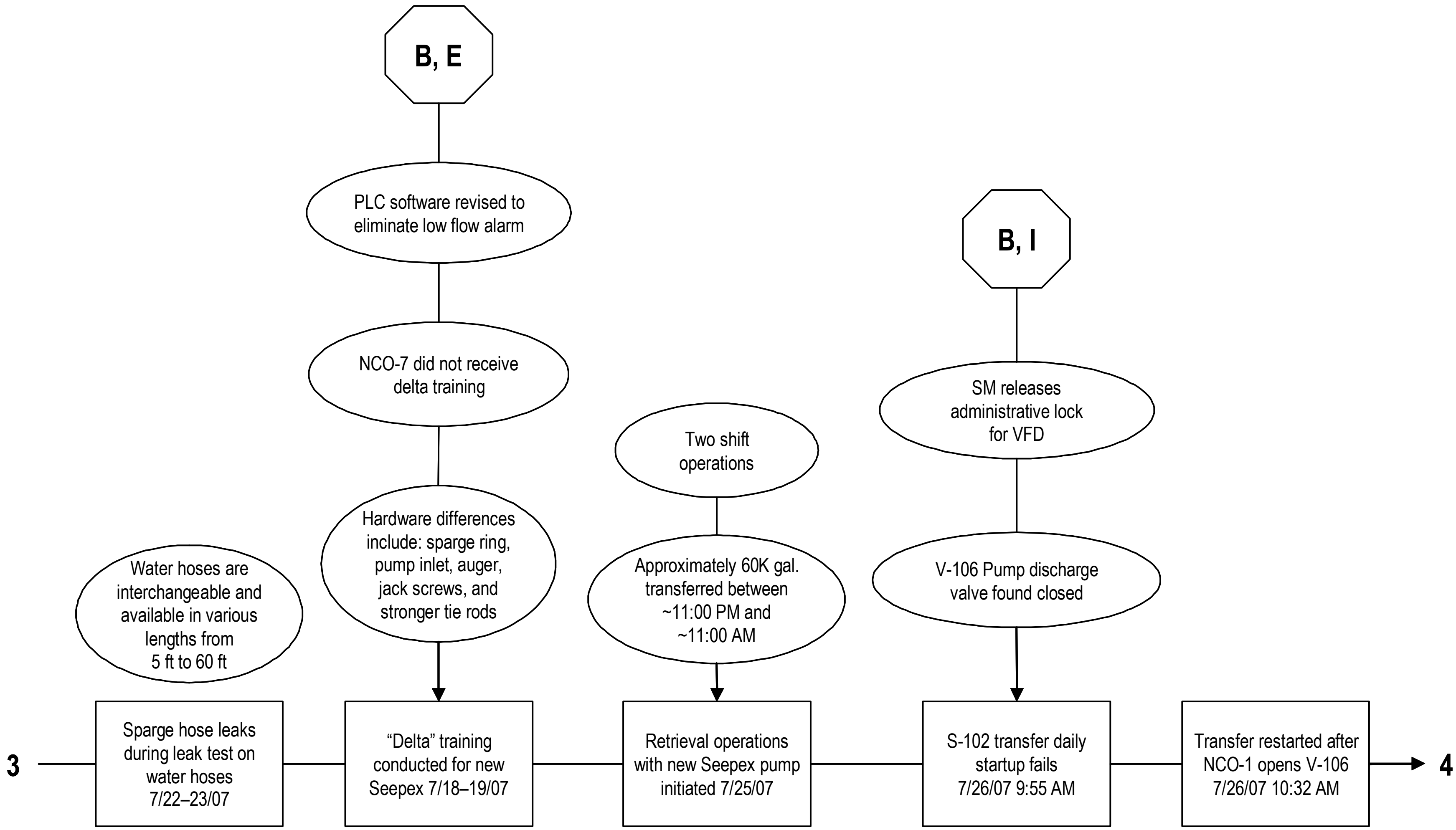
	Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
10,	Mandatory use of supplied breathing air discontinued in tank farms with the exception of Vapor Control Zones (VCZ).	PPE specified commensurate with work outside of VCZs. Maintenance work area at the pump not considered a VCZ.	No respiratory protection for workers at the time of the spill.	Workers could have been exposed to the chemical spill.
11.	Untested pump configurations used in new application with difficult waste (S-102).	Prototype testing conducted with simulated slurry to verify pump operability.	Potential for backpressure during reverse operations not identified.	Conditions leading to the spill not recognized and managed.
12.	Chemical hazard not recognized concurrent with radiation hazard.	All potential hazards considered.	Potential for chemical exposures not recognized or mitigated.	Two individuals potentially received acute exposure.
13.	TO-420-905 did not provide adequate instructions for timely response to abnormal radiation levels and confirming that waste did not leak (no pooling).	Clearly defined purpose for radiological measurements and conservative decision-making in executing response actions to potential spills that cannot be ruled out.	Operations did not complete required action “confirm no pooling” of waste in a timely manner after discovery of high radiation levels	Recognition of the spill condition was delayed and the number of potentially affected/exposed personnel was increased.
14.	AOP used as standalone instruction for responses.	AOP supplements, but does not replace existing tank farm procedures and protocols unless specified.	Errors in establishment of controls to ensure safety and prompt assessment of conditions.	Inadequate/incomplete controls for worker protection and delayed involvement of industrial hygiene.

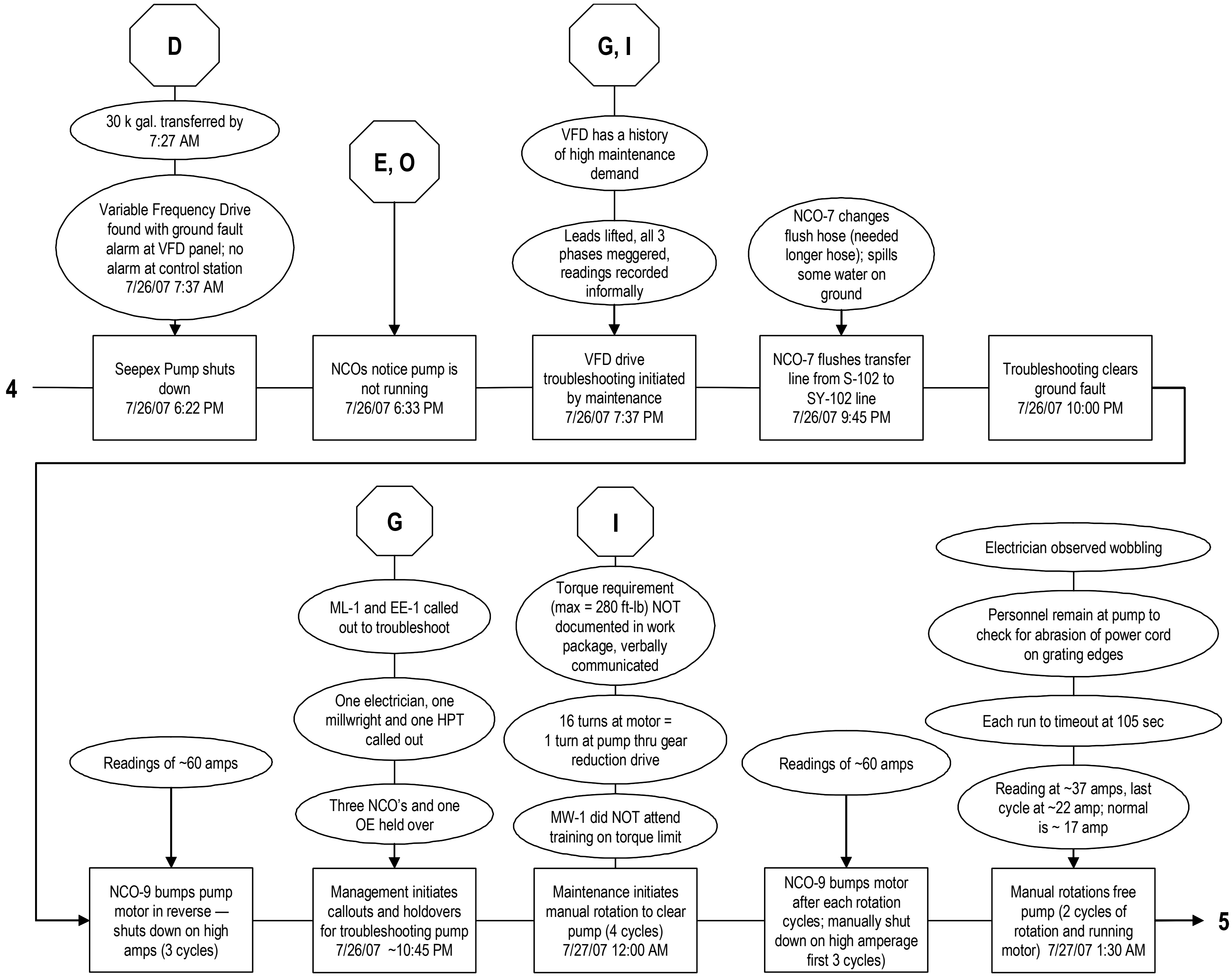
Events and Causal Factors Chart

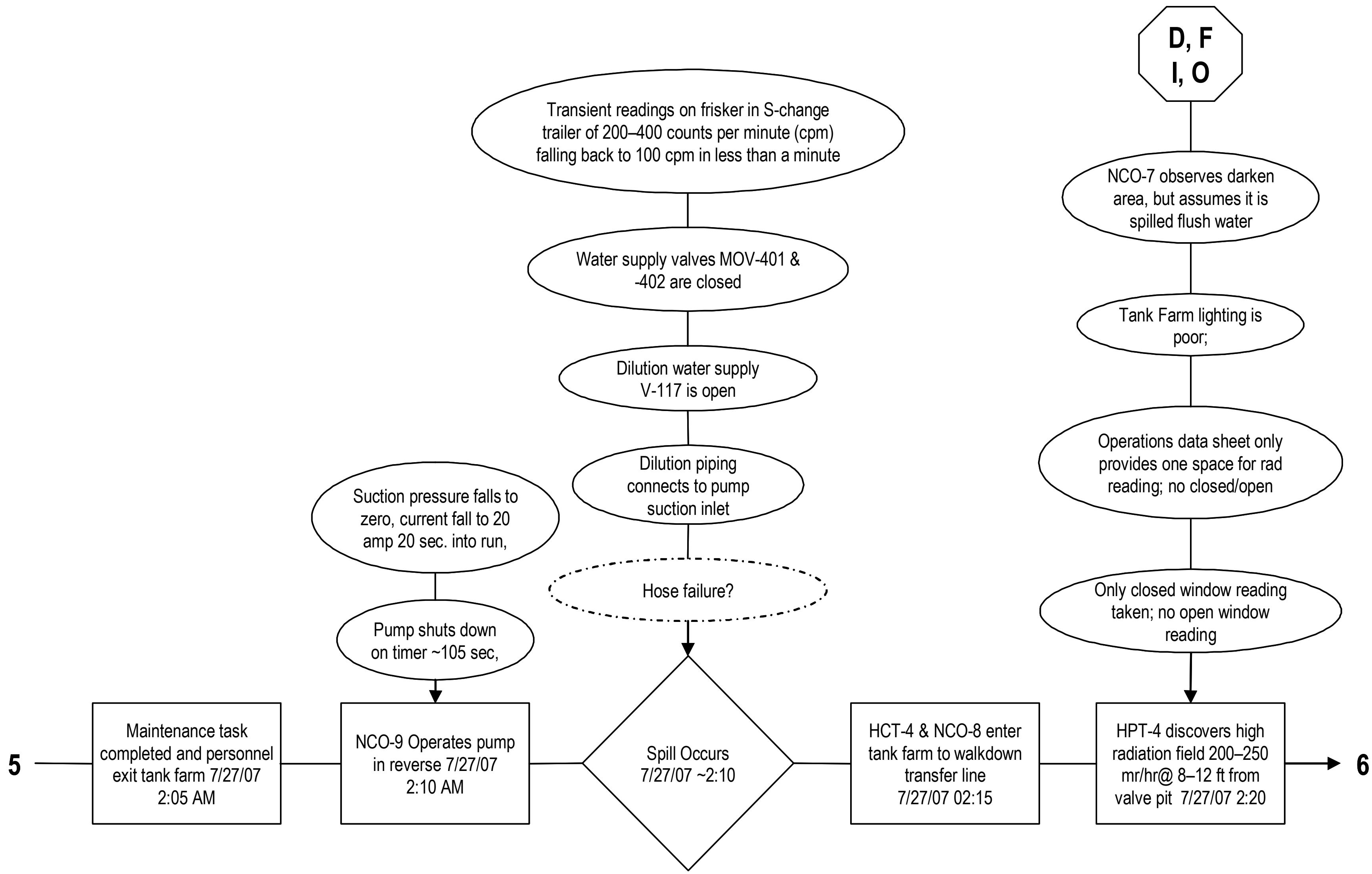
A	Failure to identify back pressurization hazard
B	Failure to apply lessons learned from previous contamination and vapor exposure incidents
C	Physical confinement for radioactive materials not safety significant
D	Procedure flow down less than adequate
E	Failure to develop response procedures for expected abnormal events
F	Failure to act as if an HRA is a leak until proven otherwise
G	Management allowed informal work activities
H	Management failed to follow procedure steps
I	Workers failed to follow procedural steps
J	Equipment failed
K	Hazards analysis not performed
L	Workers were not wearing necessary PPE for the work being performed
M	Industrial hygiene monitoring not performed
N	Abnormal operating procedures less than adequate
O	Operating procedures less than adequate
P	Event not analyzed in Emergency Planning Hazard Assessment (EPHA)
R	Schedule pressure

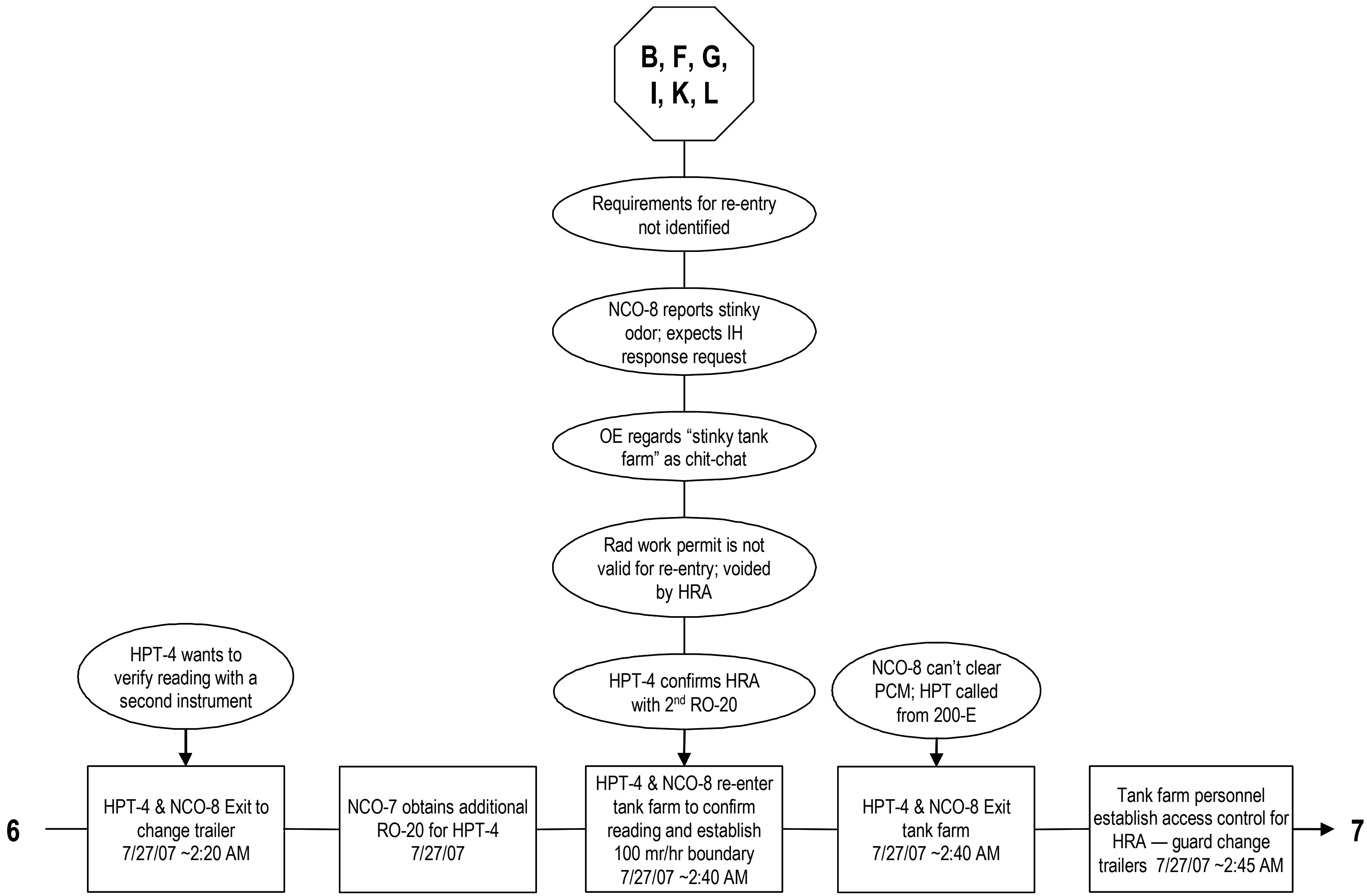

D
Potential magnitude of reverse pressure not recognized
Comment resolution based on operating procedure — run dilution water while reversing pump
S-112 Seepex Pump procurement review comment identifies potential for pressurizing dilution line during pump reversal 10/17/03
A, C D, R
Seepex pump system
S-112 90% Design Review 12/19/2003
Seepex pump retrieval systems
S-102 90% Design Review 5/13/2004
S-112 Retrieval Operations with Seepex Pump
4 incidents with training and management issues
S-112 Retrieval incident 11/15–17/2003
Enforcement Action 2005-01 3/10/05
C-202 Personnel Contamination Incident 7/2005
Mission Acceleration Phase of Project 2004–2005
Seepex Pump P-201 Installed in S-102 Riser 6 10/2004
Start Retrieval Operations with Seepex Pump P-201 12/17/2004
Seepex P-201 operations reached “diminishing returns” (7% retrieval)
Gorman Rupp Pump installed on S-102 Riser 7 10/31/2005
2

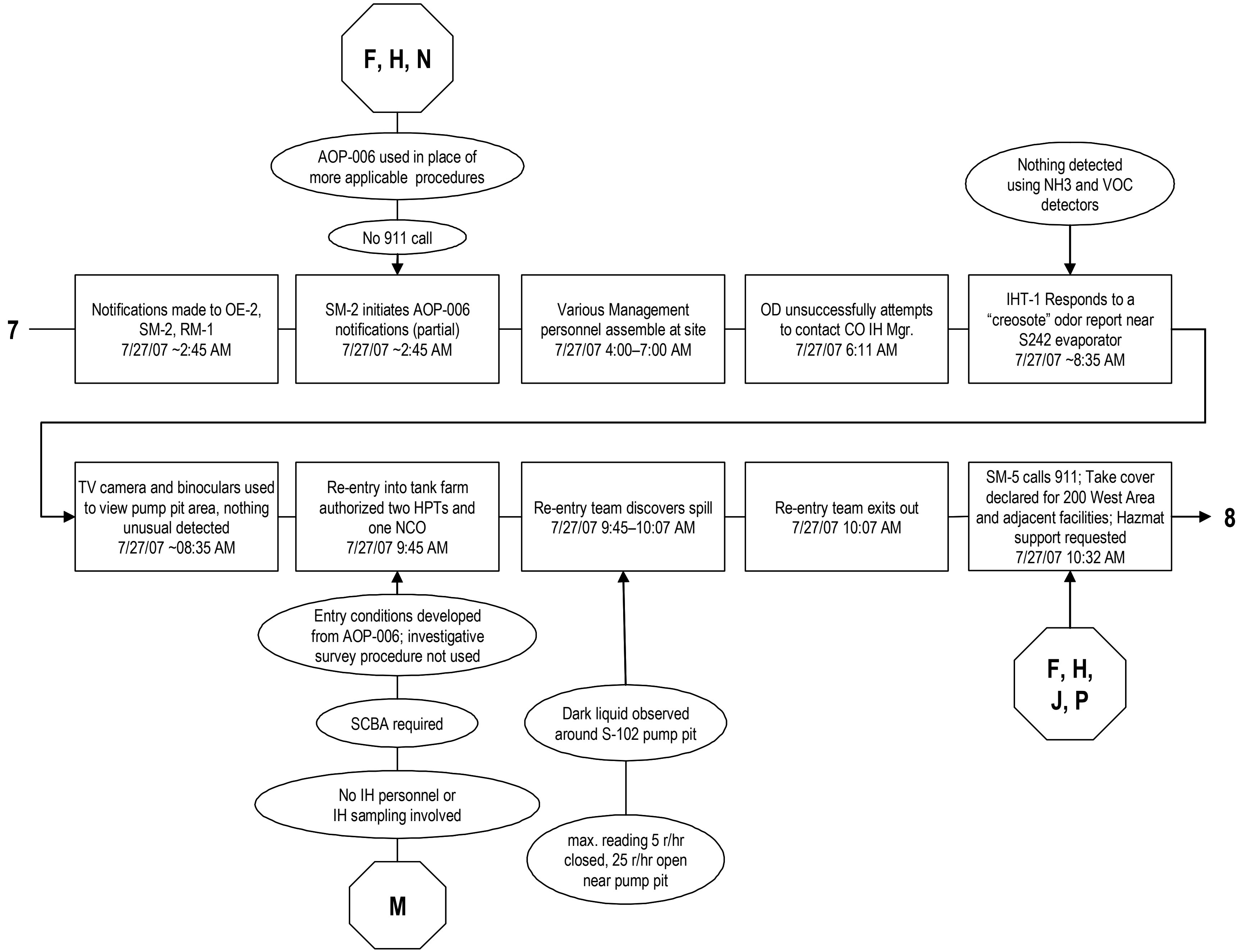

Analysis and visual inspection show excess torque failed universal joint, tie rods broken
SCBA, chemical suits required
Improved operation perceived with HPMs
Tri-Party Agreement milestone [M45-05A] calls for completion of S-102 retrieval by March 2007
2
G-R Pump fails (45 % retrieval) 3/2006
Work Hazard Analysis 10/2006
Retrieval operation resume with Seepex pump P-202 10/18/2006
High Pressure Mixers installed 11/2006
Old Seepex Pump Inoperable after manual reverse rotation (92% retrieval) 3/14/2007
G-R Pump removed from S-102 R-7 for new Seepex installation
D
Dilution hoses hydro tested at completion of assembly from hose stock and fittings [two batches 2002 and 2005]
First installation of new Seepex P-202 in S-102 R-7 7/12/07
Pump blocked-up, new guide holes drilled
Second installation of Seepex P-202 in S-102 R-7 7/17/07
Second installation of New Seepex in S-102 R-7 7/17/07
PM inspection of connectors satisfactory; unable to inspect hoses due to insulation 7/19/07
3

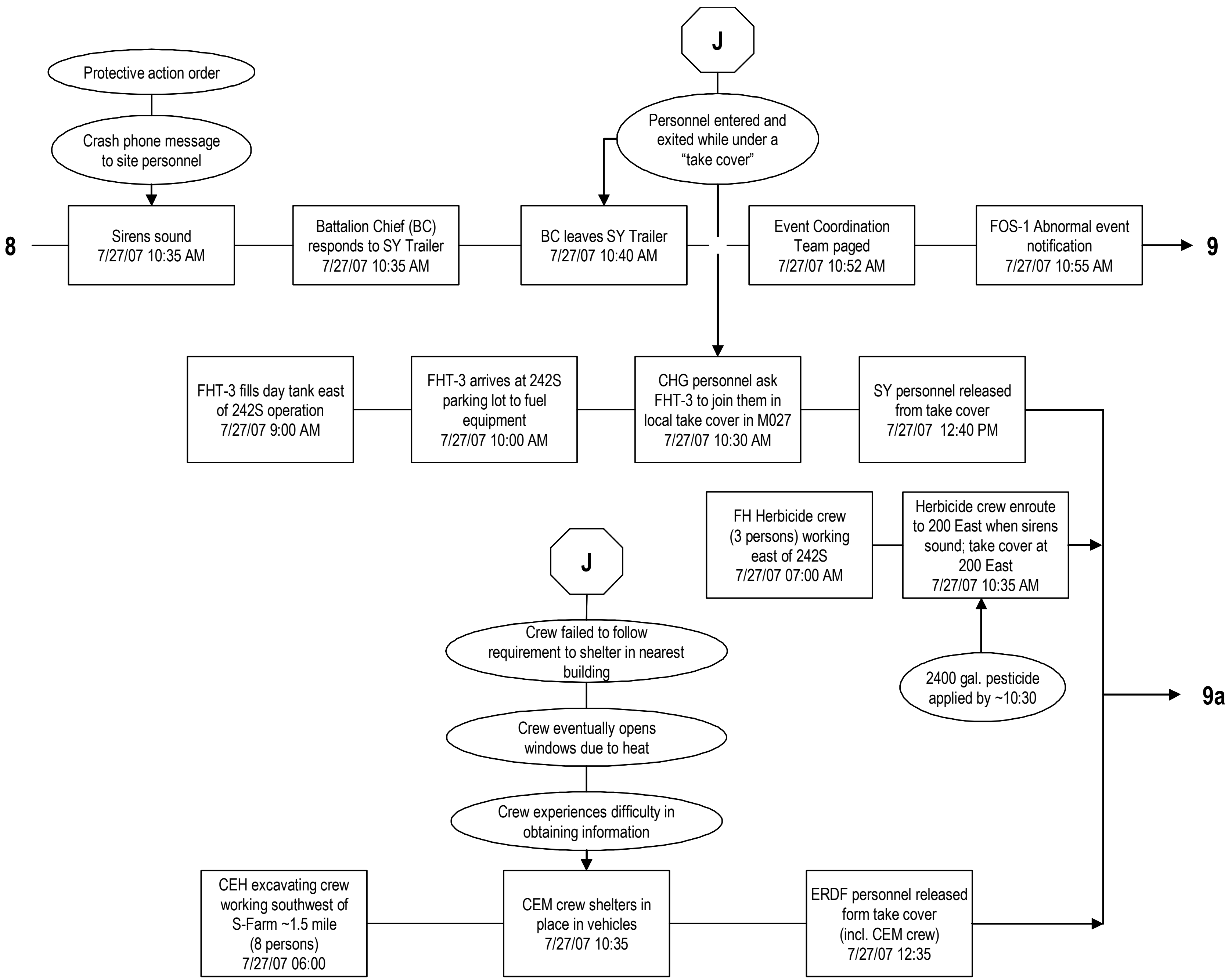

B, E
PLC software revised to eliminate low flow alarm
NCO-7 did not receive delta training
Hardware differences include: sparge ring, pump inlet, auger, jack screws, and stronger tie rods
Water hoses are interchangeable and available in various lengths from 5 ft to 60 ft
Two shift operations
Approximately 60K gal. transferred between ~11:00 PM and ~11:00 AM
B, I
SM releases administrative lock for VFD
V-106 Pump discharge valve found closed
3
Sparge hose leaks during leak test on water hoses 7/22–23/07
“Delta” training conducted for new Seepex 7/18–19/07
Retrieval operations with new Seepex pump initiated 7/25/07
S-102 transfer daily startup fails 7/26/07 9:55 AM
Transfer restarted after NCO-1 opens V-106 7/26/07 10:32 AM
4

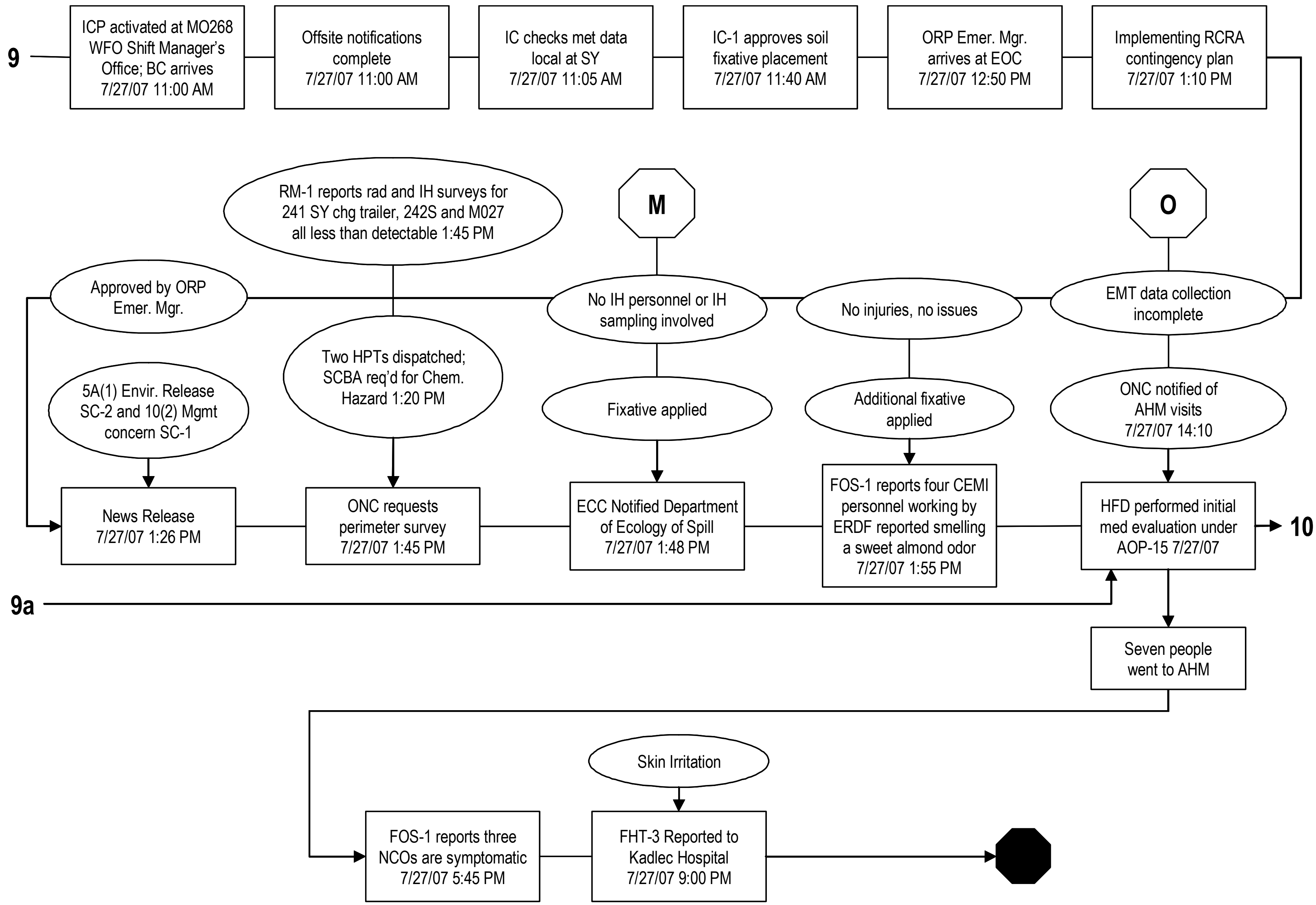

D
30 k gal. transferred by 7:27 AM
Variable Frequency Drive found with ground fault alarm at VFD panel; no alarm at control station 7/26/07 7:37 AM
E, O
G, I
VFD has a history of high maintenance demand
Leads lifted, all 3 phases meggered, readings recorded informally
NCO-7 changes flush hose (needed longer hose); spills some water on ground
4
Seepex Pump shuts down 7/26/07 6:22 PM
NCOs notice pump is not running 7/26/07 6:33 PM
VFD drive troubleshooting initiated by maintenance 7/26/07 7:37 PM
NCO-7 flushes transfer line from S-102 to SY-102 line 7/26/07 9:45 PM
Troubleshooting clears ground fault 7/26/07 10:00 PM
G
ML-1 and EE-1 called out to troubleshoot
One electrician, one millwright and one HPT called out
Three NCO's and one OE held over
I
Torque requirement (max = 280 ft-lb) NOT documented in work package, verbally communicated
16 turns at motor = 1 turn at pump thru gear reduction drive
MW-1 did NOT attend training on torque limit
Electrician observed wobbling
Personnel remain at pump to check for abrasion of power cord on grating edges
Each run to timeout at 105 sec
Reading at ~37 amps, last cycle at ~22 amp; normal is ~ 17 amp
Readings of ~60 amps
Readings of ~60 amps
NCO-9 bumps pump motor in reverse — shuts down on high amps (3 cycles)
Management initiates callouts and holdovers for troubleshooting pump 7/26/07 ~10:45 PM
Maintenance initiates manual rotation to clear pump (4 cycles) 7/27/07 12:00 AM
NCO-9 bumps motor after each rotation cycles; manually shut down on high amperage first 3 cycles)
Manual rotations free pump (2 cycles of rotation and running motor) 7/27/07 1:30 AM
5

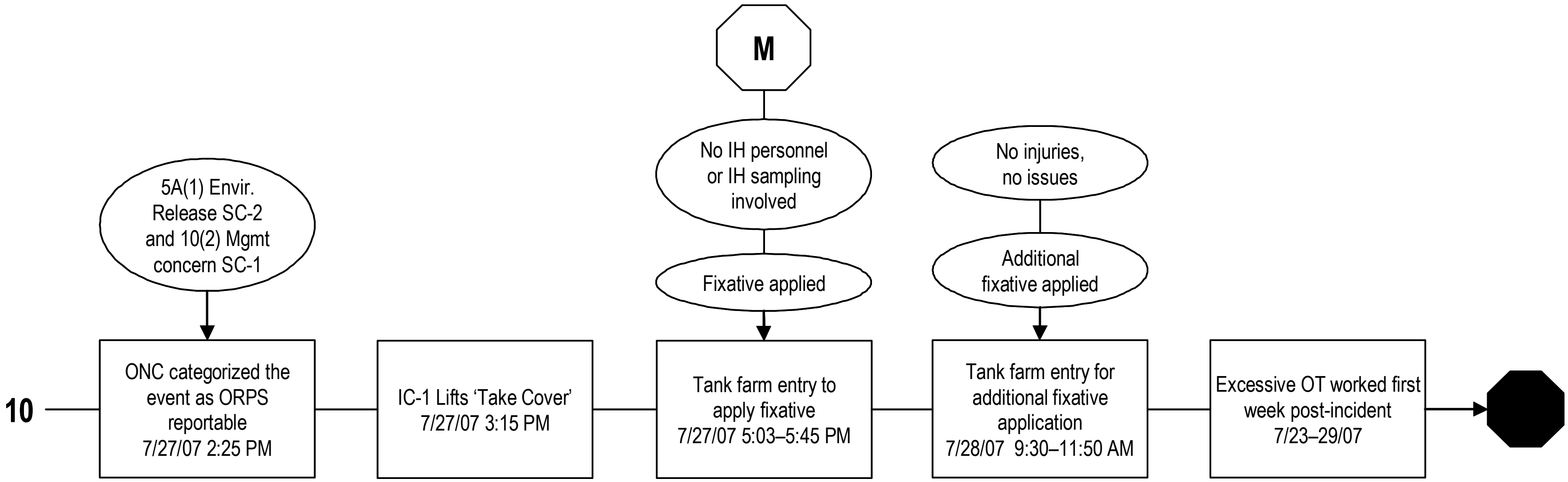

D, F
I, O
Transient readings on frisker in S-change trailer of 200–400 counts per minute (cpm) falling back to 100 cpm in less than a minute
Water supply valves MOV-401 & -402 are closed
Dilution water supply V-117 is open
Dilution piping connects to pump suction inlet
Hose failure?
Suction pressure falls to zero, current fall to 20 amp 20 sec. into run,
Pump shuts down on timer ~105 sec,
NCO-7 observes darken area, but assumes it is spilled flush water
Tank Farm lighting is poor;
Operations data sheet only provides one space for rad reading; no closed/open
Only closed window reading taken; no open window reading
5
Maintenance task completed and personnel exit tank farm 7/27/07 2:05 AM
NCO-9 Operates pump in reverse 7/27/07 2:10 AM
Spill Occurs 7/27/07 ~2:10
HCT-4 & NCO-8 enter tank farm to walkdown transfer line 7/27/07 02:15
HPT-4 discovers high radiation field 200–250 mr/hr@ 8–12 ft from valve pit 7/27/07 2:20
6


B, F, G, I, K, L
Requirements for re-entry not identified
NCO-8 reports stinky odor; expects IH response request
OE regards "stinky tank farm" as chit-chat
Rad work permit is not valid for re-entry; voided by HRA
HPT-4 wants to verify reading with a second instrument
HPT-4 confirms HRA with 2nd RO-20
NCO-8 can't clear PCM; HPT called from 200-E
6
HPT-4 & NCO-8 Exit to change trailer 7/27/07 ~2:20 AM
NCO-7 obtains additional RO-20 for HPT-4 7/27/07
HPT-4 & NCO-8 re-enter tank farm to confirm reading and establish 100 mr/hr boundary 7/27/07 ~2:40 AM
HPT-4 & NCO-8 Exit tank farm 7/27/07 ~2:40 AM
Tank farm personnel establish access control for HRA — guard change trailers 7/27/07 ~2:45 AM
7


F, H, N
AOP-006 used in place of more applicable procedures
No 911 call
Nothing detected using NH3 and VOC detectors
7
Notifications made to OE-2, SM-2, RM-1 7/27/07 ~2:45 AM
SM-2 initiates AOP-006 notifications (partial) 7/27/07 ~2:45 AM
Various Management personnel assemble at site 7/27/07 4:00–7:00 AM
OD unsuccessfully attempts to contact CO IH Mgr. 7/27/07 6:11 AM
IHT-1 Responds to a "creosote" odor report near S242 evaporator 7/27/07 ~8:35 AM
TV camera and binoculars used to view pump pit area, nothing unusual detected 7/27/07 ~08:35 AM
Re-entry into tank farm authorized two HPTs and one NCO 7/27/07 9:45 AM
Re-entry team discovers spill 7/27/07 9:45–10:07 AM
Re-entry team exits out 7/27/07 10:07 AM
SM-5 calls 911; Take cover declared for 200 West Area and adjacent facilities; Hazmat support requested 7/27/07 10:32 AM
8
Entry conditions developed from AOP-006; investigative survey procedure not used
SCBA required
No IH personnel or IH sampling involved
M
Dark liquid observed around S-102 pump pit
max. reading 5 r/hr closed, 25 r/hr open near pump pit
F, H, J, P


J
Protective action order
Crash phone message to site personnel
Personnel entered and exited while under a "take cover"
8
Sirens sound 7/27/07 10:35 AM
Battalion Chief (BC) responds to SY Trailer 7/27/07 10:35 AM
BC leaves SY Trailer 7/27/07 10:40 AM
Event Coordination Team paged 7/27/07 10:52 AM
FOS-1 Abnormal event notification 7/27/07 10:55 AM
9
FHT-3 fills day tank east of 242S operation 7/27/07 9:00 AM
FHT-3 arrives at 242S parking lot to fuel equipment 7/27/07 10:00 AM
CHG personnel ask FHT-3 to join them in local take cover in M027 7/27/07 10:30 AM
SY personnel released from take cover 7/27/07 12:40 PM
FH Herbicide crew (3 persons) working east of 242S 7/27/07 07:00 AM
Herbicide crew enroute to 200 East when sirens sound; take cover at 200 East 7/27/07 10:35 AM
J
Crew failed to follow requirement to shelter in nearest building
2400 gal. pesticide applied by ~10:30
9a
Crew eventually opens windows due to heat
Crew experiences difficulty in obtaining information
CEH excavating crew working southwest of S-Farm ~1.5 mile (8 persons) 7/27/07 06:00
CEM crew shelters in place in vehicles 7/27/07 10:35
ERDF personnel released form take cover (incl. CEM crew) 7/27/07 12:35


9
ICP activated at MO268 WFO Shift Manager's Office; BC arrives 7/27/07 11:00 AM
Offsite notifications complete 7/27/07 11:00 AM
IC checks met data local at SY 7/27/07 11:05 AM
IC-1 approves soil fixative placement 7/27/07 11:40 AM
ORP Emer. Mgr. arrives at EOC 7/27/07 12:50 PM
Implementing RCRA contingency plan 7/27/07 1:10 PM
RM-1 reports rad and IH surveys for 241 SY chg trailer, 242S and M027 all less than detectable 1:45 PM
M
O
Approved by ORP Emer. Mgr.
No IH personnel or IH sampling involved
No injuries, no issues
EMT data collection incomplete
5A(1) Envir. Release SC-2 and 10(2) Mgmt concern SC-1
Two HPTs dispatched; SCBA req'd for Chem. Hazard 1:20 PM
Fixative applied
Additional fixative applied
ONC notified of AHM visits 7/27/07 14:10
News Release 7/27/07 1:26 PM
ONC requests perimeter survey 7/27/07 1:45 PM
ECC Notified Department of Ecology of Spill 7/27/07 1:48 PM
FOS-1 reports four CEMI personnel working by ERDF reported smelling a sweet almond odor 7/27/07 1:55 PM
HFD performed initial med evaluation under AOP-15 7/27/07
10
9a
Seven people went to AHM
Skin Irritation
FOS-1 reports three NCOs are symptomatic 7/27/07 5:45 PM
FHT-3 Reported to Kadlec Hospital 7/27/07 9:00 PM


M
No IH personnel or IH sampling involved
Fixative applied
No injuries, no issues
Additional fixative applied
5A(1) Envir. Release SC-2 and 10(2) Mgmt concern SC-1
10
ONC categorized the event as ORPS reportable 7/27/07 2:25 PM
IC-1 Lifts 'Take Cover' 7/27/07 3:15 PM
Tank farm entry to apply fixative 7/27/07 5:03–5:45 PM
Tank farm entry for additional fixative application 7/28/07 9:30–11:50 AM
Excessive OT worked first week post-incident 7/23–29/07