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HAZARDS & OPERABILITY STUDY FOR THE SURFACE
MOISTURE MONITORING SYSTEM

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Page 1 of 1

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Hazards and Operability Study for the Surface Moisture Monitoring System

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This Hazards and Operability (HAZOP) study performed on the Surface Moisture Monitoring System (SMMS) is the basis for determining safety documentation requirements for authorization of the SMMS.

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**HAZARDS AND OPERABILITY STUDY FOR THE SURFACE
MOISTURE MEASUREMENT SYSTEM**

Prepared By:

LOS ALAMOS TECHNICAL ASSOCIATES, INC.
Richland, WA

For:

WESTINGHOUSE HANFORD COMPANY
Richland, WA

March 1996

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LIST OF TERMS

EMI	electromagnetic inductance
HAZOP	Hazards and Operability
PCB	Polychlorinated biphenyl
SMMS	Surface Moisture Measurement System

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HAZARDS AND OPERABILITY STUDY FOR THE SURFACE MOISTURE MEASUREMENT SYSTEM

1.0 INTRODUCTION

The Hanford Nuclear Reservation Tank Farms' underground waste tanks have been used to store liquid radioactive waste from defense materials production since the 1940's. Waste in certain of the tanks may contain material in the form of ferrocyanide or various organic compounds which could potentially be susceptible to condensed phase chemical reactions. Because of the presence of oxidizing materials (nitrate compounds) and heat sources (radioactive decay and chemical reactions), the ferrocyanide or organic material could potentially fuel a propagating exothermic reaction with undesirable consequences. Analysis and experiments indicate that the reaction propagation and/or initiation may be prevented by the presence of sufficient moisture in the waste. Because the reaction would probably be initiated at the surface of the waste, evidence of sufficient moisture concentration would help provide evidence that the tank waste can continue to be safely stored.

The Surface Moisture Measurement System (SMMS) was developed to collect data on the surface moisture in the waste by inserting two types of probes (singly) into a waste tank--a neutron probe and an electromagnetic inductance (EMI) probe. The sensor probes will be placed on the surface of the waste utilizing a moveable deployment arm to lower them through an available riser. The movement of the SMMS within the tank will be monitored by a camera lowered through an adjacent riser. The SMMS equipment is the subject of this study.

Hazards and Operability Analysis (HAZOP) is a systematic technique for assessing potential hazards and/or operability problems for a new activity. It utilizes a multi-discipline team of knowledgeable individuals in a systematic brainstorming effort. The results of this study will be used as input to an Unreviewed Safety Question determination.

2.0 SCOPE

The HAZOP covers the engineered systems used for the Surface Moisture Measurement System, including the data-collecting van, the deployment system, the decontamination system, the neutron probe, and the EMI probe. Because the safety of using a camera in a riser has already been assessed, and design requirements developed for such activities (Stokes 1995) the camera system was not analyzed in detail. A crane will be utilized for lifting various components, and abnormal events initiated by the crane were considered as part of the study.

Each of the engineered systems was used as a HAZOP study node. Table 2-1 lists the equipment associated with each node.

Table 2-1. Node Descriptions.

Node	System	Equipment
1	Data collection van	Data recording equipment; computer console; operator interface; probe storage
2	Deployment arm	Jointed arm with winch system and riser interface; signal cables
3	Decontamination system	Pressurized water system for decontamination equipment contacting contaminated areas
4	Neutron source	CF-252 neutron source; neutron detectors; amplifiers
5	EMI probe	Electromagnetic inductance probe; detectors; amplifiers, etc.

3.0 ORGANIZATIONAL RESPONSIBILITIES

The HAZOP was led by an individual from Los Alamos Technical Associates, Pacific Northwest Office. The HAZOP team included individuals from Hi-Line Engineering and various Westinghouse Hanford organizations. The Westinghouse organizations represented included Safety Analysis, Tank Farms' Operations, Nuclear Safety, Quality Assurance, and the SMMS project. Information about the qualifications of the team members is included in Appendix A.

4.0 METHODOLOGY

A HAZOP study (described in detail in Appendix B) documents the effects of deviations from the design intent of the various "process parameters." The major equipment within a process is designated as nodes. Pertinent process parameters (guide words) such as flow, pressure, level, and temperature are chosen, and a series of questions is asked about each parameter. Each "question" concerns an abnormal condition of the parameter (for example, "no flow"). The team, based on design knowledge and operating experience postulated the cause(s) and effects of the abnormal process condition. From this information, a qualitative consensus estimate of the worst case consequences of the abnormal condition was obtained. The estimate can then be used as a screening tool to determine the need for further analysis.

The HAZOP product is a series of tables (Appendix C) showing the results of the team discussions. The results are further categorized to include a list of potential abnormal conditions which might cause consequences in the various categories and a list of comments and recommendations made by the team.

5.0 RESULTS

The summary of the results of the HAZOP study is included in this section.

The results of the HAZOP analysis were a number of postulated abnormal events which were ranked by the team members with respect to safety consequences. The first cut, qualitative, consensus estimates of the safety severity of the consequences were ranked according to the following alphanumeric system:

- S0 No effect outside the immediate area with no safety concerns for the facility worker, the onsite worker, or members of the general public.
- S1 Potential industrial injury, radiological dose consequences, or chemical exposure to the facility worker
- S2 Potential significant radiological dose consequences or chemical exposure to the onsite worker at the nearest adjacent facility
- S3 Potential significant radiological dose consequences or chemical exposure to the offsite population

The HAZOP tables are included in their entirety in Appendix C. Abnormal events having potential safety implications are summarized here. The types of events having potential worker safety (S1) consequences include:

1. Heat exhaustion caused by hot weather and failure of the air conditioning in the data collection van.
2. Ignition of small fire resulting from offgassing from the batteries.
3. Toxic offgas from a riser affecting the individual in the van.
4. Carbon monoxide hazard (possible in cold weather due to proximity of data collection van and camera van).
5. Worker exposure to cold weather if van heater failed.
6. Fire caused by fuel spill during field refueling of data collection van.

7. Worker electrocution hazard due to improper grounding of van combined with electrical fault.
8. Worker radioactive contamination due to previous worker having entered the van with contaminated clothing. (Note that the van will be parked in a surface contamination area).
9. Worker injury due to failure of lifting device (crane).
10. Worker injury due to electrical shorting caused by crane boom hitting electrical equipment.
11. Worker exposure to toxic gas from open riser.
12. Worker exposure due to recovery actions for improper positioning of deployment arm.
13. Worker exposure to radioactive contamination due to improper contamination control procedures during deployment arm installation.
14. Worker injury from catastrophic failure of decontamination system pump.
15. Worker injury from electrical short caused by spill of process water from the decontamination system.
16. Worker injury caused by high pressure water from the decontamination system.
17. Worker injury caused by difficulties in withdrawing deployment arm mast (specifically interference of lost decontamination system nozzle).
18. Worker contamination caused by inadequate operation of the decontamination system.
19. Worker radiation dose caused by separation of neutron source from probe.

The types of events judged to potentially have S2 consequences include:

1. Events which result in a spark in the tank headspace when flammable but not detonatable concentrations of gas are present. These include:
 - a. grounding the van to the wrong tank (assuming that controls for non-flammable gas tank are used on a flammable gas tank);
 - b. parking the van with non-spark-resistant electrical equipment next to an open riser during an episodic release of flammable gases;

- c. an ignition of flammable gases in the tank caused by a fire in the van propagating down a riser;
 - d. propagation of a fuel fire during field refueling to a tank flammable atmosphere;
 - e. failure of the tank electrical safety barriers resulting in igniting a flammable atmosphere;
 - f. ignition of an undiscovered flammable atmosphere due to not using flammable gas controls;
 - g. ignition of a flammable gas buildup in the decontamination system pump casing (failure to isolate pump after decontamination) propagating to the tank;
 - h. ignition of a flammable atmosphere due to dropping equipment; and
 - i. ignition of a flammable atmosphere in the winch box due to failure of electrical barriers between non-intrinsically-safe electrical equipment and the winch box atmosphere.
- 2. A criticality in the tank caused by dropping the neutron source from the probe in a region which is only slightly subcritical.
 - 3. A release of radionuclides caused by pressurization of the tank resulting from hooking up air instead of water to the decontamination system .
 - 4. Toxic release of Polychlorinated biphenyl (PCB) oil if crane boom hits transformer.

The events which were judged to have potential for S3 (public) consequences consisted of tank dome collapse by various mechanisms. They were:

- 1. Exceeding dome loading limits because of misplacement of the data van (wrong spot on the tank or wrong tank).
- 2. Exceeding dome loading limits because of misuse or misplacement of the crane.
- 3. Addition of organic material to tank due to hooking a fuel line up to the decontamination water supply piping (judged extremely unlikely). It is assumed that this would result in an energetic deflagration and possible dome collapse.
- 4. Spark source in detonatable atmosphere (see S2 for mechanisms) resulting in dome collapse.

6.0 RECOMMENDATIONS/COMMENTS

1. Because the data collection van is a late model Ford van, it is suggested that the action be taken to determine whether or not it has a defective ignition switch which might catch fire because of recent recall data on such vans.
2. A fire extinguisher should be kept in the data collection van.
3. The hazards of field refueling the van should be evaluated against time lost if it ran low on gas during a sampling period.
4. It might be well to keep a stepoff pad near the van door, since it will be located in a surface contamination area. The van will have to be parked in a regulated vehicle area.
5. The potential for damaging the tank wall by striking it with SMMS equipment should be evaluated because of the environmental consequences of a tank leak.
6. The necessity for a requirement that devices within the swing radius of the probe should be rotated out of the way prior to deployment of the probe should be evaluated. Entanglement of the probe or the deployment arm with such devices could result in inability to retrieve the probe because of the interferences in small risers.
7. Because the barrier between the winch box and any electrical equipment could potentially leak, the winch box atmosphere should be checked periodically when the SMMS is in place over a particular riser for an extended period of time.
8. Because of the potential for relative motion caused by keeping the truck running for extended periods, other power sources for air conditioning should be considered.

7.0 REFERENCES

Stokes, T. I., 1995, *Design Requirements Document for Surface Moisture Measurement System*, WHC-SD-WM-DRD-002, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A
TEAM MEMBER BIOGRAPHIES

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APPENDIX A

TEAM MEMBER BIOGRAPHIES

B. D. Board

Brett Board has been a safety analysis engineer at Hanford since 1993. During that time he has been lead author for the Hanford Waste Storage Tank bump accident analysis; the Hanford Waste Storage Tanks common cause analysis; the Unreviewed Safety Question (USQ) Screening of gas release event in watchlist tank; the hazard classification of 306E Non-Destructive Examination (NDE) Laboratory; and the safety class determination of portable CO₂ decontamination unit. He has been a technical contributor to the Hanford Waste Storage Tank ventilation system accident analysis; the Hanford Waste Storage Tank dome collapse accident analysis; the Hanford Waste Storage Tank steam release accident analysis; and the Hanford Waste Storage Tank accident analysis comment resolution on various topics. Brett's responsibilities have included project management, performance monitoring, and sub-contractor work oversight, as well as developing analysis technique and performing analysis.

R. D. Crowe

Ralph Crowe has worked the past five years performing safety analysis within the DOE environment for a number of facilities, including high level waste tanks, the Plutonium Finishing Plant, and Spent Nuclear fuel storage. Safety documents authored include Safety Assessments, SAR Accident Analyses, and USQ evaluations. Prior to that time, Ralph worked in the area of waste tank monitoring and characterization. Ralph has approximately seventeen years experience using multi-dimensional, time dependent neutron kinetics, and thermal hydraulic calculations, including developing and analyzing in-core instrumentation from a number of reactor types. He has Master's degrees in Nuclear Engineering and Engineering Management, and a Bachelor's degree in Mathematics.

L. S. Krogsrud

Dr. L. S. Krogsrud received a PhD in chemistry from Northwestern University in 1977. He has worked at WHC for approximately five years, for the past three years in Tank Waste Remediation Nuclear Safety. While in that group, he has been responsible for nuclear safety aspects of the tank 101-SY hydrogen mitigation project, hazard and safety analysis review, and field work within watchlist tanks. Previous to joining Westinghouse, Dr. Krogsrud was employed by the Department of Defense, working both as a Health Physics Officer, and in the area of toxic chemical safety and decontamination.

M. L. McElroy

Michael L. McElroy is a Principal Engineer working as a Quality Assurance Engineer, with the Characterization Project for TWRS. Mike has worked at Hanford for five (5) years in the area of quality assurance. He was the primary QA interface for the design, fabrication, procurement, testing and installation of the "Hydrogen Mitigation Pump," in 101-SY, along with all of the ancillary equipment that is used to measure and monitor for the hydrogen mitigation effort. Mike has worked closely with engineering, safety analysis organizations, and operations, and is well versed in the design and maintenance of new equipment.

D. P. Niebuhr

Daniel P. Niebuhr is a Senior Plant Engineer who has been at WHC for five years. Dan is qualified as a Tank Farms Operation Shift Manager and is involved in the classroom and field training of Nuclear Process operators and Shift Manager Trainees. He has been part of successful field operations of varying complexity including the Void Fraction Meter, Viscometer, and 101-SY mixer pump removal operations; contaminated underground pit and fault work; removal of highly contaminated equipment from waste storage tanks, and installation of new and modified systems. His experience prior to WHC included 8 years operational service in the Nuclear Navy. Dan will be the primary field Person in Charge (PIC) for field deployment of the SMMS system during cold and hot testing.

J. M. Siemer

Judith M. Siemer, the HAZOP team leader, is currently employed by Los Alamos Technical Associates (LATA). Judy has over fifteen years of experience in engineering analysis, including safety analysis, reliability and risk assessment, and stress analysis. She has been at Hanford for ten years, and was at the Idaho National Engineering Laboratory (INEL) prior to that. Projects supported at the INEL include the Loss of Fluid Test Facility (LOFT), the Sodium Loop Safety Facility (SLSF), and the New Waste Calcining Facility and the associated Calcined Solids Storage Facilities. Facilities and activities supported at the Hanford site include PUREX, B Plant, the UO3 plant, the Plutonium Finishing Plant, the Waste Receiving and Processing Facility, Spent Fuel, the Multi-function Waste Tank Facility, and Hanford Tank Farms. She has contributed to all phases of safety analysis and all of the types of safety documentation produced at Hanford. Her HAZOP experience includes two training courses and leading numerous HAZOP and PHA teams. Judy has a B. S. in Industrial and Management Engineering, with graduate work in structural and safety engineering.

T. S. Stokes

Troy Stokes is currently employed by Hi-line engineering. He has a BSME and has completed 90% of his coursework on an MSME. He is a licensed professional engineer in Washington state. He has over 6 years of experience with WHC in custom design,

fabrication, testing, installation, and operation of unique Tank Farms' equipment, most of which was installed inside the most hazardous waste tanks at Hanford. For the last three years he has been the project manager of multi-company and multi-discipline teams; he was in charge of critical project interfaces such as safety basis development with LANL, design engineering, fabrication and acceptance testing, and supervising the field operation of the viscometer and void fraction instruments.

G. F. Vargo, Jr.

George Vargo graduated from the University of Detroit in 1972 with a degree in electrical engineering after serving 5 1/2 years in the nuclear submarine Navy. He has completed 95% of the work for a masters degree and is a registered professional engineer in the states of Michigan (1976) and Washington (1984). George has worked as the chief engineer and vice president of engineering for various electronics and computer firms in the automotive instrumentation, computer systems, and computer machine tool industries. He is co-inventor of a radio frequency packet radio modem and was the co-founder and vice president of engineering of the firm that designed, manufactured, and marketed the modem. George has ten years of experience with Westinghouse, mainly in the special instrumentation areas. He was project engineer for the data acquisition and control system (DACS), that controls and monitors the mixer pump and special instrumentation, installed in Hanford waste tank 241-SY-101. He is a principal engineer and is project engineer for the surface moisture measurement system. He is lead electrical engineer on the flammable gas interlock design and project engineer for the surface moisture probe interface to the light duty utility arm (LDUA).

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APPENDIX B
HAZOP FORMS

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APPENDIX B

HAZOP FORMS

A HAZOP study consists of a detailed examination of the possible deviations of various process parameters from their design intent, with the causes and consequences of the deviation listed.

The HAZOP process consists of subdividing system flow diagrams into segments known as study nodes. Each major piece of process equipment is a node, and all lines (piping, electrical, etc.) connecting the equipment pieces can be divided into one or more nodes (usually at branch points). Process parameters of importance are designated for each node, and a series of appropriate "questions" are asked about the process parameters. Guide words, phrases or words used to describe process deviations, are used as questions asking tools to explore the means by which process parameters might vary from their design intent. The causes and consequences of the deviations are examined, and the consequences ranked to determine possible safety significance.

Process parameters which may be examined include flow, temperature, pressure, viscosity, composition, phase, level, addition, reaction, maintenance, testing, instrumentation, sampling, etc. Guide words which are applied to process parameters and their meanings are listed below:

"No/none"	negation of design intent
"More"	quantitative increase
"Less"	quantitative decrease
"As well as"	qualitative increase
"Part of"	qualitative decrease
"Reverse"	logical opposite of intent
"Other than"	complete substitution.

A sample of the HAZOP form to be used is shown in Table B-1. The first column, designated "Node," is a numeric identifier, while the second column, designated "Description" is the functional description of the node. The third column, "Process Variable," states which parameter is being analyzed. The fourth column, "Deviation" is a guide word which applies to that process parameter. The fifth column labelled "Possible Causes," lists the potential cause of the deviation. The sixth column, labelled "Detection/Mitigation," lists the means by which the parameter deviation could potentially be discovered or the potential consequences of the deviation mitigated.

The seventh column is labelled "Potential Consequences." The Consequences column contains a qualitative estimate of the result of the deviation. Both the immediate consequence of the deviation (overflowing vessel, for example) and the potential release consequences are listed. The Consequence Ranking column is a "first cut," qualitative,

consensus estimate of the safety and operational severity of the consequences. An alphanumeric system was used to designate the severity, with the following "S" rankings characterizing safety consequences:

- S0 No effect outside the immediate area with no safety concerns for the facility worker, the onsite worker, or members of the general public.
- S1 Potential industrial injury, radiological dose consequences, or chemical exposure to the facility worker
- S2 Potential significant radiological dose consequences or chemical exposure to the onsite worker at the nearest adjacent facility
- S3 Potential significant radiological dose consequences or chemical exposure to the offsite population.

SURFACE MOISTURE MEASUREMENT SYSTEM

PARTICIPANTS: J. M. SIEMER, G. F. VARGO Jr., M. L. Mc ELROY, B.D. BOARD, L. S. KROGSRUD, D. NEIBUHR, T. I. STOKES

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APPENDIX C
HAZOP TABLES

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SURFACE MOISTURE MEASUREMENT SYSTEM

DATE: 2/9/96

PARTICIPANTS: J. M. Siemer, J. Bussell, G. F. Vargo Jr., M. L. Mc Elroy, R. Crowe, L. S. Krogsrud, D. Niebuhr, T. I. Stokes

Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
1	Van	Placement	Other than (wrong riser)	Human error	Job walkdown	Exceed dome load limitations	S3	Check the following: 1. Ford van model. Can ignition switch ignite fire? 2. Extinguisher should be present in van
					Riser preparations (JCS system)	Poor measurement	S0	
					Person in charge/ designated Cog. Engineer	Grounding van to wrong tank (using controls for nonflammable tank?)	S2	
					Checklist	Parked by an open riser during episodic release deflagration	S2	

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PARTICIPANTS: J. M. Siemer, J. Bussell, G. F. Vargo Jr., M. L. Mc Elroy, R. Crowe, L. S. Krogsrud, D. Niebuhr, T. I. Stokes

Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
1	Van	Temperature	High	Weather	Human/air conditioning	Heat stress	S1	
				Sun position		Overheating of instrumentation, causing inaccurate measurement	S0	
				Fire	Worker observation	Offgassing from batteries	S1	
						Hydrogen explosion hazard (riser involved)	S2	
						Van parked outside exclusion zone/ respiratory hazard/ worker hazard	S1	
						Ignition of flammable gas (if propagated to atmosphere)	S2	
						Fuel spill causing field refueling fire	S1(a)	
							S2(b)	(b) If fire propagates to tank

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SURFACE MOISTURE MEASUREMENT SYSTEM

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PARTICIPANTS: J. M. Siemer, J. Bussell, G. F. Vargo Jr., M. L. Mc Elroy, R. Crowe, L. S. Krogsrud, D. Niebuhr, T. I. Stokes

Node	Description	Process variable	Deviation	Possible causes	Detection/ mitigation	Potential consequence	Rank	Remarks
1	Van	Temperature	Low	Weather	Human agent CO monitor (in van)	Condensation in instruments CO in closed van VCR inoperable in closed environments Worker discomfort Problems with operability of controls	S0 S1 S0 S1 S0	
1	Van	Temperature	Low (van or generator or front bumper)	Long term operation of air conditioner	Gas gauge/ engine stops	Operational delay to refuel	S0	Not decided if van will be refueled in the field
1	Van	Grounding	Less	Human error Broken cables Improper location (bad ground grid)	Measurement Independent verification	Inaccurate instrument readings Sparking (static charge) Possible failure of tank safety barriers* / ignition of flammable atmosphere Electrocution	S0 S0 S2 S1	*Unlikely Prevented by grounding to same point Combined with electrical fault in van

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SURFACE MOISTURE MEASUREMENT SYSTEM

DATE: 2/9/96

PARTICIPANTS: J. M. Siemer, J. Bussell, G. F. Vargo Jr., M. L. Mc Elroy, R. Crowe, L. S. Krogsrud, D. Niebuhr, T. I. Stokes

Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
1	Van	Contamination	High (any)	Worker with contaminated clothing enters van	Survey prior to entry	Delay	S0	We have no backup plan for parking a contaminated van
					Health physics routines	Worker contamination	S1	Should be parked other than in contaminated area
					Regulating entry			
2	Deployment arm installation	Bonding	No/less	Human error	Inspection	Ignition of tank flammable atmosphere	S2	
		Grounding		Grounding/ Bonding equipment failure	Measurement			
		Static protection		Improper ground location	Verification			
				Equipment bonded or grounded to itself				

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SURFACE MOISTURE MEASUREMENT SYSTEM

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PARTICIPANTS: J. M. Siemer, J. Bussell, G. F. Vargo Jr., M. L. Mc Elroy, R. Crowe, L. S. Krogsrud, D. Niebuhr, T. I. Stokes

Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
2	Deployment arm installation	Lifting devices (cranes and rigging)	Less than (not sufficient load bearing capacity)	Human error (procedure violation)	Inspections load testing	Worker injury	S1	
				Equipment failure, crane unattended/overextended	Verification of capacity	Tank structural damage (loss of confinement)	S1	
				Improper installation of rigging	Procedures for deployment	Potential for damaging other safety class equipment	S0	
					Qualified/designated rigging specialist			
2	Deployment arm installation	Crane/boom placement	Other than	Human error	Work plan/procedure	Exceeding* dome loading	S3	*If crane is heavy enough in combination with other loads
				soft footing (unbalanced)	Inspections	Damaging safety equipment with boom	S0	
				Wrong tank/wrong riser		Electrical shorting via boom(hitting power poles/lines, breaker box, instrument shack, transformers etc.	S1	
						Loss of containment	S2(a)	
								(a) Toxic release if PCB oil spilled

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SURFACE MOISTURE MEASUREMENT SYSTEM

DATE: 2/9/96

PARTICIPANTS: J. M. Siemer, J. Bussell, G. F. Vargo Jr., M. L. Mc Elroy, R. Crowe, L. S. Krogsrud, D. Niebuhr, T. I. Stokes

Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
2	Deployment arm installation	Riser access checks/ preparatory geometry, placement location	Failure to perform check	Human error	Procedures	Undetected flammable atmosphere in tank and for in winch box (possible deflagration during later operations)	S2(a)	(a) If deflagration occurs
			Check not properly performed	Faulty meter combustible gas	Trained personnel Calibrated equipment	Out of round riser resulting equipment being stuck in riser	S0	The barrier between the winch box and the electrical equipment could potentially leak; hence, the winch box atmosphere should be checked periodically when the SMMS is in place on a particular riser for an extended period
						Undetected toxic gas resulting in worker exposure	S1	

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Node	Description	Process variable	Deviation	Possible causes	Detection/indication	Potential consequence	Rank	Remarks
2	Deployment arm installation	Arm insertion positioning	Other than/ wrong angle	Human error/ equipment failure	Low load/ high load	Verification	S1	Difficulty retrieving arm
			Other than/ ball valve not closed	Human error/drop	Low load	Riser damage/ loss of confinement	S1	
			Other than/ insertion speed too fast	Human error equipment failure	Impact protection	damage to ball valve	S1	
						damage source/drop	S1	
						dropping source/ sparks	S2	
						damage to riser/drop	S1	
						equipment stuck/potential to damage tank	S1 (a)	
							(a)	Environmental consequences/ should be evaluated

WHC-SD-WM-HIE-006

Rev. 0

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Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
2	Deployment arm installation	Contamination control	No/less	No sleeving Not enough sleeving Bag damage Breaking a window on the winch box	Contamination surveys Visual inspection Procedures/training	Local spread of contamination	S1	

Notes:

CO = carbon monoxide.
 JCS = job control system.
 PCB = polychlorinated biphenyl.
 SMMS = surface moisture measurement system.
 VCR = video cassette recorder.

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Node	Description	Process variable	Deviation	Possible causes	Detection/ mitigation	Potential consequence	Rank	Remarks
3	Decon system	Flow	No	Pump failure	In tank camera	Worker injury due to pump disassembly	S1	Note: Positive displacement pump has PRV (pressure relief valve)
				Out of gas		Time delay	SO	
				Plugged line				
				Valve lineup wrong		Could put excessive H ₂ O in tank	SO(a)	It is doubtful that structural damage could be done to the tanks by overfilling because of the flow rate
				Broken hose				
				Human error	Visual	Spill of process water	S1 (b)	(b) Causing worker injury due to electrical problems
				Water freezing in winter		High water pressure worker injury		
3	Decon system	Flow	More	Loss of nozzle	Pressure would go down	Potential source of interference with deployment of mast during withdrawal	S1 (a)	(a) Due to ALARA problems during withdrawal
						Too much water in tank (see above)		

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Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
3	Decon system	Flow	Less Other than "Air"	See "no" Human error	Pressure gauge	Pressurization of tank Pump damage	S2 S1	Note that: Water fittings and air fittings are interchangeable in some areas
3	Decon system	Flow	Other than (fuel)	Hooking supply line to fuel tank*	Visual	Addition of organics to tanks leading to deflagration	S3	*The fittings are probably not compatible
3	Decon system	Flow	Reverse	Leaving hose connected to decon system when not in use	Visual/ requirement to disconnect hose because of lightning protection requirements	Flow of flammable gas from tank atmosphere (if present) to pump casing. Potential to cause deflagration if pump started prior to opening inlet valve	S2	This scenario is highly unlikely
3	Decon system	Pressure	High	Plugged nozzle	Pressure gauge/mitigation relief valve	Worker injury Equipment damage Time delay	S1 S1(a) S0	(a) If water damages other equipment and causes electrical shock hazard
3	Decon system	Pressure	Low	Open line Pump failure	Pressure gauge	Time delay/inadequate decontamination	S1	

Notes:

ALARA = as low as reasonably achievable.

PRV = pressure relief valve.

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Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
2	Deployment arm installation	Orientation	Wrong(a)	Broken cable	In tank camera, inclinometer, torque limiters on cranks	Bad sample	S0	Possibly require that devices within the swing radius of the probe be rotated out of the way
		a. radial				Broken detector tube-no data	S0	
		b. vertical		Jammed cable				
		c. rotational		Stuck probe		Broken cable inability to retrieve probe/potential criticality issue (if dropped in wrong place...)	S2(a)	
				Inclinometer failure/arm not deployed low enough during installation		Hitting tank wall,dome, or in-tank equipment (FIC, ENRAF, Manual tape/particularly vulnerable	S0(b) S1(c)	
							S2(d)	(a) Criticality probably not credible (b) OSR problem (c) Based on equipment recovery (d) If cause of sparking on flammable atmosphere
						Jammed or broken cable blocking riser.	S1(e)	(e) ALARA problem on a small diameter riser
2	Deployment arm	Vertical orientation	Too high (doesn't clear riser)	Human error	Camera	See above for consequences of broken cable or riser blocking.		
				Human error	Camera	Inadequate data	S0	

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Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
2	Deployment arm	Vertical orientation	Too low	Human error	Camera	Probe immersed in waste Probe entangled or stuck on waste in bottom of tank	S1(a)	(a) See criticality issue above (ALARA problem)
2	Deployment arm operation	Orientation	Wrong	Human error Relative motion of van due to brake failure, etc.	Camera Limit stops for known obstructions Torque limiter	Break neutron detector Bend arm to make it difficult to retrieve Loss of signal/ Breaking cables above ground by excessive twisting Winding too tight, resulting in breaking control cables in tank, causing a spark source from arm going down suddenly and breaking a shear pin (deflagration in flammable atmosphere)	S1 S1(a) S0 S2	(a) ALARA problem
2	Deployment arm operation	Contamination control	No/less	Breaking a window on the winch box	Visual inspection	Local spread of contamination	S1	

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Node	Description	Process variable	Deviation	Possible causes	Detection/mitigation	Potential consequence	Rank	Remarks
4	Neutron source	Position	Outside of probe	Human error	Neutron detector	Worker exposure	S1	
				Equipment failure	Administrative controls	Equipment not retrievable	S1	
				Dropped during installation	Second party inspection	Accountability issue	S0	
				Probe not controlled				
5	EMI probe	Electrical field	More (excessive voltage or current)	Human error	Data potentially outside of expected values (skewed)	No data or wrong data	S0	(a) If flammable atmosphere deflagration
				Equipment failure		Error or equipment failure causing loss of intrinsic barriers could result in a spark	S3(a)	

Notes:

ALARA = as low as reasonably achievable.

FIC = Food Instrument Corporation.

OSR = operational safety requirements.