COMPLETE

ENGINEERING CHANGE NOTICE

Page 1 of 3

1. ECN 630696

Proj. ECN

2. ECN Category (mark one) Supplemental ☐ Direct Revision ☒ Change ECN ☐ Temporary ☐ Standby ☐ Supersedure ☐ Cancel/Void ☐	3. Originator's Name, Organization, MSIN, and Telephone No. JW LENTSCH, 74E10, S7-14, 373-5252	3a. USQ Required? ☐ Yes ☒ No	4. Date 06/24/96
	5. Project Title/No./Work Order No. TANK 241-SY-101 MITIGATION PROGRAM	6. Bldg./Sys./Fac. No. TANK 241-SY-101	7. Approval Designator SQ
	8. Document Numbers Changed by this ECN (includes sheet no. and rev.) WHC-SD-WM-SAD-033, REV 1-E	9. Related ECN No(s). 630663/630670/ 630671/630674/630676/ 630677/630678/630680 630681/630682/630686/ 630687/630688/630689/ 630690/630691/630692/ 630693	10. Related PO No. NA

11a. Modification Work ☐ Yes (fill out Blk. 11b) ☒ No (NA Blks. 11b, 11c, 11d)	11b. Work Package No. NA	11c. Modification Work Complete N/A Cog. Engineer Signature & Date	11d. Restored to Original Condition (Temp. or Standby ECN only) N/A Cog. Engineer Signature & Date

12. Description of Change

Complete rewrite.

13a. Justification (mark one)

Criteria Change	☐	Design Improvement	☒	Environmental	☐	Facility Deactivation	☐
As-Found	☐	Facilitate Const	☐	Const. Error/Omission	☐	Design Error/Omission	☐

13b. Justification Details

HISTORICAL REVISION FOR FILE

14. Distribution (include name, MSIN, and no. of copies)

DC LARSEN	T4-08
PROJECT FILES	H5-09
CENTRAL FILES	A3-88
J. M. Vann	H6-33

RELEASE STAMP

JUL 01 1996

DATE:

STA: 21

HANFORD RELEASE

ID:

21

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15. Design Verification Required	16. Cost Impact				17. Schedule Impact (days)	
	ENGINEERING		CONSTRUCTION			
☐ Yes	Additional	☐ $NA	Additional	☐ $NA	Improvement	☐ NA
☒ No	Savings	☐ $NA	Savings	☐ $NA	Delay	☐ NA

18. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 12. Enter the affected document number in Block 19.

SDD/DD	☐	Seismic/Stress Analysis	☐	Tank Calibration Manual	☐
Functional Design Criteria	☐	Stress/Design Report	☐	Health Physics Procedure	☐
Operating Specification	☐	Interface Control Drawing	☐	Spares Multiple Unit Listing	☐
Criticality Specification	☐	Calibration Procedure	☐	Test Procedures/Specification	☐
Conceptual Design Report	☐	Installation Procedure	☐	Component Index	☐
Equipment Spec	☐	Maintenance Procedure	☐	ASME Coded Item	☐
Const. Spec.	☐	Engineering Procedure	☐	Human Factor Consideration	☐
Procurement Spec.	☐	Operating Instruction	☐	Computer Software	☐
Vendor Information	☐	Operating Procedure	☐	Electric Circuit Schedule	☐
OM Manual	☐	Operational Safety Requirement	☐	ICRS Procedure	☐
FSAR/SAR	☐	IEFD Drawing	☐	Process Control Manual/Plan	☐
Safety Equipment List	☐	Cell Arrangement Drawing	☐	Process Flow Chart	☐
Radiation Work Permit	☐	Essential Material Specification	☐	Purchase Requisition	☐
Environmental Impact Statement	☐	Fac. Proc. Samp. Schedule	☐	Tickler File	☐
Environmental Report	☐	Inspection Plan	☐		☐
Environmental Permit	☐ NA	Inventory Adjustment Request	☐ NA		☐

19. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number Revision
NA		

20. Approvals

	Signature	~~Date~~		Signature	Date
OPERATIONS AND ENGINEERING			ARCHITECT-ENGINEER		
Cog. Eng. JW LENTSCH	JW Lentsch	6-28-96	PE		
Cog. Mgr. JW LENTSCH	JW Lentsch	6-28-96	QA		
QA See EDT 611302 for signatures			Safety		
Safety " " " "			Design		
Environ.			Environ.		
Other			Other		
			DEPARTMENT OF ENERGY Signature or a Control Number that tracks the Approval Signature		
			ADDITIONAL		

ENGINEERING DATA TRANSMITTAL

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1. EDT ~~Nº 611302~~

2. To: (Receiving Organization) Waste Tanks Safety Program	3. From: (Originating Organization) Mitigation Program	4. Related EDT No.: 160341/140556/140802/ 140807/160236/600678/ 600681/600683/140814/ 602299/603252/602204/ 602244/602279/140846/ 602288/602242
5. Proj./Prog./Dept./Div.: 101-SY Mitigation Project	6. Cog. Engr.: JW Lentsch	7. Purchase Order No.: N/A
8. Originator Remarks: This document was prepared by Los Alamos National Laboratory for the U.S. Department of Energy		9. Equip./Component No.: N/A 10. System/Bldg./Facility: Tank 241-SY-101
11. Receiver Remarks:		12. Major Assm. Dwg. No.: N/A 13. Permit/Permit Application No.: N/A 14. Required Response Date:

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Impact Level	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	LAUR-92-3196	All	14	Safety Assessment for Proposed Pump Operation to Mitigate Episodic Gas Releases in Tank 241-SY-101	SQ	1	1	

16. KEY

Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
1, 2, 3, or 4 (see MRP 5.43)	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Impact Level for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.
1	1	Cog.Eng. LANL	R.P. Johnson	4/25/95	H5-09	TRG	D.C. Larsen by R.P. Johnson (per telcon)	4/26/95	R1-51	1	1
1	1	Cog. Mgr. JW Lentsch			S7-15	TRG		5/9/95		1	1
1	1	QA	Michael L. McElroy	5/16/95	~~G1-57~~ S7-07	TRG				1	
1	1	Safety	for N.W. Islam	5/11/95	R3-08	SEAC	R M Marusich for JLD	5/10/95		1	
1	1	TRG	R.P. Johnson	4/25	H5-09						
1	1	TRG	P. E. Panisko	Apr 26, 95							

18. JW Lentsch 4/26/95 Signature of EDT Originator / Date	19. P8-34 JW Lentsch Authorized Representative for Receiving Organization / Date	20. JW Lentsch Cognizant/Project Engineer's Manager / Date	21. DOE APPROVAL (if required) Ltr. No. [] Approved [] Approved w/comments [] Disapproved w/comments

BD-7400-172-2 (07/91) GEF097

A SAFETY ASSESSMENT FOR PROPOSED PUMP MIXING OPERATIONS TO MITIGATE EPISODIC GAS RELEASES IN TANK 241-SY-101: HANFORD SITE, RICHLAND, WASHINGTON

LOS ALAMOS NATIONAL LABORATORY for
WESTINGHOUSE HANFORD COMPANY, Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-87RL10930

EDT/ECN: 630696 UC: 2030
Org Code: 74E10 Charge Code: N2138
B&R Code: EW3120072 Total Pages: 876

Key Words: Tank 241-SY-101, mitigate, safety assessment

Abstract: This safety assessment addresses each of the elements required for the proposed action to remove a slurry distributor and to install, operate, and remove a mixing pump in Tank 241-SY-101, which is located within the Hanford Site, Richland, Washington. The proposed action is required as part of an ongoing evaluation of various mitigation concepts developed to eliminate episodic gas releases that result in hydrogen concentrations in the tank dome space that exceed the lower flammability limit.

Printed in the United States of America. To obtain copies of this document, contact: WHC/BCS Document Control Services, P.O. Box 1970, Mailstop H6-08, Richland WA 99352, Phone (509) 372-2420; Fax (509) 376-4989.

JUL 01 1996
DATE:
HANFORD
RELEASE
STA: 21
ID: 21

Karen [illegible] Noland 7/1/96
Release Approval Date

Release Stamp

Approved for Public Release

RECORD OF REVISION

(1) Document Number: WHC-SD-WM-SAD-033, REV 0-A

Page 1

(2) Title

SAFETY ASSESSMENT FOR PROPOSED PUMP MIXING OPERATIONS TO MITIGATE EPISODIC GAS RELEASES IN TANK 241-SY-101: HANFORD SITE, RICHLAND, WASHINGTON

CHANGE CONTROL RECORD

(3) Revision	(4) Description of Change – Replace, Add, and Delete Pages	Authorized for Release (5) Cog. Engr.	(6) Cog. Mgr.	Date
0-A	(7) Revision of appendices, misc. page changes throughout. (ECN-630663)	CE Hanson CE Hanson	CE Hanson CE Hanson	
0-B	Revision of appendices, revised chapter 6. (ECN-630670)	CE Hanson CE Hanson	CE Hanson CE Hanson	
0-C	Chapter 6, misc. control changes, revision of appendices. (ECN-630671)	CE Hanson CE Hanson	CE Hanson CE Hanson	per telecon
0-D	Misc. page changes (ECN 630674)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	per telecon
0-E	Misc. page changes (ECN 630676)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/22 per telecon
0-F	Misc. page changes (ECN 630677)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/22 per telecon
0-G	Misc. page changes (ECN 630678)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/22 per telecon
0-H	Misc. page changes (ECN 630680)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/22/96 per telecon
0-I	Misc. page changes (ECN 630681)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/22/96 per telecon
0-J	Misc. page changes (ECN 630682)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/22/96 per telecon
0-K	Misc. page changes (ECN 630686)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/22/96 per telecon
0-L	Misc. page changes (ECN 630687)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/24 per telecon
1	Complete replacement entire document (ECN 630688)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	5/30/96 per telecon
1-A	Misc. page changes (ECN 630689)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	6/11/96 per telecon
1-B	Misc. page changes (ECN 630690)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	6/20/96 per telecon
1-C	Misc. page changes (ECN 630691)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	6/26/96 per telecon
1-D	Misc. page changes (ECN 630692)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	6/24/96 per telecon
1-E	Misc. page changes (ECN 630693)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	6/25/96 per telecon
2 RS	Complete rewrite (ECN 630696)	JW Lentsch JW Lentsch	JW Lentsch JW Lentsch	6/28/96 per telecon

Los Alamos
NATIONAL LABORATORY

Technology & Safety Assessment Division
TSA-6, Engineering & Safety Analysis, MS K557
Los Alamos, New Mexico 87545
(505) 667-8893, FAX (505) 665-7429

Date: April 25, 1995
Refer to: TSA-6-95-067 (M110)

Jack Lentsch
Westinghouse Hanford Company
P.O. Box 1970, H5-09
Richland, WA 99352

Dear Jack:

Submittal of Revision (Rev.) 14 of the Mixer Pump Safety Assessment

Enclosed is the Revision (Rev. 14) of the Mixer Pump Safety Assessment (SA).

Revision 14 is a complete rewrite of the SA. Most of the changes are editorial in nature. Also, the document's structure has been modified to make it more "user friendly" than it has been in previous revisions. The number of appendices has been substantially reduced by combining related topics and analyses into a single appendix. Also, during the rewrite process, we tried to enhance the self-consistency in the analyses' assumptions, input, and results. To help the reviewers, we prepared a "Summary of Changes," which is enclosed.

The analyses presented in Rev. 14 were completed before the new Risk Acceptance Guidelines (WHC-CM-4-46, Release 12) became effective. The consequences computed in this SA revision are compared with the previous acceptance guidelines. Our preliminary assessment indicates that most of the accident consequences computed in Rev. 14 will not meet the new toxicological acceptance guidelines for the waste release from Tank 241-SY-101. We plan to address this issue in Rev. 15 of the SA.

Sincerely,

Kemal O. Pasamehmetoglu

Enc. as stated

Cys: A. S. Neuls, TSA-6, MS K557
E. A. Rodriguez, TSA-6, MS K557
J. R. White, TSA-6, MS K555
CIC-10, MS A150
TSA-6 file

A SAFETY ASSESSMENT FOR PROPOSED PUMP MIXING OPERATIONS TO MITIGATE EPISODIC GAS RELEASES IN TANK 241-SY-101: HANFORD SITE, RICHLAND, WASHINGTON

by

L. Harold Sullivan
Principal Author

US DEPARTMENT OF ENERGY

Revision 14

March 31, 1995

DISCLAIMER

The analyses presented in this SA revision were completed before the new risk acceptance guidelines (WHC-CM-4-46, Release 12) became effective. The consequences computed in this SA revision are compared with the previous acceptance guidelines.

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ACKNOWLEDGMENTS

Contributors to the development of this SA include the listed personnel.

Project Manager

L. H. Sullivan

Team Leaders

J. N. Edwards and K. O. Pasamehmetoglu

Principle Investigator

J. R. White

Technical Contributors

F. Biehl
C. Brown[1]
J. Bueck[1]
W. Birchler
T. Butler
J. Clark[4]
R. Davidson
S. Eisenhawer
D. Ericson[1]
R. Farman
S. Fischer
W. Kubic
R. Fujita
L. Goen
J. Hanson
J. Heneage[1]
H. Hoida
J. Holderness[3]
R. Johnson
S. King[3]
G. Medford[3]
D. MacFarlane
R. T. Perry
E. Rodriguez
M. Ross
D. Sanzo
J. Sapir
K. Sasser
N. Schnurr
L. Shephard[1]
D. Smith[2]
J. Spore
R. Stevens
L. Trujillo
C. Unal[1]
J. Teel[1]
J. Travis[1]
T. Wilson

1. Ogden Environmental and Energy Services Co.
2. Westinghouse Hanford Company
3. Science Applications International Corp.
4. Science & Engineering Associates Inc.

Editors

L. Rothrock and M. Timmers

ACRONYMS

1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional
ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ALARA	As Low As Reasonably Achievable
ALE	Arbitrary-Lagrangian-Eulerian
ANSI	American National Standard Institute
ARM	Area Radiation Monitor
ASAP	As Soon As Possible
ASME	American Society Of Mechanical Engineers
ASTM	American Society For Testing And Materials
ATG	Enraf-Nonius™ 854 Advanced Technology Gauge, manufactured by the Enraf-Nonius Company of Stafford, Texas
B/W	Black And White
B&K	Bruel & Kjaer (Manufacturer of the Ammonia Monitor)
BCD	Binary Code Decimal
C layer	Convective Layer
CAM	Continuous Air Monitor
CASS	Computer-Assisted Surveillance System
CCW	Counter-Clockwise
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DACS	Data Acquisition Control System
DAS	Data Acquisition System
DBA	Design Basis Accident
DBE	Design Basis Earthquake
DDT	Deflagration-to-Detonation Transition
DOE	Department of Energy
DOE/RL	DOE/Richland (Field Office)
DP	Differential Pressure
DST	Double-Shell Tank
E	Emergency
E-STOP	Emergency Stop
EAC	Energy Absorption Capacity
EDE	Effective Dose Equivalent
ERPG	Emergency Response Planning Guideline
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
ES&H	Environment, Safety, and Health
FCT	Flux-Corrected Transport

FDC	Functional Design Criteria
FEA	Finite-Element Analysis
FEM	Finite-Element Method
FIC*	Food Instrument Corporation
FMEA	Failure Mode and Effects Analysis
FM-approved	Factory Mutual-Approved
FTIR	Fourier Transform Infrared
GC	Gas Chromatograph
GRE	Gas Release Event
HASP	Health And Safety Plan
HazOp	Hazards and Operability
HazOps	Hazards and Operability Study
HEPA	High-Efficiency Particulate Air
HLW	High-Level Waste
HMS	Hanford Meteorological Station
HMS/TRAC	Hydrogen Mixing Study/Transient Reactor Analysis Code
HTWRS	Hanford Tank Waste Remediation System
HVAC	Heating, Ventilating, and Air Conditioning
I/O	Input-Output
ICE	Implicit Continuous Eulerian
ICRP	International Commission on Radiological Protection
IDLH	Imminently (or Immediately) Dangerous to Life or Health
IEEE	Institute of Electrical and Electronics Engineers
INEL	Idaho National Engineering Laboratory
JEG	Joint Evaluation Group
LANL	Los Alamos National Laboratory
LFL	Lower Flammability Limit
MAWB	Maximum Allowable Window Burp
MAXSPD	Maximum Speed Parameters
MCC	Motor Control Center
MIT	Multifunction Instrument Tree
MJTG	Mitigation Joint Test Group
MOS	Metal-Oxide Semiconductor
MPF	Multiport Flange
MPR	Multiport Riser
MS	Mass Spectrometer
MTTF	Mean Time to Failure
MW	Maximum Window
NC layer	Nonconvective Layer
NCAW	Neutralized Current Acid Waste
NCRW	Neutralized Cladding Removal Waste

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* Registered trademark of the Food Instrument Corporation.

NEC	National Electrical Code
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NIOSH	National Institute of Occupational Safety and Health
NIST	National Institute of Standards and Technology
NSSFC	National Severe Storms Forecast Center
ORR	Operational Readiness Review
OSD	Operational Safety Document
OSHA	Occupational Safety and Health Administration
OSR	Operational Safety Requirement
OVM	Organic Vapor Meter
P&IDs	Piping and Instrument Diagrams
PEL	Permissible Exposure Limit
PLC	Programmable Logic Controller
PNL	Pacific Northwest Laboratory
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PSICSF	Pump System Installation Containment Seal Fixture
PWM	Pulse Width Modulated
QA	Quality Assurance
RA	Reliability Assessment
RAM	Random Access Memory
RSS	Remote Supervisory Station
SA	Safety Assessment
SAR	Safety Analysis Report
SC	Safety Class
SCBA	Self-Contained Breathing Apparatus
SCF	Standard Cubic Feet
SCO	Safety Condition for Operation
SDRCSF	Slurry Distributor Removal Containment Seal Fixture
SOE	Safe Operating Envelope
SRS	Shock Response System
SRSS	Square Root of the Sum of the Squares
SS	Stainless Steel
SSC	Stainless Steel Carbon
SST	Single-Shell Tank
ST	Short Term
SY Tank Farm	241-SY Tank Farm
Tank 101-SY	Tank 241-SY-101
TC	Thermocouple
TCT	Thermocouple Tree
TGA	Thermal Gravimetric Analysis
TLV	Threshold Limit Value

TLV-C	Threshold Limit Value—Ceiling
TLV-STEL	Threshold Limit Value—Short-Term Exposure Limit
TLV-TWA	Threshold Limit Value—Time-Weighted Average
TRAC	Transient Reactor Analysis Code
TRG	Test Review Group
TSR	Technical Safety Requirement
TTL	Transistor-Transistor Logic
TWA	Time-Weighted Average
UOR	Unusual Occurrence Report
UPS	Uninterruptible Power Supply
USNRC	US Nuclear Regulatory Commission
UT	Ultrasonic Transducer
V&V	Validation and Verification
VDTT	Velocity, Density, Thermocouple Tree
VOF	Volume of Fluid
VSD	Variable Speed Drive
WHC	Westinghouse Hanford Company
ZND	Shepherd Zel'dovich, Von Neumann, and Döring
ZPA	Zero Period Acceleration

TABLE OF EFFECTIVE PAGES

for

A SAFETY ASSESSMENT FOR PROPOSED PUMP MIXING OPERATIONS TO MITIGATE EPISODIC GAS RELEASES IN TANK 241-101-SY: HANFORD SITE, RICHLAND, WASHINGTON

The enclosed table lists all pages contained in Los Alamos report LA-UR-92-3196, "A Safety Assessment for Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-101-SY: Hanford Site, Richland, Washington," up to and including Rev. 14.

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T of C (iv)	14	3/31/95	TEP-5	14	3/31/95
T of C (v)	14	3/31/95	TEP-6	14	3/31/95
T of C (vi)	14	3/31/95	TEP-7	14	3/31/95
T of C (vii)	14	3/31/95	TEP-8	14	3/31/95
T of C (viii)	14	3/31/95	TEP-9	14	3/31/95
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T of C (xii)	14	3/31/95	TEP-13	14	3/31/95
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T of C (xiv)	14	3/31/95	Ex. Sum. (2)	14	3/31/95
T of C (xv)	14	3/31/95	Ex. Sum. (3)	14	3/31/95
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EXECUTIVE SUMMARY

This safety assessment (SA) addresses each of the required elements associated with the installation, operation, and removal of a mixer pump in Tank 241-SY-101. This tank, which contains ~3785 m^3 (1 million gal.) of high-level radioactive waste, is located within the Hanford Site in Richland, Washington. The action was initiated as part of an ongoing evaluation of various mitigation concepts developed to eliminate episodic gas releases resulting in hydrogen concentrations in the tank dome space that exceed the lower flammability limit. In addition, the scope of this SA covers the installation, operation, and removal of the water-lance assembly (used during mixer pump installation) and the water wands (used during mixer pump removal). The installation, operation, and removal of the multiport riser, multiport flange, *in situ* viscometer, and voidmeter also are covered within the scope of this SA.

The pump was installed on July 3, 1993, and was tested through several phases of a test plan designed to increase the pump's operating speed and duration slowly. The test program was effective in demonstrating that, under present tank conditions, the mixer pump will minimize gas suspended in the waste and maintain the waste in the tank at a low level. The SA continues to be modified to take into account information learned from the test program. The earlier revisions of this SA were written before the mixer pump was installed. Thus, operations were tightly restricted so that tank conditions would not deteriorate beyond initial conditions. As information has been gained through continued operation, new problems have been identified and have been addressed in revisions to this SA. This SA currently is in transition from covering the testing over a limited time span to continued long-term operations to maintain tank mitigation. The mixer pump appears to be effective in keeping the tank mitigated; however, the pump must be operated routinely to mitigate the tank and prevent pump failures as a result of plugging.

In this SA, potential hazards associated with the proposed action were identified and evaluated systematically. Several potential accident cases that could result in radiological or toxicological gas releases were identified and analyzed and their consequences assessed. Administrative controls and procedures required to eliminate or reduce the potential of hazards were identified.

Most accident sequences were evaluated using deterministic methods. The sequences were found not to result in radiological, toxicological gas, or structural consequences that would cause a breach of the tank below the level of the waste.

The load capacities of the pump structure, 106.68-cm (42-in.) tank riser, tank bottom, tank wall, tank dome, and pump pit were computed. The drop loads of the pump with the shock absorber installed were found to be within the capacity limit of the structures, provided that procedural controls for pump lifting are maintained. The seismic and rollover loads were found to be within the capacity limits of the pump and tank. The misalignment loads associated with pump installation and removal were computed and compared with the riser capacity; controls and procedures then were developed to prevent unacceptable damage to the riser. The loads associated with the possible accident scenario of missile ejection caused by disintegration of the pump assembly were found to be within the capacity limits of the tank bottom and side wall. Criticality associated with the concentration of fissile material in the tank was examined and found to be impossible. We found the loads associated with a postulated hydrogen burn in the pump support column to be within the capacity limits of the pump support column. The structural loading associated with a burn in the tank was found to be within the capacity limits of the tank structure, provided that the gas release is limited by waste level controls.

Accident sequences that could result in either radiological or toxicological gas releases were analyzed and found to be within the risk acceptance guidelines, provided that the activities were performed in accordance with approved procedures and specified administrative controls. These accident sequences consisted of the following:

- gas releases and burns during pump installation or pump removal;
- gas releases and burns during pump operation;
- spills of radioactive material associated with contaminated pump removal;
- release of radioactive material associated with a spray of waste outside the tank, resulting in failure of pressure-sensing devices; and
- release of radioactive material associated with drops of a contaminated pump assembly.

Mitigation by mixing requires that the pump continue to be operated routinely to prevent excessive gas accumulation and plugging. If the pump fails and cannot be replaced, the tank could revert back to its unmitigated condition. Furthermore, time is limited to remove the pump and replace it with a spare. This time becomes critically short if the waste level is allowed to rise because of a lack of pump operation. If pump removal and installation are not performed quickly, the waste may even reach a level where pump replacement could not be performed, and the replacement work would have to be delayed until after a natural gas release event. In this case, we would experience gas releases, if ignited, that could result in tank failure. Mitigation of the tank using a mixer pump is not without risk; however, we believe (as demonstrated by this SA) that the risks associated with mixer pump operation are preferable to allowing the tank to revert back to its unmitigated state.

Also, the waste properties are changing slowly with time, with or without pump operations. How operations interfere with expected long-term changes in the waste properties is not fully understood. As a result, the pump may not be a successful long-term mitigation tool. For instance, the waste is expected to cool with time, independent of pump operations. In a few years, the temperature may fall below a threshold value where additional precipitation of solids or an increase in the viscosity and strength of the waste could reduce the pump's success in mitigating the tank. Consequently, it is extremely important that the tank and pump parameters be monitored closely while evaluating the long-term trends as mitigation operations continue.

1.0. SCOPE

1.1. General Introduction

This SA addresses each of the proposed elements required to (1) eliminate episodic gas releases that result in hydrogen concentrations that exceed 25% of the LFL in Tank 101-SY, (2) characterize the waste, and (3) provide access to the tank for added instrumentation and mitigation concepts. The subject tank is located within the Hanford Site, Richland, Washington. Specifically, this SA addresses the proposed action to install, operate, and remove a mixer pump; the installation, operation, and removal of the MPR also is addressed in this SA. Addendum 1 (included in Rev. 10) addresses the action necessary to install, operate, and remove an *in situ* viscometer. Addendum 2 (which begins in Rev. 11) addresses installation, operation, and removal of the voidmeter.

The mixer pump provides the primary means for mitigation of the episodic gas releases. Figure 1-1 illustrates the mixer pump as installed in Tank 101-SY. The addition of the MPR provides tank access to (1) test other mitigation concepts; and (2) increase tank instrumentation, while retaining provisions for tank venting. The design features of the MPR are shown in Fig. 1-2. Deployment of the *in situ* viscometer is expected to provide crucial knowledge of the rheological properties of the waste material (see detailed discussion in Add. 1). Waste void fraction data from the different layers also are required to develop and validate predictive models of the flammable gas-producing events and to support analyses of the behavior of the waste under accident conditions (see detailed discussion in Add. 2).

The objective of this SA is to (1) systematically identify each of the potential hazards associated with these proposed actions, (2) analyze each of the resultant accident sequences, (3) assess the consequences of the accident sequences, and (4) identify the controls and procedures necessary to eliminate or reduce the potential hazards. Specifically, this SA (1) presents a physical description of the SY Tank Farm, which includes Tank 101-SY, and a detailed description of the proposed actions; (2) identifies potential hazards associated with the proposed actions; (3) analyzes each of the hazards relative to their potential severity; (4) calculates the anticipated consequences related to each potential hazard; (5) assesses the consequences; and (6) describes the controls necessary to minimize the probability of any significant accidents occurring.

1.1.1. Background and Purpose of the Proposed Action

DOE is responsible for the management and storage of the waste accumulated from processing defense reactor irradiated fuels for plutonium recovery at the Hanford Site. These wastes, consisting of liquids and precipitated solids, are stored in underground storage tanks pending final disposition. A systems approach, managed as part of the HTWRS, has been adopted to address the complex and interrelated activities associated with the management and disposal of Hanford tank wastes. The goal of the HTWRS is to reduce the environmental, safety, and health risks inherent in the Hanford tank waste operation and remediation. The highest priority for this program is to identify a corrective action strategy for each Priority 1 waste tank safety issue and to mitigate known safety concerns. The four Priority 1 safety issues include (1) hydrogen gas generation and concentrations that exceed the LFL;[1] (2) tanks containing mixtures of ferrocyanide compounds and nitrate/nitrite materials that could, if specific concentrations and conditions were to occur, support an exothermic reaction leading to an explosion; (3) tanks containing organic compounds that could, if locally concentrated, support an exothermic reaction; and (4) Tank 241-106-C, which contains a strontium source generating high heat that requires periodic cooling.[2–3]

There currently are 23 Hanford waste tanks on the watchlist that can generate, store, and periodically release various quantities of hydrogen and other gases. Some tanks release larger amounts of gas than others, but only Tank 101-SY has been found to release concentrations greater than the LFL during episodic events. In the unlikely event that an ignition source were present during these periods, a burn or explosion could occur, with a conceivable release of nuclear waste possibly resulting in exposure to onsite or offsite personnel. A Waste Tank Safety Logic Program has been developed for dispositioning the safety issues listed in the DOE response to Congress on Public Law 101-510, Sec. 3137. This logic program lists the hydrogen gas issue as the first item on the priority list and identifies Tank 101-SY for "accelerated evaluation" leading to either a mitigation or remediation resolution.

The primary objective of the overall mitigation project for Tank 101-SY is to eliminate gas releases that result in a hydrogen concentration in the tank exhaust header >25% of the LFL in the gas mixture of interest. Several mitigation concepts intended to reduce the frequency of large gas releases from the waste involve maintaining a near steady-state condition between the rate at which gas is generated within the waste and the rate at which gas is released from the waste to the tank dome space and ventilation system.[4–5] These include (1) mitigation by ultrasonic agitation, (2) mitigation by heating the waste, (3) mitigation by diluting the waste, and (4) mitigation by mixing using various pumping concepts.[6] These concepts have been developed using the information available from the tank to identify the primary conditions believed responsible for gas retention within the nonconvecting bottom layer and an understanding of the processes needed to alter these conditions to release the gas. Although each of these concepts appears plausible, many developmental requirements currently preclude the deployment of the first three mitigation concepts in the tank. This SA addresses one of the proposed mitigation concepts: the installation, operation, and removal of a mixer pump in Tank 101-SY.

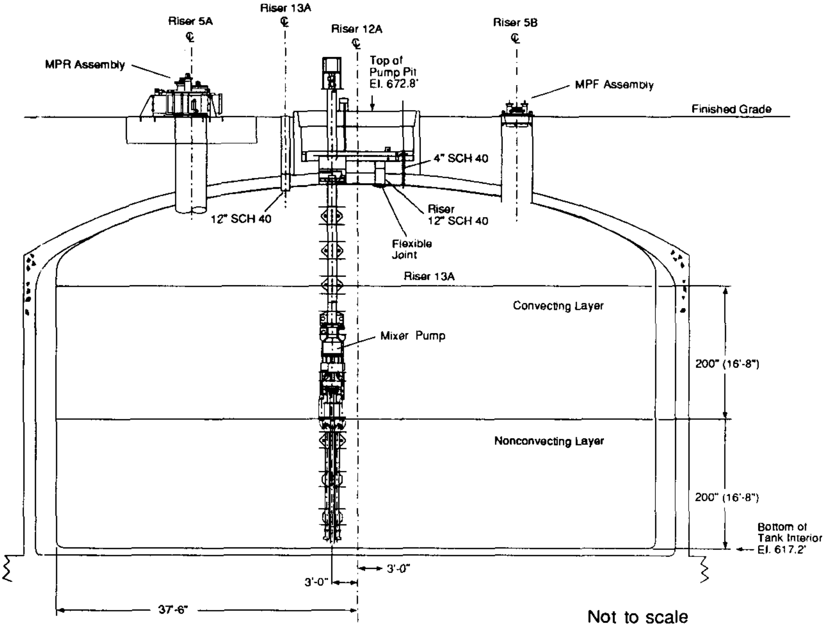

Fig. 1-1. Cross section of Tank 101-SY showing the MPR and MPF. [C and NC layers represent the approximate waste configuration before mitigation (see Sec. 1.3.)]

In summary, the primary purpose of this proposed action was to (1) evaluate the efficacy of pump mixing to promote the sustained release of gas to the tank dome space, (2) limit the amount of gas retained in Tank 101-SY, and (3) reduce the concentrations of hydrogen released during episodic events to <25% of the LFL. In addition, the data and information gathered from this demonstration are used to evaluate the waste and tank hardware responses to the pump mixing operation. Detailed designs, operational procedures and controls, and performance requirements are developed as a result of the planned evaluations. Finally, the information acquired during this evaluation may be used to develop design modifications to enhance the effectiveness of pump mixing and to establish whether pump mixing is a feasible, long-term mitigation concept.

As discussed later, after nearly 2 yr of testing, the mixing concept appears to be successful in mitigating the episodic releases in Tank 101-SY under the present tank conditions. Therefore, the purpose of the proposed action has shifted from testing and evaluating the mixing concept to using the mixing concept as a long-term mitigation tool.

1.1.2. No-Action Alternative

In addition to the proposed action, a "no-action" alternative was considered. For this alternative, Tank 101-SY would continue to generate flammable gases, and episodic gas releases exceeding the LFL would be likely to occur, unmitigated, until the controlling processes and mechanisms were abated. These episodic releases could have lead to a burn or deflagration, potentially resulting in a release of radioactive material. The no-action alternative would not have provided the information needed to evaluate the effectiveness of pump mixing in promoting the gradual release of gas from the nonconvecting bottom layer or in reducing the concentration of gas released during an episodic event. This alternative would have delayed development of a mitigation approach for reducing the concerns pertaining to a Priority 1 waste tank safety issue and would have precluded pump mixing from further consideration as a mitigation option until data on the effects of mixing on the waste and on the waste tank structural components could be obtained. This option would not have satisfied the specific need for the proposed action and would have delayed an accelerated evaluation of a possible mitigation approach.

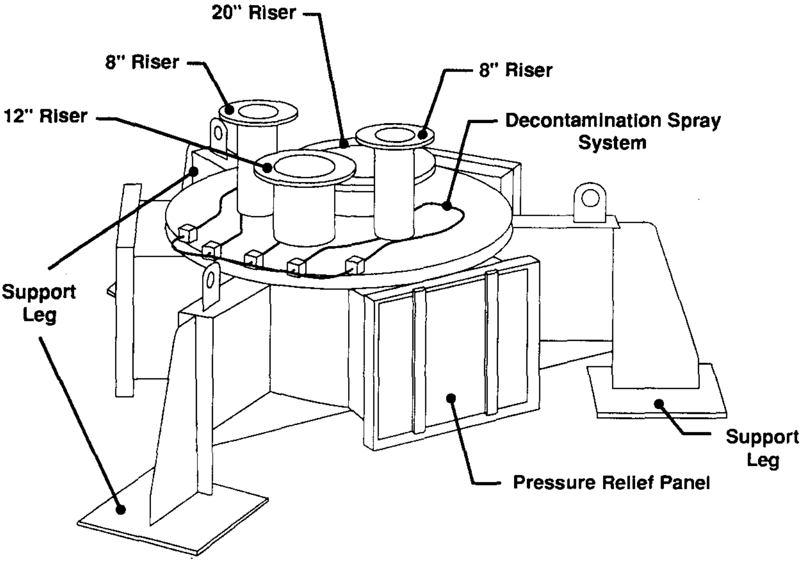

Fig. 1-2. Perspective view of the MPR assembly.

Currently available data indicate that mixer pump operations are successful in mitigating the episodic gas release problem. Consequently, the no-action alternative of halting mixing operations would not be acceptable because the tank would revert back to its historic behavior. Mixer pump operations may be stopped if (1) the data indicate that mixing operations are creating long-term problems in the tank and/or (2) a more efficient and effective mitigation alternative (such as sonification, dilution, or heating) can be found for continued mitigation, and/or (3) the waste properties change in such a way that the mixer pump may no longer keep the tank mitigated.

If the MPR or MPF is not installed on the tank as planned, the ability to apply a variety of new instruments simultaneously in the tank will be precluded because of a lack of access. Any additional mitigation devices to be tested, such as the sonic probe or heating equipment, will further limit the availability of instrumentation access required to measure the mitigation effectiveness or to monitor tank conditions.

1.1.3. Safety Assessment Approach

The approach implemented in the development of this SA incorporates a systematic evaluation of the potential hazards related to installation, operation, and removal of a mixer pump. Evaluations were completed to establish the potential severity of these hazards and the resultant consequences of accidents that may arise. These evaluations consisted of detailed analyses using analytical and numerical techniques, engineering calculations, and/or a review of existing information to establish the consequences of these hazards. Finally, the SA identifies the procedures and controls necessary to prevent or mitigate the consequences.

Section 2 of the SA provides detailed descriptions of the processes and systems associated with the tank farm and the implementation of the mitigation pump test. Section 3 presents the results of a HazOp analysis conducted to identify the hazards associated with the hydrogen mitigation pump test. Section 4 presents an evaluation of the postulated accidents associated with the proposed action. Section 5 presents the consequences associated with each postulated accident scenario. Section 6 discusses the controls used in the pump test to ensure an additional level of safety beyond that provided in the design of the pump structure. These controls include a description of the safety features associated with the pump, special training, and procedures.

1.2. Facility Overview: Description of SY Tank Farm

The SY Tank Farm consists of three similar 4391-m^3 (1.16-million-gal.) DSTs (Tanks 101-, 102-, and 103-SY) located just east of the 242-S Evaporator in the 200-West Area (Fig. 1-3).[7] Tank 102-SY is the feed tank for the 242-S Evaporator. The tank farm was constructed from 1974 to 1976 and became operational in 1977. Primary waste containment for each tank is provided by an inner carbon-steel tank with a diameter of 22.9 m (75 ft) and a height of 14.0 m (46 ft). An outer steel tank with a diameter of

24.4 m (80 ft) serves as secondary containment to the primary tank and protects the environment from direct leaks from the primary tank. The gap between the inner and the outer tanks, termed the annulus, is 76.2 cm (30 in.). The outer tank is completely encased within reinforced concrete. There are ~55 to 60 risers in the primary tank and annulus. These risers are used to monitor the tank contents and support waste processing activities. The risers for the primary tank are required for performing liquid level, sludge level, temperature, and pressure measurements and for remote observations. In addition, risers for the primary tank and annulus are required for processing operations, including tank ventilation, slurry distribution, supernatant pumpout, drainage collection from various pits, encasements, and leak detection monitoring. A minimum of 2 m (6.5 ft) of earth overburden covers each tank. The operating specifications for the SY Tank Farm tanks limit the waste level to ~4391 m^3 [1.16 million gal., or equivalent to a height of 10.7 m (422 in.)] to prevent overfilling the tank and overstressing it as a result of hydrostatic head. To prevent exceeding this limit, the tank is equipped with a high-level alarm set to annunciate at ~4353 m^3 [1.15 million gal., or equivalent to a height of 10.6 m (419 in.)].

Gaseous emissions from the tanks during steady-state conditions are removed by the continuous operation of a ventilation system that is common to all three tanks

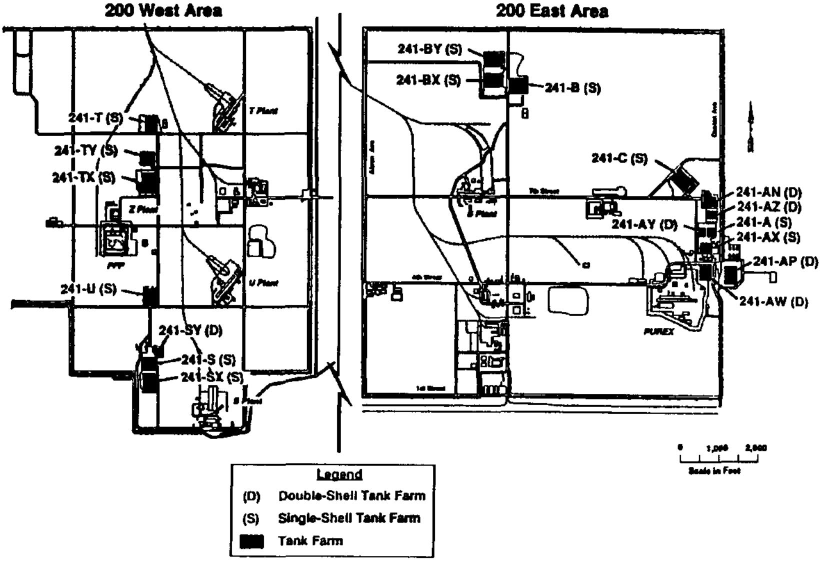

Fig. 1-3. Location of the 241-SY Tank Farm within the 200-West Area.

in the SY Tank Farm. The ventilation system consists of two completely separate systems: a primary tank ventilation system and an annulus ventilation system. The primary ventilation system maintains a pressure inside the tank slightly less than the atmospheric pressure outside the tank [generally, -2.5 to -10.2 cm (-1 to -4 in.) w.g.]. The offgas is processed by means of a moisture separator and heater followed by two stages of HEPA filtration. The primary system is capable of handling flow rates of 28.3 m^3/min (1000 ft^3/min). The primary exhaust stack contains CAMs for radiation and routine air sampling. The annulus ventilation system cools the tanks, minimizes moisture condensation in the annular space, and serves as a sensitive method for detecting leakage of radioactive materials from the primary tank. The annulus system is capable of handling maximum flow rates of 243.5 m^3/min (8600 ft^3/min) through two HEPA filters. Both subsystems are equipped with ports in the ductwork that allow in-place testing of the filter integrity. Differential pressure gauges, which monitor the pressure drop caused by the buildup of particulates on the filters, and ports for psychrometric testing of the primary system also are provided on the ventilation system.

1.3. Description of Tank 101-SY Waste Contents and Gas Release Mechanisms

Tank 101-SY contains ~3785 m^3 (1 million gal.) of waste that was concentrated at the 242-S Evaporator and placed in the tank between 1977 and 1980. Initially, 1073.2 m^3 (274,000 gal.) of double-shell slurry (the most concentrated material produced by the evaporators and containing high concentrations of hydroxide, nitrate, and aluminate) was pumped into the tank. Subsequent additions of waste to the tank included complexed concentrate waste (an evaporator product similar to double-shell slurry but not as concentrated and containing significant organic complexant concentrations) and double-shell slurry waste through 1980.[1] Shortly after the waste was pumped into the tank, the waste began to expand from the generation of gases, which include hydrogen, nitrous oxide, nitrogen, and ammonia. In 1990, this tank was declared to have an Unreviewed Safety Question because (1) the gas release was not addressed in the SARs for the tank facility; (2) the episodic release of hydrogen and nitrous oxide into the tank dome space periodically exceeds the LFL; and (3) there is only a limited understanding of the physical and chemical processes controlling gas generation, storage, and release mechanisms. Efforts to characterize the tank contents have included gas sampling and analyses, temperature monitoring, displacement monitoring, core sampling to characterize the tank contents, and remote video observations.

Between rollovers, the waste used to settle into two distinct layers. The C layer (see Fig. 1-1) is assumed to be mobile and remains mixed as a result of convective motion. Consequently, gases generated in this layer are assumed to be released steadily. The bottom NC layer (see Fig. 1-1) does not move and is assumed to retain all of the gas that is generated in this region until a rollover. The C- and NC-layer terminology is inferred from the observed axial temperature profiles in the tank between rollovers. A flat temperature profile in the C layer indicates convective mixing, whereas an almost parabolic temperature profile in the NC layer represents conductive heat transport.

Several mechanisms have been proposed to explain the generation, retention, and release of gas.[4] Although considerable uncertainty exists with these mechanisms, the existing data suggest that a "rollover" of the NC layer occurs periodically, which releases the gas.[8]

The chemical reactions occurring in the tank that result in gas generation have not been fully characterized. However, it is known that the reactions involve the organics and are assisted by the radiation. In the C layer, the motion of the fluid brings the gas generated in that layer up to the surface, where it can be released; as a result, the gas does not accumulate in the fluid layer. However, in the NC layer, the waste does not move, and most of the gas formed in this layer is retained. As gas accumulates, the NC layer becomes less dense. The temperature rises, with several possible consequences: (1) the accumulated gas expands, further decreasing the density; (2) the viscosity of the material decreases; (3) some of the solid material redissolves in the warmer temperature; and (4) the chemical reaction rate may increase. As a result of some or all of the above occurrences, the NC layer reaches a critical density and becomes buoyant. This causes instability, and the lower region rolls over to the top (Rayleigh-Taylor instability, as discussed in Ref. 8). When this happens, the hydrostatic head decreases, the pressure on the accumulated gas drops, and the bubbles expand, which further increase the buoyancy. The gas releases when it reaches the surface.

Eventually, enough of the accumulated gas is released so that the density increases and the solids settle out. The NC layer forms again on the bottom, and the cycle begins again.

The description provided above summarizes the understanding of the episodic gas release mechanisms before mixer pump operation. In <100 h of operation in the 17 months following installation, the mixer pump appears to have broken the cycle described in the previous paragraph. As of November 1, 1994, the waste level remains quasi-steady between 10.16 and 10.21 m (400 and 402 in.), and the temperature profiles indicate fully mixed waste except at the top and bottom 76.2 to 101.6 cm (30 to 40 in.). Figure 1-4 illustrates the axial temperature profiles measured before the GRE in June 1993 shortly before installation of the mixer pump in comparison to the axial temperature profiles measured in October 1994 (15 months after pump installation). As shown in this figure, in October 1994 there is only an apparent NC layer of <1.016 m (40 in.) at the bottom of the tank as compared to 6.1 m (240 in.) of NC layer observed before pump installation. Before mixer pump operation, the historical minimum waste level recorded was 10.21 m (402 in.). During the first 17 months, no episodic releases resulting in hydrogen concentrations >25% of the LFL have been observed. After November 1993, gas releases during or immediately after pump operation resulted in maximum gas

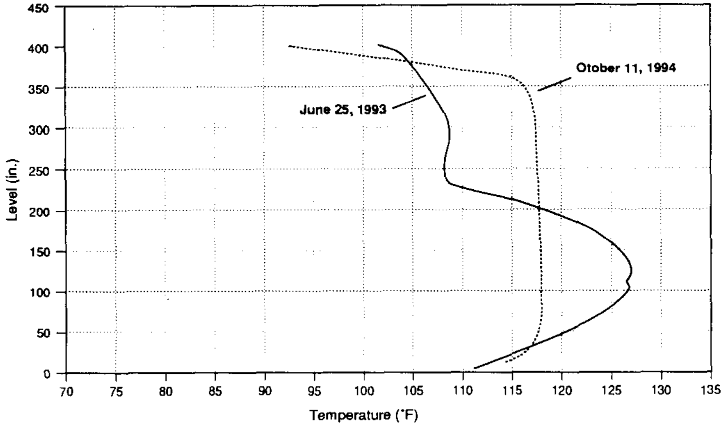

Fig. 1-4. Axial temperature profiles before and 16 months after pump installation.

concentrations of <1000 ppm (0.1%) in the dome space. Presently, we believe that the gas being generated is released continuously as a result of pump operation. When averaged over multiple pump operations, the rate of storage for the generated gas is nearly zero. Further details for the level and gas release data during pump operation may be found in Refs. 9 and 10. If during a 20-month period the mixer pump had not been used, we would have expected at least four or five episodic releases with hydrogen concentrations >25% of the LFL and possibly exceeding the LFL.

1.4. Summary of Significant Characteristics of the SY Tank Farm and Its Environment

A detailed and comprehensive description of the Hanford Site is presented in documents developed by ERDA, DOE, and PNL.[11-13] This section summarizes results presented in these references and others as they apply to the 200 Areas. The DOE Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State. The Hanford Site occupies an area of ~1450 km^2 (570 mi^2) north of the confluence of the Snake, Yakima, and Columbia Rivers. This land, with restricted public access, provides a buffer for the smaller areas currently used for the production of nuclear materials, waste storage, and waste disposal; only ~6% of the land area has been disturbed and is actively used. The Columbia River flows through the northern part of the Hanford Site, and, turning south, it forms part of the Site's eastern boundary (Fig. 1-5).[14]

The SY Tank Farm is located within the 200-West Area, ~8.0 km (5 mi) from the Columbia River and outside the 100- and 500-yr floodplain. The terrain of the central and eastern parts of the Hanford Site is relatively flat, with evidence in the central part of the Site (including the 200-Area Plateau) of minimal erosion since the deposition of Hanford Formation sediments by glacial floodwaters ~13,000 yr ago. The soil beneath the tank farm consists of silt, sand, and gravel. The principal geologic units beneath much of the 200-West Area are, in ascending order: (1) the Columbia River Basalt Group, with interbedded sediments of the Ellensburg Formation; (2) the Ringold Formation; (3) the Plio-Pleistocene unit; and (4) the Hanford Formation. The Ringold Formation is ~47.2 m (155 ft) below the surface of the SY Tank Farm.[15]

Two areas of shallow, swarm seismic activity, Coyote Rapids and Cold Creek, are located within 16.1 km (10 mi) of the 200-West Area. The Coyote Rapids swarm area

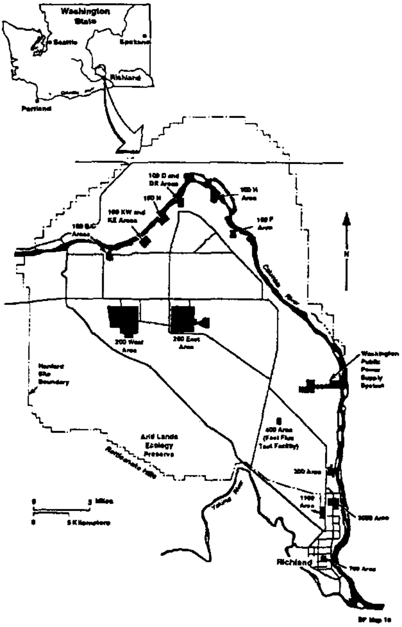

Fig. 1-5. Location of 200-West Area within the Hanford Site.

has been the site of eight swarms consisting of 91 shallow seismic events during the period between 1969 and 1986. The depth distribution of these seismic events is bimodal, with maximum activity occurring near the surface and at a depth of 4.0 to 6.9 km (2.5 to 4.3 mi). The Cold Creek swarm area, located 12.9 km (8 mi) south of the 200-West Area, includes 32 events from 1979 to 1986 that occurred at depths up to 4.8 km (3 mi).

Several surface ponds and ditches associated with fuel and waste processing activities are present within the 200-West Area (Fig. 1-6).[16] These ponds and ditches are used primarily as wasteways for process and cooling water and sometimes contain small quantities of radionuclides (both fission products and transuranic elements). Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system along the southern boundary of the Hanford Site. Both streams drain areas to the west of the Hanford Site and cross the southwestern part of the Site toward the Yakima River. The potential for flash flooding from the Cold Creek drainage system has been examined, and a maximum flood depth of 2.1 m (7 ft) was estimated along the southwestern part of the 200-Area plateau. However, the maximum probable flood has not been well-defined for the Cold Creek drainage system. A 100-yr peak stage flood, estimated to be ~0.9 m (3 ft) above the Cold Creek Valley floor, would not reach the 200-West Area.[17]

Wastewater ponds on the Hanford Site have recharged the unconfined aquifer below the 200-West Area artificially. The increase in water table elevations was most pronounced from 1950 to 1960 and had approached equilibrium between the unconfined aquifer and the recharge between 1970 and 1980, when only small increases in water table elevations occurred. Wastewater discharges from the 200-West Area were reduced significantly in 1984 (Ref. 18) with an accompanying decline in water table elevations. Depth to groundwater currently is ~50 to 60 m (164 to 197 ft) in the 200-West Area. Groundwater flow direction is generally in an easterly and southeasterly direction, toward the Columbia River.

Lateral groundwater movement occurs within a shallow, unconfined aquifer consisting of fluvial and lacustrine sediments lying on top of the basalts and within deeper confined-to-semiconfined aquifers consisting of basalt flow tops, flow bottom cones, and sedimentary interbeds.[18] Sources of natural recharge to the unconfined aquifer are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia Rivers. Artificial recharge to the unconfined aquifer results from the disposal of wastewater to the ground below the 200 Areas from the surrounding highlands. This recharge to the aquifer [5.5 by 104 m^3/ d (1.5 by 107 gal./d)] is ~10 times the natural recharge entering the unconfined aquifer below the 200 Areas.[18] Beneath the disposal ponds, groundwater mounds have developed in response to the artificial recharge. Beneath U Pond, located in the

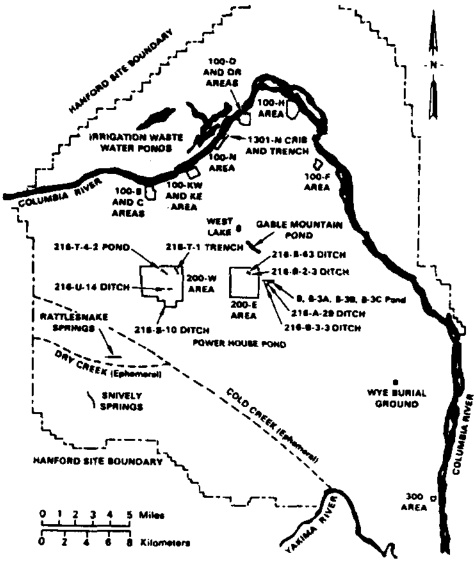

Fig. 1-6. Locations of surface-water ponds, ditches, and ephemeral streams on the Hanford Site.

200-West Area, the water table rose ~24.4 m (80 ft) from the start of disposal operations in 1944 (Refs. 19 and 20) until U Pond was decommissioned in 1985. From the recharge areas to the west, the groundwater flows down the gradient to the discharge areas along the Columbia River, interrupted locally by the groundwater mounds in the 200 Areas. The horizontal and vertical extent of these mounds appears to be related directly to the surface discharge of wastewater from facilities in this area.[21]

Climatological data are available from the HMS, which is located between the 200-East and 200-West Areas. Data have been collected at this location since 1945. Temperature and precipitation data also are available from nearby locations for the period of 1912 through 1943. A summary of these data through 1980 has been published by Stone et al.[22] Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200-Area Plateau.

The prevailing winds on the 200-Area Plateau are from the northwest. Secondary maxima occur for southwesterly winds. Diurnal and monthly averages and extremes of temperature, dew point, and humidity are contained in Stone et al.[22] Ranges of daily maximum temperatures vary from normal maxima of 2°C (36°F) in early January to 35°C (95°F) in late July. The record maximum temperature is 46°C (115°F), and the record minimum temperature is -32.8°C (-27.0°F). Relative humidity/dew-point temperature measurements are made at the HMS and at the three 61.0-m (200-ft) monitoring tower locations. The annual average relative humidity at the HMS is 45%. It is highest during the winter months (averaging ~75%) and lowest during the summer (averaging ~35%). At the Hanford Site, the severe-weather phenomenon that occurs most frequently and has the greatest effect is the dust storm.[23] The maximum recorded peak gust at 15 m (50 ft) above ground was 128 km/h (80 mi/h), which occurred in January 1972. A 100-yr return period peak gust of 138 km/h (86 mi/h) has been calculated at the 15-m (50-ft) elevation.

Precipitation measurements have been made at the HMS since 1945. Average annual precipitation at the HMS is 16 cm (6.3 in.). Most of the precipitation occurs during the winter, with nearly half of the annual amount occurring in the months of November through February. Rainfall intensities of 1.3 cm/h (0.5 in./h) persisting for 1 h are expected once every 10 yr. Rainfall intensities of 2.5 cm/h (1.0 in./h) for 1 h are expected only once every 500 yr. The Hanford Site is not a major thunderstorm area. On average, only about 10 thunderstorm days per year are recorded at the Hanford Site, although this number has varied from a low of 3 to a high of 23 thunderstorm days per year. Thunderstorms theoretically can occur during any month of the year; however, they occur most frequently from April through September. The largest number of thunderstorm days recorded in a single month is eight, which has occurred in both June and August. Large differences in electric potential can occur during thunderstorms, which, in turn, can lead to lightning strikes. In general, ~20% of lightning strikes are cloud-to-ground/ground-to-cloud discharges. Lightning strikes in the summer have occasionally ignited range fires in the Hanford Site region. Estimates of the extreme thunderstorm winds, based on peak gusts observed from 1945 through 1980, are given in Stone et al.[21] Using the National Weather Service criteria for classifying a thunderstorm as "severe" [i.e., hail with a diameter ≥20 mm (0.8 in.) or wind gusts ≥93 km/h (84.8 ft/s)], only 1.9% of all thunderstorm events observed at the HMS have been "severe" storms; all met the criteria based on wind gusts.

The nearest volcano is in the Cascade Range, more than 100 km (62 mi) from the Hanford Site, and most eruption products are deposited within 50 km (31 mi) of their source. There is no evidence that volcanic lava flows, debris flows, or mudflows from the Cascade Range volcanoes reached the Pasco Basin during the Quaternary period.

Flows of lava, debris, and mud tend to be confined to existing drainage channels, and because no streams flow directly from the Cascade Range to the Hanford Site, these types of volcanic deposits are not considered likely at the 200-West Area.

Tornadoes are infrequent and generally small in the northwest portion of the United States. The HMS climatological summary and the NSSFC database list 22 separate tornado occurrences within 161 km (100 mi) of the Hanford Site from 1916 through August 1982. Two additional tornadoes have been reported since August 1982.

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2.0. DESCRIPTION OF ACTION

Several mitigation and/or remediation concepts are being considered to reduce the frequency and concentration of large gas releases from the nonconvecting bottom layer in Tank 101-SY.[1] Many of these concepts incorporate approaches that attempt to maintain a near steady-state condition between the rate at which gas is generated within the waste and the rate at which gas is released from the nonconvecting bottom layer to the tank dome space and ventilation system. These concepts have been developed using (1) tank information currently available to identify the primary conditions believed to be responsible for gas retention within the nonconvecting bottom layer and (2) an understanding of the processes needed to alter these conditions and release the gas.

The actions described below consist of the operations necessary to support the installation, operation, and removal of a mixer pump in Tank 101-SY. These operations are governed by a management plan, test plans, and procedures that prescribe the sequence of steps necessary to complete the pump installation and operation safely and with minimal environmental impact. Procedures also have been developed for removal and disposal of the mixer pump.

This section also covers the actions planned for installation of the MPR on Riser 5A.

2.1. Tank Farm Design and Contents

The SY Tank Farm consists of three 4391-m^3 (1.16-million-gal.) tanks (101-, 102-, and 103-SY) that are connected by a common ventilation system (Fig. 2-1). These tanks essentially are identical, with the exception of two additional process pits in Tank 102-SY. The tanks are of the same basic construction and consist of three concentric structures:[2] (1) an outer, reinforced concrete tank designed to sustain induced loads from soil, seismicity, and thermal gradients between the radioactive wastes and the outside soil; (2) a secondary carbon-steel tank that lines the concrete tank and is designed to serve as a leak barrier; and (3) a free-standing carbon-steel primary tank resting on an insulating concrete pad within the secondary tank (Fig. 2-2). The primary tank contains the waste material; the secondary tank, which is 1.52 m (5 ft) larger in diameter, encloses the primary tank to create the annulus. The completely enclosed annulus serves as the containment barrier for primary tank leaks. The annulus is ventilated and monitored constantly for evidence of primary tank leakage. If a leak should occur, the secondary tank is designed to contain the liquid waste until it can be removed and stored in a different tank.

The primary tank is 14.0 m (46 ft) high and 22.9 m (75 ft) in diameter. It rests on a slotted, insulating concrete pad that is designed to (1) provide drainage to leak detection equipment, and (2) permit airflow for leak detection and cooling purposes.

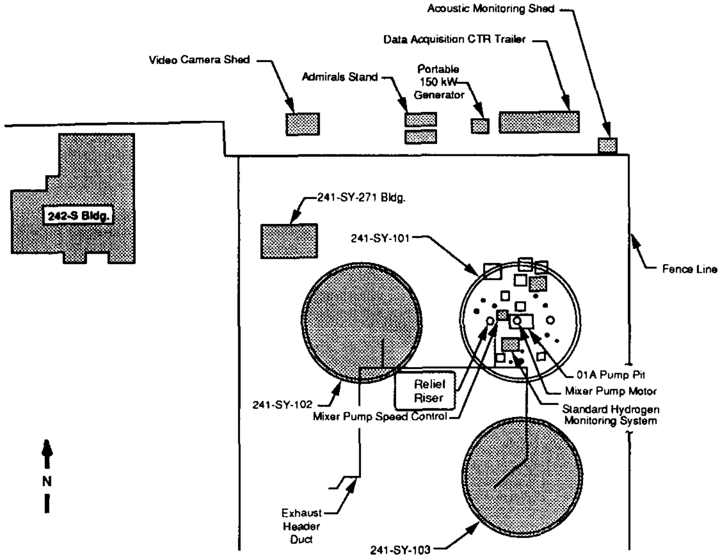

Fig. 2-1. Configuration of the 241-SY Tank Farm.

The thickness of the welded carbon-steel plate used for construction varies from 2.54 cm (1 in.) on the floor to 0.925 cm (0.364 in.) on the dome.[3] The primary tank is designed to withstand up to 15.24-cm (6-in.)-w.g. vacuum and 152.4-cm (60-in.)-w.g. internal pressure. Other design features include a maximum design tank wall temperature of 107°C (225°F), a heat generation rate of 52,752 kJ (50,002 Btu) per hour per tank, a pH range from 8 to 14, and a specific gravity of the waste material of 1.7.

The secondary tank is 14.0 m (46 ft) high and 24.4 m (81 ft) in diameter. It surrounds the primary tank and also is constructed of welded carbon-steel plates that vary in thickness from 1.27 to 0.953 cm (0.5 to 0.375 in.). The secondary tank is encased completely in 46 cm (18 in.) of reinforced concrete. The gap between the primary and secondary tank, or annulus, is 76 cm (30 in.). The annulus is used to extract heat from the primary tank shell and to provide leak detection for the primary tank. The annulus requires a separate ventilation system. The secondary tank rests on a concrete foundation that contains drain slots to remove any liquid that might leak from the secondary tank. Any significant volume of liquid that reaches the foundation is drained to a leak detection pit.

Each tank contains several risers extending vertically from the tank domes into pits or extending above grade level (Fig. 2-2). The risers consist of various sizes of pipe, some of which are blind-flanged at the top, and are used as tank accesses for monitoring devices, observation points, sample ports, and sludge measurements. A general list of the process pits for the SY Tank Farm include (1) central pump pits, (2) annulus pump pits, (3) leak detection pits, (4) drain pits, (5) flush pits, (6) service pits, (7) ventilation pits, and (8) sluice pits. These pits (1) contain the processing equipment necessary for operating the tanks, (2) protect equipment from weather, (3) provide shielding for workers, and (4) function as secondary containment. In addition, Tank 102-SY has two extra process pits: the 02D drain pit, which surrounds the riser that receives liquid draining from the 241-S-152 diversion box and SY valve pits; and the 02E feed pump pit, which surrounds the riser from which the evaporator feed was pumped.

The SY Tank Farm contains six cleanout boxes associated with waste-transfer lines and three buried seal pots. A cleanout box consists of a metal structure that contains nozzles to connect transfer cleanout lines. The cleanout line flush pipes are tied directly into the transfer line. When the transfer pipes are under pressure, the flush pipes also are under pressure. If the transfer line becomes plugged, a water hose is

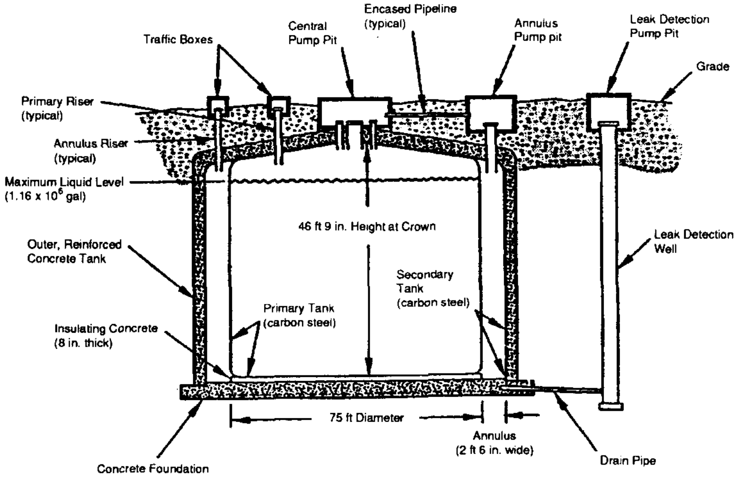

Fig. 2-2. Generalized cross section of a DST showing approximate configuration and dimensions.

fed into the cleanout box flush lines and then into the waste-transfer line. Water then is pumped into the hose to dissolve the plug. The seal pots are small buried tanks that function as large drain traps to collect drainage from several sources; each pot has one overflow drain line extending to the final receiver tank. The seal pots are used to isolate two systems of dissimilar vapor environments while still allowing liquid to drain.

The ventilation system for the SY Tank Farm consists of two completely separate subsystems: a primary tank ventilation system and an annulus ventilation system. Both subsystems are common to all three tanks. The systems have no redundancy; unlike other tank farms, the duct work is above ground. The two subsystems combined can remove nominally 105,500 kJ (100,000 Btu) of heat per hour from each tank. The exhaust systems use HEPA filters to maintain low radioactive particulate emissions. Ductwork routes the ventilation air from the primary tank and annulus of each tank to the respective exhaust fans. Both subsystems are equipped with ports in the ductwork that allow in-place testing of the filter integrity. Differential pressure gauges, which are installed to monitor the pressure drop caused by the buildup of particulates on the filters, and ports for psychrometric testing of the primary system also are provided on the ventilation system.

The primary tank ventilation system is designed to remove vapors from the primary tank and to maintain a pressure inside the tank that is slightly less than the atmospheric pressure outside the tank [generally -2.5 to -10.2 cm (-1 to -4 in.) w.g.]. Slight positive tank pressures have been measured during episodic gas releases. This constant negative pressure is maintained by exhausting the infiltration air from the tanks at flow rates of up to 0.47 m^3/s (16.66 ft^3/s). Operational ventilation rates are monitored; rates for Tank 101-SY typically range between 0.19 and 0.28 m^3/s (6.5 and 10 ft^3/s). The exhaust unit contains a deentrainment pad to remove entrained moisture; a steam heater to prevent condensation on the filters; a prefilter; two HEPA filters in series; and an exhaust stack with a flow measuring device, air sampler, and radiation monitor. The HEPA filters are commonly used for nuclear service because of their high efficiency in removing particles as small as 0.3 μm in diameter. For this installation, the HEPA filter package must pass a leak test to remove 99.95% of exhaust particles that have a mean particle size of 0.5 μm.

The existing instrumentation associated with the ventilation system includes

1. a hydrogen monitor in the extension of the ventilation system that connects to Tank 101-SY,
2. a differential pressure indicator for determining if the exhaust fan is running,
3. a differential indicator across each of the two HEPA filter banks,

4. a radiation monitor placed immediately before the location where the exhaust exits the system,
5. a relative-humidity probe that extends into the Tank 101-SY ventilation header,
6. a gas chromatograph sampling system (two gas chromatographs) off the Tank 101-SY ventilation header,
7. two continuous ammonia monitoring systems, one off the Tank 101-SY ventilation header (also measures nitrous oxide) and one off the exhaust stack,
8. a cryogenic sampling system off the Tank 101-SY ventilation header,
9. a temperature element in the Tank 101-SY ventilation header, and
10. an OVM that samples from the SY Tank Farm primary exhaust stack.

The safety characteristics of the hydrogen monitor and the technical basis for its use are well documented.[4] All differential pressure indicators are connected to an alarm panel in Building 241-SY-271 and to the CASS. The radiation monitor is connected to alarms in the 241-S and 242-S control rooms. The hydrogen monitor is to be used for observation only and is not alarmed; during operations, an operator is assigned to monitor this meter. A backup portable exhaust unit is connected to the ventilation line near the existing primary exhauster.

The annulus ventilation system cools the tanks, prevents condensation in the annular space, and serves as a sensitive method to detect leakage of radioactive materials from the primary tank. Outside air is supplied through carbon-steel pipes located inside the annulus and embedded in the insulating concrete material underneath the primary tank bottom. From the center of the insulating concrete, the air flows radially outward to the annulus through slots in the insulation under the primary tank. The exhaust unit filtration system used for the annulus contains a deentrainment pad to remove entrained moisture; an electric heater to prevent condensation on the filters; two HEPA filters; and an exhaust stack with a flow measuring device, air sampler, and radiation monitor.

Each tank is equipped with an automatic liquid level gauge located on a primary riser This gauge uses a plummet suspended in the primary riser. A continuous electrical circuit is maintained between the plummet and the liquid surface. Daily level readings are accomplished by lowering the plummet until it contacts the waste surface. The tape reading is converted automatically to an electrical signal for remote readout, and the tape then is repositioned 5.08 cm (2 in.) above the waste.

Each tank also is equipped with TCs that are distributed vertically and radially for monitoring temperatures within the tank waste and tank dome space. There are ~126 TCs; however, some of them may not be functional or are located in areas that will not be influenced by the mixer pump operation. Two MIT probes containing 22 TCs each are used to monitor waste temperatures at two different azimuthal orientations (95 and 135 deg). One MIT (in Riser 17B) has TCs distributed axially from 10.16 cm (4 in.) to just under 1021 cm (402 in.) above the tank bottom. The other MIT (in Riser 17C) has TCs distributed axially from 10.16 to 1082.04 cm (4 to 426 in.) above the tank bottom. The concrete walls and dome contain 24 TCs located at the outer surfaces. Twenty-four additional TCs are located in the interior next to the steel in the primary tank dome and the steel liner. Nine TCs are located in the concrete slab base. Twenty-four TCs are located in the insulating concrete layer next to the bottom of the primary tank.

Three pole-mounted ARMs provide overall surveillance of radiation levels in the SY Tank Farm. In addition to the leak detection provided by the CAMs, conductivity probes have been installed in the annulus, process pits, and encasements. These areas normally are dry; the presence of any liquid indicates a leak and causes the probe to sound an alarm in the instrument building.

2.2. Tank 101-SY

Under undisturbed conditions, the contents of Tank 101-SY settle into a bottom, NC layer of sludge and slurry ~508 cm (200 in.) thick.[5] A liquid C layer ~533 cm (210 in.) thick lies on top of the NC layer. After more than 20 months of intermittent pump operations, the waste appears to be almost fully suspended. The temperature profiles indicate that the NC layer no longer exists except, perhaps, at the bottom 1 to 1.27 m (40 to 50 in.). Figure 1-4 (in Sec. 1) shows the temperature profile under mitigated tank conditions in comparison with the temperature profile that existed before Window I when the mixer pump was installed. The waste in Tank 101-SY consists of "double-shell" slurry and complexed concentrate waste (Table 2-1). Double-shell slurry is waste that has been concentrated using crystallizer evaporators. The product of this process consists of a solution high in NaOH, $NaNO_3$, $NaNO_2$, $NaAlO_2$, dissolved organic complexants (EDTA, HEDTA, NTA, etc.), and minor concentrations of other salts (sulfates and phosphates).[6] The slurry also contains solids consisting primarily of $NaNO_3$, $NaNO_2$, and $NaAlO_2$. The slurry, or "complexed concentrate," contains ~6 M organic carbon, again from organic complexants, with salt concentrations that are not as high as in the double-shell slurry.[7]

Instrumentation for monitoring tank behavior during the mixer pump operations is provided at various locations throughout the tank (Fig. 2-3). Of primary importance to determining success of the test is the measurement of the waste level and gas concentrations within the tank and vent header. In addition, the remaining instrumentation provides information that is used to control the test, provide abort capabilities, and protect equipment.

TABLE 2-1
COMPOSITION OF WASTE CONTAINED IN TANK 241-SY-101[6]

Component	Amount of Waste in Tank
NaOH	3.22 M
$NaAlO_2$	1.90 M
$NaNO_2$	3.28 M
$NaNO_3$	4.23 M
Na_2CO_3	0.62 M
Na_2SO_4	0.12 M
Na_3PO_4	0.19 M
Pu	713 g
Sr	2.187×10^{11} µCi
Cs	3.10×10^{12} µCi
TOC	26.24 g/L
H_2O	594,600 gal.

Note: The concentrations are based on a present average tank height of 10.4 m (408 in.).

The tank contains a total of three 1.07-m (42-in.)-diam risers. The mixer pump is installed in the central riser (Riser 12A) located in the central pump pit. Before mixer pump installation, Risers 5A and 5B contained TV camera and light assemblies. To mitigate the consequences of an unexpectedly large gas release and burn, the light assembly in Riser 5A was removed and the riser was fitted with a cover so that this riser would open as a result of the tank pressure increase. An anchoring system was installed in the riser to constrain the relief riser during a burn. The relief riser later was replaced with an MPR assembly. A new camera subsequently was installed into the MPR.

Based on the results of an NFPA-Classified Locations for a Hydrogen Atmosphere study, the unmitigated Tank 101-SY was divided into several NFPA-classified locations.

- The tank dome space above the liquid level is a hydrogen environment approaching hazardous conditions at somewhat unpredictable intervals and accordingly is classified as a Class I, Div. 1, Group B space. This SA is based on the assumption that all equipment in this area meet applicable requirements and be rated for use under these hazardous, albeit temporary, conditions. If a prompt release could result in hydrogen concentration ≥60% of the LFL, all electrical equipment in the dome space, or directly communicating with the dome space, that does not meet Class I, Div. 1 must be deenergized or otherwise placed in a safe condition.

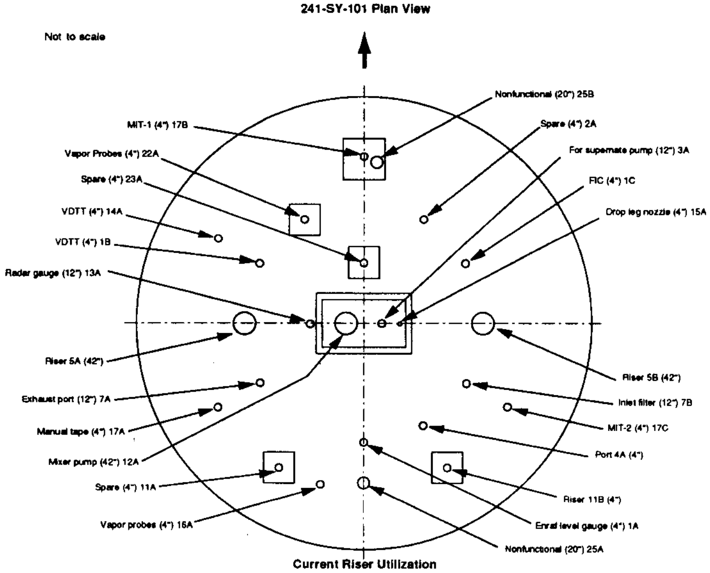

Fig. 2-3. Plan view of Tank 101-SY showing locations of risers and sensors currently in tank.

- The space in the pump pit is classified as having a possible hydrogen environment at certain times and is classified as a Class I, Div. 2, Group B space. Equipment located in this environment was designed for use in an explosive environment and must be intrinsically safe.

- The tank space below the liquid is nonhazardous. Equipment located in this area is not required to be intrinsically safe. Although this area is considered nonhazardous according to NFPA-classified location divisions, confined voids within the liquid space are potentially hazardous.

- The open space above the pump pit is classified as a nonhazardous location. Equipment located in this area is not required to be intrinsically safe.[8]

The NFPA hazard classification requirements for the temporary equipment placed in the dome under the current mitigated tank conditions are discussed in App. AA.

2.3. Pump Design and Description

The final design report for the mixer pump[9] provides a detailed description of the pump that was installed in Tank 101-SY. The pump has been designed with many specific safety features incorporated that are summarized in Table 2-2. The remainder of this section presents a detailed description of the mixer pump characteristics.

A Hazelton submersible pump with an overall length of 17.1 m (56 ft) and an 112-kW (150-hp) motor was installed through Riser 12A into Tank 101-SY (Tables 2-3 and 2-4; Fig. 2-4).[9] The pump construction materials are primarily austenitic steels. The pump assembly weighs ~9070 kg (20,000 lb). The twin-volute, single-stage centrifugal pump with close-coupled suction is driven by a submersible, 460-V, three-phase, 176-amp motor with a VSD that allows the speed of the motor to be controlled over a range of 100 to 1180 rpm. The pump has a flow capacity of 0.18 m^3/s (46.67 gal./s) and develops a total dead head of 34.75 m (114 ft). Particles up to 5 cm (2 in.) in diameter may pass through the pump without damaging the impeller. The submergence rating of the pump (i.e., the allowable external fluid pressure on the seals) is 22.9 m (75.1 ft). The pump intake is submerged to a waste depth of ~3.7 m (12 ft). If seal leakage occurs, it may be detected by the moisture monitors in the motor cavity.

Electrical power is supplied to the pump assembly through conduits inside the support column. These conduits are rated for use in an explosive hydrogen environment, and the support column is filled with inert nitrogen. The support column also acts as a raceway for various instrument leads from the motor, pump, and discharge piping locations, through the dome, and out the pump pit to the control system trailer. All motor connections, cable, wire, and conduit connections are located below the surface of the waste (C layer) in a nonhazardous location within the tank. Only the upper column passes through the tank vapor space, terminating 0.61 to 0.91 m (2 to 3 ft) below the waste. The upper column is sealed completely by seal welds around all conduit or water line penetrations. Guiderails or bumper assemblies incorporate nylon wear pads in the upper column to preclude sparking during pump installation, operation, and removal. All motor connections are contained in the motor shroud.

The three-phase, squirrel-cage induction motor was manufactured by the Reliance Electric Company to Hazelton specifications. This design uses no brushes and does not spark during operation. The motor chamber has been filled with mineral oil and sealed. Moisture detectors installed in the motor chamber to detect in-leakage have been wired into the DACS, which provides the required flexibility for alarms and automatic shutdown. The motor chamber-to-shaft seal is a multispring, John Crane, 8-1S double mechanical seal. The seal housing contains a barrier fluid that provides double protection against external liquid entering the seal. The barrier fluid (mineral oil) is fed by gravity from a reservoir on the side of the pump.

TABLE 2-2
PUMP DESIGN AND OPERATIONS SAFETY FEATURES

Safety Feature	Description
1. Hydrogen Monitoring	Pump operation should not cause a release of hydrogen gas >25% of the LFL for the gas mixture of interest. (All electrical equipment in the dome is designed to operate in a Class I, Div. 1, Group B environment.) Hydrogen monitors (existing) in the ventilation and dome space of the tank are provided to detect H_2 gas and determine when the hydrogen concentration exceeds 25% of the LFL.
2. Grounding/Bonding Straps and Cables	All pump equipment should be grounded to control and/or eliminate static electricity; these straps and cables are in place and checked by administrative procedures.
3. Pump Collar Stabilizers	Eight centering jacks are mounted on the pump collar to align and prevent side movement in the riser and to transfer load to tank dome. (Jack shoes are made of bronze to prevent sparks.) Prevents the overload of the pump flange mounting bolts and possible failure of tank riser during normal or abnormal pump operation.
4. Pump Chamber Instrumentation	Monitors, alarms, and controls pump operation and local and emergency manual shutdown of all pump operations.
5. Nitrogen-Filled Support Column	Provides an inert environment in the support column. (The support column contains electric cables in conduits that carry large electrical loads for the pump motor and instrumentation.) Note: Conduits meet NEC code for use in an explosive, hydrogen environment.
6. Overcurrent Protection, Circuit Breakers, and Fuses	Provides overcurrent protection for the mixer pump motor if short circuit or other overload condition occurs. Of the five sets of overcurrent protection circuitry, the fastest response time is 4 ms (Ref. 10).
7. Strain Gauges on Pump Support Column	Detects a plugged nozzle, frozen jet, asymmetric nozzle flow, or other abnormal loading on the support column. Operations will be terminated if the strain gauges show that the oscillating load on the pump column exceeds its infinite fatigue life load.
8. Pump Vibration Accelerometers	Provide early detection of pump failure and cavitation and any other condition that would cause excessive vibration, leading to a pump failure.
9. Pump Nozzle Flow Indication	Detects plugged nozzle, asymmetrical flow, or other failure leading to reduced flow or asymmetrical loads.
10. Pump Discharge Pressure	Detects plugged nozzle, frozen jet, asymmetric nozzle flow, or other abnormal conditions leading to asymmetric loads.
11. Pump Motor Speed	Monitor pump motor speed, and, if necessary, shut down motor before unsafe conditions develop. Provides controlled startup of pump motor.
12. Waste Temperature Limits	Pump operation will cease if waste temperature exceeds 57.2°C (135°F); annulus exhaust must be capable of handling temperature increase up to 57.2°C (135°F).
13. Pump-to-Riser Seals	A series of seals is provided. These are metal disks attached to the pump assembly with rubber wipers. The wipers seal against the inside of the riser as the pump is lowered. At least one seal is in the riser at all times. Use of the seal ensures that the pump will be centered in the riser.

TABLE 2-2 (CONT)
PUMP DESIGN AND OPERATIONS SAFETY FEATURES

Safety Feature	Description
14. Internal and External Water Flush Capability	Internal flush bars and nozzles are provided to decontaminate the interior of the pump assembly while it is still in the tank. External nozzles will decontaminate the external portions of the pump while the pump is extracted through the riser/pit area. The flush water will be demineralized and will be provided at the following conditions: 65.5°C (150°F) and 20,700 kPa (3000 psi) pressure.
15. Video Camera	Pump operation should not cause foaming. A video camera will monitor conditions inside dome area to allow for the identification of foaming and permit early shutdown of the pump.
17. Pump Vibrator System	The pump vibrator system was developed to ensure that any blockage to the pump nozzles can be cleared away. The pump vibrator system consists of two rotary vibrators attached near the nozzle end of the pump discharge lines. The vibrators consist of rotating cylindrical weights whose center of mass is offset from the center of rotation. Rotation of the cylinder, which is driven by compressed air, produces a periodic force that causes vibration in the structure to which the device is attached. An additional vibrator is installed to provide impetus to start the two main vibrators.

TABLE 2-3
CHARACTERISTICS OF MIXER PUMP

Characteristic	Specification
Manufacturer	Barrett, Haentjens, & Co.
Model No.	447-150-1200
Type	Hazelton submersible liquid jet pump
Dimensions	Overall height: 17.1 m (56 ft) Diameter: 40.4 to 91.4 cm (16 to 36 in.)
Weight	~9070 kg (20,000 lb)
Horsepower	112-kW (150-hp) oil-filled motor
Rotational Speed	100 to 1180 rpm
Electrical Power Requirements	460-V, three phase, 60 Hz, 176 amps max.
Motor Design	Induction; oil-filled chamber
Support Column Design	Steel; nitrogen-filled
Pump Design	Single-stage centrifugal, twin-volute nozzles
Pumping Capacity	10,600 L/min (2800 gal.)/min
Pump Life	~8 yr
Pump Particle Size	5.08 cm (2 in.) max
Total "Dynamic" Head	34.74 m (114 ft)
Discharge Nozzle Diameter	6.6 cm (2.6 in.)

TABLE 2-4
CHARACTERISTICS OF MIXER PUMP MONITORING INSTRUMENTATION

Instrumentation	Manufacturer	Range	Location
Strain Gauge	JP Technologies WSG-RK 06H-0622C-350-F6C-50	0 to 9999 µ in./in.	Support Column
Motor Temperature Transmitter (2)	Translogic 5261	0 to 100°C	Motor Oil
Pump Discharge Pressure Sensors (4)*	Hottinger-Baldwin P6P-20	0 to 2030 kPa (0 to 294 psi)	Absolute Discharge Pressure
DC Alarm	Moore Industries		
Pump Flowmeters (4)*	Controlotron 191 NW	0.03 to 12.2 m/s (1 to 40 ft/s)	Upper Discharge Leg (2) Lower Discharge Leg (2)
Vibration Monitor	Scientific Atlanta M99-3	0.1 to 80 g	Support Column
Moisture Detector	B/W Controls 5300-P-V-OC		Motor Oil Reservoir
Pump Discharge Temperature (4)[a]	Translogic 5261	0 to 100°C	Upper Discharge Leg (2) Lower Discharge Leg (2)
Pump Discharge Ultrasonic Modules[a]	Ames		Support Column
Discharge Leg Pressure	Precise Sensors 401-300-01-S-340-2M-Q2719	2071 kPa (0 to 300 psia)	Upper Discharge Leg (2) Lower Discharge Leg (2)
Column Pressure	Omega PSW-521		No Contact Purge Gas

[a] These instruments are located in the waste material.

The DACS controls the variable-frequency drive. The output from the power supply is fed through a circuit breaker. The breaker, which supplies power to the variable-speed drive, also is tripped by shutdown signals from the DACS. This provides redundant electrical shutdown and isolation for the pump motor to ensure that power to the pump is interruptable (assuming that one breaker is subject to a single failure). Each breaker is operated by a control circuit that can trip the pump from the DACS, both by a shutdown switch and by a remote shutdown switch that is "locked and tagged" when the pump is not operating, to prevent inadvertent pump startup. The DACS itself uses duplicate computer systems to provide reliable control and safety functions.

The pump is equipped with vibration monitors, flowmeters, and pump discharge pressure meters to detect abnormal conditions resulting from a plugged nozzle, frozen jet, or other malfunction. A 40.6-cm (16-in.)-diam support column suspends the mixer pump assembly from the upper support structure. Strain gauges are mounted on the column to detect abnormal loading from a plugged nozzle, frozen outlet jet, or other abnormal loads.

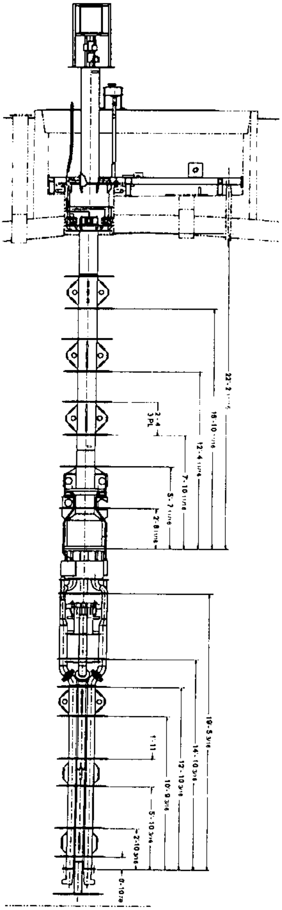

Fig. 2-4. Schematic of the submersible pump for the mitigation test.

The load distribution frame is designed to support all loading experienced by the pump structure. The load distribution frame also serves as a base for the decontamination spray ring and the riser-to-pump transition piece. The transition piece is required because the pump's mating flange originally was machined for use in Tank 102-AP, which has different mounting dowels than those on Tank 101-SY. The frame was designed to be adjustable because the actual pump pit "as-built" dimensions were not available. The load frame is made of 15.2-cm (6-in.)-square tubing 1.27 cm (0.5 in.) thick and weighs ~1364 kg (3000 lb). The frame is constructed to carry all the downward and side loading placed on the pump. The load frame transfers vertical loading of the pump to the pump pit floor. The pump transition piece is bolted to the load frame, and the load frame is secured to the pump pit to prevent uplift of the pump in the event of a burn in the tank. To prevent the overload of the pump flange mounting bolts, "stabilizers" were added to the pump section that interfaces with the riser.

The stabilizers are designed to transfer side movement to the riser. The stabilizers consist of eight hydraulic button jacks that expand to firmly fix the pump column in the center of the riser. A total of eight jacks will be mounted to interface with the riser. After the pump is installed in the pump pit, the jacks are pressurized to fix and center the pump in the riser. The jacks are tied into a common manifold. After the jacks are pressurized, each jack is isolated from the other, and redundancy was maintained. To prevent sparks, the jack "shoe" is bronze. During a rollover or seismic event, side loadings or moments induced into the pump structure will be transformed into a force couple. The forces then will be carried by the riser, the supporting dome concrete, and the pump load frame.

An impact limiter mitigates damage to the bottom of the tank if the pump drops during installation or removal. The impact limiter consists of two honeycomb impact limiter structures (Fig. 2-5).

The pump support column includes the inner (lower) impact limiter, which is mounted between two crush plates. A machined notch in the pump's upper mounting plate is designed to fail at an impact load of 266,893 to 667,233 N (60,000 to 150,000 lbf). Failure of the notch will result in the pump column crushing the inner impact limiter and transferring ~1,334,466 N (300,000 lbf) impact load via the bottom crush plate and upper pump mounting assembly to the pump support frame. The outer (upper) impact limiter is located under the pump support frame and is designed to transfer a total of 2,440,070 N (548,550 lbf) impact load to the pump pit floor. This impact load includes 1,361,070 N (305,980 lbf) from the pump's upper column and rotating mechanism. The impact limiters will attain a maximum crush distance of 30.5 cm (12 in.) under the design impact load of ~2,440,070 N (548,550 lbf); this distance will maintain a nominal 15.2-cm (6-in.) clearance between the bottom of the pump and the tank bottom.

The pump has a 92-cm (36-in.)-diam steel plate mounted on the bottom of the discharge nozzles to protect them during installation. Twin discharge piping connects the volute with two nozzles to discharge liquid horizontally at right angles to the mixer pump axis. The 15-cm (6-in.)-diam discharge piping, which is ~6.1 m

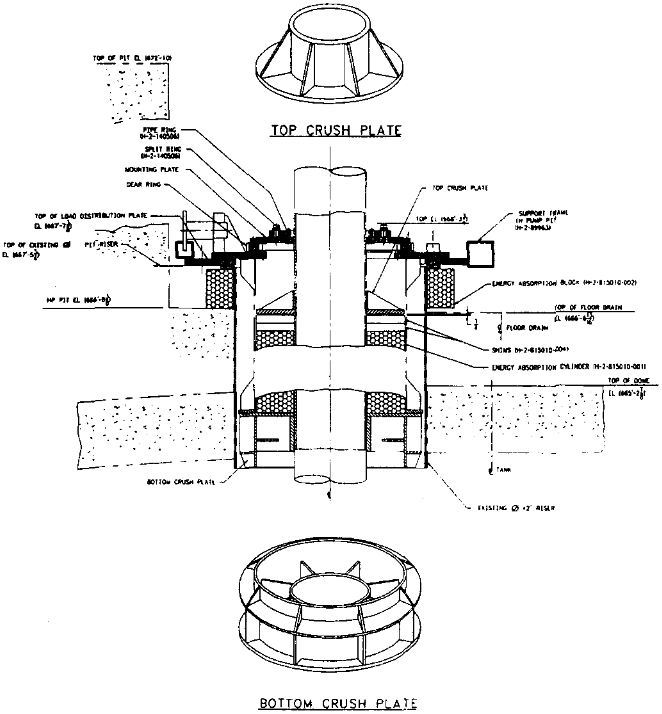

Fig. 2-5. Cross section of impact limiter with top and bottom crush plates and pump support column.

(20 ft) long, extends vertically. This piping is stiffened by the addition of two dummy legs and connections to the intake to the pump. The two discharge nozzles are located in a plenum at the end of the discharge piping, ~81 cm (32 in.) above the bottom of the tank; their inlet ports are located in the convective fluid (under unmitigated conditions).

The pump and motor assembly has a drive mechanism that rotates the pump. This mechanism consists of a (1) 1-hp motor, (2) worm gear, (3) gearbox, and (4) ring-and-pinion gear. The ring-and-pinion gear connects the support column to the pump assembly. The drive mechanism rotates the support column (and thus, the pump discharge nozzles) through a 190-deg arc. Because of the gearing ratios of the drive mechanism, up to 2 min are required to rotate the pump support column the full 190 deg. A Selsyn resolver provides position information to the controller and readout throughout the 190-deg rotation.

A replacement pump was designed to replace the test mixer pump. The replacement mixer pump is identical in concept and operation to the presently installed mixer pump. Design modifications have been introduced into the new pump based on experience with the test pump and the need to more thoroughly and easily decontaminate the device when removed from the tank. Because the existing pump has been analyzed exhaustively, the replacement pump was compared to the present pump for modifications that could have adverse safety impacts. The methodology was to determine whether any modification degraded the safe installation, operation, or removal of the pump or the toxicological and radiological impacts of the modification. This evaluation of the design modifications of the replacement pump is described in App. Z.

2.4. Data Acquisition and Control System

The DACS has been designed to control the Tank 101-SY hydrogen mitigation testing systems, ancillary systems, and equipment (see App. S for details). The DACS consists primarily of a computer-based system, including CPUs, CRTs, user keyboards, and data storage devices, as well as other peripherals to complete the system. The DACS can display data in real time, as well as graphically, on CRT monitors so that the information is easily understood. The system records the data as fast as is practical for the signal type. The DACS data files are archived in the system and are backed up periodically.

The DACS provides appropriate alarms and initiates corrective actions required to maintain the tank testing systems in a safe mode of operation. If conditions deteriorate, the DACS also will safely shut down equipment to prevent equipment damage. The operator is able to interface with the various test and auxiliary systems through operator stations or by controls located on a control panel, both of which will be located in a control area in a utility trailer near the tank site.

2.5. Mixer Pump Installation

Installation of the mixer pump includes (1) installing the load distribution frame, (2) installing the mixer pump, and (3) reinstalling the cover blocks on the pump pit. These operations are controlled by the mixer pump installation procedure, which specifies the requirements for the pump installation process. The safety features prescribed by the procedures controlling pump installation are summarized in Table 2-5.

The current mixer pump successfully was installed through a 107-cm (42-in.)-diam riser (Riser 12A) located 91.44 cm (36 in.) from the center of the tank (see Fig. 2-3) in

July of 1993. The replacement pump will be installed in the same riser after the current pump is removed.

During installation, the load distribution frame, with the PSICSF installed, is offloaded from the truck and positioned next to the pump pit so that the lifting crane can raise the frame over the pit. The load distribution frame is raised, and the removal cable, attached to the SDRCSF, is threaded through the load distribution frame and the PSICSF. The load distribution frame then is installed according to the design drawings listed in the final design report.[10]

The mixer pump is offloaded from the truck and moved with a boom crane to a position above the riser. A load path is established to minimize the consequences of a drop as the pump is moved over the tank. The PSICSF is opened, the pump is lowered into the tank and positioned on the guide pins on the load distribution frame, and the flange bolts are installed and torqued. The cover blocks, with sleeves for routing the hydraulic and water lines and electrical cables to the exterior of the pump pit, are installed on the pump pit.

Specific measures are taken during installation of the mixer pump to mitigate the potential for excessive personnel exposures or releases to the environment of radioactive or other hazardous material. These measures incorporate factors related to weather conditions, monitoring requirements, lifting, rigging, and handling (see Sec. 6 for more detail). Similar measures will be taken during subsequent pump replacement activities.

2.6. Mixer Pump Operation

Similar to the current mixer pump, a "run-in" test of each mixer pump will be completed to demonstrate that the modified mixer pump and the associated instrument and control subsystems mounted on the mixer pump are operable and functioning properly.[11] A secondary objective of the "run-in" test is to provide preparatory training for (1) handling the mixer pump using critical lift procedures, (2) installing the mixer pump and associated equipment, (3) preoperational verification and checkout of installed equipment, and (4) operating the mixer pump system.

The safety features prescribed in the procedures controlling the operation of the pump are summarized in Table 2-6. The current mixer pump has been successfully operated in Tank 101-SY for more than 20 months. The logic in developing the safety envelope for various phases of mixer pump operation has evolved as mixing tests progressed and more information was gained about the tank behavior with or without mixing. The safety logic of each phase is discussed in detail in App. R and summarized here.

TABLE 2-5
PUMP INSTALLATION PROCEDURAL SAFETY FEATURES

Systems or Conditions	Description of Safety Feature
1. Pump Assembly/Support Equipment	The pump must be lifted into place (or removed from the tank) so as to preclude damage to critical safety equipment if a drop were to occur.
2. Maximum and Minimum Lift Loads	The lift loads of the pump (both maximum and minimum loads) will be limited, as specified in Sec. 6. If these loads are exceeded, operations will be terminated, and the pump will be placed in a safe shutdown condition.
3. Lift Heights	Lift heights using the crane should be the minimum practicable, and maximums have been specified as conditions for operation.
4. Primary Tank Breach Mitigating Features (Pump Drop)	During installation and removal, several design features will protect against breach of the primary liner as a result of a pump drop accident: (1) The pump will have a drag plate on the bottom of the discharge nozzles. (2) An impact load on the pump pit will be distributed over an annular region around the riser, the pump mounting flange, and the load-limiting crushable material. (3) An energy absorber or impact limiter will limit drop loads on the riser area of the pump pit to less than 813,500 N-m (600,000 ft-lbf). The design will include the capability to withstand a 17.7-m (58-ft) drop from 1.98 m (6.5 ft) above the riser flange. (4) The design of the pump support column will prevent any part of the pump assembly from escaping the riser, falling over, and impacting the side wall of the primary liner.

In earlier phases, a very cautious test plan was developed and was motivated primarily by the following short- and long-term considerations:

- Analyses estimating the gas inventory in Tank 101-SY have indicated that a considerable amount of gas might be retained in the tank, even after a large GRE.[12] We postulated that the mechanisms of a gas release during a natural tank rollover may be different than during a pump-induced gas release. In a natural release, the density instability is driven by gas buildup. In a pump-induced event, the pump introduces lower-density C layer material into the NC layer. This dilutes the NC layer, which has two effects: (1) the diluted waste becomes buoyant in the NC layer and (2) large decreases in the viscosity are created. These differences in basic behavior could cause an induced GRE larger than what historically has been seen if the assumed quantity of gas is present. To avoid large induced releases,

TABLE 2-6
PUMP OPERATION PROCEDURAL SAFETY FEATURES

Systems or Conditions	Description of Safety Feature
1. Pump Assembly Restraints	The pump assembly is attached to the load distribution frame and bolted to the pump pit to prevent ejection.
2. Excessive Hydrogen Concentration in Dome	Hydrogen concentration is monitored by existing detectors. If the hydrogen level exceeds 25% of the LFL of hydrogen in a nitrous-oxide atmosphere, the pump operation will be terminated.
3. Excessive Dome Pressure	Dome pressure is monitored by existing instruments. If the dome pressure increases to a level greater than -250 Pa (-1 in. w.g.), pump operation will be terminated.
4. Foaming of Liquid Layer	Foaming is monitored by the video camera. If foaming occurs, pump operation will be terminated. Foaming also is monitored by level measurements. Experience to date indicates that pump operations do not cause excessive foaming.
5. Waste Level Too High	Waste level is detected by existing measurement devices, including radar ranging. If the waste level exceeds 10.3 m (406 in.), the pump operation will be terminated.
6. Excessive Heating of Waste	Heating of the waste is monitored by existing thermocouples. If any location in the tank exceeds 57.2°C (135°F), pump operations will be terminated.
7. Pump Flow Rates	The pump flow rate is monitored by pump outlet pressure measurements and pump rpm's. If the waste level is high, pump operation will be terminated.
8. High Pump Pressures	Pressures are monitored by pump outlet pressure measurements using mounted transducers to determine that the pressure is within the operating range and the flow is evenly distributed.
9. High Motor Speed	Motor speed is monitored by a pump speed indicator. If the motor speed limit is surpassed, pump operation will be terminated.
10. Excessive Vibration of Pump and Column	Vibration is monitored by outlet nozzle pressure and a pump accelerometer.
11. Excessive Bending or Vibration on Support Column	Support-column-mounted strain gauges and outlet nozzle pressure are used to detect any bending or vibration. Operations would be terminated if the strain gauges show that the oscillating load on the pump column exceeds the column's infinite fatigue life load.
12. Loss of Nitrogen in Support Column	Nitrogen is measured by column internal pressure.
13. Overload Electric Power	Overload electric power is prevented by circuit breakers and fuses located on pump electrical power lines.
14. Portable Exhauster	A portable exhauster is available if the primary ventilation system fails.
15. Waste Level Low	In earlier tests, if the waste detected by existing measurement devices was too low, pump operation would be terminated. This requirement later was eliminated in favor of keeping the gas inventory in the tank as low as possible.
16. Excessive Ammonia Concentration	Pump operation will be terminated if ammonia concentration is >3000 ppm.

TABLE 2-6 (CONT)
PUMP OPERATION PROCEDURAL SAFETY FEATURES

Systems or Conditions	Description of Safety Features
17. Waste Temperature Low	Waste temperature is monitored by existing thermocouples. If the average waste temperature is <110°F, pump operation will terminate.
18. Primary Ventilation Flow Rate Low or High	Pump operation will be terminated if the primary ventilation flow rate is <400 ft^3/min or >700 ft^3/min.

in the early testing we minimized the perturbations to the waste's natural state by operating the pump very cautiously.

- The effects of pump operation on long-term behavior of the waste (altered gas generation, retention and release mechanisms, modified gas composition, accelerated heating or cooling, foaming, accelerated erosion and corrosion, salt cake formation, enhancement of crust formation, etc.) are addressed in Ref. 13. Given all the uncertainties in our knowledge of the tank behavior, it is unclear whether mixer pump operation adversely would affect long-term tank behavior. Because we could not demonstrate with high confidence that the mixer pump would mitigate the episodic gas releases, the risk of possibly worsening the GRE behavior was not warranted. These long-term considerations also prompted a cautious test plan, where we minimized the perturbations to the tank's natural state.

In App. R, we provide the safety envelope developed for the earlier phase of the testing program. This discussion includes the earlier test phases (Phases A and B and full-scale testing). Considerable knowledge was gained about the mitigation capability of the pump and the possible prompt gas release behavior before the full-scale testing phase (during Phases A and B). Nevertheless, we exercised further caution during the full-scale testing phase until we could demonstrate that the waste level (and thus, the gas inventory) could be controlled by mixer pump operation.

At the end of full-scale testing, there was strong evidence that the mixer pump is capable of controlling the gas inventory in the tank and of mitigating the episodic gas releases under the present tank conditions. We obtained sufficient data to develop an induced gas release model as a function of waste level whereby some of the excessive conservatism in the earlier model was removed. As discussed in Ref. 13 and summarized in App. P, some of the long-term concerns could not be completely eliminated, whereas others (e.g., foaming and accelerated heating or cooling) were shown not to be a major concern. Primarily, we are concerned still about the magnitude of the future GREs if the tank is allowed to return to episodic gas releases. While there is no evidence that future GREs could be worse, with the current level of knowledge, we could not eliminate this possibility with high confidence. Mixer pump operation appears to have mitigated a real safety problem of episodic gas releases; therefore, slowing down or terminating these operations in favor of a postulated situation does not appear to be warranted. The tests and data for Phase A, Phase B, and full-scale testing are discussed in detail in Refs. 14 and 15.

Following full-scale testing, the safety logic changed to require that we keep the tank mitigated and the tank levels as low as possible. Keeping the waste inventory (and thus, the waste level) as low as possible by operating the pump enhances our confidence that, upon failure, the pump may be replaced successfully and mitigation may continue. Within this logic, we use the pump and the mixing concept as a method of mitigating the postulated accident where future GREs may be worse than the historical GREs. Thus, we removed the minimum waste level control, which was implemented in the earlier safety logic as partial protection from some of the long-term concerns. The safety logic and resulting envelope for long-term pump operation also are discussed in App. R.

Also, the waste properties slowly are changing with time, with or without pump operations. How pump operations interfere with the expected long-term changes in the waste properties is not fully understood. As a result, the pump may not be a viable long-term mitigation tool. For instance, the waste is expected to cool with time, independent of pump operations. In a few years, the temperature may fall below a threshold value where additional precipitation of solids or an increase in the viscosity and strength of the waste may reduce the pump's success in keeping the tank mitigated. Consequently, the tank and pump parameters must be monitored closely while evaluating the long-term trends as mitigation operations continue. Many long-term monitoring controls are included in Sec. 6 of the SA.

2.7. Mixer Pump Removal

The process of removing the mixer pump after completion of the mitigation test is similar to that followed during the installation process but in reverse order. These operations must be controlled by approved procedures that specify the requirements for (1) bonding the mixer pump and cover blocks with the waste tank, (2) attaching conductive plastic to each component removed, (3) lifting each component, (4) flushing each component for decontamination, and (5) disposing of or storing each component as appropriate. The safety features prescribed in the procedures controlling the removal of the mixer pump are similar to those controlling the pump installation and are summarized in Table 2-5.

The pump pit cover blocks will be removed to permit access to the mixer pump. Airborne contamination and radiation levels will be surveyed as the cover blocks are removed. The dose rates at ground level with the cover blocks removed range from 300 to 800 mrem/h, based on previous measurements taken with the cover blocks off. The bottom surfaces of the cover blocks are expected to be slightly contaminated. The cover blocks will be wrapped in plastic to prevent the spread of contamination.

The mixer pump will be removed from the tank using a boom crane. A load path will be established to minimize the consequences of a drop as the pump is moved over the tank. Water wands decontaminate the pump during pump removal before the pump enters the riser. The assessment of the hazards associated with installation, operation, and removal of the water wands is described in App. W. A spray ring in the tank riser flushes the external surfaces of the mixer pump before the pump is removed from the tank. Flush lines will be used to decontaminate the internal pump volume and the pump discharge legs. We estimate that the amount of water required for decontamination[16] is ~45 m^3 (8900 gal.), which includes the required flush for all exposed surface areas (including the portion of the pump assembly exposed to the vapor space of the tank). The spray ring delivers 55°C (130°F) demineralized water at a pressure of 20,684 kPa (3000 psi) and at a rate of 0.48 m^3 (120 gal.)/min. Dose rate levels will be measured as the mixer pump is raised from the riser.

The mixer pump will be drawn into a flexible receiver as it is raised from the riser. A "blast shield" is an integral part of the flexible receiver assembly that prevents the high-pressure water jets on the spray ring from damaging the plastic receiver bag. The flexible receiver is sealed against the load distribution frame and provides confinement for liquids as the pump is removed from the tank. The mixer pump and flexible receiver will be lowered into a shipping container before being transported out of the tank farm for storage before disposal.

Specific measures taken during removal of the mixer pump will minimize the potential for excessive personnel exposures or releases to the environment of radioactive or other hazardous material. These measures incorporate factors such as related weather conditions, monitoring requirements, lifting, rigging, and handling. These and other safety measures are discussed in greater detail in Sec. 6.

2.8. MPR—Description of Action

Plans exist for additional mitigation devices and instrumentation for Tank 101-SY, and currently there are insufficient access points to install all of these devices. The MPR and MPF have been designed to fit onto the existing 1.07-m (42-in.)-diam Risers 5A and 5B, respectively. The MPR already is installed and provides additional but smaller access points into the tank and facilitates the installation, operation, removal, and decontamination of these devices/instruments in the tank. As of this revision of the SA, the MPF is not yet installed.

The actions to install, operate, and remove the MPR and/or MPF from Tank 101-SY are governed by the procedures and controls contained in Sec. 6 of this SA. WHC has developed detailed operating procedures to accomplish the installation, operation, and removal of either the MPR or the MPF in accordance with this SA. Similar procedures must be developed for MPF installation, operation, and removal before installation of the MPF.

2.8.1. Effects on Tank 101-SY

Section 2.2 describes the composition of the waste inside Tank 101-SY and lists the instrumentation that currently is installed in the tank and available for monitoring tank behavior during mitigation procedures. The primary changes to this description as a result of implementing the MPR are the replacement of the cover on Riser 5A with an MPR and the replacement with an MPF of the existing TV and lights assembly in Riser 5B. The pressure-relief features of the existing cover on Riser 5A are provided by the vent doors on the MPR. A new TV camera and light assembly already is installed into the MPR.

2.8.2. MPR Design and Description

This section paraphrases the requirements contained in WHC multiport design documents to provide insight into issues that are addressed in this SA.

With the increase in mitigation and detection tools as part of the Hydrogen Mitigation Test program, the 1.07-m (42-in.)-diam risers in the Hanford waste tanks must to be used more efficiently. The addition of multiple penetrations through the available 1.07-m (42-in.)-diam risers allows a greater number and more diverse set of test probes, as well as equipment access to the tanks. The MPR or the MPF assembly replaces existing 1.07-m (42-in.)-diam riser assemblies with an assembly providing four smaller ports. Each small port can be used independently for access to Tank 101-SY with equipment and instruments as needed.

The MPR assembly is a steel fixture placed directly over a 1.07-m (42-in.)-diam riser and sealed to the existing riser flange. The assembly structurally is supported by the concrete pad around the riser. Multiple penetration ports (one 30.48-cm [12-in.]-, one 50.8-cm [20-in.]-, and two 20.32 cm [8-in.]-diam ports) provide access to the tank environment through a shielding plate. A decontamination spray system attached to each penetration port is available for the spray-washing of each test probe, each instrument, or other equipment during removal operations from the MPR. The decontamination spray system is designed such that it does not interfere with the operation of the pressure-relief function of the MPR.

The MPR assembly's three main functions are to (1) contain the vapor/gas contents of the tank under all normal operation conditions, (2) provide pressure relief in case of a burn accident, and (3) provide multiple penetration risers into Tank 101-SY. The MPF differs from the MPR in that the MPF does not provide any pressure-relief capability. Also, the MPF mounts directly to the 1.07-m (42-in.)-diam riser flange; therefore, all loads on the MPF are carried directly by the 1.07-m (42-in.)-diam riser instead of being transferred to the concrete pad around the riser.

The FDC document[17] and the final design review[18] provide a detailed description of the MPR and its functional requirements. The design includes many specific safety features, as listed in Table 2-7.[17] The MPF is similar to the MPR in that it seals to the 1.07-m (42-in.)-diam riser and provides one 30.48-cm (12-in.), one 50.8-cm (20-in.), and two 20.32 cm (8-in.) risers through the existing 1.07-m (42-in.)-diam riser. The

MPF does not include the pressure-relief panels or the load-carrying base of the MPR; therefore, the entire load of the MPF is supported by the existing 1.07-m (42-in.)-diam riser.

Because the MPF does not include pressure-relief panels and because the MPF mounts directly to the 1.07-m (42-in.)-diam riser, those items in Table 2-7 that apply to the pressure-relief panels, the supporting equipment, and the supporting structure of the MPR and the concrete pad do not apply to the MPF.

The three pressure-relief panels for the MPR are each 76.2 cm wide by 60.96 cm high (30 in. wide by 24 in. high). As specified in Ref. 17, the relief panels provide containment of the tank vapor and gas environment up to 6.0 psig, and the panels do not open below this pressure. This containment function is met for all design and environmental conditions, including earthquake, wind, ash fall, ice storms, snow storms, and sand storms.

The pressure-relief panels for the MPR provide pressure relief during a burn accident by opening to the atmosphere an area determined by the accident analysis, nominally the equivalent area of an open 1.07-m (42-in.)-diam riser. The pressure-relief panels open to full flow within 0.1 s after the pressure reaches 41.38 kPa [6.0 (±1) psig]. The pressure-relief function meets the intent of NFPA 68.

2.8.3. MPR and MPF Installation and Removal

The MPR was installed as follows.

1. The MPR is supported by three legs, each of which contain individual height-adjusting jacks. A remotely positioned mobile crane lifts the MPR from its transportation case; the operator then places the MPR over the tank surface.

2. The mobile crane moves the MPR over the surface of the tank to Riser 5A.

3. The MPR is placed over Riser 5A using the mobile crane; the unit then is lowered onto its three jacks. This operation places the MPR 2.54 cm (1 in.) above the riser flange interface.
4. The MPR jacks then are used to lower the MPR into position, compressing the closed-cell rubber foam gasket 0.3 to 0.64 cm (0.125 to 0.25 in.). This sealing gasket serves to isolate mechanically the 1.07-m (42-in.)-diam riser from combined motions of the MPR and its massive concrete support pad.

TABLE 2-7
MPR DESIGN SAFETY FEATURES

Items	Safety Classification	Safety Functions Safety Issues	Rationale/Comments
Pressure release panels and structural components that ensure proper functioning of release panels during a burn event	SC-2	Relieve tank overpressure from a burn event	Tank venting is required to mitigate pump ejection during removal/ installation. Venting does not provide much additional margin for tank structural limit during burn event; consequently, the lack of venting functionality does not compromise SC-1 tank containment system.
Pressure release panel retention features that maintain closed doors during a GRE	SC-2	Panels must not open during a GRE (without burn)	Premature vent door opening during a GRE projects an explosive mixture of hydrogen gas across tank surface in area of spark sources, creating an unacceptable hazard. This hazard may lead to a major tank burn event that endangers the tank structural integrity. Premature venting also exposes personnel to an unacceptable level of ammonia gas.
Concrete anchor, base plate, and assembly support	SC-2	Anchor assembly to concrete pads, restrain assembly from becoming missile during hydrogen burn event, isolate assembly loads from tank riser.	Support prevents assembly from becoming a missile during a hydrogen burn event. Loads transmitted to tank dome during burn event will not rupture tank liner below the waste level. Reimpaction of airborne debris will not impair tank SC-1 criteria.
Remainder of multiport assembly body	SC-3	Forms part of confinement boundary for tank and provides shielding.	The SC-2 tank ventilation system will provide adequate in-flow to prevent SC-2 (significant onsite) release should the assembly develop leakage paths. Loss of confinement or shielding presents an ALARA or SC-3 hazard.

TABLE 2-7 (CONT)
MPR DESIGN SAFETY FEATURES

Items	Safety Classification	Safety Functions Safety Issues	Rationale/Comments
Leveling jack and crank	SC-3	Aligns and temporarily supports assembly during installation to ensure that proper seal is established.	The tank ventilation system limits release of material to less than SC-2 limits if seal is not well established. However, such a release presents ALARA (SC-3) concerns.
Decontamination rings	SC-3	Provide for decontaminating equipment before removal from riser.	No SC-1 or SC-2 implications. Control is provided upstream to limit the quantity and pressure of water sprayed into the tank. The decontamination rings are ALARA (SC-3) items because they limit worker exposure when workers are maintaining or replacing equipment inserted through the MPR.
Grids around pressure release panels	SC-3	Protect tank farm workers from injury from opening pressure release panels.	Item protects facility workers from injury.
Grounding and bonding connections	SC-2	Prevent static discharges from igniting tank burp.	Radiological consequences of a burp with burn could approach 5 rem at onsite receptor location.

The soft gasket also provides added protection against a drop of the MPR, although the primary protection comes from the jacks impacting the concrete support block, not from the MPR impacting on the riser flange. These features ensure against unpredictable extraneous loads being imposed on the riser. The mobile crane then is disconnected and removed.

5. The bolts that anchor the MPR support jacks to the concrete support block are installed and torqued to the manufacturer's recommended torque values.

At this point, MPR installation is complete. Removal of the MPR reverses the preceding sequence of steps.

The MPF unit is installed and can be removed in a manner similar to the above sequence, except that the MPF is bolted directly to Riser 5B, as opposed to the support jack concept used on the MPR.

2.8.4. MPR and MPF Operation

The MPF has no active features; it provides ports for increasing the equipment access to the tank. Thus, it has no operational considerations. Operations for decommissioning this flange unit are beyond the scope of this document.

The MPR functionally is comprised of the vent door system and the decontamination spray rings for the individual riser ports. Before removing an instrument or probe from the MPR, hot-water valves will be opened to cleanse the unit. Through controls imposed in Sec. 6.0, we avoid introducing excessive water into the tank. The MPR vent door system is conceptually simple, involving door static seals and door fracture retention clips. Vent door actuation does not occur unless there is a GRE with burn. To ensure future functionality of the vent system, the doors are inspected periodically. The MPR uses two static seals to maintain the integrity of the tank confinement. The external seal is visible; periodic checks can verify that no deterioration occurs over time. The vent door FDC require that the seals be replaced once in their 20-yr life span. Controls in Sec. 6.0 provide for the necessary inspections and maintenance functions.

2.9. Principal Safety Criteria

WHC standard controls include a series of WHC documents that define the safety envelope for the tank farm. The primary document is the HASP manual;[19] other documents include the double-shell flammable gas watchlist tank safety basis document[20]and the interim safety basis document.[21]

The relevant and applicable principal safety requirements established by DOE Orders for controlling the mixer pump operations have been evaluated to determine the degree to which the proposed operations comply with the requirements (App. A). The results of this evaluation indicate that the design, operation, and removal processes meet the intent of the requirements established in the DOE Orders. The design, operation, and removal processes were reviewed against the relevant requirements of the following DOE Orders:

1. DOE Order 6430.1A, "General Design Criteria";
2. DOE Order 5400.1, "General Environmental Protection Program";
3. DOE Order 5400.5, "Radiation Protection of the Public and the Environment";
4. DOE Order 5480.4, "Environmental Protection, Safety, and Health Protection Standards";
5. DOE Order 5480.5, "Safety of Nuclear Facilities";
6. DOE Order 5480.7, "Fire Protection";
7. DOE Order 5480.10, "Contractor Industrial Hygiene Program";

8. DOE Order 5480.11, "Radiation Protection for Occupational Workers";
9. DOE Order 5700.6C, "Quality Assurance"; and
10. DOE Order 5820.2A, "Radioactive Waste Management."

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3.0. IDENTIFICATION OF HAZARDS

This section presents the results of a HazOps study[1] used to formally identify all hazards associated with the proposed action.

The primary condition of concern is the release of radioactive and toxic materials, with the direct consequence being exposure of the public sector and/or onsite personnel to unacceptable hazards. Airborne, underground, and surface release pathways are considered in the study. In addition, any structural damage of the tank that would cause major damage in the dome area or leaks in the liquid region is evaluated in lieu of analyses of the long-term radiological and toxicological releases associated with these types of tank structural damage.

The results of the HazOp analysis (described in Sec. 3.1) indicate that the potential hazards contributing to the release of radioactive and toxic materials and structural damage to the tank can be combined as follows:

1. flammable and/or toxic gas release;
2. flammable gas release with burn;
3. releases from the ventilation system, tank penetrations, and dropped components;
4. external events, e.g., flooding, fire, and seismic;
5. nuclear criticality;
6. larger-than-normal release of flammable and/or toxic gases because of pump operation; and
7. other hazards associated with pump operation.

3.1. Methodology

The hazards associated with the proposed actions were identified through a HazOps.[1] HazOp is a qualitative hazard analysis technique used to conduct a structured review of process operations; its principal purpose is to identify hazards.[2] The HazOps divides the overall process into discrete "study nodes" that may include an operational procedure (e.g., mixer pump installation) or the physical regions associated with certain process equipment (e.g., exhaust stack and gas dome). At each node, key process parameters (e.g., toxic gas concentration and hydrogen concentration) are identified, and the potential consequences from any deviation (e.g., public and worker exposure to toxic gas via stack release) are characterized. The consequences may include one or more of the hazards of concern from the study. The HazOps is documented through tables identifying the key parameters, deviations, causes, and consequences, along with other information that may be of importance for a particular application (e.g., means for detection and approaches for prevention/mitigation).

A HazOps is qualitative and deliberately does not attempt to quantify the likelihood of a contributing cause, nor does it express the potential consequences in quantitative terms. It does not provide a detailed breakdown of the contributing causes at the root-cause level unless the root cause is important in differentiating potential consequences.

Several potential hazards, including burn below the crust, burn of the crust, and burn in the liquid, were eliminated from consideration during the HazOps. A previous analysis[3] considered the possibility of a burn of gas trapped between the liquid and crust. This analysis assumed that the crust was solid and could trap gas between the liquid and the crust. Recent observations have shown that the crust is porous (not an impermeable solid); thus, trapping significant quantities of gas under the crust is not possible. A previous analysis[3] also considered the possibility of crust combustion during the burning of gas in the dome. The results showed that the crust does not sustain combustion and that the surface of the crust is charred only to a depth of 0.001 m (0.04 in.) by a burn in the dome. The analysis was based on a very conservative estimate of the organic content of the crust. Core samples[4] show that the actual organic content is much less than the sample used in the analysis. A gas burn of any substantial magnitude within the C or NC layers was not considered credible. A substantial burn requires that the gas coalesce into a large bubble. Diffusion rates are too low to account for the formation of large bubbles. We believe that the gas distribution is approximately uniform throughout the tank, so bubbles must migrate horizontally to coalesce. If the bubbles are sufficiently mobile to coalesce, they also will be rising because of their buoyancy. Large bubbles cannot form and be retained in the waste; therefore, a substantial gas burn in the waste is not considered credible.

The final result of the HazOps is a list of potential hazards and their causes, as discussed in the next section. The results are summarized in Tables 3-1 through 3-3.

3.2. Results of Mixer Pump HazOp Analysis

The original HazOp analysis[1] conducted for the proposed action in Tank 101-SY examined four processes: (1) removal of the slurry distributor from Tank 101-SY, (2) installation of the mixer pump into Tank 101-SY, (3) operation of the mixer pump, and (4) removal of the mixer pump from Tank 101-SY. The slurry distributor already has been removed from the tank. Thus, the hazards associated with slurry distributor removal no longer are addressed in the SA. The analysis does not consider the hazards associated with transportation of the contaminated pump from the tank farm or its ultimate decontamination and disposal. This activity is included in the SARs for site transportation and waste storage and handling.

TABLE 3-1
TANK 101-SY HAZARDS IDENTIFICATION FOR INSTALLATION OF MIXING PUMP

Hazard	Cause
Gas Release	• Unexpected GRE from Tank 101-SY (window burp) • Unexpected GRE from neighboring tank • Gas release induced by localized mixing during installation operations
Gas Release with Burn	• Gas release AND ignition source • Gas accumulation AND ignition source • Ignition sources - Ignition within tank · Metal-on-metal spark (pump assembly/riser contact) · Static electricity · Lightning · Instrumentation or power system cable/equipment short or failure - Ignition in HVAC system · Fan blade strikes housing · Fan overheating · Instrumentation or power system cable/equipment short or failure - Ignition in pump pit · Metal-on-metal spark (pump assembly/riser contact) · Instrumentation or power system cable/equipment short or failure - Ignition at surface · Tool drop · Vehicle/equipment impact · Vehicle/equipment operation · Instrumentation or power system cable/equipment short or failure · Lightning
Pump Ejection	• GRE with a burn
Filter System Release	• Filter train failure caused by gas release and burn
Tank Penetration	• Small parts drop • External event (earthquake) • Pump drop - Internal - External
Spill during Removal (Failure to Install)	• Spill from contaminated pump assembly after removal
Contamination from Dropped Pump (Failure to Install)	• Drop of contaminated pump assembly after removal
Flooding of Tank	• Inadvertent water addition to tank • External event (flood)
Unfiltered Release through Open Riser	• Overpressure in tank releases material through open riser - Unexpected GRE - HVAC failure - Burn or detonation • Exhaust HEPA filters failed • External event (earthquake, tornado, high wind, flooding)
Spray of Waste into Dome Region	• Splashing in C layer during pump assembly installation

TABLE 3-2
TANK 101-SY HAZARDS IDENTIFICATION FOR PUMP OPERATION

Hazard	Cause
Gas Release	• Unexpected GRE in Tank 101-SY (window burp) • Unexpected GRE in neighboring tank
Gas Release with Burn	• Gas release AND ignition source • Gas accumulation AND ignition source • Ignition sources - Ignition within tank · Metal-on-metal spark (pump assembly/riser contact) · Static electricity · Lightning · Instrumentation or power system cable/equipment short or failure - Ignition in HVAC system · Fan blade strikes housing · Fan overheating · Instrumentation or power system cable/equipment short or failure - Ignition in pump pit · Metal-on-metal spark (pump assembly/riser contact) · Instrumentation or power system cable/equipment short or failure - Ignition at surface · Tool drop · Vehicle/equipment impact · Vehicle/equipment operation · Instrumentation or power system cable/equipment short or failure · Lightning
Pump-Induced Gas Release	• Pump-induced waste chemical changes • Pump-induced waste heating • Pump-induced modified gas production • Pump-induced modified gas retention
Pump-Induced Gas Release with Burn	• See above AND ignition source
Nuclear Criticality	• Pump-induced waste densification and relocation
Filter System Release	• Filter train failure caused by hydrogen release with burn
Foaming	• Pump-induced waste foaming
Tank Penetration	• Dropped pump assembly - Support column failure - External event (earthquake) • Catastrophic failure and disassembly of pump (missiles) • Failure of discharge pipe assembly • Descaling of tank wall • Tank wall erosion resulting from jet impact • Accelerated corrosion resulting from mixer pump operation
Flooding of Tank	• Inadvertent water addition to tank • External event (flood)
Spray of Waste into Dome Region	• Discharge manifold leak
Pump-Operation-Induced Releases	• Pump control system failures • Electrical failures • Mechanical failures
Waste Spill	• Mechanical failures

TABLE 3-3
TANK 101-SY HAZARDS IDENTIFICATION FOR MIXER PUMP REMOVAL

Hazard	Cause
Gas Release	• Unexpected GRE from Tank 101-SY (window burp) • Unexpected GRE in neighboring tank • Gas release induced by localized mixing during pump removal operations
Gas Release with Burn	• Gas release AND ignition source • Gas accumulation AND ignition source • Ignition sources - Ignition within tank · Metal-on-metal spark (pump assembly/riser contact) · Static electricity · Lightning · Instrumentation or power system cable/equipment short or failure - Ignition in HVAC system · Fan blade strikes housing · Fan overheating · Instrumentation or power system cable/equipment short or failure - Ignition in pump pit · Metal-on-metal spark (pump assembly/riser contact) · Instrumentation or power system cable/equipment short or failure - Ignition at surface · Tool drop · Vehicle/equipment impact · Vehicle/equipment operation · Instrumentation or power system cable/equipment short or failure · Lightning
Pump Ejection	• GRE with a burn • Pump-induced GRE, even with a burn
Filter System Release	• Filter train failure caused by hydrogen release with burn
Tank Penetration	• Small parts drop • External event (earthquake) • Dropped pump assembly - Internal - External
Spill during Removal	• Spill from contaminated pump after removal
Contamination from Dropped Pump	• Drop of contaminated pump assembly after removal
Flooding of Tank	• Inadvertent water addition to tank • External event (flood)
Unfiltered Release from Tank through Open Riser	• Overpressure in tank releases material through open riser - Unexpected burp - HVAC failure - Burn or detonation • Exhaust HEPA filters failed • External event (earthquake, tornado, high wind, flooding)
Spray of Waste into Dome Region	• Splashing in C layer during pump assembly removal

The breakdown of the overall process into study nodes is based partly on the types of activities required to complete each of the individual processes. The additional rationale for node selection includes explicit consideration of important flow paths (such as individual release pathways to the environment) and physical tank regions (e.g., the C layer and pump pit).

Key parameters in the HazOps are those physical parameters that characterize the operations associated with individual processes. For example, key parameters for the nodes associated with the HVAC process include airflow, pressure, temperature, and relative humidity. Also included are parameters that are a measure of potential hazards, such as hydrogen concentration, toxic gas concentration, and radioactivity. The key parameters for the fluid mixing process are temperature, level, flow, pressure, and hydrogen concentration. Additional operability parameters for the mixer pump include electrical and mechanical integrity.

Tables 3-1 through 3-3 list the hazards identified in the HazOp analysis. These tables are organized according to the life-cycle phases identified above and have been grouped into hazard categories. These hazard categories are analyzed further in Secs. 4 and 5 of this report.

3.3. MPR—Identification of Hazards

3.3.1. Hazards Appraisal

This section of the SA document identifies hazards associated with installation and removal of the MPR and its pressure relief function in Tank 101-SY. The release of radioactive and toxic materials, direct radiation exposure to personnel, or structural damage to the confinement vessel during the installation or removal of the MPR (or its failure to properly function) is possible. Accident scenarios and specific events of documented concern that lead to these events are included in Sec. 3.0. Specific events of documented concern are:

- flammable and/or toxic gas release;
- flammable and/or toxic gas release with burn;
- releases from the ventilation system, tank penetrations, and/or dropped components;
- external events, e.g., flooding, fires, seismic, windstorms, and lightning; and
- direct personnel radiation exposure owing to streaming.

Hazards associated with future decontamination and transportation of the MPR upon removal of the MPR are covered by standard WHC procedures and not by this document. Also, this analysis does not address hazards associated with work-related injuries, e.g., normal industrial hazards associated with lifting heavy objects.

3.3.2. Hazards Identification

Table 3-4 identifies hazards for the MPR assembly. The first column of the table identifies the hazard of concern. The second column identifies the cause(s) of the hazard. The third column summarizes the hazards analysis performed to ensure mitigation of the issues involved. This process of hazards evaluation has lead to adaptations in the MPR design, extensive design analyses, inspection verification, and implementation of administrative controls to ensure that the SC-1 integrity of the Tank 101-SY is not compromised. These considerations are contained in Sec. 4.6; references to appropriate sections are contained in Table 3-4.

We require that only those functions essential to monitoring the behavior of Tank 101-SY are operating when the MPR installation and removal tasks are in process. All potential sources of spark generation must be effectively controlled to minimize the hazards identified in Table 3-4.

TABLE 3-4
HAZARDS IDENTIFICATION FOR INSTALLATION/REMOVAL AND FUNCTIONALITY OF THE MPR

HAZARD	CAUSE	SAFETY ANALYSIS
Flammable and/or Toxic Gas Release	Loss of tank vapor containment coupled with unexpected GRE	
	• Riser open during MPR installation or removal	• Toxicological and radiological issue mitigated by virtually no pressure difference (Sec. 4.6.3.1). Installation/removal controls in Sec. 6.0 on waste level to ensure against unexpected GRE
	• MPR door actuation by decontamination spray system	• MPR spray ring design arranged to preclude accident. WHC analysis performed on spray momenta revealed insufficient pressure force to dislodge door
	• Vent door retention failure and/or opening below pressure differential specifications, causing premature actuation	• Product testing and periodic inspection are used to ensure against vent door prematurely opening (Sec. 4.6.4.1). Sec. 6.0,Controls, requires inspection
	• Radiation or chemically damaged seals	• Seal materials selected to withstand stringent environmental conditions; materials specs contained in WHC documentation (Ref. 5, Sec. 3.2.2)
	• Vent doors open during maintenance	• Work controls imposed in Sec 6.0, to limit exposure time during MPR maintenance operations
Flammable and/or Toxic Gas Release with Burn	Hydrogen accumulation and ignition source, with effects of MPR equipment on the following:	
	• MPR ignition source at tank surface	
	• Static electricity discharge	• Properly grounded equipment (Ref. 5, Sec. 4.3.4; Sec. 6.0, Controls)
	• Mechanical impact from tools, equipment, etc.	• Use of nonsparking materials (300 SS), (Ref. 5, Sec. 2.2)
	• Lightning strike	• Electrically grounded equipment (Sec. 6.0, Controls)

TABLE 3-4 (CONT)
HAZARDS IDENTIFICATION FOR INSTALLATION/REMOVAL AND FUNCTIONALITY OF THE MPR

HAZARD	CAUSE	SAFETY ANALYSIS
Filter System Release from Ducts or HEPA Filter (not associated with burn)	• MPR drop onto HEPA filter	• Work plan control for transit of MPR over vulnerable structures (Sec. 4.6.3.3 and Sec. 6.0, Controls)
Loss of Confinement	Dome/tank liner integrity breached	
	• Dome structural integrity compromised by relative motion of MPR/concrete pad with respect to riser interface	• Structural dynamic response studies of seismic events show no loss of containment (Sec. 4.6.4.3)
	Dome/tank liner integrity breached	
	• Crane accident or crane infringement onto tank boundary	• Hazardous overloading of dome structure controlled administratively (Sec. 6.0, Controls)
	• MPR vent door fails to open	
	• Seismic event damages vent door latch mechanism	• WHC structural analysis shows hazard mitigated by design (Sec. 4.6.4.3)
	• Icing of vent door latch mechanism	• WHC structural analysis shows hazard mitigated by design (Sec. 4.6.4.3)
	• Structural failure of MPR	• WHC structural analysis shows hazard mitigated by design (Sec. 4.6.4.3)
	• Insufficient vent area	• Vent area sizing analysis shows one fully assembled MPR to be adequate (Sec. 4.4.2.2)
	• Drop of MPR onto tank riser from heights greater than several feet	• Drop of 6600-lb MPR from height greater than a few inches becomes a structural issue (Sec. 4.6.3.4). Controls, Sec. 6.0, imposes administrative controls to prevent liner damage
	• Environmentally induced strains on tank riser from massive MPR concrete pad (soil heave, thermal effects)	• WHC structural analysis shows hazard mitigated by design (Sec. 4.6.4.3)
Flooding of Tank	Uncontrolled fluid source	
	• Inadvertent or excessive operation, or failure of decontamination spray system	• Sec. 4.6.4.6; administrative controls; Sec. 6.0, Controls.
Radiation Exposure	Radiation through MPR	
	• Open riser	
	• Personnel exposure	• Sec. 4.6.4.4; Ref. 5, Sec. 5.1.4; Ref. 6 documents dose rate calculations
	• Inadequate shielding provisions	• MPR design features eliminate shine, administrative controls (Sec. 4.6.4.4, and Sec. 6.0, Controls)
	• Removal and decontamination work results in adjacent equipment becoming contaminated	• Decontamination spray confined to internal surfaces; crevices, natural entrapments eliminated. Administrative controls to ensure against personnel hazards (Sec. 6.0, Controls)
Ejection of Riser Port Assembly	Riser port ejection from unexpected gas release and/or burn event	
	• MPR restraining bolt failure	• WHC structural analysis of bolt restraint system for burn event validated design (Sec. 4.6.4.5)
	• MPR support flange failure	• WHC structural analysis of flange weldment design for burn event validated design (Sec. 4.6.4.5)
Unfiltered Release through Open Riser (not including GRE and Burn)	Vent doors open or not latched properly	
	• Unexpected vent door opening from seismic event, tornado, high winds, etc.	• WHC analysis of vent door release system for various disturbances validated design.

4.0. HAZARDS ANALYSIS

In Sec. 4.1, we develop accident sequences based on the hazards identified in Sec. 3. The methodology used to analyze these hazards is presented in Sec. 4.2. Hazards that have been identified but do not have sequences shown in the analyses are assessed in Sec. 4.3. Hazards that have sequences will be discussed in Sec. 5.

4.1. Accident Sequence Development

Accident sequences with potential consequences based on the hazards and causes identified in Sec. 3 are developed in this section.

The accident initiators were derived from the Cause columns in Tables 3-1 through 3-3. Some hazard causes were grouped and considered as single initiators. The ignition sources from Tables 3-1 through 3-3 were considered conditional events and are required for all accident sequences involving burns. Accident sequences were developed using the identified accident initiators. All accident sequences except those involving a GRE are single-initiator, single-consequence sequences. For the GRE-initiated accident sequences, there are multiple consequences; therefore, a generic event tree, as shown in Fig. 4-1, is used to develop the accident sequences. Their outcomes depend on whether (1) an ignition source is present, (2) the ventilation system is operating, and (3) the MPR panel inadvertently opens without a burn. The generic event tree is applicable to the GRE cases for all phases of the operations considered in this SA.

The results of the accident sequence development are presented in Tables 4-1 through 4-3. Each row in Tables 4-1 through 4-3 represents an accident sequence that has been evaluated. The evaluation of the accident sequences resulted in the sequences being classified as either (1) accidents that have radiological, toxicological, and structural consequences or (2) accidents that have none of these consequences. Accidents in the first category are analyzed in Sec. 5. Accidents in the second category are analyzed in Secs. 4.3 through 4.5. Appendix J provides the sources for the accident initiator and sequence frequencies used in these tables.

The frequencies listed in Tables 4-1 through 4-3 have not been determined rigorously, and estimates have been used in several cases. The use of these frequencies is limited to providing relative frequencies, which are used to compare the consequences with acceptance criteria in Sec. 5.

Several GRE-initiated accident sequences in Tables 4-1 through 4-3 reflect the variations in the conditions assumed for each analysis (i.e., analysis conditions) as part of the accident evaluation.

TABLE 4-1
ACCIDENT SEQUENCES DURING PUMP INSTALLATION

Accident Outcome	Accident Initiators	Accident Sequence/ Event Tree	Mean Frequency	Reference Section
Flammable or Toxicological Gas Release	GRE during installation window (level ≤404 in.)	GRE - no ignition source - ventilation operable - closed MPR panel - no pump ejection Fig. 4.1, Branch 3	1.5×10^{-3}/yr	5.4.2
Flammable or Toxicological Gas Release	GRE during installation window (level ≤404 in.)	GRE - no ignition source - ventilation operable - open MPR panel - no pump ejection Fig. 4.1, Branch 4	7.2×10^{-7}/yr	5.4.2
Flammable or Toxicological Gas Release	GRE during installation window (level ≤404 in.)	GRE - no ignition source - ventilation inoperable - closed MPR panel - no pump ejection Fig. 4.1, Branch 5	7.2×10^{-6}/yr	5.4.2
Flammable or Toxicological Gas Release	GRE during installation window (level ≤404 in.)	GRE - no ignition source - ventilation inoperable - open MPR panel - no pump ejection Fig. 4.1, Branch 6	3.5×10^{-9}/yr	5.4.2
Flammable Gas Release With Burn	GRE during installation window (level ≤404 in.)	GRE - ignition source - ventilation operable - no pump ejection Fig. 4.1, Branch 1	2.0×10^{-6}/yr	5.4.2
Flammable Gas Release With Burn	GRE during installation window (level ≤404 in.)	GRE - ignition source - ventilation inoperable - no pump ejection Fig. 4.1, Branch 2	9.6×10^{-10}/yr	5.4.2
Flammable Gas Release With Burn	Flammable gas accumulation in dome, riser, or ventilation duct	Flammable gas accumulation - ignition source - ventilation operable - no pump ejection	—	4.3.1
Flammable or Toxicological Gas Release	GRE in neighboring tank	- no longer considered to result in burn	2.8×10^{-4}/yr	4.3.2
Pump Ejection	GRE during installation window (level ≤404 in.)	GRE - ignition source - ventilation operable - pump ejection	2×10^{-6}/yr	5.4.3

TABLE 4-1 (CONT)
ACCIDENT SEQUENCES DURING PUMP INSTALLATION

Accident Outcome	Accident Initiators	Accident Sequence Event Tree	Mean Frequency	Reference Section
Filter System Release	Flammable gas release with burn		—	5.2.4.
Tank Penetration	- Dropped pump assembly, internal or external - Small parts drop - External events		—	4.3.4
Spill during Removal	Failure of installation	Failure of installation - Spill from contaminated pump	6.0×10^{-4}/yr	5.4.4
Contamination from Dropped Pump	Failure of installation	Failure of installation - No spill - Drop of contaminated pump	3.8×10^{-5}/yr	5.4.5
Flooding of Tank	- External event - Inadvertent water addition		—	4.3.5
Unfiltered Release through Open Riser	- Ventilation system failure - External events		7.4×10^{-6}/yr	5.4.1.
Spray of Waste into Dome	Splashing during pump installation			4.3.6

TABLE 4-2
ACCIDENT SEQUENCES DURING PUMP OPERATION

Accident Outcome	Accident Initiators	Accident Sequence Event Tree	Mean Frequency	Reference Section
Flammable or Toxicological Gas Release	GRE during pump operation (level ≤406 in.)	GRE - no ignition source - ventilation operable - closed MPR panel Fig. 4.1, Branch 3	4.2×10^{-3}/yr	5.5.1
Flammable or Toxicological Gas Release	GRE during pump operation (level ≤406 in.)	GRE - no ignition source - ventilation operable - open MPR panel Fig. 4.1 ,Branch 4	2.0×10^{-6}/yr	5.5.1

TABLE 4-2 (CONT)
ACCIDENT SEQUENCES DURING PUMP OPERATION

Accident Outcome	Accident Initiators	Accident Sequence Event Tree	Mean Frequency	Reference Section
Flammable or Toxicological Gas Release	GRE during pump operation (level ≤406 in.)	GRE - no ignition source - ventilation inoperable - closed MPR panel Fig. 4.1, Branch 5	2.0×10^{-5}/yr	5.5.1
Flammable or Toxicological Gas Release	GRE during pump operation (level ≤406 in.)	GRE - no ignition source - ventilation inoperable - open MPR panel Fig. 4.1, Branch 6	9.7×10^{-9}/yr	5.5.1
Flammable Gas Release with Burn	GRE during pump operation (level ≤406 in.)	GRE - ignition source - ventilation operable Fig. 4.1, Branch 1	5.5×10^{-6}/yr	5.5.1
Flammable Gas Release with Burn	GRE during pump operation (level ≤406 in.)	GRE - ignition source - ventilation inoperable Fig. 4.1, Branch 2	2.6×10^{-8}/yr	5.5.1
Flammable or Toxicological Gas Release	GRE during dome intrusion	GRE - no ignition source - ventilation operable - closed MPR panel Fig. 4.1, Branch 3	1.0×10^{-3}/yr	5.5.2
Flammable or Toxicological Gas Release	GRE during dome intrusion	GRE - no ignition source - ventilation operable - open MPR panel Fig. 4.1, Branch 4	4.8×10^{-7}/yr	5.5.2
Flammable or Toxicological Gas Release	GRE during dome intrusion	GRE - no ignition source - ventilation inoperable - closed MPR panel Fig. 4.1, Branch 5	4.8×10^{-6}/yr	5.5.2
Flammable or Toxicological Gas Release	GRE during dome intrusion	GRE - no ignition source - ventilation inoperable - closed MPR panel Fig. 4.1, Branch 6	2.3×10^{-9}/yr	5.5.2
Flammable Gas Release with Burn	GRE during dome intrusion	GRE - ignition source - ventilation operable Fig. 4.1, Branch 1	1.3×10^{-6}/yr	5.5.2

TABLE 4-2 (CONT)
ACCIDENT SEQUENCES DURING PUMP OPERATION

Accident Outcome	Accident Initiators	Accident Sequence Event Tree	Mean Frequency	Reference Section
Flammable Gas Release with Burn	GRE during dome intrusion	GRE - ignition source - ventilation inoperable Fig. 4.1, Branch 2	6.2×10^{-9}/yr	5.5.2
Flammable Release with Burn	Flammable gas accumulation in dome, riser, or ventilation duct	Flammable gas accumulation - ignition source - ventilation operable - MPR closed or open		4.4.1
Flammable Release with Burn	Flammable gas accumulation in pump pit	Flammable gas accumulation - ignition source	—	4.4.12
Flammable or Toxicological Gas Release	GRE in neighboring tank	- No longer considered to result in burn	2.5/yr	4.4.2
Nuclear Criticality	Pump-induced waste densification and relocation			4.4.3
Filter System Release	Flammable gas release with burn		—	5.2.4.
Foaming	Pump-induced waste foaming			4.4.5
Tank Penetration	- Dropped pump assembly • support column failure • external event • failure of pump discharge pipes • pump - Disassembly - Missiles			4.4.6
Flooding of Tank	- External event - Inadvertent water addition to tank			4.4.7
Spray of Waste into Dome Region	Discharge manifold break			4.4.8
Pump-Operation-Induced Releases	- Pump control system failures - Electrical failures - Mechanical failures		5.0E-3 /yr	4.4.9

TABLE 4-2 (CONT)
ACCIDENT SEQUENCES DURING PUMP OPERATION

Accident Outcome	Accident Initiators	Accident Sequence Event Tree	Mean Frequency	Reference Section
Waste Spill through Auxiliary Piping	- Mechanical failures -Leak in pump discharge pressure measuring system			4.4.10 and 5.5.3
Waste Spill through Vibrator	Mechanical failures			4.4.11

TABLE 4-3
ACCIDENT SEQUENCES DURING PUMP REMOVAL

Accident Outcome	Accident Initiators	Accident Sequence/ Event Tree	Mean Frequency	Reference Section
Flammable or Toxicological Gas Release	GRE during removal window (level ≤404 in.)	GRE - no ignition source - ventilation operable - closed MPR panel - no pump ejection Fig. 4.1, Branch 3	1.5×10^{-3}/yr	5.6.2
Flammable or Toxicological Gas Release	GRE during removal window (level ≤404 in.)	GRE - no ignition source - ventilation operable - open MPR panel - no pump ejection Fig. 4.1, Branch 4	7.2×10^{-7}/yr	5.6.2
Flammable or Toxicological Gas Release	GRE during removal window (level ≤404 in.)	GRE - no ignition source - ventilation inoperable - closed MPR panel - no pump ejection Fig. 4.1, Branch 5	1.5×10^{-3}/yr	5.6.2
Flammable or Toxicological Gas Release	GRE during removal window (level ≤404 in.)	GRE - no ignition source - ventilation inoperable - open MPR panel - no pump ejection Fig. 4.1, Branch 6	7.2×10^{-7}/yr	5.6.2
Flammable Gas Release with Burn	GRE during removal window (level ≤404 in.)	GRE - ignition source - ventilation operable - no pump ejection Fig. 4.1, Branch 1	2.0×10^{-6}/yr	5.6.2

TABLE 4-3 (CONT)
ACCIDENT SEQUENCES DURING PUMP REMOVAL

Accident Outcome	Accident Initiators	Accident Sequence/ Event Tree	Mean Frequency	Reference Section
Flammable Gas Release with Burn	GRE during removal window (level ≤404 in.)	GRE - ignition source - ventilation inoperable - no pump ejection Fig. 4.1, Branch 2	2.0×10^{-6}/yr	5.6.2
Flammable Gas Release with Burn	Flammable gas accumulation in dome, riser, or ventilation duct	Flammable gas accumulation - ignition source - ventilation inoperable - no pump ejection		4.5.1
Flammable or Toxicological Gas Release	GRE in neighboring tank	- no longer considered to result in burn	2.8×10^{-4}/yr	4.5.2
Pump Ejection	GRE during removal window (level ≤404 in.)	GRE - ignition source - ventilation inoperable - pump ejection	2×10^{-6}/yr	5.6.3
Filter System Release	Filter train failure caused by gas release with burn		—	5.2.4.
Tank Penetration	- Dropped pump assembly, internal or external - Small parts drop - External events			4.5.4
Spill during Removal	Spill from contaminated pump		6.0E-4/yr	5.6.4.
Contamination from Dropped Pump	Drop of contaminated pump		3.8E-5/yr	5.4.4
Flooding of Tank	- External event - Inadvertent water addition to tank			4.5.5
Unfiltered Release through Open Riser	- Loss of negative tank pressure - External events		0.125/yr	5.6.1
Spray of Waste into Dome Region	Splashing in C layer during pump installation			4.5.6

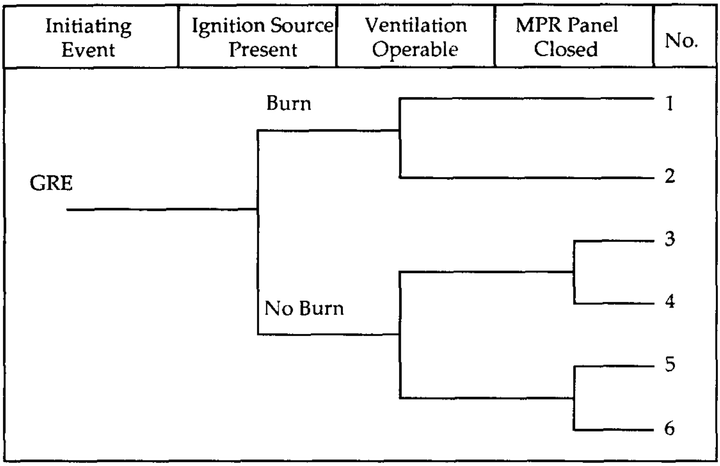

Fig. 4-1. Generic event tree for GRE accidents.

Similarly, these accidents are modified to reflect the difference in the assumptions for the volume of gas released to the tank dome space during an episodic event. These assumptions are discussed in Sec. 4.2. The Event Tree column of Tables 4-1 through 4-3 includes assumptions about the ventilation system and whether a burn occurs.

The level of detail used in analyzing the accident sequences was a function of the frequency of the initiator, the frequency of the different accident sequences resulting from an initiator, and the potential consequences. Initiating event frequencies and event-tree branch-point split fractions often are difficult to assess and require subjective opinion if actual operational data are unavailable. Some frequencies were developed in this SA using UORs obtained from WHC to derive estimates based on actual operating experience. In addition, other WHC SAs and SARs were used to obtain estimates as needed.

Each accident initiator identified for pump installation, operation, and removal was screened before detailed analyses were completed. This results in screening out all external event-related accidents associated with installation and removal activities because the exposure time during these periods is ~8 h/yr (0.001 yr/yr). When combined with the frequency of the external events, the frequencies are $<10^{-6}$/yr.

4.2. Accident Analysis Methodology

The methodology used to evaluate the accident sequences that have consequences reportable in Sec. 5 is discussed here.

4.2.1. Flammable or Toxic Gas Release

A release of flammable gas that exceeds the LFL could occur while many of the actions required to conduct the mixer pump mitigation test are being performed. Although each of these actions is evaluated fully in the SA, the processes and mechanisms resulting in the generation and subsequent episodic release of gas are not completely understood. Therefore, a conservative approach has been adopted for defining the safety analyses included in this SA and for defining the input parameters for actions that may produce a postulated gas release and/or the potential for an ignition source. Data were used to determine the maximum gas release as a result of a naturally occurring GRE. The gas release for all other GREs was determined from an empirical model described in App. C.

In developing the analysis methodology, several factors were considered: (1) the phenomena to be modeled, (2) the complexity of data transfer between codes or models, and (3) the accuracy in the results that could be achieved. For the postulated GREs with no combustion (no ignition source), we assumed that the gas from a release event went into the dome space and was released to the atmosphere through available leakage paths. For the postulated burn events, an ignition source was assumed to exist at the time when the released gas had mixed with the air to form a worst-case combustion event. Tank 101-SY has a ventilation system that affects the amount of mixing and limits the flammable gas concentration in the dome space. The operation and capacity of the ventilation system and its connection to Tanks 102- and 103-SY were considered in the analysis.

The GRE analysis methodology (Fig. 4-2) consists of

- using the gas release model in App. C to determine the maximum gas released and adjusting for the particular accident conditions;
- using HMS/TRAC to model the dome-space mixing, including the ventilation system;
- analyzing a dome-space combustion if required, including its effects on the ventilation system and the other two tanks;
- calculating the resulting radioactivity and toxic gas concentrations in the dome-space atmosphere;
- calculating the release of dome-space gas to the atmosphere through tank out-leakage and the ventilation system;

- using the AI-RISK results with the HMS/TRAC results to calculate the radiological doses and toxic gas concentrations, both onsite and at the Site boundaries; and
- using ABAQUS with the HMS/TRAC dome pressure boundary conditions to determine the structural effects on Tank 101-SY, including whether the tank fails as a result of the burn.

Four major computer codes are used to perform these analyses: (1) HMS,[1] which is linked to (2) TRAC[2] and (3) AI-RISK[3] for the dispersion and dose analysis, and (4) ABAQUS[4] (used to analyze the structural response). These codes are described in Apps. D, K, and G. The injection and mixing of the release gas within the dome-space atmosphere is modeled in the HMS/TRAC analysis. If combustion could to occur, the calculation is performed for the period when a maximum flammable gas inventory is reached. The radioactivity source term in the dome-space atmosphere considers the convective entrainment of waste particles from the surface. In analyzing leakage to the atmosphere, four paths were considered: (1) leakage through tank penetrations that are inlets under normal conditions, (2) flow through the ventilation system with a HEPA filter (assumed to have failed during the combustion cases), (3) releases from any potential failures in risers or in the tank itself and from risers that could be open during the window activities, and (4) an inadvertently opened MPR panel (without a burn). The release of radionuclides to the atmosphere was determined with HMS by integrating the mass flow rate leaving the tank, as determined by TRAC. AI-RISK combines the calculated atmospheric release and a dispersion model combined with the Hanford Site meteorology to predict onsite doses for the closest facilities and offsite doses at the Site boundaries.

4.2.2. Drops and Spills

The methodology used to compute the consequences of drops and spills consists of computing the source term, estimating a release fraction, and then computing the consequences using the unit release quantities shown in App. G.

4.2.3. Pump Ejection

A pump ejection accident could occur during the installation and/or removal of the pump assembly. This accident is possible only when a GRE with a burn occurs because the pressure rise in the dome in a GRE is not sufficient to elevate the pump column. The analysis method considered pump motion caused by the burn pressure in the dome. The ejection accidents are discussed in App. M. The acceptance criterion for a GRE with burn during pump installation and removal is set such that the maximum allowable release, if ignited, does not result in upward pump motion as a result of pressure forces exceeding the pump weight.

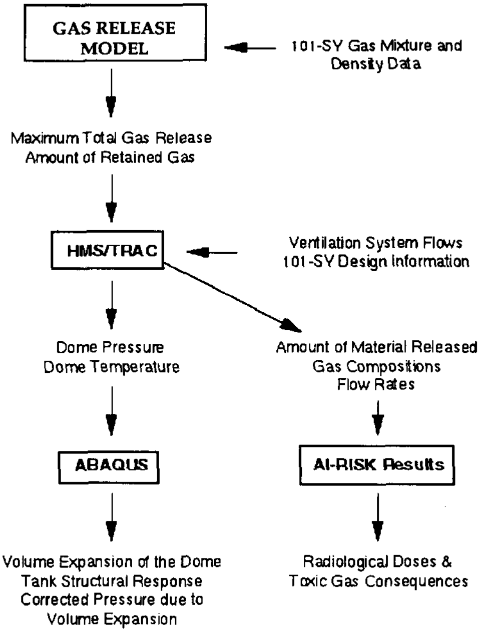

Fig. 4-2. Analysis methodology.

4.3. Accident Assessment—Pump Installation Accidents

In Sec. 4.1, accident sequences were developed for all accident initiators identified from the HazOp analysis. In Sec. 4.2, the methodology for analyzing the accidents was presented. All accident sequences developed in Table 4-1 (Accident Sequences during Pump Installation) have been analyzed; the analysis results discussed in this section are for those consequences having no radiological, toxicological, or unacceptable structural consequences. The analysis of accident sequences with radiological, toxicological, or structural consequences is discussed in Sec. 5.

4.3.1. Flammable Gas Release with Burn (Flammable Gas Accumulation)

This case considers a condition where flammable gas accumulates in a pocket and is ignited by a source present at that location. The main concern is that a stagnant pocket can exist for a long time, thus increasing the likelihood that if a random spark source were to occur there would be a combustible quantity of flammable gas at that location, which would cause a deflagration. We considered three conditions to determine if a pocket is hazardous. First, there could be an accumulation in an area because of the unique geometry such that the area is not ventilated by normal ventilation flow. Second, pockets could accumulate if the normal ventilation flow is lost. Third, a pocket could have unique features that make a burn at that location potentially more hazardous than flammable gas accumulation in the tank and a burn. We considered accumulations in the risers, pump pit, and ventilation system.

During pump installation or removal, the pump pit is open, and accumulation cannot occur in the pump pit. Controls are established for the minimum ventilation flow for operations when the tank is open. If ventilation flow is lost, all operations will stop so that possible spark sources associated with work in progress will be minimized. The auxiliary ventilation fan will be started, and other corrective action will be taken to restore full ventilation flow. If the riser is open, it will be closed. If the equipment being removed or installed is suspended from a crane and ventilation cannot be restored quickly, the equipment will be placed in the safest condition by either reinstalling the item or completing the removal operation. However, during pump removal, the ventilation system intentionally may be turned off to prevent the excessive contamination of the system as a result of entrained droplets. The ventilation system will be started quickly if excessive ammonia or hydrogen concentration is detected in the dome space.

We concluded that additional risk associated with accumulations of pockets of flammable gas during installation and removal operations is minimized by the controls that are in place for these operations and that the hazards are bounded by the analyses for burns during installation and removal operations discussed in Secs. 5.4 and 5.6.

4.3.2. Flammable or Toxic Gas Release with or without Burn (GRE in the Neighboring Tank)

The SY Tank Farm consists of three separate tanks (101-, 102-, and 103-SY) connected by a common ventilation system. Most of the accidents identified in this SA are restricted to Tank 101-SY. The neighboring tank GRE analyses consider the possibility of accidents that are initiated or are in combination with accidents in the other two tanks in the SY Tank Farm. Tank 102-SY has been monitored previously, and there is no indication that it exhibits periodic releases. However, Tank 103-SY does have indications of gas releases. A potential concern is that Tank 103-SY could affect the accidents being analyzed for Tank 101-SY. This section investigates the potential for Tank 103-SY to affect accidents being postulated for pump installation in Tank 101-SY or to provide an initiator for accidents.

Tank 103-SY has been identified as the second tank in the SY Tank Farm that has demonstrated evidence of crust drops, indicating possible gas releases. It also is believed that organic material was part of the waste originally stored in the tank. Organic material has been identified as a leading contributor to, or an important part of, generation and storage of flammable gas in a tank. On this basis, Tanks 101- and 103-SY are the only tanks in the tank farm that can release large qualities of flammable gas. The information obtained from Tank 103-SY indicates that crust drops are between 1.78 and 5.84 cm (0.7 and 2.3 in.); 10 GREs occurred between March 27, 1989, and January 20, 1992.[5] The differences in the Tank 101-SY vs Tank 103-SY GREs are that (1) events are smaller in magnitude [5.1 cm (2-in.) maximum crust drop in Tank 103-SY vs ~25.4 cm (10-in.) drops in Tank 101-SY); (2) Tank 103-SY has more free volume in the dome space [the waste height is ~10.16 m (400 in.) in Tank 101-SY and is ~6.86 m (270 in.) in Tank 103-SY]; (3) Tank 103-SY events do not correlate well with tank pressure rise and waste temperature changes to strongly suggest a rollover event; and (4) events appear to occur in a cycle of two GREs ~120 d apart, followed by one gas release in ~80 d. The largest GRE, which had a crust drop of 5.84 cm (2.3 in.), only produced a 6.4-mm (0.25-in.)-w.g. pressure change. Two of the largest GREs occurred in October 1990 and January 1992, with estimated gas releases of 65.1 and 79.3 m^3 (2300 and 2800 ft^3) (as calculated by the FATHOMS code). If we assume that the gas composition is the same as in Tank 101-SY and that a release of 79.3 m^3 (2800 ft^3) occurs, the calculated peak hydrogen concentration is 0.06%.[5–6] The LFL for the Tank 101-SY release gas mixture is 3.5% (see App. B); therefore, the peak hydrogen concentration is ~7% of the DOE limit of 25% of the LFL and provides a margin to account for any data uncertainties.

Mixer pump installation can have three possible effects: providing an initiation source for a burn in Tank 101-SY, providing a source for additional flammable gas in Tank 101-SY, and changing the pressure or ventilation system flow to Tank 101-SY. Four observations from the discussions of gas releases support the conclusion that Tank 103-SY should not affect the pump installation.

1. The largest GRE to date did not exceed 25% of the LFL and therefore would not be an ignition source.
2. Even if there were simultaneous gas releases in Tanks 101- and 103-SY, the effect on pump installation would be small because the Tank 103-SY concentration is far below the LFL, and there is little pressurization from a gas release.
3. The probability for simultaneous gas releases is small.
4. The ventilation system flow rate and pressure in Tank 101-SY would not be affected because the pressurization in Tank 103-SY during a gas release is small.

Pump installation will occur immediately after removal of the current mixer pump; therefore, because the tank has been mitigated for an extended period of time and the level has been maintained at ~10.16 m (400 in.), the chances of a natural or a pump-induced GRE are greatly reduced. Using the above information, we calculated the frequency for a gas release in Tank 103-SY to be ~3.4/yr. The probability of having a combined GRE in both tanks is <2.4E-5 without a burn and ~2.4E-8 with a burn. The accident with a burn is of concern because without the burn there would be very small effects. The Tank 103-SY gas release does not pressurize or release a large gas volume that could affect Tank 101-SY.

4.3.3. Filter System Release

The filter system release accident sequence is assumed to be caused by a gas release with a burn that could occur during the pump installation operation. No other accident initiators are considered because these additional initiators are considered part of normal tank farm operations. As described in Ref. 7, the primary ventilation system removes vapors from the primary tank and maintains a negative internal tank pressure relative to atmospheric pressure. Above-ground piping in the SY Tank Farm connects one primary riser from each tank to the tank farm's primary exhaust system. The primary exhaust system in the SY Tank Farm consists of a moisture separator (deentrainer), a heater to prevent condensation on the filters, a bank of HEPA filters, and a fan. Radionuclide collection on the HEPA filters creates a radiation field in the vicinity of the filter bank. As described in Ref. 7, administrative controls prevent this field from exceeding 200 mrem/h.

The radiological consequences of filter system release are discussed in Sec. 5.2.4.

4.3.4. Tank Penetration

The accident sequences associated with the pump installation discussed in Sec. 4.1 were evaluated using deterministic methods and resulted neither in tank penetration below the level of the waste nor penetration of the dome region.

The capacities of the pump structure, the 1.07-m (42-in.) riser, tank bottom, tank wall, tank dome, and pump pit were computed (see Apps. L and N). The drop loads of the pump with the shock absorber installed were compared with these capacities and found to be within the limits of the structures, provided that the controls for the pump lifting heights were maintained (see Sec. 6 and App. L). The seismic and rollover loads on the pump structure were computed and found to be within the capacity of the pump (see App. N). The misalignment loads associated with pump installation and removal were computed and compared with the riser capacity, and lifting limits were developed to prevent damage to the riser (see Sec. 6 and App. L). The structural loading associated with a burn in the tank was computed for pump operation (see Sec. 5.3.2 and App. K). These burn loads bound the maximum loading that could occur during pump installation. We found that the tank's structural integrity was maintained both below the level of the waste and in the dome region.

We concluded that tank-penetration accident sequences during pump installation do not warrant further analysis.

4.3.5. Flooding the Tank

In Ref. 8, flooding of the 200-West Area (the location for Tank 101-SY) was examined. Probable maximum floods on streams and rivers, surge and seiche flooding, flooding resulting from ice dams and tsunamis, and flooding resulting from dam failures were examined. The worst-case flood was found to be caused by a hypothetical direct-hit detonation of a nuclear warhead on Grand Coulee Dam. In this case, we concluded that the elevation of the floodwaters [~140.2 m (460 ft)] would be well below the elevation of the 200-West Area [~213.4 m (700 ft)]. As a result, we eliminated flooding as an external initiating event.

Inadvertent excessive water addition to the tank during washing operations is a possible accident initiator that could lead to a loss of waste from the tank. In Ref. 9, the safety issues associated with the addition of water to Tank 101-SY, including the hydrostatic, chemical, and physical effects, were addressed. Several operations require the addition of water to the tank to flush and decontaminate the mixer pump. To ensure that excessive water will not be added to the tank, controls in Sec. 6 require monitoring of water addition and limitations on the amount of water that can be added to the tank.

We concluded that external events leading to flooding of the tank can be eliminated from further consideration and that adequate controls will be established to monitor and limit water addition to the tank that is required for flushing and decontamination of equipment.

Water lancing may be required for pump installation. The hazards and controls are evaluated in Apps. U and V. However, if the pump were removed immediately after installation, pump decontamination also would be required. If water addition were required, the amount of water added would be limited to the quantity specified in Sec. 6.

4.3.6. Spray of Waste into Dome Region

This accident sequence assumes that waste could be sprayed in the dome region of the tank during pump installation. In Sec. 5.6.4, a spill of waste external to the tank is discussed.

No mechanism has been identified that would cause a spray of waste into the dome region during pump installation that would be larger than the spill discussed in Sec. 5. We reasoned that the consequences of a spill inside the tank would be several orders of magnitude lower than the consequences of a spill external to the tank. We concluded that no further analysis of the spray of waste into the dome region during pump installation is warranted.

4.4. Accident Assessment—Pump Operation Accidents

In Sec. 4.1, accident sequences were developed for all accident initiators identified as a result of the HazOp analysis. In Sec. 4.2, the methodology for analyzing the accidents was presented. All accident sequences developed in Sec. 4.1, Table 4-2 (Accident Sequences during Pump Operation) have been analyzed; the analysis results discussed in this section are for those sequences having no radiological, toxicological, or unacceptable structural consequences. The analysis results of accident sequences with radiological, toxicological, or structural consequences are discussed in Sec. 5.

4.4.1. Flammable Gas Release with Burn (Flammable Gas Accumulation)—Flammable Gas Leak into the Pump Motor or Support Column

The area between the pump and the column consists of (1) a short pipe 76.2 cm (30 in.) in diameter and (2) a conical section between the 40.6-cm (16-in.) and 76.2-cm (30-in.) pipes. The 76.2-cm (30-in.) pipe, which contains the electrical connections between the cable and the pump, connects to the pump with a flanged and gasketed joint. Because of the radiation and vibration environment in which these flange gaskets are operating, the possibility and consequences of leakage were examined. Leakage here seems possible, and because uninsulated electrical connections exist in this area, a burn was considered. A burn in this area and the structural effects were analyzed in App. N. We determined that the burn would be contained and that the pump column would remain intact.

Flammable gas leakage into the motor has been examined. The motor is filled with oil and has two shaft seals. The space between the seals is filled with oil supplied by a pipe from a 0.07-m^3 (18-gal.) oil reservoir. A moisture detector in the pump motor and two temperature detectors near the upper bearing will detect a loss of oil or accumulation of waste in the motor area before bearing failure or deflagration occurs. A burn in the motor volume was analyzed; we do not expect the burn to cause structural damage, but we expect it to render the pump inoperative because of fire damage.

An additional postulated scenario is that flammable gas could accumulate in the pump casing and leak past the seals into the motor housing. The pump and motor housings actually are separate in the vicinity of the shaft, and the shaft passes through an intervening space that contains waste. Thus, any gas accumulating in the pump and leaking past the seals would return to the waste. Therefore, we consider accumulation of flammable gas in the motor housing from this source impossible.

4.4.2. Flammable or Toxic Gas Release with or without Burn (GRE in the Neighboring Tank)

As discussed in Sec. 4.3.2, the gas releases from Tank 103-SY do not pressurize the dome and are not large enough to affect Tank 101-SY.

4.4.3. Criticality

The conditions necessary for criticality are summarized in App. I. Based on a calculated total ^{239}Pu inventory of 910 g, which was based on core sample data, and using highly conservative assumptions of a ^{239}Pu-water solution, we found that the inventory would need to be concentrated 16,000 times before a critical configuration could be obtained. There is no conceivable physical or chemical process that could cause the total ^{239}Pu inventory to be so concentrated. We performed a more realistic calculation with a ^{239}Pu-sludge mixture and we found that no amount of concentration of the ^{239}Pu inventory could cause criticality. Based on these analyses, we concluded that the ^{239}Pu inventory in Tank 101-SY does not present a criticality hazard under any conceivable condition.

4.4.4. Filter System Release

We assumed that the filter system release accident sequence is caused by a GRE with a burn that is postulated to occur during pump operation. No other accident initiators are considered because these additional initiators are considered part of normal tank farm operations. This is the same accident sequence discussed in more detail in Sec. 4.3.3.

4.4.5. Foaming

Because foaming was observed in simulated waste studies, previous assessments of long-term effects considered the possibility of foaming as a result of both induced rollovers and continuous pump operation. However, no foaming ever was observed in the tank or during natural rollovers. Phase B testing induced several rollovers during which no foaming was observed, even under periods of extended pump operation at the maximum allowable speed. Based on the observed tank behavior, foaming is not considered a safety problem.

4.4.6. Tank Penetration

The accident sequences associated with the pump operation discussed in Sec. 4.1 were evaluated by deterministic methods and found to result neither in tank penetration below the level of the waste nor penetration of the dome region.

The seismic and rollover loads on the pump structure were computed and found to be within the capacity of the pump (see App. N). Loads associated with missiles from a breakup of the pump assembly were computed and found to be below the tank bottom and side wall capacities (see App. N). A postulated burn in the pump support column was computed and found not to result in failure in the pump support column (see App. N). The structural loading associated with a burn in the tank was computed for pump operation (see Sec. 5.3.2 and App. K). These burn loads bound the maximum loading that could occur during pump operation, provided that the test operation is limited to limit the maximum allowable release (see Sec. 6). We found that the tank structural integrity is maintained both below the level of the waste and in the dome region.

Additional modes of tank penetration are discussed in the following subsections: Sec. 4.4.6.1 (erosion/corrosion), Sec. 4.4.6.2 (wall descaling), Sec. 4.4.6.3 (jet impingement), and Sec. 4.4.6.4 (detonation).

We concluded that tank penetration accident sequences during pump operation do not warrant further analysis.

4.4.6.1. Erosion/Corrosion. Testing conducted at PNL evaluated the potential for erosion/corrosion in other DSTs as part of the Hanford DST Retrieval Technology program. In tests using two different simulated wastes, carbon-steel coupons were exposed to impinging jets of the simulants over a range of temperatures [82 to 103°C (180 to 217°F)] and fluid jet velocities [0 to 16.76 m/s (0 to ~55 ft/s) for the NCRW simulant test and 0 to 4.57 m/s (0 to 15/ft/s) for the NCAW simulant test]. These tests and their results are described in detail in Ref. 10.

In general, accelerated weight loss of carbon steel was observed in either case for coupons exposed to the fluid jets as compared with control coupons exposed to the same fluids and temperatures but under quiescent conditions. The increase was attributed to increased mass transport because when the coupon's surfaces were examined after testing, it was apparent that the surfaces of the coupons had not been worn away by an abrasive fluid. Rather, the weight loss appeared to be solely a result of typical aqueous corrosion of the carbon steel. This was evidenced by scratches on the surfaces of the coupons created by the original surface finishing that was not eroded away but preserved in the surface oxide layers after the tests.

"Miller tests" for flurry abrasivity[11] performed on the simulants (slurries) also confirmed that the waste simulants tested should not be abrasive compared with other typical slurries (i.e., sand/water, limestone/water, and bauxite/water). This low abrasivity probably can be attributed to very fine particle sizes of the solids in the simulants (and in most cases, the actual DST wastes). This is significant because if the solids in Tank 101-SY also are very small, the Tank 101-SY slurry probably will not be abrasive at similar jet impingement velocities. In that case, typical aqueous corrosion of the carbon steel likely will be controlling and probably would be accelerated to some degree because of the greater mass transport occurring with the moving fluid, as was seen in the erosion-corrosion studies.

One of the two simulants tested was a simulated NCRW, and the other was a simulated NCAW. However, they were similar in that they had relatively high concentrations of NaOH to match the caustic solution, which purposely was added to the wastes for corrosion control in the carbon-steel tanks. Therefore, if corrosion of the 101-SY steel tank containing complexant concentrate waste were inhibited in a similar manner by the addition of a caustic solution (pH ~12 to 13), similar slightly accelerated corrosion of the carbon steel likely would occur as a function of increased mass transport from mixer pump action.

Quiescent corrosion rates observed on the control coupons in the NCRW and NCAW tests were ~7.6 μm/yr (0.3 mil/yr). Corrosion rates measured for the impingement coupons ranged from 25.4 to 101.6 μm/yr (1 to 4 mil/yr). If we assume (1) a similar result with the Tank 101-SY waste, (2) that the mixer pump will be operated such that the velocities at the tank wall are much lower than the maximum tested, and (3) that the pump will be operated only intermittently to limit energy addition to the tank, then accelerated corrosion of the tank wall should be minimal.

4.4.6.2. Descaling the Walls. If the tank's inner wall has an incipient leak or if a leak has gone undetected in the past and has resealed with saltcake, pumping the waste could initiate a leak by descaling the walls. There is no indication that these conditions exist; however, the condition of the tank walls is not well characterized.

To reduce the possibility of initiating a leak as a result of pump operation, initial pump operation was limited to minimize the velocity at the walls. After nearly 2 yr of testing, occasionally at pump speeds as high as 1000 rpm, there is no indication that the pump jets are descaling the wall and causing a leak in the primary liner.

After more than 100 h of pump operation, transient temperature data indicate that the bottom 0.3 m (1 ft) of sludge does not appear to be disturbed at the MIT locations.[12]

4.4.6.3. Jet Impingement. If we assume that the jet from the pump nozzles will behave like a fully turbulent buoyant jet, the resulting impact velocities on the wall will be small. The conservative maximum magnitude for the impingement velocity is ~1.83 m/s (6 ft/s), which results in an impingement pressure of 2760 Pa (0.4 psi). However, this estimate ignores the finite yield strength and the non-Newtonian nature of the fluid. The worst-case scenario is that the jet forms a channel in the sludge where the size of the channel is determined by the yield strength of the sludge. In the case of such channeling behavior, the jet impingement velocity may be as high as 18.3 m/s (60 ft/s). This magnitude corresponds to an impingement pressure of 152 kPa (22.0 psi) acting over a circular area 8.13 cm (3.2 in.) in diameter. The resulting stresses are very small compared with the yield strength of the tank wall, which is 240 MPa (35,000 psi). Thus, the impingement is not a safety concern in the wall failure. Because the pump has been installed and operated for nearly 2 yr, the tank temperature profiles show that the tank is well mixed by pump operation; therefore, the turbulent jet is the best model of jet behavior under the current mixed conditions.

4.4.6.4. Evaluation of Detonation. Based on work performed at SNL, we have quantified the relative risk of a DDT. Details are reported in App. E. The SNL methodology found two parameters to predict the likelihood of DDT. First, the closer a hydrogen-air mixture was to stoichiometric, the more likely that a DDT could occur. SNL listed five categories for mixtures related to equivalence ratios. The second key parameter was the geometry. SNL found that confined geometries with obstacles promoted flame acceleration and DDT; thus, they developed five classes for the geometric effects. The equivalence ratio can be calculated quantitatively, but the geometric effects are subjective. Based on these two parameters, SNL developed a matrix of the likelihood of DDT, as discussed in App. E.

We calculated the equivalence ratios of the hydrogen, nitrous oxide, and oxygen for the worst locations in the Tank 101-SY dome and for the connection to the ventilation system.

We found that there were no mixture class 1 concentrations for the 296.77-m^3 (10,480-ft^3) release and that the total volume of mixture classes 2+3 was <3%. This small percentage justifies the assumption that the volume is open and unrestricted and therefore is the least likely geometry class. This assumption yields a DDT probability of highly unlikely to impossible.

For the 370.96-m^3 (13,100-ft^3) release at the point where $H_2/N_2O/N_2$ is injected into the dome space, we calculated that the mixture is in the most sensitive category for a short period of time; however, we found that the percentage of the dome volume that had this sensitive mixture was a small fraction of the total dome volume (1.5%). From this small percentage, we concluded that the geometry is open and unconfined and therefore is in the least sensitive geometry class with the lowest potential for DDT. Using the Table E-2 results and considering the SNL experiments and the fact that the equivalence ratio is just over the threshold of mixture class 1, we judge the probability of DDT as possible but unlikely.

The ventilation system components (both the inlet filter ventilation stack and the exhaust ductwork) were examined because they are considered confined geometries and were judged to be class 2. An analysis of the equivalence ratio shows that the ventilation system is never below mixture class 5. With a class 2 geometry, the ventilation system has a results class 4, which characterizes the DDT probability as possible but unlikely.

In the SNL studies, experimental data were obtained for H_2/air mixtures. In our system with $H_2/air/N_2O$, the equivalence ratios developed for H_2/air mixtures are not expected to be directly applicable, although the geometry classes are applicable. In the tank dome during a 371-m^3 (13,100-ft^3) GRE, the gas concentration in the computational cell where the gas is released reaches 29%. Even though the equivalence ratios are not directly applicable, this gas concentration in a nitrous-oxide environment is considered a sensitive mixture. In the ventilation system, the hydrogen concentration reaches 10%. There is no dilution of this value in the ventilation system from the other tanks because the gas release pressurizes the ventilation system, and flow is toward Tanks 102- and 103-SY.

On the basis of these considerations, we conclude that DDT is possible but unlikely. This assessment of the likelihood of DDT occurring is based on the assumption that ignition has occurred with a probability of one. If we consider that the probability of an ignition also is unlikely, then the probability that detonation will occur is possible but very unlikely.

4.4.7. Flooding the Tank

As described in more detail in Sec. 4.3.5, we concluded that external events leading to flooding of the tank can be eliminated from further consideration and that adequate controls required for decontamination of equipment will be established to monitor and limit the water addition to the tank.

No water addition is planned as part of pump operation. However, water may be added during pump operation to flush or unplug the pump or instrument lines. If it became necessary to add water to the tank, the amount added would be limited to the quantity specified in Sec. 6. These operations have been analyzed and controls established in App. T.

4.4.8. Spray of Waste into Dome Region

This accident sequence assumes that waste could be sprayed in the dome region of the tank during pump operation. The only conceivable mechanism for the spray of waste in the dome region, beyond the normal spray that occurs as a result of rollovers, is a rupture of a pump discharge, causing the waste to be ejected into the dome space. This accident sequence is considered incredible because the pump discharge pipes are near the bottom of the tank, and no conceivable rupture could be expected to cause significant spraying in the dome region. Even if spraying were to occur, it is highly unlikely that any significant amount of radioactive material would escape the tank and the HEPA filters in the ventilation system. We concluded that no further analysis of a spray of waste into the dome region during pump operation is warranted.

4.4.9. Pump-Operation-Induced Releases

Although the mixer pump was designed to be operated safely in a flammable gas environment and the test plan was prepared with an emphasis on safety, accidents still are possible and are identified in Sec. 3, Hazards Identification. The consequences of potential accidents related to pump operation are analyzed in this section to evaluate the risks of the pump operation. We have considered various mechanical faults in the pump, electrical faults, and failures of the control system. We concluded that even though the pump may be damaged and further operation is prevented, none of the accidents considered will lead to a burn in, or structural damage to, the tank. In this sense, the hazards associated with these accident initiators are within the acceptance criteria.

4.4.9.1. Pump Startup Overload. During startup, the pump will be operated and controlled from the DACS. Pump speed, motor current, flow rate, discharge pressure, pump vibration, support column strain, and motor temperature will be monitored. Normal operating ranges for these parameters have been determined; if operation outside the normal range is detected, the pump will be shut down. The pump is protected further by breakers between the variable-speed power supply and the pump and also by breakers at the power supply. Thus, overload conditions will be detected and terminated and will not lead to accident conditions with any safety consequences. This case could lead to disabled equipment and the inability to continue pump operations; however, these consequences are unlikely because of the redundant breakers and trips.

4.4.9.2. Pump Overspeed. Pump overspeed can occur from two sources. First, failure of the power supply could result in a high-frequency condition, causing the pump to overspeed. For a pump that discharges a liquid, the pump power is proportional to the speed cubed. As this power increases, the electrical breakers discussed in the previous section would trip the power supply and terminate the accident case. Second, fluids could be forced through the pump at high velocity, which can occur under certain conditions in a pressurized water reactor. Because no high-pressure fluid sources exist in Tank 101-SY that could cause the pump to operate at high velocity, this case is not considered credible.

Although a severe overspeed case is considered incredible (the control system will be protected from being a single-point failure with over-rotation of the pump because of procedural and control features described in App. N), we analyzed a postulated breakup of the pump impeller under these conditions. The analysis examined the largest missiles that could be expected from the pump and the consequences of the missiles. We assumed that the full rotational energies of the pump parts are available at the maximum pump velocity. The pump rotates at 1180 rpm, and the 45.7-cm (18-in.)-diam rotor has a peripheral velocity of <30.5 m/s (100 ft/s). At this velocity there is insufficient energy to fracture the pump or motor housings. Details of this calculation are presented in App. N.

4.4.9.3. Pump Shaft Break. We have examined the possibility of a break of the pump shaft to see if this could cause a missile that might puncture the tank or initiate a burp and burn. The pump shaft is designed such that the shaft has various diameters, with the largest diameters being at the top. This design prevents the pump shaft from falling out of the bottom of the pump if the shaft were to break.

We also examined the pump design features that make missiles unlikely for pump shaft break. The design of the 15.2-cm (6-in.)-diam outlet pipes tend to contain and reduce the velocity of any pump parts that could fail.

4.4.9.4. Bearing Failures. The pump and motor are mounted on a common shaft supported by two bearings. The bearings are located in the motor housing, and the pump impeller is mounted outboard from the lower bearing. The motor and both bearings are located in the motor casing, which is sealed and filled with oil. Two temperature detectors are located near the upper bearing; one moisture detector is located near the bottom bearing. The temperature detectors can sense hot oil at the top of the motor, and the moisture detector can sense a leak of waste into the motor. The normal pump operating parameters are monitored by the DACS to detect abnormal operation and prevent bearing failures. If a bearing failure occurred, the two concerns would be a broken shaft or a locked rotor.

We have examined the possibility of a locked rotor by assuming that the full rotational energy of the pump is transmitted to the pump column. The resulting torque would cause the pump assembly to rotate on the column support bearings. The torque would be resisted by the rotation gear, which has a shear pin in the drive shaft. This pin would break, and the column would rotate. The electrical and instrumentation cables above the tank could be torn out and whipped around above the tank, creating a fire and personnel hazard. The electrical cables are isolated by their respective breakers.

4.4.9.5. Loss of Pump Oil. Failure of the pump motor casing or cooling circuit could result in leakage of pump oil into the waste or intrusion of waste into the pump. The concern is that this mixture could produce an exothermic reaction. To address this issue, PNL performed compatibility studies using sodium nitrate/nitrite as a waste simulant and two oils under consideration for use in the mixer pump, Chevron Turbine Oil GST ISO 32 and Chevron Turbine Oil GST ISO 68.[13] Stoichiometric mixtures of both oils and the dry nitrate/nitrite salts were subjected to differential scanning calorimetry and TGA (including differential TGA) over a temperature range of 50 to 550°C (122 to 1022°F). The results indicate that no exothermic reactions occur below 350°C (662°F). Further, the loss of oil by vaporization in the test configuration suggests that no reaction would occur in an unconfined mixture over the entire temperature range. From these results, we concluded that oil/waste compatibility is satisfactory and that there are no energetic consequences associated with the leak of pump oil.

4.4.9.6. Motor Shorts to Ground and Electrical Cable Failures. The electrical design of the pump is described in Sec. 2. The pump motor is located in the liquid waste area and is oil-filled. The electrical cables are contained in conduits where they pass through the support column, and the column has an inert nitrogen atmosphere. Electrical faults to ground are not expected to occur in flammable atmospheres and quickly will be isolated by the redundant supply breakers.

If these precautions are inadequate, we have considered the possibility of explosion in the support column and have analyzed the consequences. We assumed also that flammable gases and nitrous oxide are present in the column or the column-to-pump pump-transition piece where the electrical connection to the pump is made. We assumed that the flammable gases and nitrous oxide are at the submergence pressure and then ignited. This results in a pressure of 1930 kPa (280 psi), regardless of the volume involved. The analysis concluded that structural integrity is maintained. Therefore, gas leakage into any volume of the mixer pump and subsequent ignition are within the acceptance criteria and will not propagate outside of the pump structure.

4.4.9.7. Inlet Line Plugging and Loss of Suction. The pump inlet suction port is designed so that the impeller is open directly to the waste. If the port becomes clogged, the pump could be damaged. However, the impeller is designed with large clearances for slurry operation, and pump damage to the extent of pump disintegration is unlikely. The result of a blocked inlet would be a loss of outlet pressure, which would be detected by the DACS; thus, the pump still could be shut down safely. If the inlet were plugged, the pump also could become unbalanced. This would be detected by the pump vibration monitor or pump column strain gauges, resulting in pump shutdown. The pump decontamination nozzles could be used to try to clean out the pump if the port became plugged. Loss of suction may be an operational problem, but it is not considered a safety issue because it can be detected before it causes a mechanical failure. Any resulting accidents are bounded by cases analyzed for the pump overspeed and locked rotor.

4.4.9.8. Pump Outlet Nozzles Plugged. Several cases of outlet nozzle plugging were considered. The pump assembly was designed using the structural analysis of a single outlet nozzle being plugged as an asymmetrical load; this was not a limiting case. A single nozzle being plugged can be detected in two ways. First, the pump operating parameters would fall outside the normal operating range; second, the strain gauges on the pump column would indicate a bending moment.

If both nozzles are plugged, the pump discharge pressure would go to shut-off head and be detected. Pumps are safe at this position, provided that they do not overheat; overheating would be detected with installed temperature detectors and alarms. Therefore, plugging of both nozzles would not cause a safety hazard. During the early phases of pump operations, the outlet nozzle was plugged. The plug was successfully detected and cleared with the injection of water.[14]

The discharge nozzles also would become plugged if the non-Newtonian nature of the waste caused one jet to freeze at one of the nozzles, break loose, and start flowing again; this process repeats with another jet, resulting in alternating jet loads. This condition would be detectable with the discharge pressure, the support column strain gauges, and possibly the pump vibration monitor. The strain gauges on the pump column will be used to detect any strain exceeding an allowable value, which would result in shutdown. The allowable strain value will be chosen based on infinite fatigue life of the pump. This approach will eliminate failure resulting from oscillating loads, such as those produced by alternating jet loads.

4.4.9.9. Loss of Electrical Power. We studied this situation to see if a power loss could create an accident or unsafe condition. This scenario is based largely on experience with reactor safety, where there are many vital electrical loads for shutdown and decay heat removal, and a loss of normal power can be a serious condition. Only one safety action can be taken during pump operations, which is to shut off the pump. Therefore, a normal power loss places the pump in a safe condition. The control and instrumentation systems have a battery-based, uninterruptable power supply to monitor tank conditions. Thus, a normal electrical power loss inherently is safe for the pump, and instrumentation power is not interrupted.

4.4.9.10. Loss of Control. The electrical design for the control system has been subjected to a single-failure analysis. The pump controls are redundant so that no single failure can result in an inability to shut the pump down promptly if both a controlled variable and the shutdown logic call for a shutdown. This is described in more detail in Apps. N and S.

4.4.10. Waste Discharge through Auxiliary Piping

The possibility of waste discharge into the atmosphere from auxiliary piping has been considered, and the consequences have been analyzed. The piping system considered is the tubing used in the pump discharge pressure measurement system and the piping that connects to the flushing and decontamination system. These cases are described below.

4.4.10.1. Pump Discharge Pressure Measurement System. This accident has consequences and is discussed in Sec. 5.5.3.

4.4.10.2. Flushing and Decontamination System. The flushing and decontamination system consists of 25.4- and 50.8-mm (1- and 2-in.) pipes that connect to the flushing-and-decontamination ring near the pump suction and extend upward through the cover blocks. The upper end of the system contains a connector and valve where the line can be connected to a high-pressure water source. The pipes also contain two check valves. A functional specification requires that the two check valves in the pipes be located inside the tank. A serious discharge into the atmosphere could occur only if both check valves and the exit valve fail simultaneously. This occurrence is judged to be incredible. Details of this analysis are in App. T.

4.4.11. Vibrator Hazards

The pump design was revised to add an air-driven vibrator ~15.2 cm (6 in.) in diameter and 30.5 cm (12-in.) long mounted on the pump discharge nozzles. The vibrator was installed to unplug the nozzle if sludge buildup occurs and cannot be removed during pump operation. This SA treats the addition of the equipment in terms of sources of spills or leak paths and issues relevant to installation. However, the SA does not address operation of the vibrator. The controls detailed in Sec. 6 require that the vibrator be flanged off and inoperable. Vibrator operation will require documented justification. A hazards assessment for vibrator installation indicates that there are no safety consequences. Details of the assessment are provided in App. T.

4.4.12. Flammable Accumulation Gas in the Pump Pit

Accumulation of flammable gas in the pump pit could lead to a burn in the pit, and the cover blocks could be blown off. The largest potential hazards exist during a GRE or burn condition in the tank dome. Two calculations were performed to bound this condition. We considered (1) the accumulation and burn of flammable gas in the pump pit and (2) the pressurization of the pump pit during a burn in the tank. For the most limiting case, we calculated the velocity of the pump pit cover blocks. Controls have been established in Sec. 6 to minimize the leakage flow paths so that the cover blocks cannot be launched. The analysis is presented in App. F.

4.5. Accident Assessment—Pump Removal Accidents

In Sec. 4.1, accident sequences were developed for all accident initiators identified as a result of the HazOp analysis. In Sec. 4.2, the methodology for analyzing the accidents was presented. All accident sequences developed in Sec. 4.1 and Table 4-3 have been analyzed; the analysis results discussed in this section are for those sequences having no radiological, toxicological, or unacceptable structural consequences. The analysis of accident sequences with radiological, toxicological, or structural consequences is discussed in Sec. 5.

4.5.1. Flammable Gas Release with Burn (Flammable Gas Accumulation)

This case considers a condition where flammable gas accumulates in a pocket and is ignited by a source present at that location. The treatment of this case for the pump-removal phase of the action is the same as the treatment for the pump installation phase (see Sec. 4.3.1 for a detailed discussion).

We concluded that during installation and removal operations, additional risk associated with accumulations of pockets of flammable gas is minimized by the controls that will be in place for these operations and that the hazards are bounded by the analyses for burns during installation and removal operations discussed in Secs. 5.4 and 5.6.

4.5.2. Flammable or Toxic Gas Release with or without Burn (GRE in the Neighboring Tank)

As discussed in Sec. 4.3.2, the gas releases from Tank 103-SY do not pressurize the dome, nor are they large enough to affect Tank 101-SY.

4.5.3. Filter System Release

We concluded that the filter system release accident sequence could be caused by a gas release with a burn occurring during pump removal. No other accident initiators are considered because they are part of normal tank farm operations. This same accident sequence is detailed in Sec. 4.3.3.

4.5.4. Tank Penetration

The accident sequences associated with the removal operation are identical to those discussed for pump installation operations (Sec. 4.3.4). We concluded that tank penetration accident sequences during pump removal do not warrant further analysis.

4.5.5. Flooding the Tank

As described in more detail in Sec. 4.3.5, we concluded that external events that could lead to tank flooding can be eliminated from further consideration and that adequate controls have been established to monitor and limit water addition to the tank, as required for decontamination of equipment.

Water addition is part of pump removal. The amount of water added to the tank will be limited to the quantity specified in Sec. 6.

4.5.6. Spray of Waste into Dome Region

This accident sequence assumes that during pump removal, waste could be sprayed in the dome region of the tank. This accident sequence is similar to the sequence discussed in Sec. 4.3.6. We concluded that no mechanism has been identified that would cause a spray of waste into the dome region during pump operation other than a spill of waste inside the tank. The consequences of a spill inside the tank would be several orders of magnitude lower than the consequences of a spill external to the tank. Thus, we concluded that no further analysis of a spray of waste into the dome region during pump removal was warranted.

4.6. MPR—Hazards Analysis

This section describes the analysis of hazards outlined in Sec. 3 for the MPR. For each class of hazard, the design features and controls necessary to eliminate the hazards are described. The consequences for hazards that result in potential accident sequences are provided in Sec. 5.

4.6.1. Hazards Analysis for MPR/MPF Activities

Many hazards associated with MPR activities are similar, if not identical, to hazards associated with mixer pump activities. In this section, we address only those hazards specific to the MPR activities.

4.6.2. Hazards Assessment—Riser Preparation

Before installing the MPR on Riser 5A or the MPF on Riser 5B, the equipment presently located in these risers must be removed. Only one riser may be opened at a time. A TV camera and light assembly were located in Riser 5B. The activities associated with removal of the TV camera are beyond the scope of this document.

4.6.3. Hazards Assessment—MPR/MPF Installation and Removal

When the controls in Sec. 6.0 are followed, the hazards associated with sparks or with personnel exposure to radiological or toxicological substances are mitigated. These controls are developed from the WHC standard controls for open-riser conditions, except that additional controls have been imposed to deal with the hazards of dropped equipment, which are detailed in subsequent subsections.

4.6.3.1. Flammable or Toxic Gas Release (Unexpected GRE). A toxic gas release could occur at various stages of installing or removing the MPR and/or MPF, either from natural convective action of the dome gas or from a GRE with the tank riser open. This safety issue has been bounded by Sec. 5, which contains an evaluation of situations with and without the ventilation system operable and with a GRE. For example, free convection of the dome gas driven by a thermal source of the hotter bulk waste results in a release through an open riser when the ventilation system is inoperable. However, as stated in Sec. 5, this gas release without a burn results in insignificant radiological consequences. Section 5 states that the projected exposure will remain within acceptance guidelines. To mitigate this issue during MPR installation and/or removal, standard WHC procedures will be implemented through administrative controls to ensure that an unexpected GRE will be a highly improbable event. A GRE during installation and/or removal is mitigated through imposition of tank intrusion criteria. These control limits, as well as remaining anticipated environmental conditions that must be avoided, are contained in Sec. 6.0.

We believe that this situation does not present any new hazards that are not presently addressed with standard WHC administrative controls. The probability that a premature opening of an MPR may occur during a GRE without a burn has been analyzed and is discussed in Sec. 4.6.4.1.

4.6.3.2. Flammable or Toxic Gas Release with Burn—MPR Installation and/or Removal Control Limits. During installation and removal operations of any equipment associated with Tank 101-SY, a spark source may exist in the proximity of a flammable gas pocket. This situation specifically was addressed in Sec. 4.3.1.

After a review of these hazards, we concluded that installation and/or removal of the MPR or MPF do not introduce any new hazards. Controls in Sec. 6.0 ensure operability of the ventilation system to avoid flammable gas accumulation; if the ventilation system is inoperable, these operations immediately are placed in a secure mode and terminated until normal conditions are achieved. WHC has used nonsparking materials in both designs; this contributes to the mitigation of the hazardous elements involved.

Neither the MPR nor the MPF assembly incorporates any instrumentation and/or electrical equipment. As presently configured, these units do not present any electrical ignition source hazards.

Flammable gas buildup and tank level variations are mitigated through operation of the mixer pump. The tank waste level characteristically remains at ~10.16 m (400 in.). Installation and removal of the MPR and/or MPF will be constrained to be within tank level limits <10.26 m (404 in.). This level provides a safe margin below the tank structural limit.

We conclude that no new risks associated with sparks have been introduced and that hazards have been mitigated through implementation of adequate controls, as well as through design features that inhibit spark production.

4.6.3.3. Filter System Release. A filter system release accident from a gas release with burn is discussed in Sec. 4.3.3; no new hazards related to this event are introduced from the MPR installation and/or removal operations. However, our hazards analysis indicates that the MPR could be dropped onto the filter system during installation or removal. If the MPR were dropped onto the HEPA filters from a height of several feet or more, we would expect gross filter structural damage to occur. In this event, we believe that most of the radioactive material confined to the filter elements would be drawn into the ventilation system because of the ventilation system's initial negative pressure. The ventilation system likely would be operable after sustaining major damage; this would place tank operations under a state of emergency. Repair and waste cleanup would correct the damaged state, at some risk to personnel. This accident must be prevented by administrative control of the crane transit path. Under no circumstances should the MPR handling operations place external tank farm critical elements at risk. The controls that mitigate this hazard are contained in Sec. 6.0.

We conclude that no new hazards will be introduced that currently are not mitigated effectively through standard WHC administrative controls.

4.6.3.4. Tank and Riser Penetration. A confinement loss of the toxic and radioactive waste from a structural failure of the dome liner is an SC-I issue. Installation, removal, and/or decontamination operations potentially constitute hazards to the structural integrity of the tank. The following subsections discuss the assessments of these situations.

4.6.3.4.1. Crane accident or infringement. An accident that would increase the dome loading either statically or from heavy impacts is a particularly serious issue. The present static tank dome loading is nearing a critical stage, and any operation that could alter this balance must be avoided. Placing the MPR on the tank riser requires a heavy lifting operation; thus, administrative controls must ensure against structural failure of the dome liner. A crane accident is possible. Procedures for installation and/or removal of the MPR must be followed to ensure that an accident, such as a crane overturning onto the dome or encroachment onto the dome's perimeter, does not occur. Administrative provisions have been identified in Sec. 6.0 to address this issue.

4.6.3.4.2. Drop of MPR onto tank riser. We assessed the consequences of dropping the MPR onto the Tank 101-SY riser during installation or removal. The analogy used and the results obtained from these calculations are contained in Ref. 15. This bounding-type analysis established the probable results if the 29,330-N (6600-lb) MPR were dropped onto the 1.07-m (42-in.)-diam riser. A consequence of this study was to constrain the drop height to ensure that the tank integrity is not breached. Administrative controls derived from this accident assessment have been placed in Sec. 6.

Handling controls are imposed to limit accidental drop exposure to values less than those cited in the study found in Ref. 15. This study shows that the drop height was limited by allowable dome material properties. The impact velocity is relatively low in comparison to high-velocity impact studies. Velocities >25.6 m/s (84 ft/s) are required before rupture of the low-carbon steel-riser tubular section would occur. However, administrative controls ensure against drops of this nature. Inertia loads of the impacting bodies also were not considered important in the velocity region of interest. Consequently, we equated the work performed by the falling body to the strain energy produced in the riser. Strains induced in the riser body were idealized using the analogy of axial loading of a tubular section under a static load.

Although differing in diameter and overall length, the risers in Tank 101-SY share common support features. Each riser is anchored into the secondary concrete tank liner with horizontal studs. The riser also is butt welded into the primary tank dome liner. Similarly, the riser weld in the tank dome liner is anchored into the concrete overlayer through a large array of studs. As part of the analysis, we assumed that these welded interfaces resist the riser impact load through a shearing action. Thus, we assumed that the steel dome rigidly supports the riser. A useful consequence of this assumption was a first approximation of drop height in terms of weld strengths. As stated, the objectives are to neither breach the riser/dome circumferential weld nor damage to the dome. Failure of this weld conceivably would result in the riser being partially driven into the tank space.

The long riser tubes are compliant in comparison to the individual weld sections. Because the horizontal riser studs are imbedded in concrete, the volume of material that can absorb energy is negligible in comparison to the riser tube. In our bounding calculations, we used the compliance in the riser tube section to absorb the energy of impact. The stress produced in the riser from this impact directly is proportional to the square root of the falling body kinetic energy and the material modulus of elasticity and inversely is proportional to riser volume. Thus, stress buildup in the riser pipe is influenced not only by the riser cross-sectional area, but by pipe length as well.

The detailed results of the bounding calculations for the MPR are found in Ref. 15. This drop analysis was based on an MPR weight of 29,330 N (6600 lb), which was supplied by WHC. We found that the riser weld to the dome liner will not be breached by dropping the MPR, based on a maximum drop height of 91.44 cm (36 in.). The studs that anchor the riser to the concrete secondary liner presumably would shear if the MPR were to drop from a height of 2.2 mm (0.086 in.). The eight studs do not offer significant protection to the dome liner from any reasonable drop height. This drop height produces a dynamic load of 576,190 N (129,643 lbf) on the riser flange area. We assume that this load uniformly is applied to the riser flange interface in this simple model.

If the riser studs were to fail as a consequence of this great of a drop height, the dome deflection under these large impact loads would be very significant. The situation of a large deflection considers how soil friction on the riser tube can reduce this impact. The choice of the friction coefficient will have a deciding effect on the result because (1) the final friction coefficient chosen is an ill-defined quantity and (2) including this term generally becomes somewhat suspect. Table 2 of Ref. 15 illustrates the effect of including this frictional term for an assumed soil density and friction coefficient. If the friction coefficient were 1.0 (a very high value by most standards), the unbalanced force exerted on the dome liner would be 180,680 N (40,653 lb) (Ref. 16 gives a static friction value of 0.3 to 0.7 for iron on stone). This is close to the maximum allowable value [165,400 N (37,214 lb)], which corresponds to the material's ultimate strength based on our elastic model. Thus, a drop height presumably approaching 91.44 cm (36 in.) for an MPR weight of 29,330 N (6600 lb) would not breach the dome liner. However, this conclusion is somewhat problematical; thus, this issue should be further analyzed if necessary. Because our administrative controls in Sec. 6.0 are based on a conservative 36,620 N (8240 lb) (+25% margin), this drop height currently must be limited to 73.66 cm (29 in.).

In a more rigorous analytical approach, we could develop an analogy for plastic strain in the dome liner; including this effect may permit drop heights >73.66 cm (29 in.) without breaching the dome liner. However, we must include the soil friction effect mentioned above, and it is doubtful that inclusion of this effect alone would prevent damage to the dome. Before we can consider compliance of the dome liner and soil friction resistance, we must be willing to shear the riser dome studs. This situation hardly seems reasonable, and more promising alternatives must be considered.

Excessive stresses develop in the steel dome liner if the MPR is dropped from any significant height. The compliance estimate for the steel liner dome, although significantly greater than the axial tube compliance, does not sufficiently reduce the impact load to an acceptable level for the MPR.

As a result of this bounding calculation of a postulated MPR drop, we recommend that an elastomer (or equivalent compliant means) be placed between Tank 101-SY's riser flange and the MPR during installation and removal. The compliant material and sizing should protect the riser studs from the impact load. Otherwise, the structural integrity of the dome liner could be challenged if the MPR is dropped. A thorough study using FEA techniques is warranted if the dome riser is not protected.

WHC has developed an installation and removal scenario whereby the three leveling jacks protect the riser. The three leveling jacks will be adjusted to a height that prevents a riser impact if the MPR is dropped. The leveling jacks will absorb the impact. The elastomeric seal on the riser flange also will protect the riser during the final adjustment of the leveling jacks.

The riser cannot be driven down below the waste level if the MPR is dropped onto the 1.07-m (42-in.)-diam riser from the heights cited above; thus, there will be no hazard to the tank bottom liner. This conclusion is valid, despite the angle at which the MPR could impact on the riser. We conclude that a rupture of the tank bottom liner wall will not occur from this postulated accident.

4.6.4. Accident Assessment-Operations

We determined MPR operation hazards considering the release of toxic or radioactive materials and the direct consequence of exposure of the general public or onsite personnel. All MPR operation accidents have been analyzed; the analysis results discussed in this section are for those consequences having no radiological or toxicological consequences or unacceptable structural consequences. The analysis of accident sequences with radiological or toxicological consequences is presented in Sec. 5.

4.6.4.1. Flammable or Toxic Gas Release (Unexpected GRE). The MPR must remain closed during a GRE condition without a burn to ensure that there is no release of toxic or radioactive gas. However, a GRE with a large release volume can build pressure in the tank. This pressure must not overcome the vent door latch mechanism. If we assume that there are no defects, unforeseen damage, or deterioration of the primary sealing mechanism, this issue should not be a problem. In our hazards assessment, we considered the possibility of a vent door malfunction or a leaking condition from seal deterioration during a conservative GRE condition. The following subsections discuss these conditions.

4.6.4.1.1. Vent door unexpected opening—retention failure. Under a closed-tank situation, a GRE with a 371-m^3 (13,100-ft^3) release volume will lead to a gradual positive buildup in pressure, peaking at a differential of 3310 Pa (0.48 psig). The present MPR FDC[17] states that a normally functioning door will not begin to release until the positive tank pressure becomes >34.5 kPa (5.0 psig). However, in this SA we are concerned that a combination of events may interact to produce this release, such as (1) severe wind storms capable of driving airborne missiles and (2) seismic disturbances. These events may occur in conjunction with a GRE, although the probability is extremely remote. WHC has made specific calculations to ensure that an adequate design margin to prevent premature door actuation based on the high relief pressure exists. Nonetheless, because of a fundamental question concerning vent door reliability, we assessed the consequences surrounding this hazardous event, as will be presented. Also, we determined the vent door's reliability for two separate failure modes (premature opening and failure to open during a major burn event). The first failure mode is discussed in this section; the second is discussed in Sec. 4.6.4.2.

Our initial assessment of the fracture clip initial design concept reliability[18] determined that 16 of the 18 clips intended to retain a vent door must fail on one door for one panel to open prematurely in a GRE. The overall failure probability for the pressure relief panels opening under less than design pressure is ~3.1×10^{-3} per rollover event. Human error contributed significantly to the estimated failure rate. This failure rate was reduced to 4.8×10^{-4} when we included a simple pressure test of the finished assembly.

We considered what the effect of this failure would be in relation to initiating a burn situation. A release at 3310 Pa (0.48 psig) would result in flammable gas being injected at ground level, where electrical apparatus is located. Because not all equipment residing in the near vicinity of the MPR will meet NEC Class 1, Div. 2 requirements, a burn condition could be initiated.

An analysis was performed using a postulated vent door retention failure in conjunction with a GRE, where dispersion of flammable gas results.

These results revealed that a positive retention scheme is essential to the MPR design. The fracture-clip-type panel retention system was adopted as the most direct method of overcoming the premature venting hazard.

4.6.4.1.2. Radiation or chemically damaged vent door seals. Under normal closed conditions, the MPR vent door panel seals the inner-tank vapor space from the surrounding air environment. Because the tank is maintained at a slightly negative pressure, any leakage would be inward, not outward. Under a tank GRE condition, the tank could reach the slightly positive pressure cited earlier [3310 Pa (0.48 psig)]. Escape of hazardous gases in this situation is limited by the nearly leak-tight vent door capability. Vent doors will be tested to ensure that leakage under a positive tank pressure of 10.3 kPa (1.5 psig) will be <0.17 m^3/h (0.1 ft^3/min).

The vent door seal interface is made of an elastomeric material that could be vulnerable to radiation damage and/or chemical attack. The seal material could deteriorate with time, which would increase the minimal leakage. To mitigate this probable hazard, the seal material selection criteria have been controlled by WHC in the functional design requirements (Ref. 17, Sec. 3.3.2). Seal materials used in the MPR must be demonstrated through an appropriate combination of testing, analysis, and operating experience and supported by auditable documentation to be capable of withstanding the environment. WHC has chosen seal materials based on previous mixer pump design experience. Because of current functional experience obtained on the mixer pump riser elastomeric seal, we know that appropriate seal materials exist. Periodic inspection and replacement of the elastomeric seal materials provide additional confidence that the hazard has been mitigated and that no new unforeseen conditions exist.

4.6.4.2. Flammable Gas Release with Burn (Flammable Gas Accumulation). This SA documents discrete accident events that may produce burn events in the dome space. The MPR provides tank pressure relief and thereby reduces serious structural consequences up to the maximum allowable release limit (Sec. 5) that may occur in the tank liner. The intent here is to analyze whether the MPR could fail in this primary function.

Consequences of a burn event and the resultant radiological and toxicological limits are addressed in Sec. 5, including the vented products.

4.6.4.2.1. GRE with burn—vent area size adequacy. The assessment of structural consequences resulting from a GRE and burn was updated for a conservative-estimate, top-down burn event (Sec. 5). Tank structural calculations reported in

App. K illustrate how the tank response interacts adversely with the rapid pressure-rise transient during the initial phase of a GRE. As part of the MPR SA analysis, the standard tank structural analyses were repeated to establish what potential effect the MPR venting characteristics could have on the structural limit. The need for quick-moving MPR vent doors was part of this evaluation.

The HMS/TRAC tank model simulated MPR vent door actuation for several cases: (1) at 20.7 kPa (3 psig), with instantaneous opening; (2) at 20.7 kPa (3 psig), with full opening occurring within 100 ms; and (3) at 67 kPa (10 psig), with full opening occurring within 100 ms. The lower-pressure door releases depart significantly from the present riser venting at ~100 kPa (14.5 psig) and were selected to simulate quick-opening vent characteristics. To ascertain other potential benefits of the MPR on the mitigation of a burn event, vent areas corresponding to 0, 66, 100, and 200% were varied parametrically, while holding the volume of the GRE constant. The initial pressure-rise transient is a strong function of this gas release value, as were as other equally important gas kinetics parameters. Very sharp pressure transients were encountered at the higher gas release values.

Several observations can be made from these HMS/TRAC solutions involving the new MPR characteristics. First, a vent area equivalent to two MPRs produces no appreciable effect on the rapid portion of the pressure-rise time. However, the peak pressure is influenced moderately by the vent area, with the 200% area producing a modest improvement over the 0% case. The most pronounced effect of the MPR is in tank depressurization, again with a 200% area producing the largest effect. The effect of MPR venting on establishing the tank structural MAB limits is detailed in Sec. 5. Also, there was no evidence that the early actuation time of the MPR was beneficial in mitigating the burn events. Release of the vent doors at a pressure >20.7 kPa (3 psig) would be within the acceptance criterion; this feature has been used to avoid hazards associated with a premature release during a burp without burn.

The primary function of the MPR is to support the auxiliary equipment items (e.g., the sonic probe); in the process, the flow area through the MPR column may become partially blocked. The actual area for venting through the MPR may be reduced to ~66%, which is why this particular percent vent area value is part of the displayed information. Little difference is observed between the 66 and 100% cases.

The radiological and toxicological consequences of a GRE in conjunction with venting through the MPR has been assessed and are reported in Sec. 5.

We concluded that the MPR does not present any new hazards, considering the possibility of a GRE with a burn. Three vent doors on the MPR provide adequate relief area, even with a fully assembled MPR where the area is rated at 66% of the present vent system area.

4.6.4.2.2. Vent door actuation failure. Failure of the MPR vent doors to actuate and relieve the tank pressure during a gas release and burn event is an SC-II issue. Design features and/or component failures from any event that precludes door actuation must be considered as SC-II items. The three pressure vent doors have been sized such that only two must open to be provide a flow area equivalent with the 1.07-m (42-in.)-diam riser opening. This feature provides redundancy.

Each MPR vent door is held in place with an array of 28 fracture clips, which are key elements in the quick-release mechanism for the door. Each fracture clip is composed of a structural element fixed at one end. The clips apply a restraining force to oppose door openings under pressure. Thus, to open a door, a pressure excursion up to 41.4 Pa (6 psig) will cause the 28 clips simultaneously to fracture. As a point of reference, the 28 fracture clips offer redundancy. Because it takes nominally 6 psig to fracture all 28 clips, only 6 clips are required to prevent premature opening up to nominally 6.9 kPa (1 psig), or roughly twice the pressure produced by a 371-m^3 (13,100-ft^3) release. This attribute was an important consideration in selecting the clip design.

Door actuation in the MPR should occur at ~41.4 (±6.9) kPa [6 (±1) psig], with a door-opening response time of 100 ms. This provides a release of pressure comparable to the present 100-kPa (14.5-psig) vent plug installed on the existing riser. Although vent door release is best under all environmental conditions, we have shown that a tank pressure transient in a burn case is affected insignificantly without venting. As a sensible precaution, WHC has included relief characteristics for all conditions in their preinstallation testing and periodic inspection activities. For completeness of the SA study, we have considered individual potential effects that may preclude door actuation and have evaluated the design concepts proposed for their mitigation. Also, damage to the door from seismic events is discussed in the following section.

We evaluated the consequence of a major burn event without the MPR vent doors opening. For the failure analysis for this postulated event,[18] we investigated the failure-to-open fault mode. This overall failure probability is ~2.0E-03 per burn event, which occurs at a frequency of 5.5 x 10^{-6}/yr for releases ≥244.9 m^3 (8650 ft^3) with burn and ventilation operable. Combining these events, we obtained a frequency corresponding to 1.1 x 10^{-8}/yr. This low value ensures that the combination of these events is highly improbable. We concluded that a door-opening failure because of manufacturing or assembly error is not likely.

In the process of examining external influences that may prevent the door panels from opening, we considered the effect of vent door icing. Because our studies have shown that the tank's structural integrity is not affected by failure of the door to open, we did not incorporate any electrical power feature to ensure vent door functionality in the presence of an icing condition. We concluded that proposed thermal insulation can prevent icing and that heat tracing would present an unacceptable hazard to mitigate icing. The vent doors possess limited capability to oppose a high internal pressure. Internal pressures caused by a major burn event would rupture the doors, releasing the internal gas pressure.

Obstructions to doors opening (drifting sand, debris, etc.) are possible problems that can be corrected through periodic surveillance or directed through simple administrative controls (Sec. 6). We concluded that by properly inspecting the vent doors periodically, monitoring the fracture clips, and inspecting for debris (debris would hamper door actuation), proper venting will occur under all tank burn situations.

4.6.4.2.3. Vent door damage—seismic event. The fracture clips will not release during a seismic event. This attribute was an important consideration in selecting the fracture clip concept for door retention and ensures that the doors will not open prematurely from a burp or seismic event. Structural studies and component tests performed by WHC confirm this observation. We concluded that the MPR will perform correctly during a seismic event involving a no-burn situation.

4.6.4.3. Loss of Confinement. A compliant seal between the MPR and the Tank 101-SY riser accommodates relative motion that may occur from environmental conditions. Events of concern are seismically induced relative motion of the concrete MPR mounting pad with respect to the dome riser and relative motion from soil expansion. Soil expansion may result from frost and/or soil moisture variances. A properly designed seal interface structurally will decouple the two components, thus avoiding potentially deleterious loading directly onto the dome liner. WHC analyzed these conditions; the conclusions are discussed in the next subsections.

4.6.4.3.1. Dome liner failure—MPR concrete pad loads. The MPR shell was mounted onto a large concrete support pad through three leg structures. The legs are structurally bolted to the concrete pad; these concrete anchor bolts must be capable of resisting the MPR ejection force from a burn event. Consequently, the structural coupling of the MPR to the concrete pad is quite substantial. Under adverse environmental conditions, high strain conditions may develop in the dome liner. A compliant seal between the MPR sealing flange and the 1.07-m (42-in.)-diam riser connects with the dome liner. This seal structurally isolates the MPR from the tank dome. If the seal does not function correctly, a breach in the tank structural integrity and subsequent loss in containment may occur.

There are several environmental effects that can transmit unacceptable loads to the dome liner. During a seismic event, a heave or lateral motion of the aforementioned concrete pad relative to the riser can occur. Relative motion between the two structural systems is likely to transmit a load through the MPR compliant sealing interface directly to the 1.07-m (42-in.)-diam riser. The riser then could transfer a sufficient load to create a structural failure of the dome liner, which would breach tank integrity. The WHC/ADVENT engineering team assessed this potential structural dynamic interaction of the pad with the surrounding soil combined with the tank dynamics. The results of their study clearly show that the compliant seal could weaken the effect of the relative motion between the two structures. Excessive dome strains did not occur. On the basis of this study, we concluded that the present MPR design effectively mitigated this SC-II issue.

4.6.4.3.2. Dome liner failure—soil expansion effects. Another concern is the natural heave of the concrete pad with respect to the tank dome, either from thermal or moisture cycling of the soil. WHC also evaluated this issue. We determined that the adequacy of the compliant interface to absorb large relative motions without serious loads being imposed on the tank was acceptable.

4.6.4.4. Radiation Exposure (Shine). During MPR installation and removal, there is a period when the 1.07-m (42-in.)-diam riser will be open. During this critical phase, personnel will be exposed to radiation and toxicological hazards from the open riser. Reference 19 states that the radiation streaming from an open 1.07-m (42-in.)-diam riser has been measured as 2 R/h.

No new hazards are anticipated from the installation and/or removal procedures[20] outlined for the MPR that would increase exposure to onsite personnel. Appropriate administrative controls for the MPR installation and/or removal are presented in Sec. 6.

An installed MPR without appropriate shielding could present a radiation (shine) hazard to personnel performing maintenance functions (e.g., inspecting the vent doors for functionality). At various phases of use, the MPR likely will not be outfitted with a full suite of equipment (i.e., some openings will be closed off). To prevent personnel exposure to radiation (shine) under these situations, WHC has designed inserts to block the potential radiation paths. WHC[19] performed dose rate calculations to ensure that this hazard was properly mitigated. This assessment required exposure limits around the MPR to be <100 mrem/h. At the closest reasonably acceptable distance [12.7 cm (5 in.) from the riser], the dose rate was calculated to be 46 mrem/h. The results of WHC's study pointed out that if a worker were to extend a hand underneath the riser, the dose exposure to the worker would increase to 173 mrem/h. A precaution to this effect has been included in the standard work controls.

On the basis of design calculations and drawings presented in Ref. 17, there are no new hazards to be addressed in the evaluation process and in Sec. 6.

4.6.4.5. Ejection of MPR. The MPR structurally is connected to the massive concrete support pad through three support brackets. A GRE with a burn will impose a large gas ejection load on these support brackets and concrete anchors. WHC/ADVENT engineering conducted structural dynamic studies based on the maximum expected gas loads and seismically induced loads to properly size these elements. Structural improvements to the MPR support leg design were incorporated to prevent failure modes, which would lead to ejection of the MPR.

These analyses also included the effects of wasteberg impacts in conjunction with the burn event in establishing their design margin.

We concluded that the MPR will survive a hypothetical ejection from a gas release and burn event.

4.6.4.6. Flooding of Tank. Decontamination operations connected with removing equipment from the MPR will introduce modest quantities of water into the tank. Adequate controls monitor and limit the water addition (Sec. 6.0).

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5.0. CONSEQUENCES OF ACCIDENTS

In this section, the consequences of accidents are discussed. Section 5.1 presents the acceptance criteria. Analysis conditions are discussed in Sec. 5.2. Section 5.3 discusses the radiological, toxicological, and structural consequences of differently sized GREs. Sections 5.4 through 5.6 present the consequences of accidents during pump installation, operation, and removal, respectively. The consequences of leaving the tank unmitigated by failing to replace the pump are discussed in Sec. 5.7. Finally, Sec. 5.8 provides a summary and conclusions of the consequence analyses.

5.1. Acceptance Criteria

This section defines the acceptance criteria used in determining the acceptability of accidents analyzed in this SA. These criteria are divided into three major areas: radiological EDE, toxic gas exposure, and structural acceptance criteria. Radiological dose limits and toxic gas (ammonia) exposure limits were taken from the material provided in the WHC "Nonreactor Facility Safety Analysis Manual"[1] and the WHC "Hanford Site Tank Farm Facilities Interim Safety Basis."[2] Structural limits were developed from these documents to maintain the integrity of the tank and prevent leakage of radioactive material.

5.1.1. Onsite and Offsite Dose Acceptance Criteria

Radiological dose acceptance criteria used in determining the acceptability of accidents with radioactivity released were obtained from Refs. 1 and 2. To use the risk guidelines, a frequency and consequence for the particular accident must be analyzed. The individual accident frequencies currently are not known precisely. The best estimates of the frequencies are given in Sec. 4, and the basis of the frequencies is discussed in App. J. These analyses reflect the best-estimate frequencies under current (mitigated) tank conditions. The present analysis was performed using conservative modeling assumptions, and the consequences have been judged using best estimates for the frequencies. References 1 and 2 provide the frequency-dependent, radiological dose limits shown in Table 5-1. Assuming a linear variation on a log-log scale within the frequency ranges shown in Table 5-1, the onsite acceptance criterion may be obtained as

$$D = \begin{cases} 1 & \text{if } 10^{-1} \le F \le 1, \\ 0.2 \times F^{-0.69897} & \text{if } 10^{-2} \le F < 10^{-1}, \\ 1.0 \times F^{-0.349485} & \text{if } 10^{-4} \le F < 10^{-2}, \\ 1.5625 \times F^{-0.30103} & \text{if } 10^{-6} \le F < 10^{-4}, \end{cases} \tag{5-1}$$

where D is the dose in rems and F is the frequency per year. Likewise, the offsite acceptance criterion is obtained as

TABLE 5-1
RADIOLOGICAL RISK GUIDELINES

Frequency Category	Frequency Range (yr^{-1})	EDE (rems)	Organ Dose Equivalent for Lens of Eye (rems)	Organ Dose Equivalent for All Other Organs (rems)
Offsite Guidelines				
Anticipated	1 to 10^{-2}	0.01 to 0.5	0.03 to 1.5	0.1 to 5
Unlikely	10^{-2} to 10^{-4}	0.5 to 4	1.5 to 12	5 to 40
Extremely Unlikely	10^{-4} to 10^{-6}	4 to 25	12 to 75	40 to 250
Onsite Guidelines				
Anticipated[a]	1.0 to 0.1	1 to 1	3 to 3	10 to 10
Anticipated	0.1 to 10^{-2}	1 to 5	3 to 15	10 to 50
Unlikely	10^{-2} to 10^{-4}	5 to 25	15 to 75	50 to 250
Extremely Unlikely	10^{-4} to 10^{-6}	25 to 100	75 to 300	250 to 1000

[a] Reference 2 indicates that to evaluate onsite risk for event frequencies >1 x 10^{-1}/yr, a guideline of 1 rem should be used for the 1 x 10^{-1} to 1/yr frequency range.

$$D = \begin{cases} 0.01 \times F^{-0.849485} & \text{if} \quad 10^{-2} \le F < 1, \\ 0.0625 \times F^{-0.451545} & \text{if} \quad 10^{-4} \le F < 10^{-2}, \\ 0.1024 \times F^{-0.39794} & \text{if} \quad 10^{-6} \le F < 10^{-4}. \end{cases} \tag{5-2}$$

The onsite and offsite organ dose criteria are obtained by multiplying Eqs. (5-1) and (5-2) by 10.

5.1.2. Toxicological Acceptance Criteria

Toxicological acceptance criteria have been developed from the guidelines presented in Refs. 1 and 2. Ammonia has been detected and measured in the gas releases from Tank 101-SY. In the referenced materials, the onsite and offsite concentration limits are given in terms of ERPGs. The ERPG values for ammonia developed by the AIHA were obtained from the Hanford Environmental Health Foundation, as required by Ref. 1. ERPG-1 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing anything other than mild transient adverse health effects or perceiving a clearly defined objectionable odor, which for ammonia has been determined to be 25 ppm. ERPG-2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action, which for ammonia has been determined to be 200 ppm (Table 5-2). ERPG-3 is the maximum

TABLE 5-2
NONRADIOLOGICAL RISK GUIDELINES FOR AMMONIA EXPOSURES

Frequency Range (yr^{-1})	Onsite Concentration Limit (ppm)	Offsite Concentration Limit (ppm)
1 to 10^{-6}	200 to 1000	25 to 200

airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing life-threatening effects, which for ammonia has been determined to be 1000 ppm.

As with the radiological acceptance criteria, we assume that the toxicological acceptance criteria vary linearly on a log-log scale within the frequency range shown in Table 5-2. Thus, the onsite acceptance criterion is obtained as

$$C = 200 \times F^{-0.1165} \quad \text{for} \quad 10^{-6} \le F \le 1 , \tag{5-3}$$

where C is the ammonia concentration in parts per million and F is the frequency per year. Likewise, the offsite acceptance criterion is obtained as

$$C = 25 \times F^{-0.150515} \quad \text{for} \quad 10^{-6} \le F \le 1 . \tag{5-4}$$

5.1.3. Receptor Locations

Reference 2 defines two receptor locations that are to be evaluated for comparison with the risk guidelines: a maximum onsite individual and a maximum offsite individual. From Ref. 2, these individuals are defined as follows:

> For tank farm releases, the maximum onsite individual is the hypothetical receptor located 100 meters from the release in the sector with the highest ground level concentration (i.e., the highest atmospheric dispersion factor). WHC-CM-4-46 requires the maximum onsite individual to be at least 100 meters from the release point. In addition to being the most conservative choice, this simplifies the analysis by allowing use of a single onsite receptor distance rather than the varying distances from each tank to the facility boundary (i.e., tank farm fence). The maximum offsite individual is the hypothetical receptor at the site boundary location with the highest ground level concentration (i.e., the highest atmospheric dispersion factor). The location of the maximum offsite individual will be different for different release locations.

Based on these criteria, the maximum onsite individual is taken to be 100 m (328 ft) from the tank, and the maximum offsite individual is taken to be 13.8 km (8.6 miles) west northwest of the tank farm. Highway 240, located 3.9 km (2.4 miles) away from the tank, is the closest that the general public can come into contact with an airborn release.

5.1.4. Structural Acceptance Criteria

The structural acceptance criteria are based on predicting structural failure of Tank 101-SY. In general, the local strains are computed and compared with a limiting strain to determine whether the liner tears. If a tear starts, local stresses will be compared to a limiting stress to determine whether the tear can propagate.

The failure criteria for Tank 101-SY are:

1. No failure of the leak-tight integrity of either the primary or secondary steel liner below the "as-designed" liquid level of 10.67 m (420 in.) is allowed. Failure of the primary or secondary steel liner is assumed when the total plastic strain exceeds the limiting uniaxial strain value of 27% with the appropriate knock-down factor for strain concentrations at any localized area.

2. No gross structural deformations of the primary or secondary steel liner are allowed above the "as-designed" liquid waste surface:

   - Rebar stresses must be maintained below ultimate strength to prevent excessive deformations.

   - Deformations extending beyond the limit of $2.5[Rt]^{1/2}$ (where R is the radius and t is the thickness) from the point of loading in either the meridional or circumferential direction in the plane of the tank's primary and secondary steel liner are considered gross deformations and are not allowed.

   - Deformations shown to be below the limits stipulated above are considered localized effects that do not affect the overall behavior or response of the tank structure.

3. No primary or secondary steel liner tears >0.254 m (10 in.) in length are allowed in the dome region or above the as-designed waste level. Failure is assumed when steel liner tears (cracks) exceed this critical flaw length. For cracks smaller than the limit stated above, assurance shall be made that under a beyond-design-basis burn event, the crack will not propagate.

The basis for the structural acceptance criteria is discussed in App. K.

5.2. Analysis Conditions

Hazards are identified in Sec. 3, and accident sequences are developed in Sec. 4. Sequences are developed based on the different phases of the proposed action (i.e., pump installation, operation, and removal). However, the actual analyses for GREs and burns are performed as a function of the size of the GRE; these results then are related back to the specific accident sequences analyzed.

5.2.1. Ignition Location and Waste Compressibility

In general, for the burn analyses, two different combustion locations for the initial ignition of the release gases are used: one at the top center of the vapor dome where the flame front propagates from the tank top to the waste surface (top-down burn) and the other at the side of the tank on the waste surface where the flame front propagates from one side of the waste surface to the tank exit ducts (bottom-up burn). The top-down burn calculations predict the fastest pressure-rise times because the flame area is maximum at any given time. Structural analyses indicate that the rate of pressurization is an important parameter for determining the structural limits of the tank. Therefore, the top-down burn results are used in the structural analyses. The bottom-up burn produce a longer pressure-rise time but results in greater radiological releases from the tank because particle transport from the waste surface to the tank exit ducts is enhanced by the sweeping path of the flame front.

Figure 5-1 shows the pressure traces obtained from HMS/TRAC simulations using a top-down burn and a bottom-up burn with inoperable ventilation system and a 245-m^3 (8650-ft^3) gas release. All top-down burn analyses (used to determine the tank's structural limit) are performed with an inoperable ventilation system. The bottom-up burn calculations used to determine the radiological consequences are performed with both an operable and inoperable ventilation system. Earlier analysis indicated that the radiological consequences of a burn accident are very insensitive to the operability of the ventilation system.

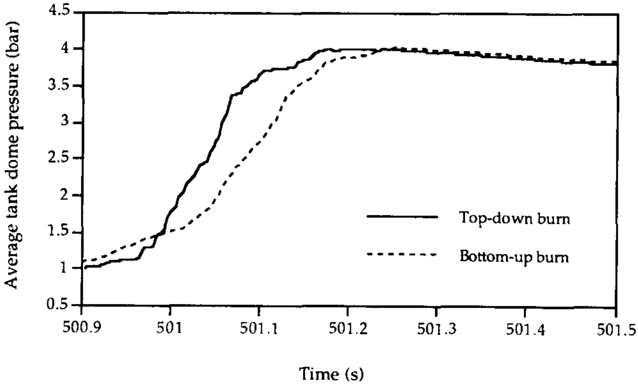

Fig. 5-1. Pressure traces for top-down and bottom-up burns for a 245-m^3 (8650-ft^3) release.

Thus, the radiological consequences of a burn are bounded by the inoperable ventilation case.

In some of the earlier analyses, we took credit for the compression of the retained gases in the liquid waste during the burn phase. We later removed this option from the burn model. In all current calculations, we assume that the waste is incompressible.

5.2.2. MPR Flow Area

Tank 101-SY utilizes an MPR with multiple access ports and pressure relief panels. If all access ports in the MPR are filled with additional equipment/instruments, the maximum flow area for pressure relief is 66% of the 1.07-m (42-in.) riser flow area. Because this case provides the minimum relief area (maximum peak pressure), all structural-limit-determination burn cases are performed using a 66% relief area. As discussed later, the radiological and toxicological consequences are very insensitive to the relief area. For the accident sequences involving the inadvertent opening of the MPR, we use a single panel opening prematurely (GRE without a burn). Opening of a single panel corresponds to 50% of the riser area.

5.2.3. Gas Composition and Gas Release Rate

The consequences of the majority of accidents analyzed in this section are affected by the gas release volume. In addition to the total volume, gas composition and the release rate also are important parameters that affect the consequences. In all accidents analyzed here, the conservative estimate for gas composition (see App. B) and the conservative gas release rate model (see App. D) are used.

5.2.4. Radiological Consequence Analysis

The radiological consequences at different locations of 1 kg (2.2 lbm) of material release from the tank are computed in App. G for unfavorable meteorological conditions corresponding to a 95% interval. These unit dose calculations are used as multipliers to compute the total consequence, given the total amount of release. The critical organ dose may be obtained by multiplying the estimated doses by 15.

WHC[3] indicated that "Kr-81 and Kr-83m are the only radionuclides where the lens of the eye is limiting." Krypton-81 has a half-life of 210,000 yr and is produced by electron capture of ^{81}Rb or by activation of ^{80}Kr. Krypton-83m has a half-life of 1.83 h; thus, it is highly unlikely that any exists in the tank waste. WHC[3] does not expect these two isotopes to be present in the tank waste. Therefore, the critical dose to the lens of the eyes will not be considered in these analyses.

For all burn cases analyzed, we assume that a fixed amount of material is released from the filter system. The radiological consequences of a postulated filter system release is estimated based on the following assumptions:

1. The ventilation system is operating at the administrative dose limit of 200 mrem/h. Thus, all components in the system are reading 200 mrem/h (ductwork, moisture separator, heater, HEPA filters, etc.)

2. The radionuclide contributing to this dose reading is ^{137}Cs.

3. Ten percent of all radioactive material in the ventilation system is aerosolized in a burp and burn event. One hundred percent of the amount aerosolized is respirable (<10 μ in size).

4. For conservatism, the isotopic density and isotopic inventory (curies per kilogram) of the waste crust is used to perform the onsite and offsite dose analysis. A value of 0.41 Ci/kg of crust for ^{137}Cs was used in the analysis. For the 200 mrem/h loading, a release of 0.15 Ci was calculated.[4] The calculated amount of material released was 0.360 kg (0.794 lbm).[4]

Table 5-3 lists the radiological consequences of releasing a total of 0.360 kg (0.794 lbm) of waste, which is based on the methodology described in App. G. In previous revisions of the SA, a more conservative value of 1.11 kg (2.45 lbm) was used. This new value, 0.360 kg (0.794 lbm), was calculated by WHC[4] based on a maximum administrative dose level reading on the exhaust system components of 200 mrem/h. The 0.360-kg (0.794-lbm) value was reviewed[5] and believed to be conservative. The actual value may be much lower than 0.360 kg (0.794 lbm) because the exhaust system normally would not be operated at the administrative limit of 200 mrem/h, and experimental evidence[6] indicates that the actual aerosolized fraction from a ventilation system failure is closer to 1 to 2% and not 10%. In addition, the actual radionuclide inventory in the exhaust system appears to be comprised mostly of ^{137}Cs (in the form of cesium salts), whereas other isotopes are more important to the dose consequences (chiefly ^{237}Np and ^{241}Am); these isotopes may not be present in the exhaust system. Thus, the values shown in Table 5-3 are considered very conservative. The release from the filter system is added to the releases from other sources during a burn.

TABLE 5-3
CALCULATED INCREMENTAL RADIOLOGICAL DOSES FOR A FILTER SYSTEM RELEASE

Receptor Location	Distance	Riser Release EDE (rem)
SY Farm Area	0.10	0.99
242-S Evaporator	0.30 W	0.20
U Plant	0.78 NE	0.042
Hwy. 240	3.9 SE	0.0032
Max. Offsite—Acute	13.8 WNW	0.00048
Max. Offsite—50-yr Committed	13.8 WNW	0.0158

The radiological accident consequences evaluations did not take credit for any protective measures such as evacuations or respiratory equipment. This is a conservative assumption because shortly after a gas release, an alarm would sound that would be audible in the vicinity of the tank farm, and onsite workers would be trained in the appropriate alarm response to minimize the consequences of the gas release. As stated in previous sections, the assumed accident consequence analysis has numerous conservatisms, including the size of the gas release, the time period of the GRE, the meteorological conditions during the accident, and no credit taken for cleanup of the site to avoid future exposure from surface contamination.

5.2.5. Toxicological Consequence Analysis

The toxicological exposure factors corresponding to 1 g/s (0.132 lbm/min) of ammonia release rate are obtained from App. G and multiplied by the actual peak ammonia release rate to estimate the ammonia exposure factors at different locations. The multipliers obtained from App. G for ammonia exposure also correspond to unfavorable meteorological conditions resulting in a 95% interval. The toxicological consequences are sensitive to three primary inputs to the analysis: (1) ammonia concentration in the release gas, (2) volume of the release gas, and (3) the rate at which the gas is released. Conservative values were used for all of these parameters.

The ammonia releases exist with the naturally occurring gas releases, and pump operation under worst-case conditions is only marginally expected to increase the exposure. During previous GREs, ammonia concentrations have been measured at the stack and the odor of ammonia has been detected, but no ammonia exposure consequences have been noted. For all the analyzed cases, the offsite toxicological consequences at 13.8 km essentially are zero (<1.0 ppm). The on-site ammonia concentrations are computed using the peak mass flow rate during a GRE. Figure 5-2 shows the ammonia mass flow rate out of an open riser during a 296.8-m^3 (10,480-ft^3) release with an inoperable ventilation system. For this case, we used a 16.5-g/s (131-lbm/h) ammonia flow rate to compute the consequences. As shown in this figure, the flow rate remains >8 g/s (63.5 lbm/h) only for 3 min and >1 g/s (8 lbm/h) only for 7 min. Considering that the acceptance guidelines are based on 1-h exposure times, the current methodology is believed to be very conservative.

5.2.6. Maximum Allowable Releases

During each phase of the operation, maximum allowable releases are determined. For pump installation and removal, the most limiting accident in determining this maximum allowable release is the ejection accident discussed in App. M. As determined in App. M, the maximum allowable releases for pump installation and removal are 103.4 m^3 (3650 ft^3) and 70.8 m^3 (2500 ft^3), respectively. Conservative level controls are implemented (see Sec. 6 and App. C) to minimize the probability of exceeding these releases. The maximum allowable release during pump operation is limited by the tank structural analysis, as discussed in App. K. To meet the

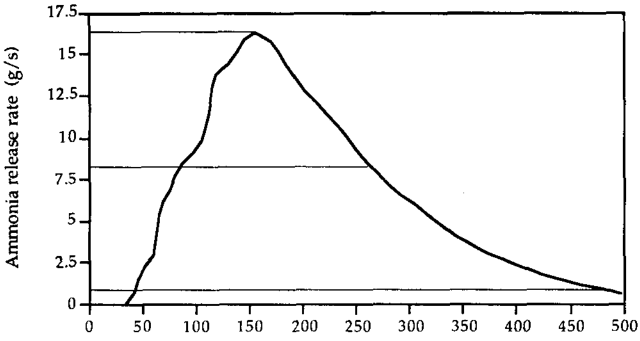

Fig. 5-2. Ammonia mass flow rate out of an open riser during a 296.8-m^3 (10,480-ft^3) release.

structural acceptance guideline, the maximum allowable release during pump operation is set to 245 m^3 (8650 ft^3) (see App. K). A conservative level control is implemented (see Sec. 6 and App. C) to minimize the probability of exceeding this release. Using the maximum level control for intrusive activities with an open riser, we computed the maximum allowable release as 155.5 m^3 (5490 ft^3) (App. Y).

Earlier revisions had a specific set of combustion analyses for each accident corresponding to the maximum allowable release for the specific phase of the activity. However, whenever one of the analyses that affected the maximum allowable release changed, all analyses were affected. As a result, the revisions became a nearly endless loop of one analysis affecting the next until the last affected the first and the loop started again. In this current revision, the loop is broken by having different bounding analyses for different cases.

5.3. Consequences of Differently Sized GREs

For all cases, we analyzed the structural consequences using the inoperable ventilation case and 66% of the riser area for the pressure relief through the MPR. The pressure trace is the important parameter obtained from the HMS/TRAC calculations and is used in the ABAQUS model to predict the structural response of the tank (see App. K).

In terms of toxicological consequences, we are concerned only with ammonia, which burns during the burn phase. Thus, the toxicological consequences were evaluated only during the gas release phase (without burn) (see App. D). As discussed in App. D, the analysis showed that the peak ammonia release rate is insensitive to the open-riser area. Therefore, we discuss only the closed tank and 1.067-m (42-in.)-open-riser case in this section. These two cases were analyzed for both operable and inoperable ventilation conditions. For the operable ventilation case, we set the ventilation flow rate to 0.19 m^3/s (400 ft^3/min). The toxicological consequences were computed using the methodology described in App. G. Using the peak ammonia release rates given in App. D and the ammonia exposure factors given in App. G, we calculated the peak ammonia concentrations in various locations.

The radiological consequences of a GRE without a burn are negligible. When the ventilation is operable, the initial peak fuel concentration in the dome before the burn is slightly less in comparison to the inoperable ventilation case. However, the differences are very small and are within the uncertainty range of the computations. Consequently, we evaluated only the consequences for the inoperable ventilation case, which are slightly more conservative than for the operable ventilation case. The radiological consequences associated with the releases were computed using the methodology described in App. G. For each gas release, the amount of gas released at the ground level, the inlet stack, and the exhaust stack was computed (see App. D for quantities). As discussed in Sec. 5.2.4, the radiological source term includes 0.36 kg (0.79 lbm) of waste as a result of the assumed filter train failure associated with the burn cases. It is not clear whether the ventilation system will survive the burn accident. Because the determination of whether the release occurs at the ground level or at an elevated location affects the dose received at both onsite and offsite receptors, the consequences are calculated conservatively using the maximum dose dispersion factors between stack and ground releases.

Because of this conservative approach in obtaining the dose rates, the radiological consequences for an open or closed tank are nearly identical (see App. D for details). The MPR opens during a burn phase. However, the radiological consequences are insensitive to the MPR area that is open. Consequently, only the closed-tank conditions are discussed in this appendix.

In most cases, the consequences of a 296.8-m^3 (10,480-ft^3) release (discussed in Sec. 5.3.1) are used to make the bounding arguments. To provide bounding arguments for different accidents, similar calculations also were performed for a 113.3-m^3 (4000-ft^3) release and discussed in Sec. 5.3.2. The structural consequences of a 245-m^3 (8650-ft^3) release are discussed in Sec. 5.3.3.

5.3.1. Consequences of a 296.8-m^3 (10,480-ft^3) Release

The December 1991 and September 1992 GREs are believed to be the largest GREs in the history of the tank in terms of the total gas release volume. The December 1991 GRE resulted in a ~271-m^3 (9570-ft^3) total release, and the September 1992 GRE resulted in a ~296.8-m^3 (10,480-ft^3) total release. Thus, we use the 296.8-m^3 (10,480-ft^3) release as a typical large GRE representative of the tank's natural releases. This magnitude also bounds all maximum allowable releases discussed above.

Next, we discuss the structural radiological and toxicological consequences of a 296.8-m^3 (10,480-ft^3) release.

5.3.1.1. Structural Consequences. As discussed in App. K, and using the current conservative models, we determined that the structural consequences of a burn accident with a 296.8-m^3 (10,480-ft^3) release do not meet the acceptance criterion.

5.3.1.2. Toxicological Consequences. Using the peak ammonia release rate from the HMS/TRAC calculations (App. D) and the toxicological consequences corresponding to a unit release rate from App. G, we estimated the ammonia concentrations at various locations (Table 5-4).

5.3.1.3. Radiological Consequences. Using the total release from the HMS/TRAC calculations (App. D) and the radiological dose corresponding to a 1-kg (2.2-lbm) release (App. G), we estimated the equivalent doses at various locations, which are shown in Table 5-5. All cases shown below correspond to an inoperable ventilation case. Also, we assume that 100% of the riser area opens for pressure venting during the burn phase.

As shown in Table 5-5, the radiological consequences of a release without a burn are very small compared to the acceptance criteria even for accidents with a frequency of 1/yr. Therefore, we will not discuss this release mechanism for the other GRE sizes.

5.3.2. Consequences of a 113.3-m^3 (4000-ft^3) Release

The 113.3-m^3 (4000-ft^3) release was chosen to represent a small release. This magnitude also bounds the maximum allowable releases during pump installation and removal.

TABLE 5-4
AMMONIA EXPOSURE (ppm) FOR A 296.8-m^3 (10,480-ft^3) GRE

Accident Sequence	SY Farm	242-S Evap.	U Plant	Hwy. 240
Operable Ventilation/Closed Tank	63.2	49.47	19.2	2.0
Operable Ventilation/Open 42-in. Riser	268.1	92.4	26.4	2.6
Inoperable Ventilation/Closed Tank	64.8	50.5	19.5	2.1
Inoperable Ventilation/Open 42-in. Riser	333.0	98.1	23.5	2.1

TABLE 5-5
RADIOLOGICAL DOSE EDE (rem) FOR A 296.8-m^3 (10,480-ft^3) GRE

Accident Sequence	SY Farm	242-S Evap.	U Plant	Hwy. 240	Max. Offsite[a]	Max. Offsite[b]
No Burn/Open 42-in. Riser	4.6E-01	9.3E-02	1.9E-02	1.4E-03	2.0E-04	6.7E-03
Burn/Closed Tank	1.2E+01	2.4E+00	4.8E-01	3.5E-02	5.2E-03	1.7E-01

[a] Acute dose.
[b] 50-yr dose.

5.3.2.1. Structural Consequences. The structural consequences of a 113.3-m^3 (4000-ft^3) release with burn meet the acceptance criteria.

5.3.2.2. Toxicological Consequences. Using the same methodology as for a 296.8-m^3 (10,480-ft^3) release, we determined the toxicological consequences of a 113.3-m^3 (4000-ft^3) release, which are shown in Table 5-6.

5.3.2.3. Radiological Consequences. Using the same methodology as for a 296.8-m^3 (10,480-ft^3) release, we determined the radiological consequences of a 113.3-m^3 (4000-ft^3) release, which are shown in Table 5-7.

5.3.3. Structural Consequences of a 245-m^3 (8650-ft^3) Release

The release volume of 245 m^3 (8650 ft^3) is obtained from the window document[7] as the maximum expected window release. The window document no longer is valid because mixer pump operations altered the statistical characteristics of the GREs. Presently, the criteria for waste-intrusive activities are discussed as a function of the pump operation schedule and waste level in App. Y. Coincidentally, the 245-m^3 (8650-ft^3) release also corresponds to the maximum allowable release during pump operations as a result of the structural response of the tank to a burn initiated at the dome apex.

For the 245-m^3 (8650-ft^3) release, we discuss the structural consequences only. The pressure traces obtained from HMS/TRAC simulations for ignition locations at the dome apex and at the waste surface near the wall are shown in Fig. 5-1. In this figure, the top-down burn (ignition at the dome apex) results in a faster

TABLE 5-6
AMMONIA EXPOSURE (ppm) FOR A 113.3-m^3 (4000-ft^3) GRE

Accident Sequence	SY Farm	242-S Evap.	U Plant	Hwy. 240
Operable Ventilation/Closed Tank	9.0	7.5	3.2	0.35
Operable Ventilation/Open 42-in. Riser	22.5	12.7	5.0	0.52
Inoperable Ventilation/Closed Tank	10.5	8.1	3.1	0.33
Inoperable Ventilation/Open 42-in. Riser	52.7	16.2	4.1	0.38

TABLE 5-7
RADIOLOGICAL DOSE EDE (rem) FOR A 113.3-m^3 (4000-ft^3) GRE

Accident Sequence	SY Farm	242-S Evap.	U Plant	Hwy. 240	Max. Offsite[a]	Max. Offsite[b]
Burn/Closed Tank	8.8 E+00	1.8E+00	3.6E-01	2.6E-02	3.9E-03	1.3E-01

[a] Acute dose.
[b] 50-yr dose.

pressurization and becomes more limiting in terms of the structural response of the tank. Details of the structural analysis are provided in App. K. As shown in App. K, the deformation, stress, strain and dome displacement velocities for a 245-m^3 (8650 ft^3) release with burn are within the structural acceptance guidelines discussed in Sec. 5.1.4.

Because the structural response shows a strong dependence on the rate of pressurization (dynamic loading), it is important to discuss the conservatism in the HMS/TRAC predictions. The pressure traces shown in Fig. 5-1 correspond to flame velocities ranging from 46 to 55 m/s (150 to 180 ft/s). Obviously, larger flame velocities result in faster pressure rise, resulting in a more restrictive structural limit. For nearly stoichiometric mixtures of hydrogen and air, the laminar flame velocities are typically 3 to 4 m/s (10 to 13 ft/s). For mixtures containing <10% H_2, which are more representative of the flammable gas mixtures observed in the waste tank, the laminar flame velocities are <0.3 m/s (1 ft/s). Thus, the values computed by HMS/TRAC are ~15 times the maximum laminar flame speed and >150 times the laminar flame speed for the lean mixtures typical of the waste. Assuming a ventilation flow of 0.19 m^3/s (400 ft^3/min), the temporally peaked, spatially averaged hydrogen concentration during a 245-m^3 (8650-ft^3) release is estimated (see Fig. AA-1 in App. AA) as 5.3% using conservative estimates for the gas composition (see App. B) and gas release rates (see App. D). The same figure shows that without an operable ventilation system, the temporally peaked hydrogen concentration in the dome space is slightly higher (5.5%).

It is difficult to demonstrate that the flame speeds predicted by HMS/TRAC are conservative with direct comparison to data because there are no large-scale experiments measuring the flame velocity in mixtures containing air, hydrogen, nitrous oxide, and ammonia. There are only small-scale tests with these mixtures or large-scale tests with hydrogen-air mixtures. Small-scale tests[8] indicate that adding nitrous oxide and ammonia has little impact on the flame speed. In addition, the literature indicates that the flame speed for hydrogen-air mixtures is greater than flame speeds of other flammable gases in air.[9]

Although the laminar flame speeds are much lower than the HMS/TRAC predictions, much higher flame speeds can be achieved in large geometries as a result of turbulence. There are no significant obstructions in the dome space of the tank; thus, the turbulence is expected to have a relatively low intensity. Furthermore, the maximum ratio of the turbulent flame speed to the laminar flame speed is reported to be 16 if there are no obstacles to produce highly accelerated flames.[10] Based on this ratio, 50 m/s (160 ft/s) is a conservative estimate of the flame speed for mixtures containing <10% H_2. Large-scale test data support this conclusion for mixtures with low hydrogen concentrations.

5.4. Accident Sequences during Pump Installation

The following accidents are analyzed for the pump installation phase:

- unfiltered release through open riser without a GRE (Sec. 5.4.1),
- GRE with an open 1.07-m (42-in.) riser with or without burn (Sec. 5.4.2),
- pump ejection during installation (Sec. 5.4.3),
- spill during removal (failure to install) (Sec. 5.4.4), and
- contamination from dropped pump (failure to install) (Sec. 5.4.5).

The consequences of these accidents are compared with the acceptance criteria in Sec. 5.4.6.

5.4.1. Unfiltered Release through Open Riser

During installation of the pump, the tank is exposed to a fully open riser and the possibility of an inoperable ventilation system. Assuming a 1-h operation period while the riser is open, the probability of an inoperable ventilation system is ~5.9×10^{-5}. The frequency for pump installation is 0.125/yr. Thus, the frequency of this type of release is 7.4×10^{-6}/yr.

In the analysis, natural convection flow patterns are established owing to the heating of the dome gas from the hotter waste surface. When we assume that 12 kW is being transferred continually from the waste surface, an HMS/TRAC analysis predicts a 0.09 m^3/s volumetric flow leaving the open 1.07-m (42-in.)-diam riser. If we assume that the concentration of waste suspended in the dome space is 5.25×10^{-7} g/cm^3 (3.38×10^{-5} lbm/ft^3) then in a 1-h period, 170 g (0.375 lbm) of suspended waste is convected to the environment at ground level.

Using the unit releases described in App. G, we determined the radiological consequences of an airborne release of 0.17 kg (0.375 lbm) of material near the riser area, which are shown in Table 5-8.

TABLE 5-8
CALCULATED RADIOLOGICAL DOSES FOR UNFILTERED RELEASE THROUGH OPEN RISER

Receptor Location	Distance (km)	Riser Release EDE (rem)
SY Farm Area	0.10	4.7E-01
242-S Evaporator	0.30 W	9.4E-02
U Plant	0.78 NE	1.9E-02
Hwy. 240	3.9 SE	1.5E-03
Max. Offsite—Acute Dose	13.8 WNW	2.3E-04
Max. Offsite—50-yr Dose	13.8 WNW	7.5E-03

For the toxic gas release, an exposure of <1 ppm is calculated from the concentration of ammonia in the dome space.

5.4.2. GRE with an Open 1.07-m (42-in.) Riser with or without Burn

For pump installation, a waste level control is established such that the maximum allowable release is 103.4 m^3 (3650 ft^3). Thus, the radiological and toxicological consequences of the 113.3-m^3 (4000-ft^3) GRE case discussed in Sec. 5.3.2 bound this accident during pump installation. If we assume that the level control for installation is <10.26 m (404 in.), the frequency of a GRE during pump installation (from App. J) is 1.5×10^{-3}/yr. The probability of the ventilation system being inoperable during the GRE also is given in App. J as 4.8×10^{-3}. From the same appendix, the inadvertent opening of the MPR panel without a burn is 4.8×10^{-4}. The probability of a spark during a GRE is 1.3×10^{-3}. The combined frequencies of different accidents with radiological and toxicological consequences are shown in Sec. 5.4.6.

The structural consequences of a 103.4-m^3 (3650-ft^3) release with burn meet the acceptance criteria based on the analysis provided in App. K.

5.4.3. Pump Ejection during Installation

The pump ejection accidents are discussed in detail in App. M. The maximum allowable release is determined such that there is no pump motion during a burn accident. The radiological and toxicological consequences of the ejection accident during installation are bounded by the consequences of an ejection accident during removal.

5.4.4. Spill during Removal (Failure to Install)

The pump is not contaminated during installation. Therefore, a potential spill accident is irrelevant during the installation phase and becomes an issue only during an emergency removal after parts of the pump assembly are contaminated. Considering the successful installation of the first mixer pump, we expect the probability for an emergency removal to be much smaller than 1. Thus, the consequences and the frequency of this accident is bounded by the spill accident that is postulated to occur during removal.

5.4.5. Contamination from Dropped Pump (Failure to Install)

This accident is bounded by the spill accident.

5.4.6. Comparison of the Installation Accident Consequences with the Radiological and Toxicological Acceptance Criteria

The accidents with toxicological consequences are listed in Table 5-9, along with the estimated frequencies. The onsite toxicological consequences and the acceptance criterion for each accident also are provided in Table 5-9. All accidents resulting in toxicological consequences are analyzed without a burn. Also, the offsite consequences for ammonia are <1 ppm for all cases and are not discussed. As shown in Table 5-9, all analyzed accidents meet the toxicological acceptance guidelines.

Similarly, the accidents with radiological consequences are listed in Table 5-10, along with the estimated frequencies. The onsite, critical organ, and offsite radiological doses and the acceptance criterion for each accident also are provided in Table 5-10. In this table, all analyzed accidents meet the radiological acceptance guidelines.

5.5. Accident Sequences during Pump Operation

The following accidents are analyzed for the pump operation phase:

- GRE with or without burn (Sec. 5.5.1),
- GRE with or without burn during an intrusion (Sec. 5.5.2), and
- waste leak in pump discharge pressure measuring system (Sec. 5.5.3).

The consequences of these accidents are compared with the acceptance criteria in Sec. 5.5.4.

5.5.1. GRE with or without Burn

For pump operation, a waste level control is established such that the maximum allowable release is 245 m^3 (8650 ft^3). Thus, the radiological and toxicological consequences of the 296.8-m^3 (10,480-ft^3) GRE case discussed in Sec. 5.3.1 bound this accident during pump operation. Given that the level control for operation is ≤10.31 m (406 in.), we obtained the frequency of the maximum GRE during pump operation from App. J as 4.2 x 10^{-3}/yr. The probability of having an inoperable ventilation system during the GRE also is given in App. J as 4.8 x 10^{-3}. From the same appendix, we determined the inadvertent opening of the MPR panel without a burn as 4.8 x 10^{-4}. The probability of a spark during a GRE is 1.3 x 10^{-3}. The

TABLE 5-9
COMPARISON OF INSTALLATION ACCIDENTS WITH TOXICOLOGICAL ACCEPTANCE CRITERIA

ACCIDENT	Frequency (yr^{-1})	Onsite Consequence (ppm)	Acceptance Criterion (ppm)
GRE/Operable Ventilation/Open Riser	1.5E-03	22.5	427
GRE/Inoperable Ventilation/Open Riser	7.2 E-06	52.7	795

TABLE 5-10
COMPARISON OF INSTALLATION ACCIDENTS WITH RADIOLOGICAL ACCEPTANCE CRITERIA

ACCIDENT	Freq. (yr^{-1})	Onsite (rem)	Limit (rem)	Organ (rem)	Limit (rem)	Offsite (rem)	Limit (rem)
Unfiltered Release	5.9E-05	0.47	29	7.01	290	2.3E-04	5
GRE with Burn	2.0E-06	8.80	81	132.0	810	3.9E-03	19

combined frequencies of different accidents with radiological and toxicological consequences are shown in Sec. 5.5.4.

5.5.2. GRE with or without a Burn during Intrusion

For intrusive operations, a waste level control was established such that the maximum allowable release is <169.9 m^3 (6000 ft^3). Thus, the radiological and toxicological consequences of the 296.8 m^3 (10,480 ft^3) GRE case discussed in Sec. 5.3.1 bound this accident during an intrusive operation. Given the level control for intrusive operation is ≤ 10.26 m (404 in.), we obtained the frequency of the maximum GRE during pump operation from App. J as 1.0×10^{-3}/yr [frequency of a release between 28.3 and 169.9 m^3 (1000 and 6000 ft^3)]. This frequency is high because it covers a wide range of release volumes. Nevertheless, the consequences are within the acceptance guidelines (as discussed in Sec. 5.5.4), and further refinement in the probabilistic model is not necessary. The probability of having an inoperable ventilation system during the GRE also is given in App. J as 4.8×10^{-3}. From the same appendix, the inadvertent opening of the MPR panel without a burn is 4.8×10^{-4}. The probability of a spark during a GRE is 1.3×10^{-3}. The combined frequencies of different accidents with radiological and toxicological consequences are shown in Sec. 5.5.4.

5.5.3. Waste Leak in Pump Discharge Pressure Measuring System

This system consists of a pressure tap at the pump discharge connected to a bellows-seal arrangement that isolates the waste from oil in a tube that extends through the cover block and terminates at a pressure transducer. There is also a flush line that extends from the waste side of the bellows seal upward through the cover block. In the unlikely event of a failure of the bellows seal and a failure of the pressure-tube/gauge connection, waste could be aerosolized at 3.20 kg/h (7.03 lbm/h). Ammonia would be released at a maximum rate of 0.25 kg/h (0.54 lbm/h).

An operational requirement is the installation of a radiation-monitoring sensor within 3.05 m (10 ft) of the pump at a height of 0.46 m (1.5 ft) above grade. The alarm sensor should have an alarm set at a value according to Table I-7 in App. I, based on the actual distance of the detector from the pump. The pump must be shut down if an alarm is triggered. The maximum discharge rate is low enough that the maximum possible ammonia release is acceptable, and the radiological consequences are shown in Table 5-11, assuming that the pump is shut down within 15 min (App. I). For comparison to acceptance criterion, the frequency of this accident is conservatively ~0.01/yr (see App. I). Functional design requirements to ensure the consequences of a pressure-tubing leak are discussed in App. I, and the corresponding controls are specified in Sec. 6.

5.5.4. Comparison of the Operation Accident Consequences with Radiological and Toxicological Acceptance Criteria

Accidents with toxicological consequences are listed in Table 5-12, along with the estimated frequencies. The onsite toxicological consequences and the acceptance

TABLE 5-11
DOSES FROM PUMP PRESSURE DETECTOR LEAKS

Location	Calculated Dose (rem)
SY Tank Farm	2.2E+00
242-S Evaporator	4.4E-01
U Plant	9.0E-02
Hwy. 240	6.4E-02
Offsite (acute)	9.5E-04
Offsite (50 yr)	3.2E-02

criterion for each accident also are provided. All accidents resulting in toxicological consequences are analyzed without a burn. Also, the offsite consequences for ammonia are <1 ppm for all cases and are not discussed. As shown in Table 5-12, all analyzed accidents meet the toxicological acceptance guidelines.

Similarly, the accidents with radiological consequences are listed in Table 5-13, along with the estimated frequencies. The onsite, critical organ, and offsite radiological doses and the acceptance criterion for each accident also are provided. As shown in this table, all analyzed accidents meet the radiological acceptance guidelines.

TABLE 5-12
COMPARISON OF OPERATION ACCIDENTS WITH TOXICOLOGICAL ACCEPTANCE CRITERIA

ACCIDENT	Frequency (yr^{-1})	Onsite Consequence (ppm)	Acceptance Criterion (ppm)
GRE/Operable Ventilation	4.2×10^{-3}	63.2	378
GRE/Operable Ventilation/Open Riser	1.0×10^{-3}	268.1	447
GRE/Inoperable Ventilation	2.0×10^{-5}	64.8	705
GRE/Inoperable Ventilation/Open Riser	4.8×10^{-6}	333.0	833
Pressure Detector Leak	1.0×10^{-2}	1.4	342

TABLE 5-13
COMPARISON OF OPERATION ACCIDENTS WITH RADIOLOGICAL ACCEPTANCE CRITERIA

ACCIDENT	Freq. (yr^{-1})	Onsite (rem)	Limit (rem)	Organ (rem)	Limit (rem)	Offsite (rem)	Limit (rem)
GRE with Burn	5.5×10^{-6}	11.8	60	177	600	5.2E-03	12.7
Pressure Detector Leak	1.0×10^{-2}	2.2	5	33	50	9.5E-04	0.5

5.6. Accident Sequences during Pump Removal

The following accidents are analyzed for the pump removal phase:

- unfiltered release through an open riser without a GRE (Sec. 5.6.1),
- GRE with an open 1.07-m (42-in.) riser with or without burn (Sec. 5.6.2),
- pump ejection during removal (Sec. 5.6.3),
- spill during removal (failure to install) (Sec. 5.6.4), and
- contamination from dropped pump (failure to install) (Sec. 5.6.5).

The consequences of these accidents are compared with the acceptance criteria in Sec. 5.6.6.

5.6.1. Unfiltered Release through an Open Riser without a GRE

The consequences of this accident are identical to the unfiltered release accident discussed for pump installation in Sec. 5.4.1. The frequency of this accident is much higher than for the unfiltered release during installation because the ventilation may be turned off intentionally during removal. Thus, the accident frequency becomes equal to the pump replacement frequency of 0.125/yr.

5.6.2. GRE with an Open 1.07-m (42-in.) Riser with or without a Burn

For pump removal, a waste level control is established such that the maximum allowable release is 70.8 m^3 (2500 ft^3). Thus, the radiological and toxicological consequences of the 113.3-m^3 (4000-ft^3) GRE case discussed in Sec. 5.3.2 bound this accident during pump removal. Given that the level control for removal is <10.26 m (404 in.), we determined from App. J that the frequency of a GRE during pump removal is 1.5×10^{-3}/yr (identical to the pump installation case). Thus, all the GRE cases discussed in Sec. 5.4.1 for installation also are applicable to pump removal.

5.6.3. Pump Ejection during Removal

The pump ejection accident during removal is discussed in App. M. The maximum allowable release during pump removal is determined by the "no-motion" criterion during a burn while the pump is being removed. Consequently, the maximum amount of material that can be entrained is that which is in the riser at the time of a GRE and burn during removal. This amount is bounded by 12.8 kg (28.2 lbm), as discussed in App. M. The doses corresponding to the entrained material are estimated using the unit dose values from App. G. The results are shown in Table 5-14. The frequency of this accident (given the waste level control) is $\sim 2.0 \times 10^{-6}$/yr using the probabilistic model in App. J.

To compute the total dose, the magnitudes calculated above must be added to releases from other locations resulting from a GRE and burn accident.

The toxicological consequences are bounded by the spill accidents discussed in Sec. 5.6.4.

TABLE 5-14
DOSES FROM MATERIAL ENTRAINED DURING EJECTION ACCIDENT

Location	Calculated Dose (rem)
SY Tank Farm	35.2
242-S Evaporator	7.1
U Plant	1.4
Hwy. 240	0.11
Offsite (acute)	0.017
Offsite (50 yr)	0.563

5.6.4. Spill during Removal

The spill accident is discussed in App. L. This accident sequence assumes that a spill occurs during the handling of the pump following removal from the tank. The radiological consequences are estimated based on many conservative assumptions, as discussed in App. L.

As described in App. I, the total amount of waste spilled is ~916 kg (2020 lbm), and assuming a release fraction of 2×10^{-4}, ~0.18 kg (0.40 lbm) of material is expected to become airborne in the tank farm area. No credit is taken for the fact that the pump assembly will be enclosed in a flexible receiver as it is removed from the riser. Using the unit releases described in App. G, we determined the radiological consequences, which are shown in Table 5-15.

The most likely location for a removal spill is in the pump pit. The ammonia release from a pump pit spill is small because the spill is confined to the pump pit. A spill outside the pump pit could result in a much larger ammonia release because the spill area could be much larger. To obtain a conservative estimate of the consequences of the ammonia release during a spill outside the pump pit, the spill is assumed to occur on a smooth flat surface, which is impermeable to the waste. To be conservative, the waste is assumed to be at the maximum allowable temperature. The mass-transfer model considers spreading of the liquid, but it neglects heat transfer. The dispersion calculations used to analyze this accident account for the fact that the pool has a finite diameter. The calculations are based on 95% meteorology. The conservative results of the ammonia exposure calculations are shown in Table 5-15.

The frequency of a spill during removal is ~6×10^{-4}/yr using a 0.125/yr pump removal frequency and a spill probability of 4.8×10^{-3} per removal.

The foregoing analysis did not consider possible chemical reactions between the waste and the aluminum load-absorbing material that is in the pump pit. LANL experience with chemical waste simulants and aluminum suggests that if waste comes in contact with the aluminum honeycombed load-absorbing material that is

TABLE 5-15
CALCULATED RADIOLOGICAL AND TOXICOLOGICAL DOSES FOR PUMP REMOVAL SPILL

Receptor Location	Distance (km)	Riser Release EDE (rem)	Ammonia Exposure (ppm)
SY Farm Area	0.10	5.0E-01	86.4
242-S Evaporator	0.30 W	1.0E-01	25.1
U Plant	0.78 NE	2.0E-02	5.9
Hwy. 240	3.9 SE	1.6E-03	0.5
Max. Offsite—Acute Dose	13.8 WNW	2.4E-04	—
Max. Offsite—50-yr Dose	13.8 WNW	7.9E-03	—

in the pump pit, chemical reactions between the aluminum and sodium hydroxide or nitrates could occur, which could heat the waste. The release fraction under these chemical reactions has not been quantified, so the potential radiological consequences of a spill have not been quantified. The maximum temperature that the waste could reach is unknown. We know that the reactions produce both hydrogen and ammonia; however, the potential flammable and toxic gas releases have not been quantified.

There are several design and procedural features that greatly reduce the likelihood of a spill during pump removal.

1. The pump will be washed externally by both the water wands and spray rings before removal.

2. Controls on radiation levels near the top of the riser have been developed that limit the amount of waste that can be expected external to the pump assembly.

3. The pump will be flushed internally through several water injection locations before pump removal.

4. The pump will be drawn into a flexible receiver as it is removed from the riser. The flexible receiver will have been tested to assure that it is leakproof. The flexible receiver acceptance tests will include:

   - a fill test to confirm that the flexible receiver bag will hold 910 kg (2000 lbm) of water without breakage.

   - a leak test whereby the bag is pressurized to 3450 Pa (0.5 psi), with no loss of pressure below 25% of initial pressure in 1 h.

- a leak test whereby the blast shield is placed on a mock load frame and increasing amounts of water are added to confirm that no leakage should occur in the pump pit when water is added inside the blast shield or water is added between the bag and blast shield.

5. Provisions will be made in the work plan for quick removal of the pump-pit drain plug in the event of a spill so that waste can drain into the tank.

6. Contingency plans have been developed in the pump removal procedures such that if a spill in the pump pit occurs, the pump pit will be flushed with water.

5.6.5. Contamination from Dropped Pump

The consequences of this accident are bounded by the spill accident discussed in Sec. 5.6.4. The drop frequency is less than the spill frequency. Consequently, the risk associated with the drop of a contaminated pump is bounded by the risk of a spill.

5.6.6. Comparison of the Removal Accident Consequences with Radiological and Toxicological Acceptance Criteria

The accidents with toxicological consequences are listed in Table 5-16, along with the estimated frequencies. The onsite toxicological consequences and the acceptance criterion for each accident also are provided. All accidents resulting in toxicological consequences are analyzed without a burn. Also, the offsite consequences for ammonia are <1 ppm for all cases and are not discussed. As shown in Table 5-16, all analyzed accidents meet the toxicological acceptance guidelines.

Similarly, the accidents with radiological consequences are listed in Table 5-17, along with the estimated frequencies. The onsite, critical organ, and offsite radiological doses and the acceptance criterion for each accident also are provided. As shown in this table, all analyzed accidents meet the radiological acceptance guidelines.

TABLE 5-16
COMPARISON OF REMOVAL ACCIDENTS WITH TOXICOLOGICAL ACCEPTANCE CRITERIA

ACCIDENT	Frequency (yr^{-1})	Onsite Consequence (ppm)	Acceptance Criterion (ppm)
Spill Accident	6.0E-04	86.4	475

TABLE 5-17
COMPARISON OF REMOVAL ACCIDENTS WITH RADIOLOGICAL ACCEPTANCE CRITERIA

ACCIDENT	Freq. (yr^{-1})	Onsite (rem)	Limit (rem)	Organ (rem)	Limit (rem)	Offsite (rem)	Limit (rem)
Pump Ejection	2.0E-06	44.0	81	720	810	2.10E-2	19
Spill	6.0E-04	0.5	13	7.5	130	2.4E-4	1.78

5.7. Consequence Assessment for Failure to Replace the Pump

Given the estimated lifetime of the mixer pump as 8 yr and the current schedule for the design of the spare pumps, we determined the frequency of failing to replace the mixer pump as ~.012/yr (App. J). If the mixer pump is not replaced upon failure, the tank will revert to its episodic gas release behavior at a frequency of ~3/yr.

Because the long-terms effects of mixer pump operation on the waste behavior is not fully understood (see App. P), we cannot predict what the release of future GREs will be if the tank is left unmitigated. It is highly likely that future GREs will be similar to the GREs before pump operation, with a maximum expected release of 296. 8 m^3 (10,480 ft^3) and an uncertainty of ±70.8 m^3 (2500 ft^3). However, there also is a possibility that future GREs may be greater (App. P). Nevertheless, in this section we assess the consequences of a 296.8-m^3 (10,480-ft^3) release assuming a frequency of 0.04/yr.

As discussed in App. K and using the current conservative models, we determined that the structural consequences of a 296.8-m^3 (10,480-ft^3) gas release do not meet the acceptance criterion. On a conservative basis, we would predict a structural failure (possible dome collapse and possible tank penetration) for a 296.8-m^3 (10,480-ft^3) gas release with burn.

The onsite toxicological consequences and the acceptance criterion for each accident also are provided in Table 5-18. All accidents resulting in toxicological consequences are analyzed without a burn. Also the offsite consequences for ammonia are <1 ppm for all cases and are not discussed.

Similarly, the accidents with radiological consequences are listed in Table 5-19, along with the estimated frequencies. The onsite, critical organ, and offsite radiological doses and the acceptance criterion for each accident also are provided.

TABLE 5-18
COMPARISON OF UNMITIGATED TANK GRE WITH TOXICOLOGICAL ACCEPTANCE CRITERIA

ACCIDENT	Frequency (yr^{-1})	Onsite Consequence (ppm)	Acceptance Criterion (ppm)
GRE/Operable Ventilation	4.0E-02	63.2	291
GRE/Operable Ventilation/MPR Open	1.9E-05	268.1	710
GRE/Inoperable Ventilation	1.9E-04	64.8	543
GRE/Inoperable Ventilation/MPR Open	9.2E-08	333.0	1000

TABLE 5-19
COMPARISON OF UNMITIGATED TANK GRE WITH RADIOLOGICAL ACCEPTANCE CRITERIA

ACCIDENT	Freq. (yr^{-1})	Onsite (rem)	Limit (rem)	Organ (rem)	Limit (rem)	Offsite (rem)	Limit (rem)
GRE with Burn	5.2E-05	11.8	30	177	300	5.2E-3	5.2

5.8. Summary and Conclusions

All accidents with toxicological consequences are summarized in Table 5-20. The computed ammonia concentrations shown in Table 5-20 are plotted in Fig. 5-3 in comparison with the acceptance criterion. Only the accidents resulting in ammonia concentrations >10 ppm are shown in the figure. In Fig. 5-3, the numbers next to the data points correspond to the accident numbers in Table 5-3. As shown in Fig. 5-3, all conservatively computed ammonia concentrations fall below the acceptance guideline using the best-estimate frequencies.

All accidents resulting in radiological consequences are summarized in Table 5-21. Comparisons with the onsite, organ dose, and offsite acceptance guidelines are shown in Figs. 5-4 through 5-6. Only the accidents with consequences >0.1 rem are shown in Fig. 5-4. Likewise, the ordinates of Figs. 5-5 and 5-6 are limited to minimum consequences of 1 rem and 0.0001 rem, respectively. In Figs. 5-4 through 5-6, the numbers next to the data points correspond to the accident numbers given in Table 5-21. As shown in Figs. 5-4 through 5-6, all conservatively computed doses fall below the acceptance guideline using the best-estimate frequencies.

TABLE 5-20
SUMMARY OF ONSITE TOXICOLOGICAL CONSEQUENCES

	ACCIDENT	Frequency (yr^{-1})	Consequence (ppm)
	PUMP INSTALLATION AND REMOVAL		
1	4000-ft^3 GRE/Operable Ventilation/Open Riser	1.5E-03	23
2	4000-ft^3 GRE/Inoperable Ventilation/Open Riser	7.2E-06	53
3	Spill	6.0E-04	86
	PUMP OPERATION		
4	10,480-ft^3 GRE/Operable Ventilation	4.2E-3	63
5	10,480-ft^3 GRE/Operable Ventilation/Open Riser	1.0E-03	268
6	10,480-ft^3 GRE/Inoperable Ventilation	2.0E-05	65
7	10,480-ft^3 GRE/Inoperable Ventilation/Open Riser	4.8E-06	333
8	Pressure Detector Leak	1.0E-02	1.4
	FAILURE TO REPLACE PUMP		
9	10,480-ft^3 GRE/Operable Ventilation	4.0E-02	63
10	10,480-ft^3 GRE/Operable Ventilation/MPR Panel Open	1.9E-05	268
11	10,480-ft^3 GRE/Inoperable Ventilation	1.9E-04	65
12	10,480-ft^3 GRE/Inoperable Ventilation/MPR Panel Open	9.2E-08	333

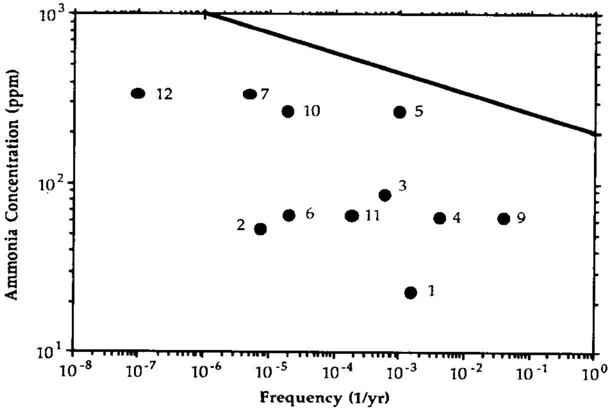

Fig. 5-3. Toxicological consequences.

TABLE 5-21
SUMMARY OF ONSITE AND OFFSITE RADIOLOGICAL CONSEQUENCES

ACCIDENT		Frequency (yr^{-1})	Onsite Dose (rem)	Organ Dose (rem)	Offsite Dose (rem)
INSTALLATION / REMOVAL					
1	Unfiltered Release	5.9E-05	0.5	7	2.3E-04
2	4000-ft^3 GRE/Burn/Installation	2.0E-06	8.8	132	3.9E-03
3	4000-ft^3 GRE/Burn/Removal	2.0E-06	44.0	720	2.1E-02
4	Spill	6.0E-04	0.5	8	2.4E-04
OPERATION					
5	10,480-ft^3 GRE/Burn	5.5E-06	11.8	177	5.2E-03
6	Pressure Detector Leak	1.0E-02	2.2	33	9.5E-04
FAILURE TO REPLACE PUMP					
7	10,480-ft^3 GRE/Burn	5.2E-05	11.8	177	5.2E-03

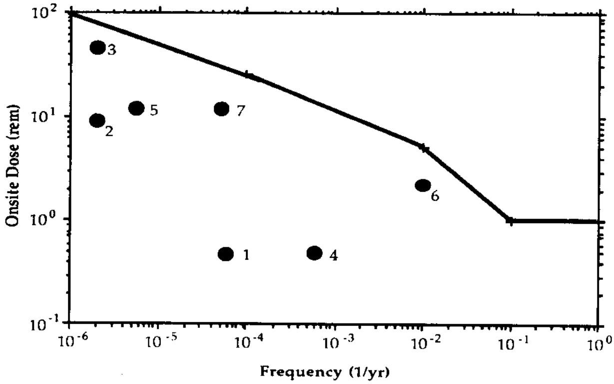

Fig. 5-4. Onsite doses.

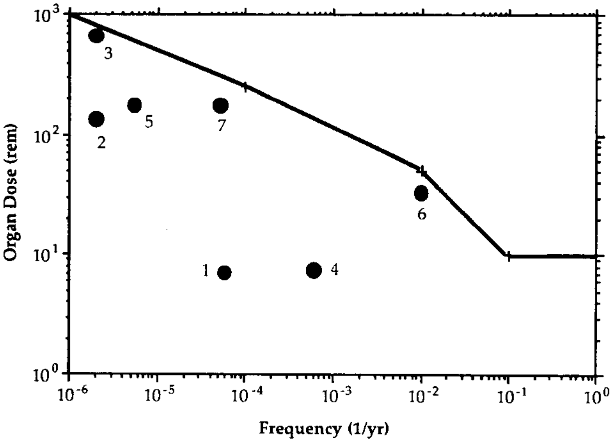

Fig. 5-5. Onsite organ doses.

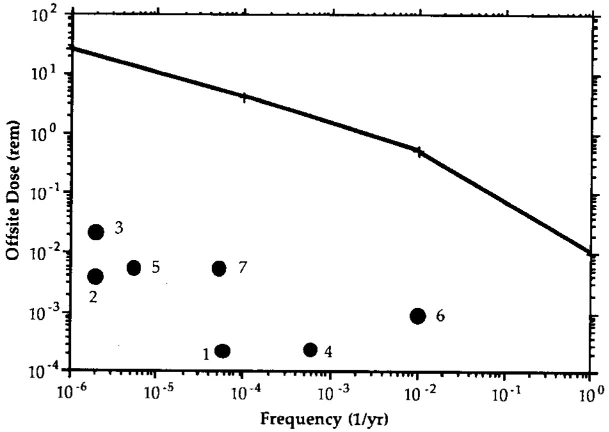

Fig. 5-6. Offsite doses.

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6.0. CONTROLS

This section provides the controls to be used for the following mitigation activities: (1) mixer pump installation (including the installation, use, and removal of the water lance); (2) mixer pump operation; (3) mixer pump removal (including the installation, use, and removal of the water wands); (4) MPR installation and removal; (5) viscometer installation, operation, and removal; and (6) voidmeter installation, operation, and removal.

A set of controls has been established for each of the activities for clearer and easier procedures development. The controls have been developed using WHC standard controls and the results, assumptions, and initial conditions of this SA. Those WHC standard controls important to the activities have been repeated in this SA for clarity; however, the set of controls listed in this SA is intended only to supplement the WHC standard controls, not replace them. WHC standard controls include a series of WHC documents that define the safety envelope for the tank farm. The primary document is the WHC Health and Safety Plan (HASP manual[1]), although other documents include the double-shell flammable gas watchlist tank safety basis document[2] and the interim safety basis document.[3] During the development of the procedures for each of the activities, the current OSRs and OSDs must be considered. The safety envelope established by the analyses shall not be changed unless approved by the Secretary of the DOE. The controls provided in this section can be modified if the appropriate organization grants approval.

Each activity is to last for a finite time period. Therefore, the controls designated for a specific activity should be followed only for that specified period of time. The time period for the applicability of the specific controls appears in the discussion of the controls for the specific activity.

Most of the controls presented in this section are based on the analyses conducted for this SA. These controls have been designed to ensure that the analysis assumptions and initial conditions are maintained throughout each of the mitigation activities. In a few cases, the controls have been developed to add an additional safety margin. Therefore, the controls should be an integral part of the procedure development process to maintain the level of safety demonstrated in this SA.

Safe conditions for operation, surveillance monitoring, and administrative controls have been developed for each system or condition required to be controlled. Safe conditions for operation are defined as the limits within which each activity will be controlled. The surveillance monitoring requirements establish how the limit shall be monitored. Administrative controls are the procedural requirements that shall be followed to ensure that the activity stays within the bounds of the SA. Safe shutdown definitions also are provided for each of the mitigation activities. These instructions provide the guidance and recommended operator actions to be taken should it be discovered that any of the controls are no longer met. As such, these sets of guidance and recommendations should be used during the development of the procedures for each activity. These actions are intended to restore the level of safety as rapidly as possible.

Sections 6.1 through 6.8 provide the specific controls to be used for the activities covered by this SA. Of these activities, pump operations are the most complex. Instrument installation and removal activities in Tank 101-SY have been performed several times and are more routine than those of the mixer pump operations. Therefore, more controls have been instituted for the operation of the mixer pump than for other processes. Because of the complexity of the mixer pump operation, these controls have been divided into three levels. Each control level requires a different level of approval for modification and for restarting operations after abnormal shutdowns.

Pump operation controls are designated as either Level I, Level II, or Level III. This graded approach reflects the importance of a particular control, the level of approval required for modification, and the level of approval required to restart pump operation if a particular limit is exceeded.

Level I controls are the most important and are under the most stringent management supervision. Level I controls ensure that the most important bounds, established in the SA, are maintained at all times, as demonstrated by the appropriate analyses for both potential prompt effects and post-operation effects. Changes to the Level I controls, if required, will be developed by the mixer pump support personnel. Any proposed change to the Level I controls must be approved by the TRG. Once approved by the TRG, the proposed change must be reviewed by WHC management. Upon WHC management approval, the proposed change must be reviewed and approved by the DOE/RL. Only when all approvals have been completed can the change to the Level I control be finalized. Test restart related to these controls will require TRG approval.

Level II controls are the next level in importance. These controls maintain the initial conditions assumed in the safety analyses and prevent damage to the pump and the installed hardware. The TRG must approve modifications to Level II control parameters and notify DOE/RL of the modifications and the technical bases for the modifications. Approval to restart pump operation after exceeding a Level II control requires TRG approval.

Level III controls are the lowest level in importance. These controls involve safety issues that can be controlled by administrative procedures. Changes to the Level III controls will be approved by the TRG, and DOE/RL will be notified of the changes and their technical bases. Restart after a shutdown involving a Level III control can be approved by the Test Manager.

Controls for other activities that are not designated as Level I, II, or III will be treated administratively as Level II controls. Changes to these controls will require TRG approval and WHC management review, and DOE/RL will be notified of the changes and their technical bases. Restart after shutdown involving a control that has no designated level will require TRG approval.

The roles of the TRG and the Plant Review Committee for the safe conduct of operations are defined in the test management plan. The test management plan also describes the procedures that will be followed if a Level I, II, or III controls violation is discovered. The composition of the TRG is defined in the test management plan.[4]

6.1. Standard Controls for Tank 101-SY

To promote consistent work plan preparation, a set of mitigation standard controls has been developed for open-tank operations. Open-tank mitigation activities include pump installation or removal of the mixer pump, installation or removal of the water lance, installation, operation, or removal of the water wands, and installation or removal of the MPR. The standard mitigation controls for open-tank operations are presented in Table 6-1. Similarly, a set of mitigation standard controls has been developed for closed-tank operations, such as mixer pump operation, operation of the water lance, or water wands (if applicable). The standard mitigation controls for closed-tank operations are presented in Table 6-2.

The standard control tables are referenced in the subsequent control tables developed for specific activities. Exceptions can be taken to the standard controls by explicitly annotating the activity-specific control tables. Likewise, the setpoints provided in the activity-specific table for a given control take precedence over the setpoints in the standard controls tables.

These standard mitigation controls have been developed from WHC standard controls that may be found in the previous safety documentation for Tank 101-SY.[1,2,3,5,6] These controls from past safety documentation are not repeated in total in this SA—only those controls considered particularly important to the activities covered by this SA are included. Several of the WHC standard controls have been modified to ensure their applicability to the activities covered by this SA. The modifications were required to match the assumptions and initial conditions used in this SA.

6.2. Pump Operation Controls

6.2.1. Description of Activity

The controls for mixer pump operation shall apply for the time period starting when the pump is bolted into place. Pump operation concludes when the pump is unbolted from the riser and the crane is attached for removal. By this definition, the operation period does not always mean the period during which the pump is running (bumping or mitigation operation). The operation period also applies to time periods when the pump is in a shutdown mode while residing in Tank 101-SY.

6.2.2. Controls

The controls used for the pump operations are more numerous and complex. Therefore, levels of controls have been established for mixer pump operations. Each control is designated as Level I, Level II, or Level III. This graded approach reflects the importance of a particular control, the level of approval required for modification, and the level of approval required to restart pump operation if a particular limit is exceeded. Tables 6-3, 6-4, and 6-5 provide the Level I, Level II, and Level III controls for mixer pump operation, respectively. The controls provided for mixer pump operation are based on the modified WHC standard controls and the analyses presented in this SA. The controls, which are based on the SA, were added to the set of WHC standard controls.

Pump bumping operations are subject to all controls for normal pump operation, except where specifically noted. During the operation period, we do not allow the tank to be open while the pump is running (including bumping). Open-tank conditions are allowed to exist when the pump is shut down, provided that the intrusion criteria and other applicable controls are met.

6.3. Pump Installation and Removal Controls

6.3.1. Description of Activity

The controls for the mixer pump installation process shall apply for the time period starting when the pump is attached to the crane and the riser is uncovered. The pump installation activity is complete when the pump is bolted down to the riser and the crane is disconnected. The controls for the mixer pump removal process shall apply for the time period starting when the pump is attached to the crane. The pump removal activity is complete when the mixer pump is removed from the riser, cleared of Tank 101-SY, and detached from the crane and the riser is covered.

A lift path, in accordance with the lift path analysis,[7] for hoisting the mixer pump should be followed so that it presents the least possibility of hitting risers or other safety-related equipment if the pump were dropped. The pump should be connected to the crane using a positive lock mechanism that ensures that the cables cannot be removed except by positive actions. The total weight on the tank dome should be considered during the designation of the crane placement and the determination of the mixer pump lift path.

6.3.2. Controls

The controls provided for the mixer pump installation and removal process are based on the modified WHC standard controls, the analyses presented in this SA and the WHC water addition safety evaluation report.[6] The controls, which are based on the SA, were added to the set of WHC standard controls. Table 6-6 provides a set of controls to be followed during the installation or removal of the mixer pump into Tank 101-SY, which is in addition to the WHC standard controls.

6.4. Installation, Removal, and Operation of the Water Lance

6.4.1. Description of Activity

The controls for the water-lance installation, operation, and removal processes shall apply for the time period starting when the water lance is attached to the crane and the riser is uncovered. The water-lancing activity is complete when the riser is covered and the crane is disconnected. The description of this water-lancing operation, the accident analysis, and the associated bases for the controls are discussed in App. V, the WHC water-lance safety basis document[8] and the WHC water addition safety evaluation report.[6] The plan for use of the water lance in the deployment of the viscometer and void fraction instrument are discussed in Adds. 1 and 2, respectively.

6.4.2. Controls

The controls provided for the water-lance installation, removal, and operation processes are based on the modified WHC standard controls, the WHC water-lance safety basis document,[8] and the analyses presented in this SA and appear in Table 6-7.

6.5. Installation, Removal, and Operation of the Water Wands

6.5.1. Description of Activity

The controls for the water-wand installation, operation, and removal processes shall apply for the time period starting when the water wands are attached to the crane and the risers are uncovered. The water-wand activity is complete when the riser is covered and the crane is disconnected. The description of this activity, the accident analysis, and the associated bases for the controls are discussed in App. W and the WHC water addition safety evaluation report.[6]

6.5.2. Controls

The controls provided for the water-wand installation, removal, and operation processes are based on the modified WHC standard controls and the analyses presented in this SA and appear in Table 6-8.

6.6. Installation and Removal of the MPR or MPR Flange

6.6.1. Description of Activity

The controls for the MPR installation and removal processes shall apply for the time period starting when the MPR is attached to the crane and the riser is uncovered. The MPR activity is complete when the riser is covered and the crane is disconnected. The description of this activity, the accident analysis, and the associated bases for the controls are discussed in Sec. 4.6.3.2.

6.6.2. Controls

The controls provided for MPR installation, removal, and operation processes are based on the modified WHC standard controls and the analyses presented in this SA and appear in Table 6-9.

6.7. Installation, Removal, and Operation of the *In Situ* Viscometer

6.7.1. Description of Activity

The controls for the viscometer installation, operation, and removal processes shall apply for the time period starting when the viscometer is attached to the crane and the riser is uncovered. The viscometer activity is complete when the riser is covered and the crane is disconnected. The description of this activity, the accident analysis, and the associated bases for the controls are discussed in Add. 1.

6.7.2. Controls

The controls provided for the viscometer installation, removal and operation processes are based on the modified WHC standard controls and appear in Table 6-10. The analyses for these controls are presented in this SA and in Add. 1.

6.8. Installation, Removal, and Operation of the Voidmeter

6.8.1. Description of Activity

The controls for the voidmeter installation, operation, and removal processes shall apply for the time period starting when the voidmeter is attached to the crane and the riser is uncovered. The voidmeter activity is complete when the riser is covered and the crane is disconnected. The description of this activity, the accident analysis, and the associated bases for the controls are discussed in Add. 2.

6.8.2. Controls

The controls provided for the voidmeter installation, removal, and operation processes are based on the modified WHC standard controls and appear in Table 6-11. The analyses for these controls are presented in this SA and in Add. 2.

6.9. Conclusions

Controls were developed for each of the following Tank 101-SY mitigation activities: (1) mixer pump installation (including the installation, use, and removal of the water lance); (2) mixer pump operation; (3) mixer pump removal (including the installation, use, and removal of the water wands); (4) MPR installation and removal; (5) viscometer installation, operation, and removal; and (6) voidmeter installation, operation, and removal. The controls for the these activities are based on WHC standard controls and the analyses presented in the SA. Modifications were made to the WHC standard controls to make them specific to each of the activities analyzed in the SA. These modified standard controls were combined with those that were based on the results of the SAs. The design of the hydrogen mitigation system, the conservative approach to the analyses, and the controls established for each activity ensure that these hydrogen mitigation activities can be performed within the bounds of the SA.

REFERENCES

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TABLE 6-1
MITIGATION ACTIVITIES STANDARD CONTROLS FOR OPEN-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Ventilation System	Both the primary exhauster and auxiliary exhauster must be available before commencing this activity	DACS, data logger, or per WHC procedure	Assure both exhausters operational before commencing activity	WHC Modified Standard Controls	If activity has not started, do not start activity unless authorized by TRG
- Primary Ventilation Flow Rate	Minimum flow 0.19 m^3/s (400 ft^3/min)	DACS	Alarm at 0.20 m^3/s (425 ft^3/min) Place tank in safe shutdown mode if primary ventilation fails and get auxiliary exhauster on line	WHC Standard Controls	Terminate activities and hold assembly in place while ventilation flow is <0.19 m^3/s (400 ft^3/min) during primary exhauster investigation. If primary exhauster flow is not available within 1 h, start auxiliary exhauster for ventilation. If assembly is in the riser, continue installation with auxiliary exhauster operating at 0.19 m^3/s (400 ft^3/min). If the assembly is not in the riser, move assembly to a holding place and wait for primary exhauster flow of 0.19 m^3/s (400 ft^3/min) to be restored
	Maximum flow 0.33 m^3/s (700 ft^3/min)	DACS	Alarm at 0.319 m^3/s (675 ft^3/min)	WHC Standard Controls	Terminate activity and investigate the reasons for ventilation flow being > 0.33 m^3/s (700 ft^3/min) from Tank 101-SY. Do not continue activities until Tank 101-SY flow is <0.33 m^3/s (700 ft^3/min)
- Hydrogen Concentration	Initiate operations when H_2 concentration <500 ppm	DACS	Do not initiate activity if H_2 concentration $\geq$ 500 ppm	SA (Apps. R and U)	Activities can be initiated only while the hydrogen concentrations are relatively low
Gas Concentrations (All Locations)					
- Maximum Hydrogen Concentration	<7500 ppm	DACS or locally	Alarm at 75% SCO value. Terminate activity if SCO value is exceeded	DOE 5480.4 (NFPA) SA (Apps. B and R)	Terminate activities and remove personnel from riser area until H_2 concentration is <500 ppm
- Maximum Ammonia Concentration	<3000 ppm	DACS	Alarm if SCO is exceeded. Terminate activity if SCO value is exceeded	SA (Apps B and R)	Terminate all operations until ammonia concentration is <500 ppm

TABLE 6-1 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR OPEN-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Crane and Loads	Critical lift procedures must be in place during installation and removal equipment in risers. Administrative controls will be developed to preclude crane-to-crane interactions	Approved work plans	The readiness review shall ensure that work plans include critical lift procedures	Reduce likelihood of drop or waste spill accidents, or damage to equipment important to safety	Do not start installation or removal activities until critical lift procedures are in place
- Load Path	Loads will not be lifted over HEPA filters, risers, or other equipment important to safety	Visual	A lift path will be developed as part of the work package that will present the least possibility of hitting HEPA filters, risers, or other safety-related equipment if the load is dropped	To minimize probability of damaging equipment important to safety as a result of a drop accident	If load is over equipment that is important to safety, move the load to a safe location immediately
- Dome Loading caused by Vehicles	The crane or other heavy vehicles [≥44,400 N (10,000 lbf) gross vehicle weight] will remain at least 6.1 m (20 ft) away from the edge of the dome unless specifically authorized by the TRG based on suitable analysis	Visual	A distance of 6.1 m (20 ft) shall be clearly marked on the ground, and observers shall monitor the vehicle's position while vehicle is in motion	To prevent overloading the dome (see Refs. 9 and 10 for additional related dome-loading controls	If the crane or other heavy vehicles encroach within 6.1 m (20 ft)of the dome, remove the vehicles immediately
Intrusion Criteria	Following the last activity that can induce a gas release, there shall be at least a 4-h waiting period		All activities completed within the intrusion criteria and within work plans and procedures	SA (App. Y)	Terminate activities and place tank in safe shutdown condition if intrusion criteria is not met

TABLE 6-1 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR OPEN-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Intrusion Criteria (Cont)					
- Tank Conditions before Beginning Intrusive Activities	The tank conditions before waste-intrusive operations will be evaluated and found to be acceptable	Approved work plans	TRG will evaluate tank conditions before opening a waste-intrusive window	Minimize probability of a GRE	If waste-intrusive operations are begun without TRG authorization, terminate activities until tank conditions can be evaluated
-No Other Open-Tank Activity	No open-riser operations are allowed without TRG approval in Tanks 101-, 102-, or 103-SY while the intrusive operation in Tank 101-SY is in progress	Communication at tank DACS	Approved procedure	One operation at a time to eliminate open-riser exposure to a possible gas release	If intrusive device is over the riser, do not continue installation. Terminate activities as soon as intrusive device is lowered to a safe place and wait for cessation of other activities (observe 4-h interval after gas-releasing operations). If intrusive device is in the riser, continue installation until complete. The riser should be covered ASAP
-Communication with DACS (Tank Farm)	Tank conditions must be monitored during installation activities via an established continuous communication	Visual verification and routine inspection	The person in charge shall be in continuous communication with the personnel in the DACS trailer	To monitor general tank conditions	If the intrusive device is over the open riser, do not continue installation. Cover riser and restore or establish communications and continue operation
-Waste Level	Waste level control must be specified by the safety basis of the specific activity The specified limit must be ≤10.26 m (404 in.)	Level measurements (Primary instrument is the FIC, the use of other instruments must be authorized by the TRG)	SCO corresponds to the FIC measurement. TRG may approve using a different gauge or 0.08 in./d growth since the last FIC data to meet this control (see Apps. C and Y)	SA (Apps. C and Y)	If the waste level is greater than value specified by SCO or TRG-determined level, terminate activity. Initiate safe-shutdown procedure
Dome Space Conditions					
- Dome Pressure	≤ 0.0 in. w.g.	DACS	Alarm at 0.0 in. w.g.	OSR limit[3]	Terminate activities and remove personnel from riser area until the dome pressure is confirmed negative and the ventilation flow is confirmed to be 400 ft^3/min

TABLE 6-1 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR OPEN-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Radiation Survey'					
-Radiation at or near Risers Containing the Viscometer, Voidmeter, or MPR	Radiation survey conducted and area appropriately posted	Survey completed	Following MPR, viscometer, and/or voidmeter installation, a radiation survey shall be conducted and the area posted as required by standard WHC procedures. Tank farm operations shall verify signs appropriately posted as part of normal rounds	Standard WHC Controls	Terminate activities, and verify all applicable conditions before restarting activities
Tank Water Addition					
- Volume	All water additions must be approved by the TRG ,with the exception of routine flushes of level instruments	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank. Check waste level to ensure 10.72-m (422-in.) level not exceeded	Ref. 6	If water addition in excess of determined limit occurs by accident, terminate all activities and hold for TRG approval
- Water Temperature	Temperature shall be ≤54.4°C (130°F)	Check water tank temperature	Ensure that water temperature is below limits.	Ref. 6	Terminate activities, correct water temperature, and hold for TRG approval before restart operations
Pump Pit or Any Other Riser Pit Access Port Usage					
- Flammable Gas Concentration	If concentration <20% LFL	Approved measuring device (see HASP Manual[1])	If any of the flammability limits exceed 20% of the LFL, work shall stop. A grab sample shall be taken, and laboratory analysis shall be performed. Work shall not continue until the flammability level drops below 20% of the LFL	WHC Standard Controls (HASP Manual[1])	Terminate activities and remove personnel from riser area until combustible gas concentrations are within limits

TABLE 6-1 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR OPEN-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Breaking of Tank Containment	5-min pause in activity on break of tank containment	Visual observation or data logger reading of Tank 101-SY dome pressure to confirm breaking of containment	Alarm at tank pressure of -6.35 mm (-0.25 in.) w.g.	WHC Standard Controls	Terminate activities until procedural control problem has been corrected
Respiratory Protection					
- Supplied Air Close to Riser	For work within containment tent or within a specified distance (if containment tent is not used) of an open riser, personnel are required to use supplied air. The specified distance must comply with - Safety basis for the intrusive operation, - HASP manual,[1] and - industrial health and safety requirements		Ensure that air respirators are supplied for all personnel operating near open riser (when required) For mixer pump installation and removal, SA requires the use of supplied air inside the containment tent If the containment tent is not used during pump installation or removal, supplied air must be used within an 8.53-m (28-ft) radius of the open riser	WHC Standard Control (HASP Manual)[1]	Terminate activities and wait for proper respiratory protection to be available
- Personnel in Tank Farm	Only essential workers shall be permitted access to the areas where ammonia has the potential to exceed the IDLH limit of 300 ppm. Evacuation plans and briefings shall be conducted. Appropriate respiratory, eye, and skin protection shall be available and utilized, as directed by industrial health and safety		Comply with HASP (Safe Work Practice) and emergency response requirements, in addition to personnel orientation and training requirements	WHC Standard Controls (HASP Manual)[1]	Remove nonessential personnel in the tank farm. Terminate activities until proper respiratory protection is available

TABLE 6-1 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR OPEN-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Gas Monitoring While Containment Broken					
- Flammable Gases, Organic or Toxic Vapors	Shall not exceed limits of HASP Manual[1]	Monitor in accordance with HASP Manual[1]	Measure in accordance with HASP Manual[1]	WHC Standard Controls	Terminate activities and remove personnel from riser area until gas concentrations are within limits
Electrical and Spark Protection					
- Electrical Equipment in the Dome	All electrical equipment in the dome space must meet the hazards classification requirements, as specified in App. AA		All electrical equipment must be designed to meet the requirements specified in App. AA	App. AA	If any electrical equipment is found to be energized that does not meet the applicable requirements (or if the ventilation requirements in App. AA are not met), de-energize the equipment immediately.
- Riser Bonding to Tank to Reduce Electrostatic Spark Sources	Electrical bonding strap in place. Resistance between tank and riser cover ≤25 Ω	Ohmmeter	Ensure electrical bonding straps in place	NEC Article 250-84, IEEE Standard 142-1991	Ensure electrical bonding straps in place
- Removal of Riser Bolts to Prevent Mechanical Sparks	Use only spark-resistant tools (exception: on loosening first full turn and final tightening torque)		Ensure that spark-resistant tools are used (exceptions noted)	WHC Standard Controls	Ensure that spark-resistant tools are used (exceptions noted)
- Electrical Bond and Ground In-Tank Equipment	All in-tank equipment or any intrusive device must be electrically bonded to tank and grounded. Resistance between tank and in-tank equipment must be ≤ 25Ω	Ohmmeter	Ensure all in-tank equipment is electrically bonded to tank, grounded, and meets all existing requirements	NEC Article 250-84, IEEE Standard 142-1991	Terminate activities until equipment is properly installed
- Ground and Tank Bonding for Objects 3.05 m (10 ft) Tall or More during Installation and Removal Activities for Lightning Protection	Electrical bonding to ground and tank for installation and removal activities. Resistance between tank and equipment must be < 25 Ω	Ohmmeter	Ensure that electrical bonding and ground in place	WHC Standard Controls	Ensure that electrical bonding and ground in place

TABLE 6-1 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR OPEN-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
External Events					
- Range Fire	No range fires within 24 km (15 mi) of Tank 101-SY when riser is open	Visual. A lookout shall determine whether activities should be terminated	Before starting activities, DACS personnel shall contact the appropriate site authority and request verification that no range fires exist within 24 km (15 mi) of the tank farm	SA (App. Q)	Terminate activities in the most timely way and place tank in a safe shutdown condition as quickly as possible (note: this may entail completing the planned operations)
- Lightning	No significant thunderstorm activity reported or predicted to occur within 8 h of opening riser and within an 80.4-km (50-mi) radius	Visual. A lookout shall determine whether activities should be terminated	Before starting activities, DACS personnel shall contact the site meteorological station and verify that no thunderstorm activity is reported or predicted to occur in the vicinity of the S Complex during the expected time of activities	SA (App. Q)	Terminate activities in the most timely way, cover the riser ASAP, and place tank in a safe shutdown condition as quickly as possible (note: this may entail completing the planned operations)
- Earthquakes	No significant seismic activity. If seismic activity occurs, terminate activities and put tank in safe shutdown mode		Before activity proceeds, there should be no indication of seismic activity	SA (App. Q)	Terminate activities in the most timely way and place tank in a safe shutdown condition as quickly as possible (note: this may entail completing the planned operations)
- Tornadoes	No conditions present for tornadoes	Visual. A lookout shall determine whether activity should be terminated	Before starting activities, DACS personnel shall contact the site meteorological station and verify that no significant bad weather activity is reported or predicted to occur in the vicinity of the S Complex during the expected time of activities	SA (App. Q)	Terminate activities in the most timely way and place tank in a safe shutdown condition as quickly as possible (note: this may entail completing the planned operations)

TABLE 6-1 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR OPEN-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
-Winds	No winds >24 km/h (15 mph)	As reported by weather station	PIC checks weather forecast to determine that no winds >15 mph are expected within the operational period	Crane operations limit SA (App. Q)	Do not initiate installation until forecast is for winds <24 km/h (15 mph) for a 2-h period
- Dust Devils	No significant dust devil activity within sight of tank farm	Visual. A lookout shall determine whether activities should be terminated	The person designated as bad-weather watch shall contact the Hanford meteorological station. If dust devils seen to develop within 1.6 km (1 mi) of tank during open-riser activities, terminate activity and put tank in safe shutdown mode	SA (App. Q)	Terminate activities in the most timely way and place tank in a safe shutdown condition as quickly as possible (note: this may entail completing the planned operations)
- Volcanic Activity	No significant volcanic activity		Before activity proceeds, there should be no indication of volcanic activity	SA (App. Q)	Terminate activities in the most timely way, cover the riser ASAP, and place tank in a safe shutdown condition as quickly as possible (note: this may entail completing the planned operations)

TABLE 6-2
MITIGATION ACTIVITIES STANDARD CONTROLS FOR CLOSED-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Ventilation System	Both the primary exhauster and auxiliary exhauster must be available before commencing this activity	DACS, data logger, or per WHC procedure	Assure both exhausters operational before commencing activity	WHC Modified Standard Controls	If activity has not started, do not start activity unless authorized by TRG
- Primary Ventilation Flow Rate	Minimum flow 0.19 m^3/s (400 ft^3/min)	DACS	Alarm at 0.20 m^3/s (425 ft^3/min) Place tank in safe shutdown mode if primary ventilation fails and get auxiliary exhauster on line	WHC Standard Controls	Terminate activities while ventilation flow is <0.19 m^3/s (400 ft^3/min). If primary exhauster flow is not available within 1 h, start auxiliary exhauster for ventilation
	Maximum flow 0.33 m^3/s (700 ft^3/min)	DACS	Alarm at 0.319 m^3/s (675 ft^3/min)	WHC Standard Controls	Terminate activity and investigate the reasons for ventilation flow being > 0.33 m^3/s (700 ft^3/min) from Tank 101-SY. Do not continue activities until Tank 101-SY flow is <0.33 m^3/s (700 ft^3/min)
- Hydrogen Concentration	Initiate operations when H_2 concentration <500 ppm	DACS	Do not initiate activity if H_2 concentration >500 ppm H_2	SA (App. R)	Initiation of activities can be done only while the hydrogen concentrations are relatively low
- Minimum Flow from Tanks 102-SY and 103-SY	Combined minimum flow from Tanks 102- and 103-SY at least 2/3 the flow from Tank 101-SY before beginning activity	Data logger or per WHC procedure	Check ventilation flows for Tanks 101-, 102-, and 103-SY	WHC Modified Standard Controls	Do not start activity and rebalance flows if it is suspected that the SCO condition is not met
Central Pump Pit Cover Blocks	Must be in place before activities can proceed. This control does not apply to water-wand operations	Inspection	Inspection	SA (Sec. 2)	Terminate activities until cover blocks installed
Pump and Load Distributor	Must be bolted down	Inspection	Inspection		Terminate activities until equipment secured
Riser Covers and Pump Pit Drain	All riser covers shall be bolted down and pump pit drain shall be plugged	Inspection	Inspection	SA (App. F)	Terminate activities until equipment is secured

TABLE 6-2 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR CLOSED-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Waste Intrusion Criteria					
-No Other Open-Tank or Waste-Intrusive Activity	No open-riser operations are allowed in Tanks 101-, 102- , or 103-SY; no other closed-riser waste-intrusive activity is allowed in Tanks 101- and 103-SY while the intrusive operation in Tank 101-SY is in progress without TRG approval	Communication at tank DACS	Approved procedure	One operation at a time to eliminate (1) open-riser exposure to a gas release and (2) a simultaneous induction of GREs	In case of concurrent waste-intrusive operations, terminate all waste-intrusive activities. Observe 4-h interval between subsequent waste-intrusive operations that can induce a gas release
-Communication with DACS (Tank Farm)	Tank conditions must be monitored during intrusion activities via an established continuous communication	Visual verification and routine inspection	The person in charge shall be in continuous communication with personnel in the DACS trailer	To monitor general tank conditions	Terminate all intrusive operations until proper communication is established
Dome Space Conditions					
- Tank Dome Pressure	< -25.4 mm (-1.0 in.) w.g.	DACS	Alarm at -38.1 mm (-1.5 in.) w.g. Terminate activities if SCO is violated	SA (App. R)	Terminate all activities immediately because increasing (less negative) dome pressure is an indication of a possible flammable gas release
Electrical and Spark Protection					
- Electrical Equipment in the Dome	All electrical equipment in the dome space must meet the hazards classification requirements, as specified in App. AA		All electrical equipment must be designed to meet the requirements specified in App. AA	App. AA	If any electrical equipment is found to be energized that does not meet the applicable requirements (or if the ventilation requirements in App. AA are not met), de-energize the equipment immediately.
- Electrical Bond and Ground In-Tank Equipment	All in-tank equipment or any intrusive device must be electrically bonded to ground. Resistance between tank and in-tank equipment must be ≤ 25Ω	Inspection	Ensure all in-tank equipment is electrically bonded to grounds and meets all existing requirements	WHC Standard Controls	Terminate activities until equipment is properly installed

TABLE 6-2 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR CLOSED-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Pump Pit Ventilation Area	Pump pit ventilation area must be sufficient. The following are required: - drain pipe plugged - minimum vent area > 729 cm^2 (113 in.^{2}) - pit free space > 11.33 m^3 (400 ft^3) - leak flow area with burn in the dome <258 cm^2 (40 in.^{2}) - seal in place on pump support column - leak flow path between the dome and the pump pit shall not exceed 3.23 cm^2 (0.5 in.^{2})	Check before installing cover blocks	Ensure that pump pit SCO conditions are met before installing cover blocks	SA (App. F)	Terminate activities if it is suspected that pump pit conditions are not met
Pump Pit or Any Other Riser Pit Access Port Usage					
- Flammable Gas Concentration	If concentration <20% LFL	Approved measuring device (see HASP Manual[1])	If any of the flammability limits exceed 20% of the LFL, work shall stop. A grab sample shall be taken, and laboratory analysis shall be performed. Work shall not continue until the flammability level drops below 20% of the LFL	WHC Standard Controls (HASP Manual[1])	Terminate activities and remove personnel from riser area until combustible gas concentrations are within limits

TABLE 6-2 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR CLOSED-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Gas Concentrations (All Locations)					
- Maximum Hydrogen Concentration	<7500 ppm	DACS or locally	Alarm at 75% SCO value. Terminate activity if SCO value is exceeded	DOE 5480.4 (NFPA) and SA (Apps. B and R)	Terminate all activities until the H_2 concentration is <500 ppm
- Maximum Ammonia Concentration	<3000 ppm	DACS	Alarm if SCO is exceeded. Terminate activity if SCO value is exceeded	SA (Apps. B and R)	Terminate all intrusive operations until the ammonia concentration is <500 ppm
Personnel Protection					
- Personnel in DACS Trailer	Personnel in DACS trailer must have respiratory protection, as required by Industrial Health and Safety Group	Monitor tank for burp	Emergency procedures shall be developed for DACS personnel protection during GREs	SA (App. H)	Terminate activities if personnel protective equipment controls are not met
- Other Personnel in Tank Farm	Only essential workers shall be permitted access to the areas where ammonia can exceed the IDLH limit of 300 ppm. Evacuation plans and briefings shall be conducted. Appropriate respiratory, eye, and skin protection shall be available and utilized, as directed by industrial health and safety. The exclusion distance may be changed to meet the IDLH limit based on revised analysis and/or data		Comply with HASP (Safe Work Practice) and emergency response requirements, in addition to personnel orientation and training requirements	WHC Standard Controls (HASP Manual)[1]	Terminate activities if personnel protective equipment controls are not met

TABLE 6-2 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR CLOSED-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
MPR Vent Doors	Doors closed and shear retention plates installed	Daily visually inspection	The MPR inspection shall be inspected as part of normal tank farm rounds	Sec. 4.6.4.1	Terminate all SY Tank Farm activities immediately until situation is corrected
- Seals	No deterioration of seal material	Regular annual visual inspection	The MPR shall be inspected as part of normal annual tank farm maintenance inspections	Sec. 4.6.4.1	Terminate all SY tank farm activities until situation is corrected
- Obstructions	Vent doors must be free of drifting sand, snow, and other obstacles	Daily visual inspections	The MPR inspection shall be inspected as part of normal tank farm rounds	Sec. 4.6.4.1	If obstructed, correct situation ASAP
External Events					
- Range Fire	No range fires within 8 km (5 mi) of Tank 101-SY during activities	DACS personnel shall determine whether activities should be terminated	Before starting activities, DACS personnel shall contact the appropriate site authority and request verification that no range fires exist within 8 km (5 mi) of the tank farm	SA (App. Q)	Terminate activities in the most timely way, and place tank in a safe shutdown condition ASAP
- Lightning	No significant thunderstorm activity reported or predicted to occur within 1 h of start of activities	DACS personnel shall determine whether activities should be terminated	Before starting activities, DACS personnel shall contact the site meteorological station and verify that no thunderstorm activity is reported or predicted to occur in the vicinity of the S Complex during the expected time of activities	SA (App. Q)	Terminate activities in the most timely way, and place tank in a safe shutdown condition ASAP

TABLE 6-2 (CONT)
MITIGATION ACTIVITIES STANDARD CONTROLS FOR CLOSED-TANK CONDITIONS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Tornadoes	No conditions present for tornadoes	DACS personnel shall determine whether activity should be terminated	Before starting activities, DACS personnel shall contact the site meteorological station and verify that no significant bad-weather activity is reported or predicted to occur in the vicinity of the S Complex during the expected time of activities	SA (App. Q)	Terminate activities in the most timely way, and place tank in a safe shutdown condition ASAP
- Earthquakes	No significant seismic activity		Before activity proceeds, there shall be no indication of seismic activity	SA (App. Q)	If there are any indications of seismic activity, terminate activities and put tank in safe shutdown mode

TABLE 6-3
MIXER PUMP OPERATION: LEVEL I CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Mixer Pump					
-Operation Time Duration	Maximum of 4 h/d pump operation (see App. R for intermediate details). The pump must be operated according to a TRG-approved operations plan. The TRG may approve deviations to operation schedule to keep pump discharge nozzles cleared	DACS	Alarm at 30 s before end of operation and terminate at specified time limit	SA (App. R)	Terminate all pump operations immediately if the operation time is exceeded or if the pump is operated outside of TRG-approved operating plans or procedures
- Pump Motor Speed	Maximum 1200 rpm (see App. R for details)	DACS	Alarm at 1190 rpm or 10 rpm less than the abort limit when operating at lower speeds (automatically implemented in DACS software)	SA (App. R)	Terminate all pump operations immediately and ensure pump shutdown, monitor waste level, waste level rise rate, and hydrogen concentration. Continue to monitor these parameters
- Bumping Pump (Short-Term Startups)	Multiple starts are permitted up to 8 s total/d at 400 rpm. This 8-s bumping may be done at levels up to 10.72 m (422 in.)		At levels greater than the pump-operating limit but <10.72 m (422 in.), do not bump the pump more than 8 s/d or exceed 400 rpm unless approved by TRG		Terminate all pump operations immediately if the operation time is exceeded or if the pump is operated outside of TRG-approved operation plans or procedures
	At tank levels below the maximum pump operation level limit, the TRG may approve one bump per day up to 5 min/bump duration (exclusive of ramp-up) at speeds ≤1200 rpm to keep the pump discharge legs clear, with no minimum wait time between bumps		Not to exceed TRG-approved limits at tank levels less than the pump operation level limit		Terminate all pump operations immediately if the operation time is exceeded or if the pump is operated outside of TRG-approved operation plans or procedures

TABLE 6-3 (CONT)
MIXER PUMP OPERATION: LEVEL I CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Bumping Pump (Short-Term Startups) (Cont)	At tank levels <10.21 m (402 in.), the TRG may approve one bump per day up to 5 min/bump duration at speeds ≤1200 rpm when the following instruments (data) or equipment are available as a minimum: - one hydrogen monitor capable of detecting 0.75% H_2 - one level measurement taken in the last 4 d - either a dome pressure gauge or a ventilation flow-rate gauge with abort setpoints - either the primary or auxiliary exhauster is operating At tank levels >10.21 m (402 in.), all other controls must be met (except where specifically noted)		Not to exceed TRG-approved limits at tank levels <10.21 m (402 in.) TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed and approved (see App. C for details) Also, TRG may approve using a 2-mm/d (0.08-in./d) growth since the last available FIC data to meet the 10.21-m (402-in.) level requirement	SA (App. R) Especially at low waste levels, bumping the pump to prevent plugging is justified, even if a few instruments temporarily are out of service	When waste level is >10.21 m (402 in.), all instruments and equipment necessary to meet the applicable controls must be available for bumping
Gas Concentrations (All Locations)					
- Maximum Hydrogen Concentration	<7500 ppm	DACS or locally	Alarm at 75% SCO value. Terminate activity if SCO value is exceeded	DOE 5480.4 (NFPA) SA (Apps. B and R)	Terminate activities and remove personnel from riser area until H_2 concentration is <500 ppm
- Maximum Ammonia Concentration	<3000 ppm	DACS	Alarm if SCO is exceeded. Terminate activity if SCO value is exceeded	SA (Apps. B and R)	Terminate all operations until the ammonia concentration is < 500 ppm

TABLE 6-3 (CONT)
MIXER PUMP OPERATION: LEVEL I CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Waste Limits -Waste Tank Level					
-Maximum Pump Operating Limit	Will be ≤10.31 m (406 in.)	DACS	If the waste level is >10.21 m (402 in.) (measured by the FIC), notify the TRG and implement an aggressive pump operation schedule The TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed and approved (see App. C for details) Also, the TRG may approve using a 2-mm/d (0.08-in./d) growth since the last available FIC data to meet the alarm and abort controls	SA (App. C)	Terminate all pump operations immediately and ensure pump shutdown, monitor waste level, waste level rise rate, and hydrogen concentration
- Waste Temperature Limit	Temperature of waste shall not exceed a peak value of 57.22°C (135°F) during pump operation	DACS	Alarm at a peak value of 54.4°C (130°F). Terminate pump operation if SCO is exceeded	FDC[5] and Test Plan for Tank 101-SY Mitigation-by-Mixing Test	Terminate pump operation using the procedures for termination of operations if the peak waste temperature limit (SCO) is exceeded

TABLE 6-3 (CONT)
MIXER PUMP OPERATION: LEVEL I CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Waste Temperature Limit (Cont)	Terminate pump operation if average temperature >51.67°C (125°F) or if average temperature <43.33°C (110°F)	DACS	The TRG shall review the temperature data to assure average temperatures are within limits. The TRG shall revisit gas composition if average temperature exceeds 49°C (120°F)	SA (Apps. C and R)	Do not restart pump operation until TRG data review is complete
Long-Term Tank Behavior	No significant adverse changes in long-term tank conditions that could make accident consequences more severe than analyzed in this SA including possible changes that could make future GREs more severe than those before the pump operations.	The TRG shall review and approve periodic reports of tank behavior to determine that no adverse long-term behavior in tank conditions exists. These reports shall be generated as required by the TRG, with an interval between reports not to exceed 3 months	The data from mitigation operations in Tank 101-SY shall be monitored and analyzed to determine whether adverse changes in tank conditions have occurred. This data evaluation shall include, but not be limited to, investigations to determine whether adverse changes in gas composition, generation, or retention, NC-layer growth, crust growth or rate-of-level increase have occurred (see App. R for details)	SA (App. R)	Do not continue pump operation if adverse changes have occurred until TRG approval is granted

TABLE 6-4
MIXER PUMP OPERATION: LEVEL II CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Ventilation System	Both the primary exhauster and auxiliary exhauster must be available before commencing this activity	DACS, data logger or per WHC procedure	Assure both exhausters operational before commencing activity	WHC Modified Standard Controls	If activity has not started, do not start activity unless authorized by TRG
- Primary Ventilation Flow Rate	Minimum flow 0.19 m^3/s (400 ft^3/min)	DACS	Alarm at 0.20 m^3/s (425 ft^3/min) Place tank in safe shutdown mode if primary ventilation fails and get auxiliary exhauster on line	WHC Standard Controls	Terminate all pump operations immediately, and investigate reason for ventilation flow of <0.19 m^3/s (400 ft^3/min) from Tank 101-SY. If primary exhauster flow is not available in the near future, start auxiliary exhauster for ventilation. Do not start pump operation until the 101-SY flow of 0.19 m^3/s (400 ft^3/min) is reestablished
	Maximum flow 0.33 m^3/s (700 ft^3/min)	DACS	Alarm at 0.319 m^3/s (675 ft^3/min)	WHC Standard Controls	Terminate activity and investigate the reasons for ventilation flow being >0.33 m^3/s (700 ft^3/min) from Tank 101-SY. Do not continue activities until Tank 101-SY flow is <0.33 m^3/s (700 ft^3/min)
- Hydrogen Concentration	Initiate operations when H_2 concentration <500 ppm	DACS	Do not initiate activity if H_2 concentration >500 ppm H_2	SA (App. R)	Activities can be initiated only while the hydrogen concentrations are relatively low
	Weekly average hydrogen concentration must be >10 ppm	DACS	If the weekly average concentration is ≤19 ppm, notify the TRG while continuing pump operations according to the schedule Do not continue pump operation if the average concentration is ≤10 ppm, and wait for TRG approval (See App. R for details)	SA (App. R)	Test termination is not required for excursions of hydrogen concentration below 10 ppm. The control is established to ensure that the long-term behavior does not decrease below 10 ppm. Details are provided in App. R

TABLE 6-4 (CONT)
MIXER PUMP OPERATION: LEVEL II CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Ammonia Concentration	<500 ppm	DACS	Do not initiate pump operation if ammonia concentration >500 ppm	SA (App. R)	Terminate all operations until ammonia concentration is <500 ppm
- Minimum Flow from Tanks 102- and 103-SY	Combined minimum flow from Tanks 102-SY and 103-SY at least 2/3 the flow from 101-SY	Data logger or per WHC procedure	Check ventilation flows for Tanks 101-, 102-, and 103-SY	WHC Modified Standard Controls	Do not start activity and rebalance flows if it is suspected that the SCO condition is not met
Dome Space Conditions					
- Tank Dome Pressure	<-25.4 mm (-1.0 in.) w.g.	DACS	Alarm at -38.1 mm (-1.5 in.) w.g. Terminate pump operation if SCO is violated	SA (App. R)	Terminate all pump operations immediately because increasing (less negative) dome pressure is an indication of a possible flammable gas release
Mixer Pump					
- Pump Plugging	Terminate operations if there is indication of plugging	DACS	Operations personnel will confirm flow once the pump is up to speed	To prevent premature pump failure	Terminate pump operation and request TRG approval for nozzle-clearing operations
- Pump Motor Current	Terminate operations if current is 1.4 times expected	DACS	Alarm at 1.2 times expected. Terminate pump operation if SCO is exceeded	To prevent premature pump failure	Terminate all pump operations immediately if pump operating limits are exceeded.
- Pump Motor Oil Temperature	<107°C (225°F)	DACS	Alarm at 88°C (190°F) Terminate pump operation if alarm setpoint is exceeded	Manufacturer Specification To prevent premature pump failure	Terminate all pump operations immediately if pump operating limits are exceeded
- Pump Oil Moisture	Terminate on alarm		Terminate pump operation on alarm	To prevent premature pump failure	Terminate all pump operations immediately if pump operating limits are exceeded. For the spare pump, sample the pump oil to deter-mine if waste has entered the motor oil
- Column Strain	Strain < 194 µin./in.	DACS	Terminate pump operation if SCO is exceeded	Mixer Pump Structural Report	Terminate all pump operations immediately if pump operating limits are exceeded

TABLE 6-4 (CONT)
MIXER PUMP OPERATION: LEVEL II CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Pump Column Gas Pressure	Terminate if pressure <48.3 kPa (7 psig)	DACS	Alarm at 62.1 kPa (9 psig). Terminate pump operation if less than SCO	FDC	Terminate all pump operations immediately if the pump column gas pressure decreases below limits, and do not restart any pump operations without TRG approval. Additional analysis may be required before restart because waste intrusion and flammable gas accumulation in the pump column has not been completely addressed in this SA
- Pump Orientation	Orient pump as required by pump operation plan (provided viscometer ball is not in tank)	Per alignment procedures	Ensure power is removed from rotating motor after orientation established or interlock installed to prevent simultaneous rotation and pump operation	SA (App. R)	Terminate all pump operations immediately if pump operating limits are exceeded or if pump is operated outside of TRG-approved pump operation plans or procedures
-Pump Orientation for *In Situ* Viscometer	Operation of mixer pump is allowed if the viscometer ball must be left at the bottom of the tank. However, the pump nozzles shall not be oriented toward the viscometer (at least 10 deg away from the viscometer). No other tank components capable of inducing a GRE are allowed to operate	DACS	TRG-approved procedure	To reduce the likelihood of a ball tangling around the pump or MIT probe	Terminate mixer pump operation if any other intrusive component starts to operate. Retrieve the ball, initiate the procedure to close the isolation valve; purge the enclosure before the isolation valve is closed, close the isolation valve, and turn power off. Resume operation after requisite time has passed for other tank operations
- Discharge Pipe Vibrator Devices	Controls are in App. T. Must not be operated until procedures are approved by TRG	Per written procedure	TRG approval of the procedures	SA [Sec. 3 (describes potential hazards), App. T]	Terminate all pump operations immediately if the pump operating limits are exceeded or if the pump is operated outside of TRG-approved pump operation plans or procedures

TABLE 6-4 (CONT)
MIXER PUMP OPERATION: LEVEL II CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Respiratory Protection					
- Personnel in Tank Farm	Only essential workers shall be permitted access to the areas where ammonia has the potential to exceed the IDLH limit of 300 ppm. Evacuation plans and briefings shall be conducted. Appropriate respiratory, eye, and skin protection shall be available and utilized, as directed by industrial health and safety. The exclusion distance may be changed to meet the IDLH limit based on revised analysis and/or data		Comply with HASP, Safe Work Practice, and emergency response requirements, in addition to personnel orientation and training requirements	WHC Standard Controls (HASP Manual)[1]	Remove nonessential personnel in the tank farm. Terminate activities until proper respiratory protection is available
Tank Water Addition					
- Volume	All water additions must be approved by the TRG, with the exception of routine flushes of level instruments	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank. Check waste level to ensure 10.72-m (422-in.) level not exceeded	Ref. 6	If water addition in excess of determined limit occurs by accident, terminate all activities and hold for TRG approval
- Water Temperature	Temperature must be <54.4°C (130°F)	Monitor truck tank temperature	Tank temperature shall be measured immediately before water addition	Ref. 6	Terminate activities, correct water temperature, and hold for TRG approval before restart operations
- Other Controls Specified in App. T				SA (App. T)	Terminate activity until all controls specified in App. T are met or until TRG authorizes continued activities

TABLE 6-4 (CONT)
MIXER PUMP OPERATION: LEVEL II CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
In-Tank Instrumentation and Equipment					
- MIT Strains	Two strain gauges must be operable per MIT probe	DACS	Determine number of operable strain gauges each day. Terminate pump operation if less than two strain gauges are operable	SA (App. AB)	If strains exceed allowable strains, terminate pump operation by tripping the pump. TRG may authorize continued operations if number of operable strain gauges is insufficient
	Measure strain less than allowable strains in Table AB-6 of App. AB	DACS	Alarm at 75% of SCO. Terminate operation if SCO exceeded	SA (App. AB)	If strains exceed allowable strains, terminate pump operation by tripping the pump. TRG may authorize continued operations if number of operable strain gauges is insufficient
- VDTT Strains	Measured strain less than allowable strains in Table AB-3 of App. AB.	DACS	Alarm at 75% of SCO. Terminate pump operation if SCO exceeded	SA (App. AB)	If strains exceed allowable strains, terminate pump operation by tripping the pump. TRG may authorize continued operations if number of operable strain gauges is insufficient
- VDTT Flowmeter	Flowmeters will not be energized	DACS	Administrative procedures have been developed to assure that the VDTT flowmeters are never energized	Ref. 11	If the VDTT flowmeters are found to be energized, immediately de-energize them
Ames Echo-Ranger System (Applicable only when the instrument is energized)	Electrical settings shall not be increased from a pulse width of 0.5 ms and frequency of 600 pulses/min	Ames Instruments	Ensure that system is operated within the SCO	SA (App. X)	Terminate operation of Ames range finder. TRG approval required for restart
	During operation of echo-ranger system, ensure that the pump automatic abort signals are functioning as required for pump operation				Terminate operation of Ames range finder. TRG approval required for restart
	Ensure that approved procedures are used for all operations				Terminate operation of Ames range finder. TRG approval required for restart

TABLE 6-4 (CONT)
MIXER PUMP OPERATION: LEVEL II CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Ames Echo-Ranger System (Cont)	Ensure that the system is operated or supervised by personnel qualified to operate the pump				Terminate operation of Ames range finder. TRG approval required for restart
Radiation Protection					
- Radiation Levels in Removed Oil (Applicable to the Replacement Pump Only)	No oil replacement activities shall be performed until suitable procedures have been developed to limit the radiation levels in the oil removed from the tank	Normal WHC job control processes	The necessary valves or fittings required to be open for oil replacement shall be tagged and locked shut until appropriate procedures for oil replacement have been developed and approved by the TRG	SA (App. Z)	If oil replacement activities have begun without TRG authorization, immediately cease activities until TRG authorization is received
- External Piping Leaks	No leaks from piping pressurized by pump operation Radiation levels within 3.05 m (10 ft) of the pump shall be <75% of the values in App. I	A continuous ARM shall be located within 3.05 m (10 ft) of the pump, with an alarm in the DACS trailer. The monitor shall be in operation when the pump is operated above 530 rpm	If the alarm level is exceeded, shut the pump down and follow procedures for high-radiation alarm	SA (App. I)	Shut the pump down and follow TRG-approved alarm response procedures for high radiation levels

TABLE 6-4 (CONT)
MIXER PUMP OPERATION: LEVEL II CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Oil Compatibility (Applicable to the Spare Pump Only)	Each time a new type of oil is used in the mixer pump, the compatibility of the oil with the waste must be evaluated and documented, in conformance with WHC QA procedures	Documented laboratory analysis	The oil compatibility study must be documented, reviewed, and approved according to WHC QA procedures	To prevent hazardous conditions that may result from spilling the oil into the waste SA (App. Z)	Do not use a new type of oil until the compatibility study is completed, reviewed, and approved
MITs Validation Probe Runs	Validation probe data for the MITs shall be taken and evaluated based on a TRG-approved schedule with a frequency ≥ once per 3 months. Each MIT shall be validated with a frequency ≥ once per 6 months. When analog-to-digital conversion units are modified on the 17B MIT, both MITs shall be validated simultaneously before beginning the alternating validation cycle. Both MITs shall be validated simultaneously and expeditiously when unexpected differences develop between the data from the two MITs.	The TRG shall review and approve periodic reports of calibration probe data from the MITs to determine if there has been a significant change in the thickness of the crust or sludge layer. These reports shall be generated as required by the TRG with an interval between reports not to exceed one per 3 months	Detailed temperature profile data shall be obtained in the region of the crust and sludge layer using the TC validation probe	SA (App. R)	If required calibrations are not performed at the specified frequency, a root-cause evaluation shall be performed and a review of the conduct of operations performed

TABLE 6-4 (CONT)
MIXER PUMP OPERATION: LEVEL II CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Mixer Pump - Long-Term Operations	The mixer pump shall be operated in accordance with a long-term operations plan.[12] Any deviation must be approved by the TRG. The pump operation plan specifies pump speed, jet direction, frequency, and duration of operations as a function of waste level	Approved operation plans and procedures	Operate the pump in accordance with the long-term operations plan	To prevent the pump from plugging, prevent nonhomogeneous gas accumulations, maximize margin for pump replacement, and maximize pump lifetime [SA (App. R)]	If it is determined that the pump has not been operated in accordance with the operations plan and within the requirements of this SA, a root-cause evaluation shall be performed

TABLE 6-5
MIXER PUMP OPERATION: LEVEL III CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Applicability of Standard Controls for Closed-Tank Operation	The controls given in Table 6-2 shall be followed for mixer pump operations	See Table 6-2	See Table 6-2	See Table 6-2 for basis of specific controls	See Table 6-2 Note: Some of the controls in Table 6-2 also appear in the Level I and Level II control tables (Tables 6-3 and 6-4). In the event of duplication, it is the intent of this SA that the controls not be downgraded to Level III controls but have the level as indicated in Table 6-3 or 6-4
Pump Rotation					
- Wiring	The pump motor shall be wired so that rotation of impeller is in the normal forward direction	Ensure phasing of wiring	Test pump wiring before pump installation	SA (App. S)	Terminate pump operation if reverse rotation of pump impeller is detected and verify wiring
- Variable Speed Drive	The pump impeller shall not be rotated in the reverse direction	Ensure that reverse direction is locked out	Lock out reverse rotation capability of variable speed drive	SA (App. S)	Terminate pump operation if reverse rotation of pump impeller is detected. Do not restart operations until DACS or variable-speed-drive software has been verified
Equipment in the Pump Pit Important to Safe Operation and Replacement of the Pump	The load distribution frame and associated hardware shall be free of corrosion	An inspection of the equipment in the pump pit shall be performed at a frequency determined by the TRG.	Based on a TRG determined schedule, the load distribution frame and associated hardware shall be inspected for signs of corrosion. If corrosion is detected, a suitable evaluation will be performed promptly to determine whether the equipment should be replaced	SA (App. R)	If required inspections are not performed according to the TRG determined schedule, a root-cause evaluation and a review of the conduct of operations shall be performed

TABLE 6-6
MIXER PUMP INSTALLATION AND REMOVAL CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Applicability of Standard Controls for Open-Tank Operation	The controls given in Table 6-1 shall be followed for mixer pump installation or removal unless specifically modified in this table	See Table 6-1	See Table 6-1	See Table 6-1 for basis of specific controls	See Table 6-1
Ventilation System	Both the primary exhauster and auxiliary exhauster must be available before commencing this activity. The primary ventilation system flow may be terminated during pump removal as long as gas conditions remain within specifications	DACS, data logger, or per WHC procedure	Assure both exhausters operational before commencing activity	WHC Modified Standard Controls	If activity has not started, do not start activity unless authorized by TRG
- Primary Ventilation—Minimum Flow Rate (Ventilation System Operable)	Minimum flow with the ventilation system operating is 0.19 m^3/s (400 ft^3/min) The primary ventilation system flow may be terminated during pump removal as long as gas conditions remain within specifications			To minimize radioactive contamination of the ventilation system	If hydrogen or ammonia concentrations reach their SCO values, restore ventilation flow immediately
- Maximum Flow—Ventilation System Operable	Maximum flow 0.33 m^3/s (700 ft^3/min)	DACS	Alarm at 0.319 m^3/s (675 ft^3/min)	WHC Standard Controls	Terminate activity and investigate reasons for ventilation flow being >0.33 m^3/s (700 ft^3/min) from Tank 101-SY. Do not continue activities until Tank 101-SY flow is <0.33 m^3/s (700 ft^3/min)

TABLE 6-6 (CONT)
MIXER PUMP INSTALLATION AND REMOVAL CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Maximum Flow—Ventilation System Inoperable	Maximum flow 0.20 m^3/s (425 ft^3/min)	DACS	Alarm at 0.19 m^3/s (400 ft^3/min)	Modified WHC Standard Controls	Terminate activities and investigate reasons for ventilation flow being greater than the SCO from Tank 101-SY. Immediately restore ventilation flow on other confirming indications of gas releases
Gas Concentrations (All Locations)					
- Maximum Hydrogen Concentration (for Removal Only—for Installation, See Table 6-1)	< 7500 ppm	DACS or locally	Alarm at 80% SCO value. Terminate activity if alarm value is exceeded. Whittakers are shown to measure 80% of the nominal concentration under high-humidity conditions[13]	DOE 5480.4 (NFPA) SA (Apps. U and W)	Immediately restore ventilation system flow if ventilation system is inoperable. Terminate activities and remove personnel from riser area until H_2 concentration is <500 ppm
- Maximum Ammonia Concentration (for Removal Only—for Installation, See Table 6-1)	< 1.0 vol %	DACS or watchtender	Alarm at 75% SCO value. Terminate activity if SCO value is exceeded	SA (App. W)	Immediately restore ventilation system flow if ventilation system is inoperable. Terminate all operations until ammonia concentration is <3000 ppm
Vibrator Operation	No use of vibrators during pump installation or removal permitted without TRG approval	Surveillance	Air supply to vibrators valved out	SA (App. T)	Immediately terminate vibrator operation and verify dome hydrogen concentrations before continuing
Tank Water Addition					
- Volume for Pump Insertion	Total water addition during installation must be ≤3.8 m^3 (1000 gal) or the the amount used during water-lancing. (if water-lancing is used before pump installation). The limit may be increased with TRG approval	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank. Check waste level to ensure 10.72-m (422-in.) level not exceeded	Ref. 6 App. U	If water addition in excess of determined limit accidentally occurs, terminate all activities and hold for TRG approval

TABLE 6-6 (CONT)
MIXER PUMP INSTALLATION AND REMOVAL CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Volume for Pump Removal	Addition of ≤33.7 m^3 (8900 gal). May be increased with TRG approval	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank. Check waste level to ensure 10.72-m (422-in.) level not exceeded	Ref. 6 App. U	If water addition in excess of determined limit accidentally occurs, terminate all activities and hold for TRG approval
Crane and Loads					
- Pump Lift off the Riser	The pump should not be lifted off the load distribution frame until all water wands reach their maximum flow rate, the dome pressure equilibrates between -25.4 mm and +25.4 mm (-1 and +1 in.) w.g., and the ventilation flow is within limits	Dome pressure	This control is applicable if the water wands are used during removal and the ventilation flow is stopped. All water-wand controls are applicable, and continuous dome pressure and ventilation flow monitoring is required	SA (App. W)	Stop pump motion until the dome pressure and ventilation flow stabilizes, then resume removal
- Impact Limiter	Impact limiter must be in place	Visual monitoring	Approved work plan	SA (App. L)	Do not proceed with installation or removal activities until impact limiter is installed
- Maximum Loads during Insertion	Insertion maximum load must be less than the initial load plus 10%	Monitored by load cell	Voice alarm at initial load plus 5%. If additional weight is required to install pump into NC layer, TRG approval is required	SA (App. L)	If the maximum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued insertion operations
- Minimum Loads during Insertion—Pump in Waste	The load must be >60% of the initial load value until the critical midsection of the pump has cleared the riser (40% unload) and >50% of the initial load value (50% unload) for the remainder of insertion	Monitored by load cell	Voice alarm at halfway between the initial load and the SCO value	SA (App. L)	If the minimum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is determined, the TRG can approve continued operations. The minimum load limits when the pump is in the riser may not be lowered by the TRG without suitable analysis addressing damage to the brake shoes or sticking of the pump assembly in the riser

TABLE 6-6 (CONT)
MIXER PUMP INSTALLATION AND REMOVAL CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Minimum Loads during Insertion—Pump Not in Waste	The load must be greater than the initial load value minus 20% of the initial load value	Monitored by load cell	Voice alarm at initial load value minus 5%	SA (App. L)	If the minimum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is determined, the TRG can approve continued operations. The minimum load limits when the pump is in the riser may not be lowered by the TRG without suitable analysis addressing damage to the brake shoes or sticking of the pump assembly in the riser
- Maximum Loads during Removal	Must be <186,200 N (41,900 lbf). TRG may not approve increasing limit in excess of the working load of the lifting equipment	Monitored by load cell	Voice alarm at 133,300 N (30,000 lbf)	SA (App. L)	If the maximum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued insertion operations
- Removal Minimum Load	Must be greater than pump weight minus 35,550 N (8000 lbf)	Monitored by load cell	Voice alarm at pump weight minus 17,780 N (4000 lbf)	SA (App. L)	If the minimum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is determined, the TRG can approve continued operations. The minimum load limits when the pump is in the riser may not be lowered by the TRG without suitable analysis addressing damage to the brake shoes or sticking of the pump assembly in the riser
- Maximum Heights for Installation and Removal	Above riser 12A—2 m (6.5 ft); above pit floor—2.3 m (7.5 ft); above ground—3 m (10 ft)	Visual monitoring	Approved work plans	SA (App. L)	If the pump is over the pump pit and is at the correct height, continue installation until riser is sealed. If not, adjust to correct height and continue installation

TABLE 6-6 (CONT)
MIXER PUMP INSTALLATION AND REMOVAL CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Sluicing in the Pump					
- Sluicing Rate	Sluicing rate ≤13.6 m^3/h (60 gal./min)(or the average flow rate used during water lancing if water lancing is performed before installation)		Record the flow rate	SA (App. U)	The water flow rate must be kept below the specified limit throughout installation
Waste Level—Installation	The pump shall not be installed when the waste level is >10.24 m (403.3 in.) or after 13 d following removal of the current mixer pump when level data is not available.	Level measurement	SCO is determined by the FIC TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed and approved (see App. C)	SA (App. C)	Do not start insertion activities if the waste level exceeds the SCO
Waste Level—Removal	The pump shall not be removed when the waste level is >10.21 m (401.8 in.). If FIC data is not available, the pump must be removed within 22 d following the failure of the current pump, provided the waste level measured by the FIC at the time of failure was ≤10.16 m (400 in.)	Level measurement	Monitor level TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed and approved (see App. C) Also, TRG may approve using 2-mm/d (0.08-in./d) growth since the last available FIC reading to meet this control	SA (App. C)	Do not start removal activities if the waste level exceeds the SCO

TABLE 6-6 (CONT)
MIXER PUMP INSTALLATION AND REMOVAL CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Gamma Dose during Pump Removal	The dose rates measured at the gamma detectors in the pump pit shall be <10 rem/h	Pump pit gamma detectors	Monitor dose rates during pump removal. Decrease the withdrawal rate of the mixer pump assembly if the dose rate is 50% of the SCO	SA (App. I)	If the gamma dose rates are higher than the SCO, decrease the withdrawal rate of the mixer pump assembly to give the spray ring longer to wash the mixer pump assembly

TABLE 6-7
CONTROLS FOR WATER-LANCE INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
INSTALLATION/REMOVAL					
Applicability of Standard Controls for Open-Tank Operation	Controls given in Table 6-1 shall be followed for water-lance installation and removal	See Table 6-1	See Table 6-1	See Table 6-1 for basis of specific controls	See Table 6-1
Crane and Loads					
- Maximum Loads	Lift loads do not exceed weight plus 25% for insertion, weight plus 50% for removal	Monitored by load cell	Voice alarm at weight plus 20%	SA (App. V)	If the maximum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued activity
- Minimum Load during Removal	Assembly weight minus 50%	Monitored by load cell	Voice alarm at assembly weight minus 40%	SA (App. V)	If the minimum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued activity
- Maximum Heights	Lifting heights are the same as those used for mixer pump installation and removal For the shield plug, the maximum lifting height over the riser is 0.6 m (2 ft)	Visual monitoring	Visual monitoring	SA (App. V)	If the assembly is over the pump pit and is at the correct height, continue installation until riser is sealed. If assembly is not over the pit and is not at the correct height, adjust to correct height and continue installation
Waste Level					
- Large Lance	The large water lance must not be installed when the waste level is greater than the maximum level for dome intrusive operations (see Table 6-1) or the TRG-determined level, as adjusted for water addition during pump replacement	Level measurement	Monitor level	SA (App. Y)	Terminate insertion if tank level conditions do not meet the SCO values

TABLE 6-7 (CONT)
CONTROLS FOR WATER-LANCE INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Controls Specific to 2-in. Water-Lance Proposed for Viscometer/ Voidmeter Operations					
-Insertion/ Removal Velocity	≤0.3 m/s (1 ft/s) for insertion. ≤1.5 m/s (5 ft/min) for removal	Crane operator judgment	Approved procedure	WHC Water-Lance Safety Basis (1992)[7]	Reduce insertion velocity < SCO
-Lift Height	Limit the lift height to 1.5 m (5 ft) above riser flange. Must have elastomer gasket in place	Visual inspection	Approved work plans	Prevent damage to riser from drop	If lift height exceeds SCO lower the load and proceed
Tank Water Addition during Installation	No water addition during installation	Visual inspection	Approved procedure	Water addition not required	Terminate water addition immediately
Tank Water Additions during Removal					
- Volume	Addition of ≤1.9 m^3 (500 gal.) for the water lance to be used before pump insertion. May be increased with TRG approval. 2-in. water lance: no water addition without TRG approval. ≤0.95 m^3/d (250 gal./d) and 3.8 m^3 (1000 gal.) total each for all viscometer- or voidmeter-related operations.	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank. Check waste level to ensure 10.72-m (422-in.) level not exceeded	Ref. 6	If excessive water addition detected, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations
- Water Temperature	Temperature must be <54.4°C (130°F)	Monitor supply truck temperature		WHC-SD-WM-SAD-016, Rev. 2	If excessive water temperature detected, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations

TABLE 6-7 (CONT)
CONTROLS FOR WATER-LANCE INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
OPERATION					
Applicability of Standard Controls for Closed-Tank Operation	The controls given in Table 6-2 shall be followed for water-lance operation unless specifically modified in this table	See Table 6-2	See Table 6-2	See Table 6-2 for basis of specific controls	See Table 6-2
Waste Level					
- Large Lance	Water lance must not be operated when waste level is higher than pump operation limit allows	Level measurement	Monitor level	Same as Level I pump operating limit	Terminate operations immediately and ensure shutdown status
Crane and Loads					
- Maximum Loads	Lift loads do not exceed weight plus 25% for insertion, weight plus 50% for removal	Monitored by load cell	Voice alarm at weight plus 20%	SA (App. V)	If the maximum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued activity
- Minimum Load during Removal	Assembly weight minus 50%	Monitored by load cell	Voice alarm at assembly weight minus 40%	SA	If the minimum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued activity
Water Lancing					
- Maximum Flow Rate	0.34 m^3/min (90 gal./min)	Flowmeter	Monitor water flow rate	SA (App. V)	If water addition rate is excessive, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations
Waste Level					
- Large Lance	The large water lance must not be operated when the waste level is greater than pump operation limit or the TRG-determined level, as adjusted for water addition during pump replacement	Level measurement	Monitor level	SA (App. V)	Do not initiate water-lance operation if tank level conditions do not meet the SCO values

TABLE 6-7 (CONT)
CONTROLS FOR WATER-LANCE INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Maximum Amount of Water	3.8 m^3 (1000 gal.) May be increased with TRG approval 2-in. water lance: no water addition without TRG approval. ≤0.95 m^3/d (250 gal./d) and 3.8 m^3 (1000 gal.) total for installation, removal, and operation of viscometer and water lance, and installation, removal, and operation of the void-meter and water lance		Monitor total amount of water	SA (App. V) Ref. 6	If excessive water addition is detected, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations
Water Temperature	≤54.4°C (130°F)	Monitor truck tank temperature		Ref. 6	If excessive water temperature is detected, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations

TABLE 6-7 (CONT)
CONTROLS FOR WATER-LANCE INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Controls Specific to 2-in. Water-Lance Proposed for Viscometer and Voidmeter					
-Waste Level (Installation, Operation, and Removal)	Water lance must not be installed when waste level higher than 10.26 m (404 in.) or TRG-determined level	Level measurement	Monitor level TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed (see App. C) Also, TRG may approve using 2-mm/d (0.08-in./d) growth since the last available FIC reading to meet this control	SA (Add. 1)	Do not begin insertion
-Tank Dome Pressure	<-25.4 mm (-1.0 in.) w.g.	DACS	Alarm at -38.1 mm (-1.5 in.) w.g. Terminate water-lance operation if SCO is violated	SA (App. R)	Terminate operation pressure less than value specified by SCO. Resume operations when pressure restored to allowable levels
-Insertion Velocity	≤0.3 m/s (1 ft/s)	Crane operator	Approved procedure	WHC Water-Lance Safety Basis (1992)[7]	Reduce insertion velocity <SCO

TABLE 6-8
CONTROLS FOR WATER-WAND INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
INSTALLATION/REMOVAL					
Applicability of Standard Controls for Open-Tank Operation	The controls given in Table 6-1 shall be followed for water-wand installation and removal	See Table 6-1	See Table 6-1	See Table 6-1 for basis of specific controls	See Table 6-1
Crane and Loads					
- Maximum Loads during Insertion	Lift loads do not exceed weight plus 25%	Monitored by load cell	Voice alarm at weight plus 20%	SA (App. W)	If the maximum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued insertion operations
- Maximum Loads during Removal	Lift loads not to exceed assembly weight plus 50%	Monitored by load cell	Voice alarm at assembly weight plus 40%	SA	If the maximum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued insertion operations
- Minimum Load during Insertion and Removal	Assembly weight minus 50%	Monitored by load cell	Voice alarm at assembly weight minus 40%	SA	If minimum load is exceeded, stop operations and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued insertion operations
- Maximum Heights	The bottom of the wand shall be ≤1.5 m (5 ft) above ground or riser		Visual monitoring	SA (App. W)	If the wand is over the riser and is at the correct height, continue installation until riser is sealed. If the wand is not over the riser and is not at the correct height, adjust to correct height and continue installation
Tank Water Addition during Installation	No water addition during installation				Terminate water addition immediately
Tank Water Additions during Removal					
- Volume	Included in Table 6-6 limits for pump removal	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank. Check waste level to ensure 10.72-m (422-in.) level not exceeded	Ref. 6	If excessive water addition is detected, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations

TABLE 6-8 (CONT)
CONTROLS FOR WATER-WAND INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Water Temperature	Temperature must be ≤54.4°C (130°F)	Monitor supply truck temperature	Check supply truck temperature just before commencing water addition	Ref. 6	If the water temperature is not within limits, terminate water addition immediately and wait for TRG approval before continuing operations
OPERATION					
Applicability of Standard Controls for Closed-Tank Operation	The controls given in Table 6-2 shall be followed for water-wand operation	See Table 6-2	See Table 6-2	See Table 6-2 for basis of specific controls	See Table 6-2
Ventilation System	Both of the primary exhausters must be available before commencing water-wand operation. The primary ventilation system flow may be terminated during water-wand operation as long as gas concentrations remain within specifications	DACS, data logger, or per WHC procedure	Assure both exhausters operational before commencing activity	WHC Modified Standard Controls	If activity has not started, do not start activity unless authorized by TRG
- Primary Ventilation—Minimum Flow Rate	The primary ventilation system flow may be terminated during water-wand operation as long as gas concentrations remain within specifications			To minimize radioactive contamination of the ventilation system	If hydrogen or ammonia concentrations reach their SCO values, restore ventilation flow immediately
- Maximum Flow—Ventilation System Operable	Maximum flow 0.33 m^3/s (700 ft^3/min)	DACS	Alarm at 0.319 m^3/s (675 ft^3/min)	WHC Standard Controls	Terminate activity and investigate the reasons for ventilation flow being >0.33 m^3/s (700 ft^3/min) from Tank 101-SY. Do not continue activities until Tank 101-SY flow is <0.33 m^3/s (700 ft^3/min)

TABLE 6-8 (CONT)
CONTROLS FOR WATER-WAND INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Maximum Flow—Ventilation System Inoperable	Maximum flow 0.20 m^3/s (425 ft^3/min)	DACS	Alarm at 0.19 m^3/s (400 ft^3/min)	Modified WHC Standard Controls	Terminate activities and investigate reasons for ventilation flow being greater than the SCO from Tank 101-SY. Immediately restore ventilation flow on other confirming indications of gas releases (including high hydrogen, high ammonia, or high dome pressure). Do not continue activities until Tank 101-SY flow is <0.17 m^3/s (350 ft^3/min)
- Minimum Dome Pressure	-15.2 cm (-6 in.) w.g.	Dome pressure	Monitor dome pressure continuously. Alarm at -10.2 cm (-4 in.) w.g.	OSR Limit (Revs. 2 and 3) SA (App. W)	Terminate water additions immediately. Wait until the dome pressure increases to an equilibrium value. Restart activity while doubling the ramp period during which the wands reach their maximum flow rate (wand operations must restart in sequence). Perform OSR violation notifications as specified in Refs. 2 and 3
- Maximum Dome Pressure	+3.81 cm (+ 1.5 in.) w.g.	Dome pressure	Monitor dome pressure continuously. Alarm at +3.81 cm (+1.5 in.) w. g	SA (App. W)	Terminate activity. Wait until the dome pressure decreases to an equilibrium value. Restart activity while doubling the ramp period during which the wands reach their maximum flow rate (wand operations must restart in sequence)
-Pressure Drop across HEPA Filters	Maintain total pressure drop <15 cm (5.9 in.) w.g.	WHC procedure	Alarm at 12.7 cm (5.0 in.) w.g. on first HEPA filter, 8.9 cm (3.5 in.) w.g. on second HEPA filter	Standard OSD limit	Terminate water additions until both HEPA filters are out of the alarm state

TABLE 6-8 (CONT)
CONTROLS FOR WATER-WAND INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Gas Concentrations (All Locations)					
- Maximum Hydrogen Concentration	<7500 ppm	DACS or locally	Alarm at 80% SCO value. Terminate activity if alarm value is exceeded. Whittakers are shown to measure 80% of the nominal concentration under high-humidity conditions[11]	DOE 5480.4 (NFPA)	Immediately restore ventilation system flow if ventilation system is inoperable. Terminate activities and remove personnel from riser area until H_2 concentration is <500 ppm
- Maximum Ammonia Concentration	<1.0 vol %	DACS	Alarm at 75% SCO value. Terminate activity if SCO value is exceeded	SA (Apps. M and W)	Immediately restore ventilation system flow if ventilation system is inoperable. Terminate all operations until ammonia concentration is ≤3000 ppm
Water Addition					
- Water Temperature	Temperature must be no greater than the dome temperature and no less than the dome temperature minus 11°C (20°F)	Monitor truck tank temperature		SA (App. W)	If water temperature outside the bounds is detected, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations
- Maximum Amount of Water	Covered in Sec. 6—Pump Removal Controls	See Sec. 6	See Sec. 6	Ref. 6	If excessive water addition is detected, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations

TABLE 6-8 (CONT)
CONTROLS FOR WATER-WAND INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Operation Sequence	Start wand operations one at a time, starting with the one with the lowest rated flow rate Do not start the operation of the next wand until the dome pressure equilibrates at a value within ±25.4 mm (±1 in.) w.g.	Monitor dome pressure	Monitor the dome pressure continuously	SA (App. W)	Terminate water addition and restart after the dome pressure equilibrates at a value within ±25.4 mm (±1in.) w.g.
- Flow Rate	The flow rate for the wands must be controlled such that the dome pressure remains within ±25.4 mm (±1 in.) w.g. The minimum ramp time in flow for each wand is 2 min. from 0 to full flow	Monitor dome pressure	The water-wand operator will be in continuous contact with the person monitoring dome pressure. The water lines shall be equipped with two valves in series, one for slowly increasing the flow, another for quickly closing the flow	SA (App. W)	Do not increase the water-wand flow if the dome pressure gets outside the ±25.4-mm (±1 in.)-w.g. control band. Wait for dome pressure to stabilize within the band specified by the SCO before increasing the water-wand flow rate

TABLE 6-9
MULTIPORT RISER INSTALLATION, REMOVAL, AND OPERATIONAL CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Applicability of Standard Controls for Open-Tank Operation	The controls given in Table 6-1 shall be followed for MPR installation and removal	See Table 6-1	See Table 6-1	See Table 6-1 for basis of specific controls	See Table 6-1
Waste Level	No installation or removal when waste level exceeds 10.26 m (404 in.) or TRG approves action based on analysis or new data	Level measurement	Monitor level TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed (see App. C) Also, TRG may approve using 2-mm/d (0.08-in./d) growth since the last available FIC reading to meet this control	Sec. 4.6.3.2	Immediately terminate installation activities until all administrative controls are satisfied
MPR Weight	Total weight <3737 kg (8240 lb)	Verify weight before installation	Operational readiness review	Sec. 4.6.3.4	Immediately terminate installation activities if MPR weight exceeds SCO
Tank Water Addition	No water addition is expected	Visual inspection	Approved procedure	Water addition not required	Terminate installation or removal operations until water addition is stopped
Crane and Loads					
- Maximum Loads	Lift loads must not exceed weight plus 25%	Monitored by load cell	Voice alarm at weight plus 20%	Sec. 4.6.3.4	If the maximum load is exceeded, stop operations and investigate cause. If the cause of the unusual load is satisfactorily determined, the TRG can approve continued insertion operations
- Minimum Loads	Lift loads must be greater than weight minus 25%	Monitored by load cell	Voice alarm at weight minus 20%	Sec. 4.6.3.4	If the load is less than the minimum load, stop operations and investigate cause. If the cause of the unusual load is determined, the TRG can approve continued operations

TABLE 6-9 (CONT)
MULTIPORT RISER INSTALLATION, REMOVAL, AND OPERATIONAL CONTROLS

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Maximum Heights	Limit maximum drop height to 0.737 m (29 in.) above the riser	Visual monitoring	The approved work plan shall call for minimizing the height of the MPR when it is above the tank and should have a maximum height above the riser of 0.737 m (29 in.)	Sec. 4.6.3.4	Terminate activity and establish correct protection before restarting activity
- Impact Limiter	Cushioning interface between load and riser must be in place as MPR is lowered into position	Visual monitoring	Approved work plans	Sec. 4.6.3.4	Do not proceed with installation until impact limiter is installed

TABLE 6-10
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
INSTALLATION/REMOVAL					
Applicability of Standard Controls for Open-Tank Operation	Controls given in Table 6-1 shall be followed for viscometer installation and removal	See Table 6-1	See Table 6-1	See Table 6-1 for basis of specific controls.	See Table 6-1
Power to Radiation Detector	The radiation detector shall be deenergized if the tank pressure is >-25.4 mm (-1 in.) w. g. or if either the enclosure or riser is open	Radiation Detector	Manually de-energize the radiation detector before opening riser. Health physics technician shall manually make radiation readings as required	To prevent sparks from nonqualified electrical equipment	Immediately deenergize (manually) radiation detector if it is found to be energized
Preparation for Viscometer Installation					
-Waste Level	No installation or operation when the waste level is >10.26 m (404 in.) or the TRG-determined level based on analysis or new data	Level measurement	Monitor level TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed (see App. C) Also, TRG may approve using 2-mm/d (0.08-in./d) growth since the last available FIC reading to meet this control	Add. 1 SA (App. C)	Do not start insertion/installation if waste level is greater than SCO. If waste level increases beyond SCO during operation, remove viscometer from the tank
-Power Connections	Power leads may not be connected during installation	Visual inspection	Approved procedure	Add. 1	If installation has begun with power connections connected, immediately disconnect power connections and continue installation activities
-Lifting Height	Viscometer enclosure shall not be raised more than 0.686 m (27 in.) above the riser	Visual observation	Visual monitoring and approved work plans	Prevent possible damage to the riser from drop accident	If viscometer higher than SCO, correct height and continue with activities

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
-Elastomer Gasket	Elastomer gasket shall be in place before moving viscometer over riser	Visual observation	Install gasket before moving viscometer over riser	Prevent possible damage to the riser from drop accident	If gasket is not installed, remove viscometer away from the riser until gasket is installed
-Isolation Valve	Isolation valve must be closed before initiation of installation and will remain closed throughout installation phase	Visual inspection	Approved procedure to ensure closed isolation valve	Prevent possible flammable or toxic gas release	If viscometer is not installed, terminate activities and close the isolation valve to proceed with installation
Water Addition and Decontamination System (Installation Only)	No water addition is allowed during installation phase without TRG approval. All decontamination system valves are closed	Visual inspection	Approved procedure	No need for water addition	Stop installation activities and terminate water addition
Removal Specific					
- Tank Dome Pressure	Must be lower than -25.4 mm (-1 in.) w.g. Do not proceed with further testing if dome pressure is not greater than -25.4 mm (-1 in.) w.g.	Confirmation with DACS	Alarm at -38.1 mm (-1.5 in.) w.g. Terminate viscometer operation if SCO is violated	The ventilation system flow rate and duration are designed with minimum dome pressure of -25.4 mm (-1 in.) w.g.	Terminate activities if the SCO is not met and remove personnel from riser area until dome pressure is confirmed negative and ventilation flow rate is 0.19 m^3/s (400 ft^3/min)
-Ball Position	Ball position must be at the reference zero initial position	Inspection by an approved procedure and verification of viscometer position encoder readout, proximity switch	Approved procedure to ensure ball is not housed properly	Ensure ball and wire are in expected position and not obviously tangled on another tank component	Stop removal activities if ball is not housed properly
-Duration of Purge before the Isolation Valve is Closed	Purge duration must be ≥15 min	Viscometer control timing center	Approved procedure	Ensure tank gasses removed from enclosure (NFPA)	Stop removal activities and purge at least 15 min
-Isolation Valve	Isolation valve is closed under viscometer operation controls	Visual observation of enclosure pressure and flow rate and manual check	Approved procedure		Stop removal activities until isolation valve is closed

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
-Purge System Flow Rate after Isolation Valve is Closed	Must be 0	Visual observation of manual flowmeter	Approved procedure	Ensure that the isolation valve is closed	Do not initiate removal and ensure that isolation valve is closed
-Enclosure Pressure	Must be 0 after venting through HEPA	Visual observation of pressure gauge after isolation valve is closed	Approved procedure	Ensure the isolation valve is closed	Stop removal activities until purge system pressure rate is within specifications. Ensure isolation valve is closed before viscometer removal
-Power	Power must be turned off and power cable removed	Visual inspection	Approved procedure	Add. 1	Stop removal activities until power cables are removed
OPERATION					
Applicability of Standard Controls for Closed-Tank Operation	The controls given in Table 6-2 shall be followed for viscometer operations	See Table 6-2	See Table 6-2	See Table 6-2 for basis of specific controls	See Table 6-2
Preparation for Viscometer Operation					
- Waste Level	Will be ≤10.26 m (404 in.) Operation of viscometer above this limit requires TRG-approved analysis. If the ball is left in the tank, during the waiting period the waste level must also be <10.26 m (404 in.)	DACS	Monitor level TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed (see App. C) Also, TRG may approve using 2-mm/d (0.08-in./d) growth since the last available FIC reading to meet this control	Add. 1 SA(App. C)	Terminate all viscometer operation. Retrieve the ball, initiate the procedure to close the isolation valve; purge the enclosure before the isolation valve is closed, close the isolation valve, and turn the power off. When the ball is left in the tank, the waste level exceeding SCO value causes termination of the operation; retrieve the ball and terminate the viscometer activity

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Tank Dome Pressure	Must be lower than -1 in. w.g. Do not proceed with further testing if the dome pressure is ≤-25.4 mm (-1 in.) w.g.	Confirmation with DACS	Alarm at -38.1 mm (-1.5 in.) w.g. Terminate viscometer operation if SCO is violated	The ventilation system flow rate and duration are designed with the minimum dome pressure of -25.4 mm (-1 in.) w.g.	Terminate all viscometer operations if tests are not started. If tests are in progress, stop operation (turn viscometer power off) and wait for permission to restart
- Power to System	No power is applied until purge is completed	Visual check to the viscometer control system	Approved procedure	No power operation before purge	
- Enclosure Pressure with Isolation Valve Closed and Opened	Enclosure pressure must be 0 in. w.g. before opening isolation valve and <0 after opening isolation valve	Visual observation of pressure gauge before the isolation valve is open	Do not initiate tests if the enclosure pressure is different than value specified by SCO before and after isolation valve is opened and investigate causes. Verify pressure gauge reading consistent with isolation valve position (closed or open)	Ensure that leakage is acceptable	Terminate activities if SCO is not met, and resolve cause of problem before continuing operations
- Purge System Flow Rate upon Opening or Closing the Isolation Valve	Must be 0 before isolation valve is opened and >0.1 m^3/min (3.5 ft^3/min) after isolation valve is opened	Visual observation of the flowmeter	Verify flowmeter reading consistent with isolation valve position (closed or opened)	Ensure that leakage is acceptable	Do not initiate tests if the enclosure flow rate is different than value specified by SCO and investigate causes
- Duration of Purge	Purge duration must not be <15 min	Viscometer control center timing	Do not initiate tests if the duration of purge is less than value specified by SCO	Ensure tank gases removed from enclosure (NFPA)	Terminate activities if SCO is not met, and resolve cause of problem before continuing operations

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Radiation Alarm	Radiation monitor must be installed on viscometer enclosure at a predetermined fixed location and tested before operation. Alarm setting must be above background radiation level and nor more than100 mrem/h	Radiation monitor on viscometer enclosure	Terminate operation if radiation level exceeds value specified by SCO	Add. 1	Investigate cause of high radiation. Decontaminate area per WHC standard practices, if required
Viscometer Operation with Ball Movement below Riser					
- Ball Speed	Maximum operating ball velocity is 1 m/s (3.3 ft/s) Maximum available speed by high-range motor is ≤2 m/s (6.6 ft/s) Higher operating speed in the range of 1–2 m/s (3.3–6.6 ft/s) needs TRG-approved justification and test plan	Viscometer control center	Implement the control in viscometer software. No entry higher than 1 m/s is allowed Verify the fuse used for the high-range motor to limit the current drawn	Data reduction requirements, and minimize the operation-induced spark potential	Terminate all viscometer operations immediately if ball speed exceeds value specified by SCO. Retrieve ball using low-speed motor or manually; close isolation system with the purge procedure applied
-Power to System	Purge flow requirements must be met before viscometer is energized and after the viscometer is de-energized. All power to viscometer will be turned off at the end of 1-d operation. Cables will be disconnected from the viscometer and control units	Visual inspection	Approved procedure and qualified hardware	No tank gases in the enclosure allowed	Terminate activities if SCO is not met, and resolve cause of problem before continuing operations

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
-Isolation Valve	Isolation valve must be closed at the end of a test period (except when ball intentionally remains in the waste). TRG approval is required to leave the isolation valve open when viscometer is unmanned	Visual check; flowmeter reading should be 0 for closed valve. Manual inspection	Approved procedure	Ensure the correct position of isolation valve	If the isolation valve cannot be closed, cease operation and investigate problem. Resume normal operation after problem is corrected
-Ball Position	Ball must be housed when the viscometer is not manned. TRG may approve procedures to leave ball in tank for extended tests If extended tests are performed, special procedure must evaluate stuck-ball condition as preliminary step	Inspection by approved procedure and verification of viscometer position encoder readout and proximity switch If the ball is in the waste before operations began, observe wire with TV camera to ensure no unexpected conditions	Approved procedure	Ensure ball and wire are in expected position and not obviously tangled on other tank equipment	Terminate activities if SCO is not met, and resolve cause of problem before continuing operations
-Enclosure Flow Rate	Flow rate must be ≥0.1 m^3/min (3.5 ft^3/min) at the end of a test and before beginning open-enclosure steps	Visual inspection or flowmeter	Approved procedure	Ensure no tank gas accumulation in the enclosure	Terminate activities if flow rate is less than value specified by SCO and investigate the problem. Resume operation after the proper flow rate is established

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Cable Tension	During normal operation (no burp or wasteberg when ball in waste), maximum cable tension is limited to 1110 N (250 lbf) If cable tension exceeds the greater of the maximum load cell setting or 1110 N (250 lbf), operation must cease and stuck-ball procedures initiated	Viscometer control center tension readout and software-generated shutdown	Software must not exceed the limiting value	Add. 1	If cable tension limit is exceeded, stop motion of ball and initiate stuck-ball procedure
- Radiation at or near Viscometer	Access to viscometer must be limited to only that required Radiation should be surveyed and determined to be within acceptable limits for any viscometer access operations Any time the bottom 10 m (33 ft) of the cable is retrieved 4 times or 40 m (131 ft) integrally, a radiation survey will be conducted to ensure that ≤65 g (0.143 lbm) of waste has been entrained in the enclosure. Example: 40 m integrally=4x10 m or 8x5 m	Radiation survey before access	Approved procedures	Add. 1	Immediately cease ball movement and evacuate area around riser. Investigate cause of alarm. Ensure proper purge flow. When problem corrected (decontamination, repair decontamination system, etc.), resume normal operation

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Power to Radiation Detector	The radiation detector shall be deenergized if the tank pressure is >-25.4 mm (-1 in.) w. g. or if either the enclosure or riser is open	Radiation Detector	Manually deenergize the radiation detector if tank pressure exceeds limits. Health physics technician shall manually make radiation readings as required	To prevent sparks from nonqualified electrical equipment	Immediately deenergize radiation detector if it is found to be energized. Manually make radiation readings as required
- Radiation Alarm	Radiation alarm setpoint is not exceeded	Visual	Approved procedure. After a radiation alarm, ensure that purge flow meets SCO value	Add. 1	Immediately cease ball movement and evacuate area around riser. Investigate cause of alarm. Ensure proper purge flow. When problem corrected (decontamination, repair decontamination system, etc.), resume normal operation
-Decontamination of Cable during Upward Motion of Ball	Wire and ball must be decontaminated before upward motion that can carry waste into riser. The ball can be allowed to move upward the minimum of either 4.57 m (15 ft) or the established minimum effective decontamination distances for the decontamination flow and duration used. If wire is retrieved without being decontaminated, a continuous radiation survey at the enclosure must be conducted. If the allowable radiation levels are exceeded, decontamination of the enclosure is required	Ball position and travel direction, as indicated by viscometer control center	Approved procedure. Health physics monitoring is required during initial operations until decontamination effectiveness is established	Add. 1	

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Open Viscometer Enclosure Activities (Normal Operations—Isolation Valve Closed)					
-Internal and External Radiation	Radiation levels external and internal to viscometer must be within allowable levels to allow opening the viscometer for necessary maintenance or reconfiguration operations. Otherwise, decontamination is required	Health physics survey	Approved radiation control plans	Add. 1	Evacuate area around riser. Investigate cause of alarm. Ensure proper purge flow. When problem corrected (decontamination, repair decontamination system, etc.), resume normal operation
-Purge System Flow Rate with Closed and Opened Valve	Ensure that there is a measurable flow rate before closing the isolation valve. Ensure that flow rate is 0 after isolation valve is closed	Visual observation from the flowmeter	Approved procedure	Prevents toxic gas release from opening enclosure. To ensure isolation valve is closed	Terminate activities if flow rate is less than value specified by SCO and investigate the problem. Resume operation after the proper flow rate is established
-Duration of Purge before the Isolation Valve is Closed	At least 10 volume air changes are required before closing isolation valve	Operator timing	Approved procedure	Clears trapped tank gases from enclosure	Do not initiate further testing if purge duration is less than value specified by SCO
-Enclosure Pressure with Closed and Open Isolation Valve	Ensure that enclosure pressure is negative and 0 before and after closing the isolation valve, respectively	Visual observation from pressure gauge	Approved procedure	Confirms that isolation valve is open and verifies operation of pressure gauge	Terminate activities if enclosure pressure is less than value specified by SCO and investigate the problem. Resume operation after proper flow rate is established
-Ball Position	The ball must be fully retracted before isolation valve can be closed (except for stuck-ball condition discussed below)	Ensure ball position with the previous operational shutdown verification	Approved procedure	To prevent closing isolation valve with obstruction present	Do not proceed tests if the isolation valve is closed while the ball is not housed properly. Investigate the problem for improper ball housing. Resume tests after problem corrected

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
-Isolation Valve Closed	Isolation valve must be closed before enclosure can be opened (except for stuck ball)	Verify valve closed by enclosure pressure and flow rate	Approved procedure	Add. 1	If the isolation valve cannot be closed, cease operation and investigate problem. Resume normal operation after problem is corrected
Open Viscometer Enclosure Activities (Ball Stuck) Change Load Cell	If ball is stuck, as indicated by high-tension readings on the wire and visual observation using the TV cameras, the following special conditions are applicable. The load cell may need to be changed to one with the highest range to measure tension required to try to free stuck ball. Initiate general procedure for stuck ball, as discussed in Sec. 4.3.4.6. Before enclosure is opened in this case, purge procedure described above (Open Viscometer Activities) must be applied to minimize presence of tank gases in the enclosure	Visual observation from tank video camera, load tension reading	Approved procedure for stuck-ball condition. TRG approval required to open the enclosure with the isolation valve open	To prevent damage to the tank components and the viscometer	
-Status	Opening viscometer with valve open shall be treated as open-riser work controls				

TABLE 6-10 (CONT)
CONTROLS FOR VISCOMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
-Radiation near or at Viscometer or Riser	Radiation near and in the enclosure should be surveyed and determined to be within acceptable limits for any viscometer access operations	Radiation survey before opening the enclosure	Approved procedure	To prevent radiation exposure when the enclosure is opened with an opened isolation valve	Immediately cease ball movement and evacuate area around riser. Investigate cause of alarm. Ensure proper purge flow. When problem corrected (decontamination, repair decontamination system, etc.), resume normal operation
-Isolation Valve	Valve may be closed as much as possible without damaging the wire. Do not reopen until enclosure is resealed		Approved procedure for stuck-ball condition	To prevent damage to the tank components and the viscometer	
Tank Water Addition					
-Volume	≤0.76 m^3 (200 gal/d) and 3.79 m^3 (1000 gal.) total (total includes operation and removal of viscometer and 2-in. water lance) The amount may be increased by TRG approval	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank. Check waste level to ensure 10.72-m (422-in.) level not exceeded	Ref. 6	If water addition accidentally occurs outside the bound of the approved procedures, terminate all viscometer operations
- Water Temperature	Temperature must be <54.4°C (130°F) for water addition above the waste surface	Monitor truck tank temperature before water is pumped		Ref. 6	Terminate decontamination activities and ensure shutdown, monitor waste level, waste level riser rate, and hydrogen concentration
- Maximum Flow Rate	Maximum flow rate is ≤0.1 m^3/min (3.5 gal./min)	Flowmeter or calculation based on source pressure and orifice size	Approved procedure		Reduce the flow rate <3.5 gal./min
Both Tank and Viscometer Inlet HEPA Filter Piping	No damage to HEPA filter is allowed	Administrative procedures to ensure proper piping orientation	Approved procedures	Prevent release	If HEPA filter piping not in place and correctly installed, do not initiate viscometer testing

TABLE 6-11
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
INSTALLATION/REMOVAL					
Applicability of Standard Controls for Open-Tank Operation	The controls given in Table 6-1 shall be followed for voidmeter installation and removal	See Table 6-1	See Table 6-1	See Table 6-1 for basis of specific controls	See Table 6-1
Waste Level	No installation when the waste level is >10.26 m (404 in.) or the TRG-determined level based on analysis or new data	Level measurement	Monitor level TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed (see App. C) Also, TRG may approve using 2-mm/d (0.08-in./d) growth since the last available FIC reading to meet this control	Add. 2	Do not start insertion/installation
Crane and Loads - Maximum Loads for Voidmeter Installation and Removal	Lift loads do not exceed weight plus 25% for insertion, weight plus 50% for removal	Monitored by load cell by crane operator	Voice alarm at weight plus 20%	Prevent a possible damage to the riser due to lateral loads	Removal: If the maximum load exceeds the value specified by SCO, stop motion and investigate cause. If the unusual load is due to the bent voidmeter column (after visual inspection), lower the voidmeter into the bottom of the tank and secure the voidmeter. TRG will decide how to proceed from this point Installation: Stop lowering the voidmeter. Investigate the cause. If the decision is to remove the voidmeter, decontaminate it first, then remove it

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Minimum Load during Removal	Assembly weight minus 50%	Monitored by load cell by crane operator	Voice alarm at assembly weight minus 40%	Prevent a possible damage to the riser due to lateral loads	Removal: If the maximum load exceeds the value specified by SCO, stop motion and investigate cause. If the unusual load is due to the bent voidmeter column (after visual inspection), lower the voidmeter into the bottom of the tank and secure the voidmeter. TRG will decide how to proceed from this point
-Lifting Height	The lifting height for the voidmeter and the associated equipment should be limited such that the impact energy during a drop accident is ≤2030 J (1500 ft-lb) This value may be increased based on TRG-approved analysis of additional impact protection (e.g., impact limiters) Impact limiter should be in place during the installation of the voidmeter	Visual observation	Visual monitoring and approved work plans	Prevent a possible damage to the riser due to drop accidents (Add. 1)	If voidmeter (or decontamination manifold or impact limiter) is at the correct height, continue the activity. Otherwise, correct the height if the lifted item is not in the riser
-Elastomer Gaskets	An elastomer gasket shall be in place before moving voidmeter over riser	Visual observation	Install gasket before moving voidmeter over riser	Prevent possible damage to the riser caused by drop accidents (Add. 1)	If gasket is not installed, remove voidmeter away from the riser until gasket is installed

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Insertion or Removal Velocity	≤0.3 m/s (1 ft/s)	Visual observation and judgment	Approved work plans	Prevent spark generation in the riser	If the SCO is exceeded, lower the insertion or removal velocity
Installation Specific Voidmeter Status before Installation					
-Status of Sampler and Valves	Pressure regulator valves must be operable Pressure relief valves must be set at a value ≤110% of the operating pressures All other functions shall be operational	Visual using the control unit	Approved procedure	To verify that voidmeter is operational	Do not initiate installation if the valves are not at their default position. Close the riser and correct the problem
- Pressures in Pneumatic Lines	Upstream of pressure regulator PVC-1 is ≥13.8 MPa (2000 psig) Downstream of pressure regulator PVC-1 is ≤4.6 MPa (660 psig) Downstream of pressure regulator PCV-2 is ≤1.5 MPa (220 psig) Downstream of pressure regulator PCV-3 is ≤3.8 MPa (550 psig) Actuator exhaust pressure ≥241 kPa (35 psia) Inlet and exhaust of actuators are ≥241 kPa (35 psia) before operation	Pressure transducer on the piping and instrumentation system	Software shall give alarm signals to indicate that SCO values are exceeded. Terminate the activity if SCO values are not within the instrumentation uncertainty	To prevent spark generation, mechanical failure of sampler and forearm, leakage, and provide a safe operation A pressure of 241 kPa (35 psia) in actuators prevents waste entering the cylinders when the voidmeter inserted into the waste	If one of the specified pressures is exceeding the SCO value, do not initiate installation. Close the riser. Investigate causes for unexpected pressures range. Correct the problem to proceed If the actuator cylinders do not stay at 241 kPa (35 psia) after they are energized and deenergized during the initial testing, do not install the voidmeter. Investigate the leakage and correct the problem

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
- Temperature inside the Enclosure	Must be <60°C (140°F) and >0°C (32°F)	Temperature readings from control unit (One of the RTDs in the part of the voidmeter located in the enclosure may be used to meet this control)	Approved work plans	To provide correct flow rates and operating conditions during the operation phase	Do not initiate the installation. Close the riser and take action to obtain an acceptable enclosure temperature
-Water Level in the Water Tank	Must be full before installation	Visual	Approved work plans	To prevent unsuccessful operation	If the water tank is not full, close the riser and fill the tank
- Plug Gauge Installation—Maximum Loads	Lift loads do not exceed weight plus 25% for insertion, weight plus 50% for removal	Monitored using load cell by crane operator	Voice alarm at weight plus 20%	Prevent a possible damage to the riser from lateral loads	If the maximum load is exceeded, stop motion and investigate cause. If the excessive load is due to riser, decontaminate the plug gauge, remove it from the riser, and close the riser with a blind flange
-Lifting Height	The lifting height for the plug gauge is such that the impact energy during a drop on or in the riser is ≤2030 J (1500-ft-lb) This value may be increased based on TRG-approved analysis of additional impact protection (e.g., impact limiters)	Visual observation	Visual monitoring and approved work plans	Prevent possible damage to the riser from drop accident	If lift height is higher than SCO, correct height, continue with activities The design of the impact limiters must be approved by the TRG if limiters are needed
Plug Gauge Insertion or Removal Velocity	≤0.3 m/s (1 ft/s)	Crane operator judgment	Approved procedure	To prevent spark	If SCO is judged to be exceeded, reduce insertion velocity to less than SCO
Plug Gauge Decontamination for Removal	Plug gauge must be decontaminated before removal from the riser	Visual observation and radiation monitoring	Approved procedure	To decontaminate the plug gauge. It may be contaminated when inserted in the riser	Proper decontamination procedures must be in place before removal
Plug Gauge Removal Water Addition-Volume	≤0.19 m^3 (50 gal.) without TRG approval	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank	Ref. 6	If excessive water addition detected, terminate water addition immediately, remove water connection, and wait for TRG approval before continuing operations

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Removal Specific Radiation Level near the Voidmeter	The radiation level shall not exceed 100 mrem/h at a distance not to exceed 45.7 cm (18 in.) as the voidmeter is being raised from the riser	Radiation monitor near voidmeter	Terminate operation if radiation level exceeds value specified by SCO	Add. 2	Immediately cease voidmeter movement and evacuate area around riser. Insert the voidmeter back into to the riser until the radiation level is below the SCO. Decontaminate the voidmeter once more and resume upward motion. If the radiation level exceeds the SCO, repeat the process described above until the radiation level is below the SCO
Decontamination of Voidmeter during Upward Motion	The voidmeter must be decontaminated before upward motion that can carry waste into the riser. The voidmeter can be allowed to move upward the minimum of either 4.57 m (15 ft) or the established minimum effective decontamination distances for the decontamination flow and duration used. If the voidmeter is retrieved without being decontaminated, a continuous radiation survey near the voidmeter must be conducted. If the allowable radiation levels are exceeded, decontamination of the voidmeter is required	Voidmeter position and travel direction, as indicated by voidmeter control center	Approved procedure. Health physics monitoring is required during initial operations until decontamination effectiveness is established	Add. 2	If SCO conditions are violated, insert voidmeter back into the riser and decontaminate the voidmeter

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Voidmeter Status before Removal					
- Status of Sampler and Valves	Sampler must be depressurized and open Forearm must be vertical All solenoids and manual valves must be at default position The lower assembly must be in the tank dome	Visual observation with video camera when voidmeter is in the dome Visual observation of control unit for status of valves	Cease the removal if the forearm is not in the vertical position	To prevent damage to the voidmeter and riser	Do not initiate removal and investigate why the forearm is not vertical. TRG may give permission for next step after reviewing the investigation results
- Pressures in Pneumatic Lines	Actuator exhaust pressure is ≥241 kPa (35 psia)	Pressure transducer on the piping and instrumentation system	Software shall give alarm signals to indicate that SCO values are exceeded. Terminate the activity if SCO values are not within the instrumentation uncertainty	To prevent backflow and leakage	If one of the specified pressures is exceeding the SCO value, depressurize the sampler and put the solenoid valves into the default positions. Investigate causes for unexpected pressures range. Do not initiate removal until TRG approves. Meanwhile, the voidmeter may be lowered to the bottom of the tank and secured to the riser
OPERATION					
Applicability of Standard Controls for Closed-Tank Operation	The controls given in Table 6-2 shall be followed for voidmeter operations	See Table 6-2	See Table 6-2	See Table 6-2 for basis of specific controls	See Table 6-2

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Waste Level	Will be ≤10.26 m (404 in.). Operation of the voidmeter above this limit requires TRG-approved analysis	DACS	TRG may approve accounting for the offset if FIC is not available and other level instruments are used to determine the level when the PNL analysis of level gauges is completed (see App. C) Also, TRG may approve using 2-mm/d (0.08-in./d) growth since the last available FIC reading to meet this control	Add. 2	Terminate all voidmeter operation. Initiate shutdown definition; put the lower assembly and all solenoid valves in default position, discharge the sampler if pressurized, deenergize the power to the voidmeter, and initiate the removal if no excessive load is observed. Otherwise, lower the voidmeter into the tank and secure it to the riser
Duration of Operation	≤16 d	Visual inspection	Maintain log of operation days	Likelihood argument is made based on the 16 d maximum operation	Terminate activities if the total operation exceeds 16 d. TRG approval is needed to continue activities

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Pressures in Pneumatic Lines	Upstream of pressure regulator PCV-1 ≤16.6 MPa (2400 psig) Downstream of pressure regulator PVC-1 is ≤4.6 MPa (660 psig) Downstream of pressure regulator PCV-2 is ≤1.5 MPa (220 psig) Downstream of pressure regulator PCV-3 is ≤3.8 MPa (550 psig) Actuator exhaust pressure ≥241 kPa (35 psia) Inlet and exhaust of actuators are ≥241 kPa (35 psia) before operation	Pressure transducer on the piping and instrumentation system	Software shall give alarm signals to indicate that SCO values are exceeded. Terminate the activity if SCO values are not within the instrumentation uncertainty	To prevent spark generation, mechanical failure of sampler and forearm, leakage and provide a safe operation	If one of the specified pressures is exceeding the SCO value, depressurize the sampler and put the solenoid valves into the default positions. Initiate removal. Close the riser Investigate the cause of shutdown. Correct the problem to proceed operation with TRG approval
Pressure in Actuators	Pressure must always be >241 kPa (35 psia) when they are not activated	Pressure transducer	Approved procedure	241 kPa (35 psia) overpressure always provided to prevent waste penetration into actuators	If the pressure in cylinders is less than SCO, terminate the operation and initiate safe shutdown procedure. Perform radiation survey if the voidmeter is removed and investigate why actuators leaks
Insertion Velocity during Sampling	≤0.3 m/s (1 ft/s)	Crane operator and control unit personnel judgment	Approved work plans	To enhance the ability of collecting correct sampling and spark protection	If the SCO is exceeded, reduce the insertion velocity
Velocity in Upward Motion	≤1 ft/s	Crane operator and control unit personnel judgment	Approved work plans	Spark protection	If the SCO is exceeded, reduce the insertion velocity

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Maximum Loads during Upward Motion	Lift loads do not exceed weight plus 25% for insertion, weight plus 50% for removal	Load cell monitored by crane operator	Voice alarm at weight plus 20%	Prevent a possible damage to the riser from lateral loads	If the maximum load is exceeded, stop motion and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued activity. If the unusual load is due to the bent voidmeter column (after visual inspection), lower the voidmeter into the bottom of the tank and secure the voidmeter. TRG will decide how to proceed from this point
Minimum Load during Downward Motion	Assembly weight minus 50%	Load cell monitored by crane operator	Voice alarm at assembly weight minus 40%	Prevent a possible damage to the riser from lateral loads	If the minimum load is exceeded, stop motion and investigate cause. Provided that the cause of the unusual load is satisfactorily determined, the TRG can approve continued activity
Temperature in Instrumentation Enclosure	Must be <60°C (140°F) and >0°C (32°F)	Temperature readings from control unit (One of the RTDs in the part of the voidmeter located in the enclosure may be used to meet this control)	Approved work plans	To provide proper flow rates for pressurization tank and actuators	If the temperature in the enclosure is not within the range specified by SCO, terminate activities by putting voidmeter in shutdown condition and investigate causes for unreasonable temperatures. Correct problem and obtain TRG approval to proceed with testing
Axial Distance between the Jet Deflector and the Top of the Load Absorber	Must be >0.3 m (1 ft)	Visual or other level measurement	Approved work plans	Instrumentation enclosure is non-classified with the assumption that the SCO value is ≥0.3 m (1 ft)	If voidmeter is lowered to violate the SCO requirements, raise voidmeter to make sure there is ≥0.3 m (1 ft) between the jet deflector and the top of the load absorber
T-2 Water Wash Tank	Must be >5% of full capacity	Level transducer	Software shall indicate an alarm signal when 5% of the full capacity	To prevent, check valve leakage	If SCO value is reached, initiate shutdown procedure. Provide water to tank and proceed with testing
Cleaning Requirement for Check Valves	After each test, check valve on the pressurizing line must be washed with water first and purged with N_2.	Software timing or manual	Software control or manual	To provide enough time for an effective cleaning	If SCO condition is violated, wash the check valve and purge with N_2 before next operation
Voidmeter Position	Lower assembly must be below the riser during operation	Ultrasonic level meter or another level gauge or visual	Approved work plans	To reduce the possibility of waste entrainment to the riser	If SCO position is violated, lower the voidmeter

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Manual Valve Positions	Valve below water tank (HV-8) is closed Valve (HV-2) is set to a position to give proper flow rates Valve HV-4 is closed Valve HV-5 is closed Valve HV-3 is open	Visual inspection before installation and operation	Approved work plans	Valve positions are important to control the flow direction and rates	Do not initiate any activity without setting these valves to positions specified by SCO
Radiation Level near the Voidmeter	The radiation level shall not exceed 100 mrem/h at a distance not to exceed 45.7 cm (18 in.) as the voidmeter is being raised from the riser	Radiation monitor near the voidmeter	Terminate operation if radiation level exceeds value specified by SCO	Add. 2	Immediately cease voidmeter movement and evacuate area around riser. Insert the voidmeter back into to the riser until the radiation level is below the SCO. Decontaminate the voidmeter once more and resume upward motion. If the radiation level exceeds the SCO, repeat the process described above until the radiation level is below the SCO

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Decontamination of Voidmeter during Upward Motion	The voidmeter must be decontaminated before upward motion that can carry waste into the riser. The voidmeter can move upward the minimum of either 4.57 m (15 ft) or the established minimum effective decontamination distances for the decontamination flow and duration used. If the voidmeter is retrieved without being decontaminated, a continuous radiation survey near the voidmeter must be conducted. If the allowable radiation levels are exceeded, decontamination of the voidmeter is required	Voidmeter position and travel direction, as indicated by voidmeter control center	Approved procedure. Health physics monitoring is required during initial operations until decontamination effectiveness is established	Add. 2	If SCO conditions are violated, insert voidmeter back into the riser and decontaminate the voidmeter
Tank Water Addition					
-Volume	≤0.76 m^3 (200 gal/d) and 3.79 m^3 (1000 gal.) total (total includes operation and removal of viscometer and 2-in. water lance) The amount may be increased by TRG approval	Monitor flow totalizers on supply truck	Maintain log of all water additions to tank. Check waste level to ensure 10.72-m (422-in.) level not exceeded	Ref. 6	If water addition occurs by accident outside the bounds of approved procedures, terminate all voidmeter operations

TABLE 6-11 (CONT)
CONTROLS FOR VOIDMETER INSTALLATION, REMOVAL, AND OPERATION

System or Condition	SCO	Surveillance Monitoring	Administrative Procedures	Basis for Control	Safe Shutdown Definition
Operation in Bottom 1.27 m (50 in.) of the Tank	Do not rotate forearm in bottom 1.27 m (50 in.) of the tank	Control unit actuator control and ultrasonic level measurements	Approved work plans and procedure	To prevent damage to the voidmeter and tank bottom	If SCO is violated, pull the voidmeter in the dome immediately and inspect the forearm visually using video camera. If no damage is determined, proceed with testing. If it is determined that the voidmeter is damaged, initiate shutdown procedure. TRG will determine further actions
Voidmeter Operation in Dome Space					
-Cover Position	Do not actuate the cover in the dome	Control unit solenoid valve position	Approved procedure	To reduce spark generation	If SCO value is exceeded, further operation requires TRG approval
-Depressurization	No depressurization into the dome	Control unit	Approved procedure	To reduce spark generation	

APPENDIX A
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
General Design Criteria 6430.1A, 0110-2	Requires that during the planning phase, alternative designs be developed in accordance with DOE Order 4700.1.	Several pump designs have been considered, including the submersible pump being used. Also, other hydrogen mitigation techniques are being considered for the future. See the "Mitigation/Remediation Concepts for Hanford Flammable Gas Generating Waste Tanks" (WHC-EP-0516).
6430.1A, 0110-5	Requires that the design of the facility protect the public and all personnel from injury and exposure to toxic materials, radiation, and other hazards in accordance with DOE requirements and allowable limits.	The mixer pump has been designed to minimize the probability that it will initiate an accident that releases toxic gas or radiation from 101-SY. This includes potential installation, operation, and removal accidents. In addition, limiting conditions and administrative controls have been established for safe operations.
6430.1A, 0111-2.2	Requires that the facility structures and their elements be designed to withstand the dead loads prescribed. These loads include the weight of permanent materials and equipment, including the structure's own weight, supported in or on a structure. Load calculations shall include an allowance for any loadings anticipated at a later date. Unit weights of materials and construction assemblies shall be those given in ANSI A58.1.	The mixer pump has been designed to support its dead weight and its loads during operation. Also, it has been designed to withstand a number of accident sequences including earthquakes, pump drop loads, and GRE loads.
6430.1A, 0111-2.7	Facilities for radioactive material handling, processing, or storage shall require application of dynamic analysis in determining structural requirements for earthquake loading as stipulated in Sec. 0111-99.0. An independent review of the seismic design shall be made for facilities and buildings where a seismic event can have a potential risk to operator lives, to public safety, or large economic loss. The review shall be made in two stages, the first at the end of the preliminary design and the second before the final design is complete. (Ref. LBL-9143 and UCRL 15910.)	The seismic effects on the pump have been reviewed as part of this SA. The review shows that the pump and pump structure can withstand the design basis earthquake (for the Hanford Site). LANL has conducted an independent review of the seismic analysis.
6430.1A, 0111-2.8	Requires that vibratory loads, earth and groundwater pressures, fluid and gas pressures, thermal forces, and creep and shrinkage forces be investigated and design-compensated or -resisted.	The pump has been designed to accommodate a wide range of loads, including GRE forces, thermal transients, GRE and hydrogen burn overpressure, and pump startup dynamics.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
6430.1A, 0111-99.0.1	Requires that safety-class structures be protected against dynamic effects that may result from natural phenomena, accidents at nearby facilities, equipment failure, and similar events and conditions inside and outside the facility.	A dynamic effects analysis (i.e., burn within the tank) has been performed. The results of this analysis show that the pump can withstand the burn. The pump has also been designed to withstand seismic and wind loads.
6430.1A, 0111-99.0.1	Requires that safety-class items, including structures, that are required to function during or following severe natural phenomena not be prevented from performing their required safety functions by the failure of components, systems, or structures that are not designed to the severe natural phenomena criteria.	The pump system needs only to keep its structural integrity during a natural phenomena event. It is not required that the pump continue to operate during the event. The analysis demonstrates that the structural integrity of the pump is sound after seismic and GREs.
6430.1A, 0111-99.0.1	Requires that confinement system barriers be adequate to meet the functional requirements for the confinement systems of which they are a part.	The installation, operation, and removal of the pump does not affect the existing confinement system barriers of the tank. In addition, the pump design includes features to preclude the confinement barriers from being affected during accident conditions.
6430.1A, 0111-99.0.1	Requires that safety-class confinement barriers be designed to withstand any secondary phenomena, such as fires, explosions, or nuclear criticality caused by the design basis natural phenomena or man-made events, as well as to withstand primary events.	The installation, operation, and removal of the pump does not affect the existing confinement system barriers of the tank. In addition, the pump design includes features to preclude the confinement barriers from being affected during both natural events (GRE) and man-made events (pump drops).
6430.1A, 0111-99.0.2	Requires the use of the tornado and extreme wind hazard models given in UCRL-53526, Rev. 1, "Natural Phenomena Hazards Modeling Project: Extreme Wind/Tornado Hazard Models for Department of Energy Sites," and the modeling approach described in UCRL-15910, "Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards."	The installation, operation, and removal of the pump does not affect the ability of the tank to withstand the tornado and extreme wind hazards presented in UCRL-53256. The ability of the tank to withstand these hazards is increased because of the tank being buried with a minimum overburden of 7 ft of soil.
6430.1A, 0111-99.0.3	Requires the calculation of design loads from flooding using the method described in UCRL-15910 and based upon a conservative approach assuming a flood level greater than the maximum historical levels recorded for the site and no less than the probable maximum flood.	The installation, operation, and removal of the pump does not affect the ability of the tank to withstand the flood loadings presented in UCRL-15910. The probability of floods exceeding historical maximum floods is sufficiently low that such an event is not expected. Furthermore, no increased risk is expected from a flood because pump operations would be terminated.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
6430.1A, 0111-99.0.4	Requires the use of the earthquake hazard models given in UCRL-53582, Rev. 1, "Natural Phenomena Hazards Modeling Project: Seismic Hazard Models for Department of Energy Sites," and the dynamic modeling approach described in UCRL-15910. Design guidance in UCRL 15910 shall be used in applying UCRL 53582, Rev. 1.	The seismic effects on the pump have been reviewed as part of this SA. The review shows that the pump and pump structure can withstand the design basis earthquake (for the Hanford Site). LANL has conducted an independent review of the seismic analysis.
6430.1A, 0111-99.0.6	Requires that potential effects of a major explosion at a nearby facility or transportation route be considered among the spectrum of external blast effects and missiles that confinement structures shall be designed to withstand or against which they shall be protected.	The installation, operation, and removal of the pump does not affect the ability of the tank to withstand external blast effects. The worst-case internal accident is a burn event, and the pump has been designed for this increased load, as well as other accidents.
6430.1A, 0111-99.0.7	Requires that the probable consequence of DBA involving internally generated missiles or blast effects shall be considered. (Such DBAs typically involve failure of high-speed rotating machinery, cranes, experimental facilities, and high-energy fluid systems.)	Missiles generated internal to the tank because of failure of the pump have been reviewed and have been found to be of no consequence to the structural integrity of the tank.
6430.1A, 0111-99.0.8	Requires that safety-class structures and structural members be designed to resist the appropriate load combinations provided in UCRL-15910.	The structure that holds the pump to the tank is considered a safety-class structure. The structure can withstand the load combinations provided in UCRL-15910.
6430.1A, 0140	Specifies that QA requirements are incorporated in accordance with DOE 5700.6B and use the elements of DOE 4700.1 and ANS ANSI/ASME NQA-1.	Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
6430.1A, 0205-2	Requires that facilities where radioactive or other hazardous materials will be used or will result from facility operation be designed to limit dispersion and to simplify periodic decontamination and ultimate facility decommissioning, disposal, or reuse.	During removal from the tank, the pump will be triple rinsed, lifted into a flexible receiver bag that confines any residual waste and placed into a shielded container as described in the WHC mixer pump removal procedures.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
6430.1A, 0262-1	Specifies that the design engineer shall determine whether the services of a corrosion control specialist shall be used in corrosion control design.	WHC has determined that a corrosion control expert is not required. The materials were examined for suitability for use in the tank in terms of corrosion. There were no concerns noted with the use of carbon steel or stainless steel in the caustic environment. This is documented in the test pump design description, WHC-SD-ER-058, Section 6.2. In terms of erosion, the extremely low use expected on the pump exceeds it's original design life. The pump is operated an average of 30 minutes - 3 times a weeks, thus, over a period of 10 years the pump total operating life is 840 hours. The required life of this pump and it's plenum, nozzles, etc was required to be in the order of 40,000 hours (HS-BP-0068, Rev. B, "Submersible Mixer Pump Procurement Specification"). The pump vendor does not recommending changing the oil in the pump until after 5000 hours of operation. Due to the low duty cycle use of this pump, erosion is not a concern.
6430.1A, 0267-2	Requires that waste products generated shall not be disposed of in a manner that will adversely affect surface water.	The waste generated during pump installation, operation, and removal will be disposed of in accordance with WHC-CM-5-16.
6430.1A, 0275-4	Requires that precautions be taken to prevent contamination of surface water. Hazardous waste tank systems shall comply with 40 CFR 260, 261, 262, 263, 264, 265, 270, and 271. Containment of spills and leaks are covered in 40 CFR 122, 264.193, and 264.194.	The waste generated during pump installation, operation, and removal will be disposed of in accordance with WHC-CM-5-16.
6430.1A, 0275-99.0.2	Radioactive waste collection, transfer, and storage systems shall be such as to avoid the dilution of radioactive waste by a waste of lower radioactivity or other waste. Systems that involve the possible dilution of radioactive waste shall be used with the concurrence of the sponsoring DOE program office.	The only dilution that the pump could cause is during wash procedures. DOE concurrence is required for pump decontamination.
6430.1A, 0532	Requires that welding of structures comply with ANS D1.1, D1.2, D1.3, and D5.2.	All welding on the mixer pump is performed in compliance with WHC standards.
6430.1A, 1300-3.1	Requires that safety-class structures, systems, and components be designed, fabricated, erected, and tested to standards and quality commensurate with the hazards and potential consequences associated with both the facility and the role of each structure, system, or component in mitigating the consequences of DBAs.	The analysis demonstrates that the quality meets that required by the QA Plan (WHC-EP-0550). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
6430.1A, 1300-3.2	Requires that the safety-class structures, systems, and components for nonreactor nuclear facilities include any structure, system, or component: 1. the failure of which would produce exposure consequences exceeding the guidelines in Sec. 1300-1.4 of DOE Order 6430.1A, Guidance on Limiting Exposure of the Public, 2. required to maintain operating parameters within the safety limits specified in the Technical Safety Requirements during normal operations and anticipated operational occurrences, 3. required for nuclear criticality safety, 4. required to monitor the release of radioactive materials to the environment during and after a design basis accident, 5. required to achieve and maintain the facility in a safe shutdown condition, 6. that controls a safety-class item , and 7. the failure of which could prevent a safety-class item from performing its required function.	The pump is considered to be a safety-class system. This is required by the design to meet a wide range of DOE Orders. Traceable records exist for the design, fabrication, and operation of structures, systems, or components, including: --DACS --Instrumentation to monitor parameters such as gas concentration, pressure, flow rate and temperatures --SY Tank Farm ventilation
6430.1A, 1300-3.3	Requires that safety-class systems be designed to ensure that a single failure does not result in the loss of capability of the safety-class system to accomplish its required safety functions.	If the instrumentation (which is critical to the safety of pump operation) fails, the pump will be turned off and the instruments will be repaired. The pump will be operated after the instruments are repaired. If the pump itself fails, a replacement pump is available.
6430.1A, 1300-3.4.1	Requires that safety-class items be designed to withstand the effects of, and be compatible with, the environmental conditions associated with operation, maintenance, shutdown, testing, and accidents.	The mixer pump has been designed to be compatible with and withstand the anticipated waste environment during operation, the effects of maintenance, shutdown and testing, and the anticipated conditions associated with GREs.
6430.1A, 1300-3.4.2	Requires that equipment design and qualification provide assurance that safety-class items will be capable of performing their safety functions under DBA conditions for at least the period of time that these safety functions are required.	None of the safety-class systems related to the pump and its operation are required to work during a DBA.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
6430.1A, 1300-3.5	Requires that safety class items be designed to allow inspection, maintenance, and testing to ensure their continued functioning, readiness for operation, and accuracy. Ancillary equipment, such as pumps, blowers, motors, compressors, gear trains, and controls shall be located in an area least likely to be contaminated. The design of equipment that must be located within confinement systems shall allow for "in-place" maintenance or replacement. The capability shall be provided for the maintenance of contaminated equipment that cannot be repaired in place. This capability shall include the necessary provisions for confinement ventilation and waste control. All process equipment shall be designed with features to minimize the self-containment of the equipment, piping, and confinement areas and to minimize the spread of contamination outside of local areas.	The structures related to securing the pump are considered safety class. There will be no ability to continuously monitor this area (pump pit). However, these structures have no active function that would require continuous monitoring. Also, these structures have been designed with a sufficient margin of safety to ensure that there would be no need to monitor them for the short duration of the test (2 yr). Periodic inspection may be required during long-term operation.
6430.1A, 1300-4	Requires an assessment of the design as early as practical to determine if the potential for a nuclear criticality exists.	Criticality has been determined not to be an issue.
6430.1A, 1300-6.1	Requires that special facilities be designed to minimize personnel exposures to external and internal radiological hazards, to provide adequate radiation monitoring and alarm systems, and to provide adequate space for health physics activities. Primary radiation protection shall be provided by the use of engineered controls (e.g., confinement, ventilation, remote handling, equipment layout, and shielding). Secondary radiation protection shall be provided by administrative control. ALARA concepts shall be applied to minimize exposures where cost effective.	ALARA concepts have been and will be implemented for the installation and removal of the pump in accordance with the "ALARA Program Manual," WHC-CM-4-11. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
6430.1A, 1300-6.2	Requires that the shielding design basis limit the maximum exposure to an individual worker to one-fifth of the annual occupational external exposure limits specified in DOE Order 5480.11. Within this design basis, personnel exposures shall be maintained ALARA. Specifically, the shielding shall be designed with the objective of limiting the total EDE to less than 1 rem/yr to workers, based on their predicted exposure time in the normal occupied area. In addition, appropriate shielding shall be installed, if necessary, to minimize nonpenetrating external radiation exposures to the skin and lens of the eye of the worker. (In most cases, the confinement barrier of the process equipment provides this shielding.)	There is no shielding structure associated with the pump design. There are WHC administrative controls that assure ALARA and minimize personnel exposure. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization. In general, the only nonaccident exposure comes from pump removal, where an effective wash system will control exposure.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
6430.1A, 1300-6.4	Requires that the design ensure that occupied operating areas do not exceed the airborne concentration limits of the DOE 5480 series of Orders for normal operating conditions. In addition, and to the extent practical, the concept of ALARA shall be used when designing confinement and ventilation systems to limit airborne contamination levels. The design shall ensure that respirators are not required to meet the dose limits for normal operations. Engineered controls and features shall also be provided to minimize the potential inhalation of radioactive and other hazardous materials under all conditions.	When entering potentially hazardous areas, personnel protective equipment shall be utilized. The ALARA Program Manual, WHC-CM-4-11, and the Industrial Hygiene Program, WHC-CM-4-3, shall be followed. Engineering controls, such as the erection of a greenhouse tent over the pump pit, will be provided.
6430.1A, 1300-6.5	Provides facility requirements for monitoring, warning, alarm, and air systems.	Radiation monitoring requirements for this activity are the same as those used throughout the tank farms. These requirements are provided in WHC-CM-4-10. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
6430.1A, 1300-12.4.5	Requires that personnel who work in a hazardous environment have convenient access to protective equipment including proper garments, emergency eyewashes, showers, and any other protective equipment necessary for the successful and safe completion of their work.	Personnel will have access to protective equipment according to current operating procedures. This requirement is beyond the scope of this SA.
6430.1A, 1300-12.4.10	Requires that the design of equipment incorporate the objective of efficient maintainability.	Maintainability is not an important component of this operation. The operation of the pump is to demonstrate mixing as a potential mitigation action for the episodic gas release and to function in this capacity until the pump is replaced with its spare.
6430.1A, 1530-1	Fire protection systems shall comply with DOE 5480.7, or fire protection systems shall incorporate an "improved risk" level of protection, as directed by DOE 5480.7.	Installation, operation, and removal of the pump does not affect the integrity of the fire protection systems.
6430.1A, 1530-8.1	All fire detection and alarm devices shall have UL-listed components or be FM-approved. Devices and systems shall comply with NFPA 71, 72A, 72B, 72C, 72D, 72E, 72F, 72G, and 72H, as applicable.	Installation, operation, and removal of the pump does not affect the integrity of the fire protection systems.
6430.1A, 1530-99.0	Requires an assessment to be made early in the design or modification to determine if the facility structures, systems, and components shall be protected against the effects of a design basis fire and explosion. A fire protection engineer or person knowledgeable in applying the principles of fire protection shall develop the fire protection system.	The assessment has been completed, and modifications have been made to reduce spark sources.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
6430.1A, 1550-99.0.1	Requires ventilation systems balancing be specified to ensure that the air pressure within the HLW tanks is always negative with respect to the outside atmosphere.	The installation and operation of the pump does not affect the ability of the tank to be operated at negative relative pressure. During removal, the ventilation may be turned off and the tank may be allowed to reach a slightly positive pressure. The consequences of this condition are analyzed in this SA and are shown to be within the acceptance guidelines.
6430.1A, 1550-99.0.2	Requires that safety-class air filtration units be designed to remain functional throughout DBAs and to retain collected radioactive material after the accident.	This is the reason the mitigation test was conducted and mitigation operations continue. The existing ventilation cannot handle current episodic gas releases in the postulated case where a flammable mixture is ignited.
6430.1A, 1550-99.0.3	Requires the system's capacity be consistent with the needs for handling off-gas from components and systems during normal operations, anticipated operational occurrences, and DBA conditions.	This is the reason the mitigation test was conducted and mitigation operations continue. The existing ventilation cannot handle current episodic gas releases in the postulated case where a flammable mixture is ignited.
6430.1A, 1589-99.0.1	Requires that airborne radioactive effluents from confinement areas be exhausted through a ventilation system designed to remove particulate matter, vapors, and gases as needed to comply with Sec. 1300-1.4.3, "Routine Releases." ALARA design principles shall be implemented to minimize effluent concentrations and quantities of released hazardous materials.	This is the reason the mitigation test was conducted and mitigation operations continue. The existing ventilation cannot handle current episodic gas releases in the postulated case where a flammable mixture is ignited.
6430.1A, 1605-1	Electrical systems shall be designed so that all components operate within their capacities and projected loads. All systems shall comply with NFPA 70 and ANSI C2.	The pump and DACS have been designed to meet WHC standards. They will have the capability to protect loads. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
6430.1A, 1630-5	Requires that lightning protection systems comply with NFPA 78, and requires lightning protection for underground power cables to facilities and buildings.	There is a lightning protection system at the SY Site, but it has not been verified that the design complies with NFPA 78. However, activities related to pump installation, operation, or removal are prohibited when the potential for lightning is high.
6430.1A, 1639-1	Grounding systems shall comply with NFPA 70 and IEEE 142. A separate ground conductor shall be used, raceway systems shall not be used as a ground path.	The grounding system for the mixer pump meets the intent of the NFPA 70 and IEEE 142 electrical requirements.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
6430.1A, 1660-2	Requires emergency power systems to comply with NFPA 37, NFPA 70, NFPA 101, NFPA 110, and IEEE 446. Emergency power shall be capable of maintaining full operation of emergency loads for the full time period specified by the cognizant DOE authority (this is normally a 24-h period).	There are no emergency loads associated with pump operation, except for the portable respirator.
6430.1A, 1660-99.0.1	Requires that safety-class emergency electrical power systems have suitable redundancy and separation, including: physical protection or separation to prevent a common event from causing a failure of the redundant systems; minimizing safety-class power connections to safety-class buses; being qualified to the requirements of DOE Order 6430.1A, 0111-99 and 1300-3.4; having a capability to periodically test and verify performance.	There are no emergency loads associated with pump operation.
6430.1A, 1660-99.0.2 1660-99.0.4 1660-99.0.5	Requires that safety-class protection systems (e.g., fire detection, radiation monitoring) be provided to minimize the risk associated with facility operation. The protection system design shall provide: 1. rapid response and the automatic control of interlocks to prevent unsafe operator actions; 2. actions to ensure that specific acceptable design limits are not exceeded; 3. automatic systems to ensure the safety of operating personnel and the public; 4. audible and visual *indications of system status;* 5. automatic initiation of protective actions with the capability for backup manual initiation; 6. suitable redundancy and diversity to ensure no single failure will result in the loss of the protective functions; 7. assurance that the protection system will fail in a safe state; 8. for separation or isolation of the protection system from other instrumentation and control systems; 9. for the periodic in-place testing and calibration of instrument channels and interlocks; and 10. allowance for periodic testing of protective functions.	The DACS meets the requirements, except for items 1 and 8. Procedures are in place to minimize the risk of not complying with these requirements.
6430.1A, 1660-99.0.6	Requires that safety-class electric power or a safety-class control air system be provided unless adequate system performance, including fail-safe shut-down, can be demonstrated when only conventional power sources are used.	Adequate system performance including fail-safe shutdown can be demonstrated with normal power.
General Environmental Protection Program 5400.1, IV.3	Requires an environmental study be conducted before the startup of a new site, facility, or process that has the potential for significant environmental impact.	An environmental assessment has been completed.
General Environmental Protection Program 5400.1, IV.1(a), 2 (a)	One objective of an environmental monitoring program is to demonstrate compliance with legal and regulatory requirements imposed by applicable federal, state, and local agencies. Environmental monitoring requirements specified by applicable federal, state, or local regulations apply.	Activities related to the mixer pump do not affect the existing environmental compliance program onsite.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
5400.1, IV.4	Requires a written monitoring plan to be prepared for each site, facility, or process that uses, generates, releases, or manages significant pollutants or hazardous materials.	Mixer pump operation does not affect the existing maintenance plan, WHC-CM-4-3.
5400.1, IV.5*	Requires environmental monitoring in two areas: effluent monitoring and environmental surveillance. Requirements are found in DOE 5400.1, Chap. IV.	Mixer pump operation does not affect the existing environmental monitoring program, WHC-CM-7-5.
5400.1, IV.10	Requires that a QA program consistent with DOE 5700.6B shall be established covering each element of the environmental monitoring and surveillance programs commensurate with its nature and complexity.	Mixer pump operation does not affect the current quality assurance program, WHC-EP-0550.
Environmental Protection, Safety, and Health Protection Standards 5480.4, Attach 2, 2.b.	Specifies the mandatory ES&H standards for environmental protection (hazardous waste regulations that are mandatory for activities conducted under the Atomic Energy Act are listed).	WHC has a set of ES&H policies with which they comply (WHC-CM-7-5). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.4, Attach 2, 2.c.	Specifies the mandatory ES&H Standards for fire protection, primarily the NFPA Codes.	Fire protection procedures will be in accordance with WHC-CM-4-3. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.4, Attach 2, 2.d.(1)	Specifies the mandatory ES&H Standards for radiation protection, primarily the ANSI codes.	Radiation protection procedures will in accordance with WHC-CM-4-10. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
5480.4, Attach 2, 2.d.(3)	Specifies the mandatory ES&H Standards for industrial hygiene, primarily TLVs, and ANSI standards.	Industrial hygiene procedures will in accordance with WHC-CM-4-3. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.4, Attach 2, 2.e.	Specifies the mandatory ES&H Standards for occupational safety, primarily construction safety under Title 29 CFR 1926, crane safety under ANSI standards, and electrical safety under ANSI/NFPA 70-1981 and ANSI C2-1981.	Occupational safety procedures will be in accordance with WHC-CM-4-3. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.4, Attach 2, 2.e.(5)	Specifies the mandatory ES&H Standards, including the "National Electrical Code," which provide the requirements for the construction and testing of electrical apparatus, or parts of such apparatus. (The pump, and related systems and apparatus must be intrinsically safe and specifically designed for the application within the flammable-gas-generating tank area. The arc from the contacts must not be sufficient to cause ignition of the gases.)	The pump has been designed to preclude sparks being generated by pump operation. The column of the pump is inerted with nitrogen.
Fire Protection 5480.7A, 9.	The fire protection goal of the pump installation, operation, and removal should conform to the "Highly Protected Risk/Improved Risk" level of fire protection, particularly including preventative features necessary to ensure satisfactory performance regarding objectives related to safety.	Spark protection has been considered in mixer pump design, installation, operation, and removal. The design minimizes the potential for spark generation.
5480.7A, 9(b).	DOE facilities qualifying as improved risks must incorporate physical improvements, internal programs, and records as specified in 5480.7, A section b.	Several modifications and improvements have been made to the mixer pump to reduce risk.
Contractor Industrial Hygiene Program 5480.10	The manager of the contractor organization performing the actual work or job-related task shall assure compliance with the provisions of DOE Order 5480.10, paragraph 9.	The existing industrial hygiene program will be used throughout the implementation of the proposed action (WHC-CM-4-3). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
Radiation Protection for Occupational Workers 5480.11, 9. a.	Requires that exposures to radiation be maintained within limiting values and ALARA.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. g.	Requires that occupational workers be monitored, as appropriate, to demonstrate compliance with the radiation protection standards, and workplaces shall be monitored for identification and control of potential exposure sources. This includes personnel dosimetry programs and internal radiation evaluation programs.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. g.(3)	a. Ambient air monitoring shall be performed in occupied areas with the potential to exceed 10% of any derived air concentration values given in Attachment 1. b. Appropriate stationary and/or portable radiation instruments shall be available and used to measure dose rates for the purpose of controlling exposure to radiation.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. g.(4)	Requires that appropriate instruments and techniques be used to provide contamination monitoring and control as described below: 1. Workplace Surfaces Outside Radiological Areas should be maintained essentially free of removable contamination. 2. Workplace Surfaces in Radiological Areas shall be posted and controlled, as appropriate. 3. Personnel and Personal Property Contamination Monitoring shall be provided, as appropriate.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
5480.11, 9. i.	Requirements apply for the release of materials and equipment from radiological areas for conditional use in controlled areas. In all cases, contaminated property shall be cleaned as thoroughly as is practical before release.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. i.(1)	Material and equipment in radiological areas established to control surface or airborne radioactive material shall be treated as radioactive material and shall not be released from radiological areas to controlled areas if any of the following conditions exist: 1. Measurements of accessible surfaces show that either the total or removable contamination levels exceed the guidelines specified in Attachment 2. 2. Prior use suggests that the contamination levels on inaccessible surfaces are likely to exceed the guidelines.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. i.(2)	Material and equipment exceeding the total and removable contamination levels specified in Attach. 2 shall be conditionally released for movement onsite from one radiological area for immediate placement in another radiological area only if appropriate monitoring and control procedures are established and exercised.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. i.(3)	Materials in excess of specified limits may be released for use in controlled areas if routinely monitored, clearly labeled, and appropriate administrative controls exercised on these items.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
5480.11, 9. i.(4)	Appropriate records must be maintained.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. j.(1)(c)	Requires, for internal radiation exposure, that the exposure of personnel to the inhalation of airborne radioactive materials be avoided under normal operating conditions to the extent reasonably achievable. This normally will be accomplished through confinement and ventilation systems.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. j.(2)	Requires that, during routine operations, the combination of design and control procedures provide that, with respect to the radiological workplace, the anticipated magnitude of the prospective committed effective dose equivalent from intakes (plus any effective dose equivalent from external exposure) not exceed 5 rem (0.05 sievert) in a year and that the anticipated magnitude of the committed dose equivalent to any organ or tissue from intakes (plus any dose equivalent from external exposure) not exceed 50 rems (0.5 sievert) in a year. Compliance with these requirements shall be demonstrated through appropriate workplace monitoring.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action. (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. k.(1)	The access to any controlled area where radioactive materials or elevated radiation fields may be present shall be clearly and conspicuously posted as a controlled area.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
5480.11, 9. k.(2)	The access to any area where an individual can, at any time during normal operations, receive a dose equivalent greater than 5 mrem (50 µSv) in 1 h at 30 cm from the radiation source, or any surface through which radiation penetrates, shall be posted as below. In addition, the anticipated dose rate or range of dose rates shall be included on, or in conjunction with, each of the following signs, as appropriate: 1. "Radiation Area," for any area within a controlled area where an individual can receive a dose equivalent > 5 mrem (50 µSv) but < 100 mrem (1 mSv) in 1 h at 30 cm from the radiation source, or from any surface through which the radiation penetrates, 2. "High Radiation Area," for any area within a controlled area where an individual can receive a dose equivalent ≥ 100 mrem (0.001 sievert) but < 5 rem (0.05 sievert) in 1 h at 30 cm from the radiation source, or from any surface through which the radiation penetrates, and/or 3. "Very High Radiation Area," for any area within a controlled area where an individual can receive a dose ≥ 5 rem (0.05 sievert) in 1 h at 30 cm from the radiation source, or from any surface through which the radiation penetrates.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. k.(2) (b)	The access to any area where airborne radioactive material concentrations greater than 0.1 of the derived air concentrations are present shall be clearly and conspicuously posted with a sign that identifies the radiological conditions that exist (e.g., "Airborne Radioactivity Area"). The type of sign used shall be consistent with the radiation protection control policies established at the facility and may be selected by the contractor with the approval of the field organization.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. k.(2) (c)	The access to any area where surface contamination levels greater than 10 times those specified in Attachment 2 to this Order are present shall be clearly and conspicuously posted with a sign that identifies the radiological conditions that exist. The type of sign used shall be consistent with the radiation control policies established at the facility and may be selected by the contractor with the approval of the field organization.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
5480.11, 9. m.(1)	Requires that records of ALARA programs be maintained by field organizations and operating contractors to demonstrate the adequacy of the ALARA plans and programs and their implementation.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
5480.11, 9. o.(2)	Requires that radiation worker training programs and retraining be established and conducted at a sufficient frequency (not to exceed a period of 2 yr) to familiarize the worker with the fundamentals of radiation protection and the ALARA process. The training should emphasize the procedures specific to an individual's job assignment.	The existing ALARA and radiation protection programs will be used throughout the implementation of the proposed action (WHC-CM-4-11 and WHC-CM-4-10). Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
Quality Assurance 5700.6C, 9.b.(2)	Requires that the performance of work be to established technical standards and administrative controls. Work shall be performed under controlled conditions using approved instructions, procedures, or other appropriate means. Items and processes shall be designed using sound engineering/scientific principles and appropriate standards. The responsible organization shall ensure that items procured, services rendered, and inspection and acceptance testing of specified items meet established standards and perform as specified.	The existing QA plan (WHC-EP-0550) will be used throughout the implementation of the proposed action. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.
Natural Phenomena Hazards Mitigation 5480.28 (10)	Requires that structures, systems, and components be designed and constructed to withstand the effects of natural phenomena hazards, in conjunction with the General Design Criteria in DOE 6430.1A.	Natural phenomena hazards were considered in mixer pump design, installation, operation, and removal. Procedures must be in place for the suspension of operations during unstable weather situations.
Start -Up and Restart of Nuclear Facilities 5480.31,9(a),9(b)	Defines the Operational Readiness Review, which is a verification of line management having achieved readiness to start up the facility, including prestart findings assessment, development of a "Lessons Learned Section," development of action plans, completion of response actions, and verification of a closure package before start-up approval. Independent oversight will be given by the Office of Environment, Safety and Health to assure compliance with ES&H orders.	An ORR will be completed before each phase of mixer pump installation, operation, and removal.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
Radioactive Waste Management 5820.2A, I.3.b.(2)	e. To the extent practical, waste shall be segregated by type (sludge, salt, high activity, and low activity) to make future processing easier.	N/A
	f. Ventilation systems shall be provided where the possibility exists for generating flammable and explosive mixtures of gases.	The ventilation cannot withstand the current level of gas release. This is the reason for mixer pump operation.
	h. Engineering controls shall be incorporated to provide liquid volume inventory data to prevent spills, leaks, and overflows from tanks.	N/A
	i. Nuclear criticality safety considerations and controls shall be evaluated for normal operations and, before any significant operational changes are made, to protect against an uncontrolled nuclear criticality incident (e.g., dissolution of sludges for removal from tank).	The potential for nuclear criticality has been evaluated and found not to be credible.
	j. Each facility shall utilize remote maintenance features and other appropriate techniques to minimize personnel radiation exposure in accordance with DOE 5481.1B.	N/A
	k. Upon the loss and subsequent recovery of normal electrical power, HLW transfer equipment shall not have the capability to restart without active operator action.	Once pump operations have been terminated, JEG must approve restart.
5820.2A, I.3.b.(3)	a. Requires that monitoring and leak detection capability provide rapid identification of failed containment. Minimum monitoring requirements are temperature, pressure, radioactivity in ventilation exhaust, and liquid effluent streams from high-level waste facilities.	N/A
	b. Leak detection systems shall be designed and operated to detect the failure of the primary containment boundary.	N/A
	c. A method for periodically assessing waste storage system integrity shall be established, documented, and reported as required in the Waste Management Plan.	N/A
	d. Electrical monitoring and leak detecting devices essential to safe operations shall be provided with backup power, as appropriate, to ensure operations under emergency conditions.	N/A
5820.2A, I.3.b.(4)	f. Each high-level waste facility shall have response procedures for credible emergencies, as identified in the SARs.	The installation, operation, and removal of the pump will not affect the normal response procedures utilized at the tank farm. The response procedures outlined in WHC-CM-4-1 and WHC-IP-0263 will be followed. Procedures for WHC compliance assessment and implementation of DOE Orders are contained in MRP 1.1 of WHC-CM-1-3, Management Requirements Procedures. Contractually, WHC must comply with all applicable DOE directives. WHC procedures have received compliance assessment with DOE Orders by the WHC QA organization.

APPENDIX A (CONT.)
MIXER PUMP PRINCIPAL SAFETY CRITERIA AND COMPARISON TO CRITERIA

DOE Order	Requirements	Disposition
Control of Heavy Loads at Nuclear Power Plants, NUREG-0612	This document provides the suggested procedures for executing heavy lifts over critical equipment at nuclear power plants.	WHC has developed critical lifting procedures based upon NUREG-0612. WHC provides detailed procedures for critical lifts in the "Hanford Hoisting and Rigging Manual," WHC-CM-6-4. Specific procedures have been developed for the installation and removal of the mixing pump. Although these procedures have not been approved by the appropriate DOE organizations, the procedures have been shown to be acceptable. Practice lifts using the critical lift procedures have been conducted using a dummy pump and also have been used for lifting the mixing pump into a test pit.
Radiation Protection of the Public and the Environment 5400.5	The requirements provided in this Order provide the basis for higher-level programmatic issues related to tank farm operation (e.g., ALARA, Effluent Monitoring, and Environmental Surveillance).	The activities associated with the installation, operation, and removal of the mixing pump will meet the requirements established in the WHC program plans, which were developed to comply with 5400.5. Examples of these plans include: WHC-CM-4-11, "ALARA Program Manual" WHC-CM-4-3, "Industrial Hygiene Program" WHC-CM-7-5, "Environmental Monitoring Program" WHC-CM-4-10, "Radiation Protection"
Nuclear Safety Public, SEN-35-91 paragraph 3.	1. Requires that the risk to an average individual in the vicinity of a DOE nuclear facility for prompt fatalities that might result from accident(s) should not exceed 0.1% of the sum of prompt fatalities resulting from other accidents to which members of the population are generally exposed. For evaluation purposes, individuals are assumed to be located within 1 mi of the Hanford Site boundary. 2. Requires that the risk in the area of a DOE facility for cancer fatalities that might result from operations should not exceed 0.1% of the sum of all cancer fatality risks resulting from all other causes. For evaluation purposes, individuals are assumed to be located within 10 mi of the site boundary.	Requirements for additional risks to individuals from prompt fatalities and cancer fatalities are met; see Sec. 5.

APPENDIX B
COMPOSITION AND THE LEAN FLAMMABILITY LIMIT FOR THE RELEASE GASES

1.1. OBJECTIVE AND SUMMARY OF RESULTS

Many of the accidents analyzed in this SA require knowledge of the release gas composition (e.g., burn and toxicological consequences of a GRE). The objectives of this appendix are:

- to obtain a conservative estimate for the release gas composition,
- to compare the estimated composition with the most recent GREs (especially those induced by pump operations),
- to quantify the conservative LFL for the gas mixture of interest, and
- to assess the adequacy of the gas monitoring instruments.

Based on the analysis of the available data, we obtained the following best-estimate and upper-bound composition for the release gases.

Gas Specie	Best Estimate (%)	Conservative Estimate (%)
Hydrogen	28.77	31.41
Nitrous Oxide	24.45	26.69
Ammonia	10.95	14.95
Nitrogen	32.82	23.51
Methane	0.35	0.53
Water Vapor	2.4	2.4
Others[a]	0.25	0.5

[a] "Others" is assumed to represent carbon monoxide in the burn calculations.

For the gas mixture, the LFL is calculated using Le Chatelier's linear mixing law. The conservative estimate for the LFL is 3.5% H_2.

Because the SA controls are written in terms of instantaneous gas concentrations, the accuracy and response time of the measuring instruments also are discussed in this appendix.

This appendix supports the following controls listed in Sec. 6 of the SA:

- periodic (once every 3 months) analysis of the gas composition data,
- maximum and minimum waste temperatures,

- maximum hydrogen and ammonia concentrations, and
- dome pressure and ventilation flow controls.

2.0. GAS COMPOSITION

The release gas composition cannot be measured directly. The measurements come from samples obtained from the dome space and diluted with air. Thus, we need a model to obtain the gas composition from the available discrete measurements.

2.1. Mathematical Model

First, we write the material balance equation for the species that are known to exist in the release gas:

$$F(H_2)+F(N_2O)+F(NH_3)+F(CH_4)+F(N_2)+F(H_2O)+F(\text{Others})=1 \ , \qquad \text{(B-1)}$$

which contains the six known gases of interest; the ones in small quantities are lumped in the volume fraction of "Others." In Eq. (B-1), F refers to the mole fraction for the specie shown in parenthesis. We have seven unknowns that require six additional relationships. First, we estimate the fraction of the hydrogen in the release gases as

$$F(H_2)=F(H_{2,dry})\left[1-F(NH_3)-F(H_2O)\right] \ , \qquad \text{(B-2)}$$

where $F(H_{2,dry})$ is the mole fraction of hydrogen in the release gas excluding the condensable gases (NH_3 and H_2O). We set $F(H_{2,dry})$ equal to a constant obtained from the grab sample data. Likewise, we estimate F(Others) as a constant from the grab sample data. We also calculate $F(H_2O)$ as a constant using the thermodynamic relationships. The remaining relationships are obtained from gas fraction ratios. The following ratios are set to constant values obtained from available data: $F(N_2O)/F(H_2)$, $F(NH_3)/F(N_2O)$, and $F(CH_4)/F(N_2O)$.

The mathematical model is based on two important assumptions:

- the composition does not change from one GRE to the next, and
- the composition of the release gases remains constant throughout the GRE.

The validity and limitations of these assumptions are discussed in Secs. 2.5 and 2.6 of this appendix. In our burn calculations, we are interested primarily in the fuel components (hydrogen, ammonia, and methane). The burn pressure results are affected also by the nitrous oxide because the combustion of hydrogen, ammonia, and methane are more energetic with nitrous oxide than with oxygen. Thus, for burn calculations, we want to maximize the concentration of these components within the uncertainty bounds. By computing the fuel equivalency of the mixture, we can show that within the parametric bounds of interest, fuel is maximized by maximizing the following parameters: $F(H_{2,dry})$, $F(N_2O)/F(H_2)$, $F(NH_3)/F(N_2O)$, and $F(CH_4)/F(N_2O)$. Later in this section, the equivalent fuel calculations are discussed. This scheme also is consistent with the toxicological consequence analysis where we want to maximize the ammonia content in the release.

2.2. Input Parameters

A detailed discussion of the data collected since the April 1990 event is provided in Ref. 1. As discussed in Ref. 1, there is considerable uncertainty in the grab sample data reported from the early phases of the gas monitoring program. In this appendix, we use only the subset of the data. For instance, the grab sample data where oxygen is used as the tie-gas are believed to be superior to the data where argon is used as the tie-gas.[2] Therefore, we used the noncondensable gas data obtained using oxygen as the tie-gas.[2] Although there were some remote ammonia measurements made in the previous events, only the on-line ammonia data are available for Event I (June 1993) and the induced events (September through November 1993) during pump operations. These on-line ammonia data are used in this analysis, as well as the on-line methane data from the same events.

The input parameters used in the mathematical model are shown in Table B-1, along with the source of the data and the pertinent discussion.

2.3. Results

The resulting gas compositions are provided in Table B-2.

Because a propagation-of-errors calculation was not used, the difference between the best-estimate and conservative-estimate ammonia fractions in Table B-2 corresponds to 1.42 std dev on the ammonia fraction, which provides a confidence interval >92% for toxicological consequences.[3] Because of conservatism in evaluating the parametric standard deviations in Table B-2, we believe that the safety margin is appropriate.

2.4. Equivalent Fuel Calculations

As mentioned previously, we maximized the fuel in the mixture within the bounds of the data uncertainty. In this process, we evaluated the fuel content of the mixture by a simple model. This model calculates the equivalent internal energy of combustion for the fuel mixture and is based on the following assumptions:

1. The process can be approximated as a constant volume combustion.
2. The only combustion products considered are water, nitrogen, and carbon dioxide. We do not account for other possible combustion products such as NO_x.

TABLE B-1
BEST ESTIMATE (BE) AND CONSERVATIVE ESTIMATE (CE) FOR THE INPUT PARAMETERS

Parameter	BE	CE	Discussion
F($H_{2,dry}$)	33.2%	38.0%	This value is obtained from Ref. 2. The CE corresponds to the BE plus 1 std dev.
F(N_2O)/F(H_2)	0.85	0.85	Because neither of these gases naturally exist in the air, this ratio can be quantified very precisely in the grab samples. Reference 2 shows that the N_2O/H_2 ratios fall within a narrow range at ~0.85 for H_2 concentrations >1% in the samples. At low H_2 concentrations, there is considerable scatter in the data. For H_2 concentrations >1.5%, all data fall below 0.86, and the BE ratio is 0.81.[3] Thus, for this parameter we use 0.85 for both BE and CE calculations. The MS data from Event I[4] shows this ratio to be between 0.67 and 0.8. The ratios data from Event I and subsequent pump-induced events (August 27, 1993, and September 17, 1993) are not easily obtainable. Hydrogen data are obtained either from the GC or the Whittaker. Nitrous oxide data are obtained from the FTIR. Different sampling and data analysis principles for these instruments make computation of the ratio difficult. Nevertheless, the discussion provided in Ref. 1 shows that the ratio used in this analysis (0.85) is supported by these later data. Further discussion of the various instruments is provided at the end of this appendix.
F(NH_3)/F(N_2O)	0.448	0.56	On-line ammonia measurements were available for Event I and the post-Event I events. Comparing Event I; the August 27, 1993, event; and the September 17, 1993, event; the maximum NH_3-to-N_2O ratio during the first 15 min was measured during Event I. We used that value of 0.448 as the BE. The upper bound is estimated using the uncertainty estimates for the FTIR as 0.56. This magnitude bounds all data within the first hour of each event analyzed. Further discussion of this parameter is provided in Ref. 1.
F(CH_4)/F(N_2O)	0.0145	0.02	The value 0.0145 is obtained from the only available frame from Event I where CH_4 could be measured. Data from the August 27, 1993, and September 17, 1993, data provide ratios ranging between 0.01 and 0.012. The standard deviation for the ratio obtained using the FTIR data is estimated to be ~38% of the BE value. Further discussion is provided in Ref. 1.
F(H_2O)	2.4%	2.4%	The water vapor mole fraction is obtained using the vapor pressure data[5] at 49°C (120°F) and at a total pressure of 2.1 atm (which are the average temperature and hydrostatic pressure in the NC layer before Event I). Later data of Norton and Peterson[6] also support the 2.4% estimate. Because of the small magnitude, we do not account for additional uncertainty over the theoretical value.
F(Others)	0.25%	0.50%	Reference 2 gives the fraction of unknown gases in the noncondensable portion of the release gases as 0.5%, including CH_4. We use 0.5% as the CE for the unknown gas fraction in the total release excluding methane. We set the BE value to half the CE value.

3. The methodology assumes that all available nitrous oxide is consumed.

4. The reactants and products behave as an ideal gas mixture.

Table B-3 lists the internal energies for the fuels oxidized by nitrous oxide and oxygen

Using these energies, we write the equivalent fuel in terms of volume of hydrogen burning in air. First, we define the fraction of the fuel that is oxidized by nitrous oxide as

$$\eta = \frac{F(N_2O)}{F(H_2) + 1.5F(NH_3) + 4F(CH_4) + F(CO)} \quad . \tag{B-3}$$

Then, using the internal energies from Table B-3, we write the equivalent fuel as

$$\begin{aligned} \text{Fuel} = {} & F(H_2)[1.35\eta + (1-\eta)] + F(NH_3)[1.84\eta + 1.32(1-\eta)] \\ & + F(CH_4)[4.71\eta + 3.32(1-\eta)] + F(CO)[1.52\eta + 1.17(1-\eta)] \quad . \end{aligned} \tag{B-4}$$

TABLE B-2
BEST ESTIMATES AND CONSERVATIVE ESTIMATES FOR RELEASE GAS COMPOSITION

Gas Specie	Best Estimate (%)	Conservative Estimate (%)
$F(H_2)$	28.77	31.41
$F(N_2O)$	24.45	26.69
$F(NH_3)$	10.95	14.95
$F(N_2)$	32.82	23.51
$F(CH_4)$	0.35	0.53
F(Others)[a]	0.25	0.5
$F(H_2O)$	2.4	2.4

[a] Others" is assumed to represent carbon monoxide in the burn calculations.

TABLE B-3
INTERNAL ENERGIES OF COMBUSTION FOR DIFFERENT FUEL-OXIDIZER PAIRS (kJ/MOLE OF FUEL)[3]

	O_2	N_2O
H_2	-240.55	-323.80
NH_3	-317.44	-442.45
CH_4	-798.31	-1132.10
CO	-281.72	-365.04

We studied the fuel maximization using this simple model. For our best-estimate gas composition given in Table B-2, we calculate an equivalent fuel as 53.14% H_2 burned in air (128 kJ/mole of release gas) in the release gas. For the conservative gas composition, the equivalent fuel becomes 62.73% H_2 combusted in air (151 kJ/mole of release gas). Using the linear propagation of errors, the standard deviation for the equivalent fuel is ~7.13% H_2 combusted in air. Thus, the difference between the best estimate and the conservative estimate is equal to 1.34 std dev.

2.5. Effect of Temperature on Gas Composition

In the composition model, we assume that the composition does not change from one GRE to the next. However, if the waste temperature changes between GREs, this assumption may not be valid.

Because ammonia is highly soluble and there may be a considerable amount of ammonia in the waste in soluble form, its release strongly is affected by the waste temperature.[7] We use the ammonia data from Window I to quantify the amount of ammonia in the release gas. The maximum temperature allowed in this SA is within the historic bounds of the tank temperature. Unfortunately, however, we do not have reliable data for ammonia amounts in the release gas from when the waste was at higher temperatures.

In quantifying the effect of temperature on the gas composition, we make the assumption that the noncondensable fraction of the release gas is not affected by temperature. The accuracy of this assumption cannot be quantified currently. However, the MS data obtained from periods at higher waste temperatures agree well with the current magnitudes in terms of nitrous oxide/hydrogen ratios. Nevertheless, the waste temperature and gas compositions must be monitored closely in the future to assure that the proposed composition remains conservatively bounding.

The maximum average waste temperature allowed in this SA is 325 K (125°F), and the corresponding NC-layer temperature would be 327 K (129°F). We evaluated the ammonia release at high temperatures using the solubility and Henry's law constant models provided in Ref. 8. When we calculated the equivalent fuel, and using the same methodology as before, we obtained the best-estimate equivalent fuel as 57.8% H_2 combusted with air and the conservative-estimate equivalent fuel to be 68.2% H_2 combusted with air. These magnitudes are ~8.8% higher than the composition computed at Window I temperatures.

On the other hand, we currently treat the temperature effects conservatively in our burn analysis. Regardless of the NC-layer temperature, we injected the total volume into the dome space at 307 K. If we were to inject the gas at 327 K, the weight of the injected gas would reduce by 6.5%.

Since the occurrence of Window I and the installation of the mixer pump, the average waste temperature has remained between 115 and 120°F. As long as the temperature remains within this range, we believe that the proposed gas composition is conservatively bounding.

Thus, currently we ignore the effect of possible higher temperatures on the ammonia release. However, the TRG must reevaluate the effects of gas compositions if, for some reason, the waste temperature becomes >120°F or <115°F. An administrative control in the SA requires that the effect of temperature on the gas composition be evaluated periodically (once every 3 months) by the data analyses team and reviewed by the TRG. The thermal inertia of the waste is very large, and drastic temperature variations in <3 months are not expected even with considerable perturbations in the boundary conditions.

2.6. Comments on Ammonia Mass Transfer

In the SA methodology, we use a constant ammonia fraction in the release gases. Inherent in this methodology is the assumption that all ammonia comes out with the released bubbles, which clearly is incorrect. Because of ammonia's high solubility, we postulated that during an event, a mass-transfer contribution to the release may be significant. Concerns were raised because of the observed increase in the NH_3/N_2O ratio with increasing release size (between Event I and the August 27 event). A detailed modeling of the ammonia mass transfer is discussed in Ref. 8. Here, we provide some brief comments to support the approach used.

First, we believe that it is conservative to use a constant ammonia fraction with respect to GRE size. Assuming that ammonia is the only species being released by mass transfer, the mass released can be formulated as

$$M = \int_{\Delta t} k_{go} \, A \, c \, \ln\left(\frac{1 - y_d}{1 - y^*}\right) dt \ , \qquad \text{(B-5)}$$

where M is the amount of ammonia mass released by mass transfer to the dome during the time period Δt, k_{go} is the overall mass-transfer coefficient based on the gas phase, A is the effective mass-transfer area, c is the total gas concentration, y_d is the fraction ammonia in the dome, and y^* is the ammonia fraction in equilibrium with the bulk gas.

The amount of ammonia released by mass transfer will depend on the size of the GRE. The two factors that are expected to be influenced most by the size of the GRE are the overall mass-transfer coefficient and the surface area that is disturbed by the rollover. The overall mass-transfer coefficient consists of two resistances: the liquid phase and the gas phase. The liquid-phase mass-transfer contribution may be formulated as a function of the Reynolds number or average mixing velocity, V, as $k_L \sim V^{2/3}$. We assume that $V \sim G$, where G represents the size of the GRE. We assume also that the gas-phase mass-transfer coefficient is independent of GRE size; thus, k_{go} approaches a constant as G increases. Based on the behavior of the two resistances, the conclusion is that $k_{go} \sim G^n$, where $n < 1$.

The effective mass-transfer area is the part of the waste surface that is disturbed during a GRE. This area is expected to increase with GRE size, but the maximum possible area is the entire tank surface. From video surveillance, the Window I event appears to have disturbed the entire surface; thus, the effective mass-transfer area is expected to be constant for GREs larger than the Window I event.

Two other factors that affect the amount of ammonia released by mass transfer are the driving force $\ln((1 - y_d)/(1 - y^*))$ and duration (Δt). The dome concentration, y_d, is expected to increase with G, which will decrease the driving force, but y^* will increase with G because of heating of the C layer. Increasing y^* will increase the driving force. Because of these opposing factors, it is impossible to determine whether the driving force will increase with GRE size. Although there is uncertainty, the opposing factors suggest that the driving force will not be a strong function of G. The duration of the GRE, Δt, is not expected to be a strong function of the GRE.

Based on the mass-transfer coefficient and the affected area, which are the two most important factors, we conclude that $M \sim G^m$, where $m \leq 1$. The analysis provided in Ref. 8 confirms this conclusion by showing that m is approximately unity for GREs smaller than Window I and that m must be <1.0 for events larger than Window I because of the gas-phase resistance limit. If the mass-transfer contribution to Window I were substantial, then using a constant ammonia fraction obtained from Window I data for larger releases is conservative.

3.0. LFL OF THE MIXTURE

Mixtures of more than one fuel require special consideration of the overall LFL. The frequently used Le Chatelier model assumes a linear dependence between the fuel concentrations and the LFL of the mixture. This linear behavior is considered ideal and is used commonly as a reference in LFL experiments. Le Chatelier's rule is observed to work well for hydrogen and hydrocarbon fuels. Deviations from ideal behavior usually are attributed to kinetic effects that may inhibit reactions and disturb reaction chains. These deviations tend to raise the LFL to the rich side of Le Chatelier's LFL, indicating that Le Chatelier's rule is a conservative estimate of the LFL of a mixture. This also is supported by the hydrogen/ammonia/air data given in Jost.[9] Other fuels in the mixture, such as carbon monoxide and methane, have concentrations much lower than 1%; therefore, their contributions to the LFL are negligible.

Using 4% for the LFL of hydrogen, 15% for ammonia, 5.5% for methane, and 12.5% for carbon monoxide, along with the best-estimate and conservative-estimate gas composition data given in Table B-2, the lower bound on the mixture LFL is 3.5% H_2. One-fourth of the LFL corresponded to 8750 ppm H_2. This estimate was conservative because:

- The Bureau of Mines data[10] show that near 4%, the peak-combustion-to-ambient-pressure ratio is very small.
- The most likely ignition location is on top of the dome. Therefore, it may be more appropriate to use the downward propagation limit, which would be higher for all the fuels of interest.
- The hydrogen/ammonia/oxygen data shown in Jost[9] indicate that Le Chatelier's law is bounding for this mixture.
- For the LFL of ammonia, 15% is the lower bound cited in the literature. The values typically range between 15 and 18.5%.

The best-estimate value for the mixture LFL may be computed to be >4%.

3.1. The Effect of Nitrous Oxide on the LFL

The studies of Hettzberg and Zlochower[11] and Jones and Kerr[12] indicate that the LFL for some fuels of interest in a nitrous oxide atmosphere is much lower than the LFL of the same fuel in air (or oxygen atmosphere).

The burn analyses in the SA are based on the assumption that within a given uncertainty range, the gas composition is constant. All gases are released at approximately the same temperature, and our analyses indicate that during a GRE, mixing in the dome space is dominated by turbulent diffusion instead of molecular diffusion that would prevail in a quiescent medium. Thus, there is no credible mechanism for the gases to segregate such that we would have a pocket of gas that is very rich in nitrous oxide and near the LFL for the fuels. For instance, for hydrogen we use 4% for the LFL. In this case, we estimate that at that location (using Table B-2), only 12.7% of the gas is release gas (87.3% air) and that there is only 3.4% N_2O. The amount of ammonia at the same location would be 1.9%. Bureau of Mines data[10] were obtained as up to 2% NH_3 with stoichiometric hydrogen/nitrous oxide mixtures diluted with air; the results confirm that using LeChatelier's law for these lean mixtures is appropriate.

The LFL value is used in the SA to develop administrative controls to reduce the likelihood of a burn accident. However, in terms of consequences of a burn accident, we do not account for the LFL, and we force the existing fuel to burn, regardless of its local concentration. Thus, the value of the LFL used in this SA does not affect the burn consequences.

Thus, we conclude that using 3.5% H_2 for the mixture LFL is appropriately conservative. The administrative controls should be set to less than or equal to a quarter of the LFL (8750-ppm H_2).

4.0. GAS MONITORING INSTRUMENTS

The instruments that provide on-line gas concentrations in the dome and in the ventilation of Tank 101-SY are summarized in Table B-4.

4.1. Whittaker Measurements

The Whittakers instrument uncertainty is reported to be 2345 ppm for a 7500-ppm measurement.[13] However, this is a worst-case scenario where the errors for the Whittakers, signal conditioning unit, and DACS system signal noise are added together. The numbers quoted appear to be the upper-bound errors corresponding to an uncertainty ≥2 std dev. Furthermore, if these are all random errors, the overall uncertainty is reduced considerably because we have multiple instruments operating during an event. Assuming that the maximum error quoted corresponds to a 2-std-dev uncertainty and taking credit for the fact that we may have four hydrogen monitoring instruments operating, the error associated with a 1-std-dev

TABLE B-4
ON-LINE GAS CONCENTRATION MEASUREMENTS

Instrument	Gas Species	Comments
GC	H_2	GC provides H_2 data every 10 min by taking a snapshot sample and analyzing it. Thus, any transient faster than a 10-min time scale may be completely missed in the GC data. GCs are suspected to show a very nonlinear response after a sudden change in the concentration.
Whittaker	H_2	The Whittaker instruments provide continuous H_2 concentration data with time. They are diffusion-based devices and consequently have a relatively slow response time associated with them. The time constant is on the order of minutes. Further discussion for Whittaker response time is provided in Sec. 3.1. When the H_2 concentration in the dome peaks during rapid transients, there may be considerable uncertainty associated with the measurement.
FTIR	N_2O, NH_3, CH_4	The FTIR analyzes the concentrations continuously. However, it provides time-averaged data. Earlier, the averaging period was 15 to 17 min, which later was reduced to 6 to 8 min. Thus, the FTIR[a] does not provide instantaneous concentration. The interpretation of the data and comparison with the hydrogen instruments require special care.

[a] FTIR spectrum analysis also may provide data on other species.

uncertainty is <600 ppm. This consideration, combined with the fact that our mixture LFL estimate is conservative, leads us to conclude that the effect of the random error in the hydrogen measurement may be minimal for the setpoints. As mentioned later, the pressure and flow-rate aborts provide much faster and reliable protection against exceeding this limit.

Also, Ref. 13 states that the instrument provides a 90% response to a step change in <2 min. Other delays are associated with the instrument, such as the transport time and time associated with mixing in the Whittaker chamber. However, those are on the order of seconds and are negligible compared to the 2-min response time. The first-order relaxation model[14] for the Whittaker instruments predicts that the data may underestimate the actual peak by ~30% if the hydrogen concentration rises from zero to its peak value in <3 min.

In Fig. B-1, we show the asymptotic relaxation model applied to the Whittaker data to obtain the actual concentration trace during Event I.[14] This figure shows that near the peak, the transient is slow enough that the Whittaker instrument responds to the data. The actual concentration predicted by this simulation is 2.93% (as compared to a 2.82% measured value). The results are influenced by the differencing scheme to a certain degree, suggesting that 12-s timesteps (DACs data interval) may be larger than necessary for an accurate accounting of the trace earlier in the transient. Also, some of these fluctuations may not be real. Instrument noise, as well as the effect of sudden pressure and temperature changes on the readings, may account for some of these spikes. Nevertheless, the following are the important observations from this simulation:

1. The actual hydrogen concentration trace is not as smooth as the Whittaker instruments indicate. In particular, earlier in the transient there may be considerable fluctuations in the hydrogen concentration. Some of these fluctuations may have a timespan of <12 s, in which case it would not be stored by the DACS. This may help explain the differences between the Whittaker measurements and the MS or GC measurements, which take a sample within a few seconds. If this sample coincides with one of the small fluctuations, the reading may be higher than the Whittaker instrument measurements.

2. The simulation indicates a sharp peak 24 to 36 s into the simulation (the peak value is ~1.51%). The timing of this peak coincides with the increase in the dome pressure and the vent flow rates, which suggests that hydrogen diffuses fairly quickly in the dome space.

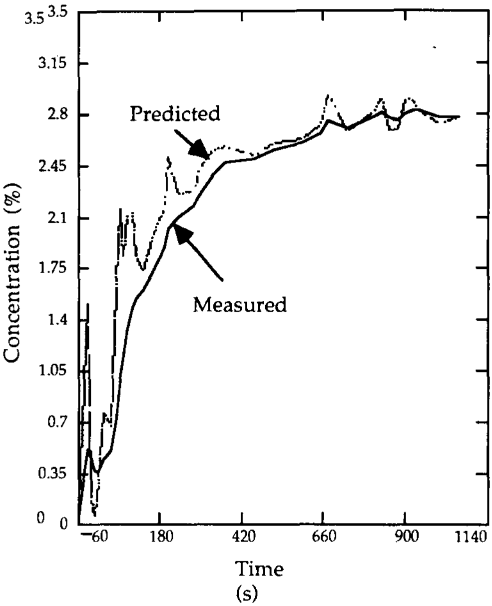

Fig. B-1. Predicted and measured hydrogen concentrations for Whittaker Instrument 7B during Event I.

3. These observations suggest that the available gas monitoring instruments may not be adequate to detect very rapid increases in the concentration (durations on the order of seconds). Consequently, they cannot be relied on for instantaneous indications of reaching or exceeding the LFL. However, for safety purposes, small clouds of hydrogen that can result in such a rapid transient are not as important as sustained high concentrations in the dome (for durations on the order of minutes). With the current instruments, such sustained high concentrations can be detected.

4.2. GC Measurements

As mentioned above, the GC provides an almost instantaneous data point every 10 min. As such, it easily can miss the actual peak in the concentration. Typical examples are given in Fig. B-2, where the GC data for the August 27, 1993, and September 17, 1993, pump-induced events are superimposed. As evidenced in this figure, especially for the August 27, 1993, event, it is difficult to predict the actual peak in the hydrogen concentration, which should fall between data points 1 and 2.

4.3. FTIR Measurements

As mentioned before, the FTIR provides time-averaged data, whereas the sample gases flow continuously through the instrument chamber. The averaging time period at the time of Event I was ~15 min. It then required ~2 min before the data was analyzed and recorded. Thus, to obtain a continuous trace, the following integral equation for each data point must be solved:

$$C_i = \frac{1}{\Delta t}\left\{ \int_{t}^{t+\Delta t} C(t)dt \right\} , \tag{B-6}$$

where Δt is the averaging time (~15 min), C_i is the data recorded at time $t + \Delta t$, and $C(t)$ is the continuous concentration trace. If there are many fluctuations within the 15-min time interval, estimating the actual peak for the concentration from the reported average values is difficult. To obtain the peak, we must use an estimated function for C(t). To demonstrate the methodology, we obtained the trace of GC data during Event I (assuming that the nitrous oxide trace is scalable to the hydrogen trace). This approach neglects the short-duration peaks observed in Fig. B-1. We assume that the area under those peaks is small and that the trace can be approximated as a smooth straight line. A more detailed analysis could be performed using the predicted curve in Fig. B-1 as C(t) in the integral given in Eq. (B-6). However, the uncertainties associated with Fig. B-1, as well as the uncertainties in the FTIR data, possibly would overwhelm the details of such an analysis. Nevertheless, our objective is to make a few points about the interpretation and use of the FTIR data; the chosen example serves that purpose. Linearizing the concentration trace, we solve Eq. (B-6) for the two data points near the peak during Event I to obtain the time-averaging starts for the first data point and the actual peak concentration. Using this methodology, the actual peak is 33,000 ppm, as compared to the apparent (measured) peak of 29,250 ppm. The details of the calculations are provided in Refs. 1 and 3.

The results of this example are illustrated schematically in Fig. B-3. A simple curve fitting of the data may be quite misleading during the rapid phases of the gas release transient (at or near the peak). The actual peak concentration may be buried in a data point other than the one that shows the apparent maximum. There may be a large time lag between the recorded data and the actual transient. In this example, the time lag between the recorded and predicted peak is ~25 min. Based on these observations, we recommend caution in comparing the FTIR data to data from other instruments (especially those that provide instantaneous sample data) at or near peak concentrations.

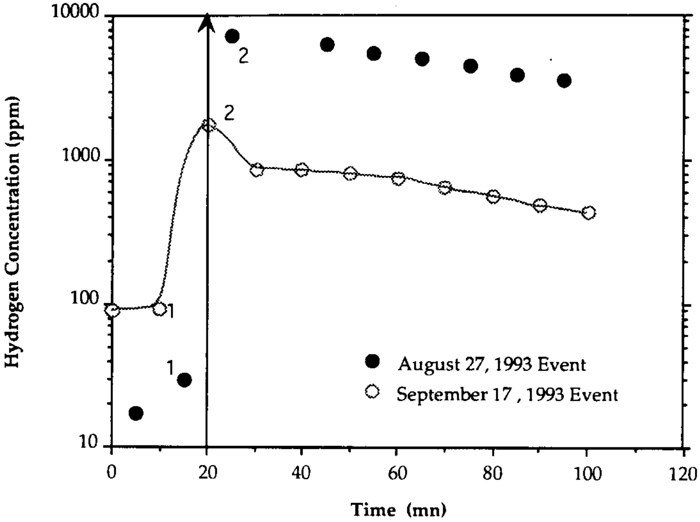

Fig. B-2. GC hydrogen data for the August 27 and September 17, 1993, events.

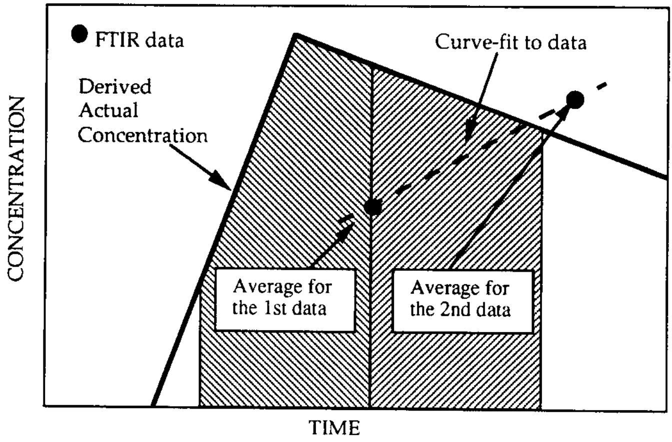

Fig. B-3. Schematic description of the FTIR data compared to a possible actual trace.

We need to compute the nitrous oxide/hydrogen ratio for the gas composition analysis. Because the FTIR does not provide data for hydrogen, we must use two different instruments for this computation. Because of the difficulties discussed above, this computation has a large degree of uncertainty. Here, for discussion purposes, we use the GC data for hydrogen. The uncertainties in the clock for the two instruments enhance the degree of difficulty in the computation. One approach would be to compare directly the peak measured values. Using this approach, we compute the ratio of nitrous oxide to hydrogen as 0.88. Another approach could be to compare the estimated peak values, which yields 0.94. Neither approach is appropriate and can introduce considerable error. For the first approach, we compare an instantaneous reading with a value averaged over a large (compared to transient timespan) time period. In the second case, we use an estimated C(t), the accuracy of which clearly is challenged by Fig. B-1. In this case, another approach could be to use a linear average for the GC over a series of points and compare that with the FTIR values. For instance, we can take the three data points near the peak for the GC that cover a timespan of ~30 min. The two FTIR data near the peak correspond to a timespan of ~35 min. This method gives the nitrous oxide to hydrogen ratio as 0.89. The values computed using any of these methods do not agree with the ratios obtained directly using the MS data where the ratio varies between 0.67 and 0.8 (Ref. 4). However, this is expected if we agree that there may be short-duration peaks during the transient. Such peaks may not have been captured in the GC data, whereas all of them would have been averaged into the FTIR data. Thus, the FTIR would result in a bias in favor of higher nitrous oxide readings compared to instantaneous GC readings.

5.0. SUPPORTING ADMINISTRATIVE CONTROLS

In this section, we discuss briefly the administrative controls reported in Sec. 6 of this SA that are pertinent to the discussion provided in this appendix. The controls are included in App. R, where the safety envelope for the pump operations is outlined.

5.1. Close Monitoring of the Average Waste Temperature and Gas Compositions

We believe that changes in the waste temperature will affect the gas composition determined in this report. The estimated gas compositions are obtained from the data available over a narrow range of waste temperatures (115 to 120°F). If the waste temperature is outside these bounds, the gas composition must be reevaluated. Fortunately, the waste inertia is very large, and quick changes in the waste temperature are not expected. We propose that the TRG be required to evaluate the gas composition based on recommendations of the quarterly data reports provided by the PNL data analysis team.

5.2. Hydrogen Concentration

We recommend that an administrative control be set to stop all operations if the hydrogen concentration is >7500 ppm, which is less than the 25% of the LFL determined in Sec. 3.1 of this appendix. In Sec. 3.1, we predict the 25% of the LFL as 8750 ppm H_2. If we allow for instrument uncertainties, the limit is set to 7500 ppm. As discussed before, the response characteristics of the hydrogen measuring devices do not permit them to detect a sudden increase in the hydrogen concentration in a timely manner. This control is aimed primarily at preventing operations when there is a continuously high hydrogen concentration in the dome space for extended periods of time.

5.3. Ammonia Concentration

We recommend that an administrative control be set to stop all operations if the ammonia concentration is >3000 ppm. As with the hydrogen monitors, the ammonia monitor is not capable of detecting a sudden change in the concentration in <15 min. Thus, this control does not provide a timely warning against an eminent GRE; however, the control is aimed at preventing operations when there is a continuously high ammonia concentration in the dome space for extended periods of time. Indirectly, the control also provides monitoring against changes in gas composition. Based on Table B-2, when the ammonia concentration is >3000 ppm, the hydrogen concentration should be >7800 ppm (best estimate). Thus, if the ammonia control setpoint is exceeded without exceeding the hydrogen control setpoint, the gas composition data should be reevaluated.

5.4. Dome Pressure and Ventilation Flow Controls

The analyses of data indicate that a sudden increase in the dome pressure and in the ventilation flow rate are the earliest symptoms of a GRE (e.g., August 27, 1993, and September 17, 1993, events). The instruments quickly can detect a GRE, and preventive measures can be taken before the dome gas concentrations exceed flammability limits. Thus, the maximum dome pressure and maximum ventilation flow rate must be controlled administratively at all times. The gas monitoring devices should not be relied on as a warning against an eminent GRE.

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APPENDIX C
PUMP-INDUCED GAS RELEASE AS A FUNCTION OF WASTE LEVEL

1.0. OBJECTIVE AND SUMMARY OF RESULTS

Many of the accidents analyzed in the SA require an estimate for the gas release for a given waste level. Also, the waste level is the most accurate indication of the gas inventory in the waste; many of the SA controls are written in terms of maximum waste levels. In this appendix, we provide a semiempirical model to quantify the gas releases at a given waste level. In this model, we account for

- pump-induced release from regions affected by pump mixing,
- spontaneous release from regions not affected by mixing (bottom layer), and
- mass transfer during a GRE.

In this appendix, we develop simple algebraic equations to obtain the best-estimate gas release and its standard deviation as a function of waste level.

Also in this appendix, we provide the basis for the waste level controls for pump installation, operation, and removal; these level controls are set to 10.25 m (403.6 in.), 10.31 m (406 in.), and 10.21 m (402 in.), respectively. These magnitudes are baselined to the FIC level data. We also discuss other level instruments in this appendix.

2.0. GAS INVENTORY

Although the episodic gas releases appear to be eliminated by the mixer pump, this does not mean that the waste is gas-free. We believe there is still considerable gas trapped in the waste in various forms. In addition to bubbles that are trapped in the waste, there is additional gas dissolved in the liquid, which possibly is adsorbed on the solids. Knowing the total amount of gas in the waste is crucial in developing predictive models for possible induced releases.

The gas inventory in the form of bubbles is discussed in Ref. 1. The inventory of dissolved and adsorbed gases is discussed in Ref. 2. The following sections summarize the findings.

2.1. Bubble Inventory

The model used in Ref. 1 is aimed at quantifying the void fraction as a function of waste level under mitigated tank conditions. We use the neutral buoyancy model as the reference state for the tank (similar to the analysis of Allemann et al.[3]). However, the parameters used in quantifying the reference state are slightly different than those used by Allemann et al.[3]

2.1.1. Bubble Inventory at the Reference State (Neutral Buoyancy)

Table C-1 provides the variables used in the neutral buoyancy model. The gas inventory at neutral buoyancy is used as the reference state for this model. The results are most sensitive to the liquid NC- and C-layer densities. The densities and associated standard deviations are obtained from the available core sample measurements.[4–5] The NC-layer thickness is obtained from Ref. 6 and corresponds to the NC-layer thickness estimate before Event G (September 1992 event). Our analysis indicates that Event G was possibly the largest GRE in the history of the tank, with almost the entire NC layer participating.[7] Thus, we reference the neutral buoyancy model to Event G and assume that the entire NC layer was neutrally buoyant in this event. The resulting bubble inventory at neutral buoyancy is given in Table C-2.

As shown in Table C-2, we predict that there is 778 m^3 (27470 ft^3) of gas [at 1 atm (14.7 psi)] trapped in the waste at neutral buoyancy. The standard deviation in this prediction, 80.4 m^3 (2840 ft^3), is obtained using a linear propagation of errors. More than 80% of the variance is a result of the uncertainties in the NC layer and liquid densities.[1] The NC-layer thickness contributes ~14% to the total variance.[1] This gas inventory estimate does not include the gas inventory in the crust. These results show that, even after the largest historical GRE [297.3 m^3 (10,500 ft^3), ±70.8 m^3 (2500 ft^3)], there is considerable gas in the waste.

2.1.2. Bubble Inventory at the Mitigated State

The mitigated state is defined as the condition where the C and NC layers are fully mixed. The gas is trapped at an average hydrostatic pressure, which is evaluated halfway between the bottom of the crust and the bottom of the tank with an estimated deviation. The average hydrostatic pressure is computed as 1.8 atm (26.5 psi), with a standard deviation of 0.21 atm (3.1 psi). The bubble inventory for the mitigated tank at different levels is shown in Table C-3. In this table, the numbers in parentheses correspond to the standard deviation associated with the state parameters. The measured waste level is designated "L." The computed standard deviations for the parameters account for a 38.1-mm (1.5-in.) std dev in the measured level.

2.2. Dissolved Gas Inventory

The inventory of dissolved gas in the tank is discussed in Ref. 2. According to this reference, only ammonia exists in large quantities in the liquid phase. Nitrous oxide is moderately soluble, but the liquid inventory is negligible compared to ammonia. Other gases are highly insoluble in the waste.

TABLE C-1
BEST-ESTIMATE AND STANDARD DEVIATIONS FOR THE INDEPENDENT VARIABLES USED IN THE PRESENT MODEL

Variable	Best Estimate	Standard Deviation	Reference
Waste Level at Neutral Buoyancy	416.5 in.	3 in.	1, 8
Crust Thickness	30 in.	6 in.	1, 3, 8
NC-Layer Thickness	220 in.	30 in.	1, 5
Crust Density	1350 kg/m^3	30 kg/m^3	1, 3
Gas-Free C-Layer Density	1520 kg/m^3	20 kg/m^3	1, 6
Gas-Free NC-Layer Density	1700 kg/m^3	43 kg/m^3	1, 7
Liquid Density	1460 kg/m^3	20 kg/m^3	1, 6

TABLE C-2
RESULTS FOR THE NEUTRAL-BUOYANCY-STATE PARAMETERS

PARAMETER	Best Estimate	Standard Deviation
In Situ Gas Volume in C layer	2420 ft^3	490 ft^3
In Situ Void Fraction in C layer	3.9%	a
C-Layer Gas Volume at 1 atm	3396 ft^3	a
Gas-Free C-Layer Thickness	160 in.	a
In Situ Gas Volume in NC Layer	11434 ft^3	2350 ft^3
In Situ Void Fraction in NC Layer	14.1%	a
NC-Layer Gas Volume at 1 atm	24077 ft^3	a
Gas-Free NC-Layer Thickness	189 in.	a
Total Gas Volume in C and NC Layer	13854 ft^3	2840 ft^3
Total Gas Volume in C and NC Layer at 1 atm	27473 ft^3	5240 ft^3
Gas-Free Waste Level (including Crust)	378.9 in.	8.2 in.
Gas-Free Average Density (without Crust)	1618 kg/m^3	28 kg/m^3

[a] The standard deviation for these parameters is not computed because it has little relevance to the final results. If needed, the standard deviation may be computed using the same approach used for the other parameters.

Ammonia inventory in the waste is ~0.332 mole/l (0.0117 mole/ft^3) (which corresponds to 0.27 wt %). The standard deviation for this estimate is 0.094 mole/l (0.0033 mole/ft^3). The dissolved ammonia inventory corresponds to ~23,220 m^3 (820,000 ft^3) of gaseous ammonia at 1 atm (14.7 psi) and 27°C (81°F). Thus, for all practical purposes, there is an infinite supply of ammonia in the liquid phase.

TABLE C-3
RESULTS FOR THE MITIGATED-STATE PARAMETERS

	L = 396 in.	L = 398 in.	L = 400 in.	L = 402 in.
In Situ Gas Volume (ft^3)	6307 (3081)	7043 (3081)	7780 (3081)	8516 (3081)
In Situ Void Fraction	4.7% (2.3%)	5.2% (2.3%)	5.7% (2.3%)	6.2% (2.2%)
Gas Volume at 1 atm (ft^3)	11,372 (5666)	12,700 (5699)	14,028 (5736)	15,355 (5777)
Void Fraction at 1 atm	8.1% (3.9%)	9.0% (3.9%)	9.8% (3.8%)	10.7% (3.8%)
Mixture Density (kg/m^3)	1542 (25)	1533 (25)	1525 (25)	1517 (25)

2.3. Adsorbed Gas Inventory

Reference 2 shows that ammonia is the only gas that can be adsorbed physically on the solid surfaces. Conservative estimates show that the physically adsorbed ammonia inventory is very small compared to the dissolved ammonia inventory. The surface chemistry in the waste is not fully understood for confidently assessing the chemisorption. Nevertheless, we do not believe that pump operations can cause a prompt release of the adsorbed gases, even if there were a large adsorbed gas inventory. Thus, we conclude that the prompt release of the adsorbed gases as a result of pump operations is not a safety concern.

3.0. GAS RELEASE MODEL

Although there may be considerable gas in the tank, even at the current low waste levels [~10.16 m (400 in.)], pump operations to date have demonstrated that (1) a prompt release of the total inventory is not likely; (2) as long as the pump is routinely operated, level growth in the tank is not expected; and (3) the mixed region in the tank will not contribute to a prompt gas release. The simple model assumes that there are three contributors to a gas release:

- bubble release induced by pump operation (Q_i),
- bubble release from regions previously unaffected by the pump (Q_o), and
- gas release as a result of mass transfer (Q_m).

Thus,

$$Q = Q_b + Q_m = Q_i + Q_o + Q_m \quad , \qquad \text{(C-1)}$$

where Q_b represent the gas release in the form of bubbles.

3.1. Pump-Induced Bubble Release

We assume that

- there is a minimum waste level (L_0) below which further prompt release cannot result from the pump operations; and
- above L_0, a pump-induced event will release all gas that contributes to level growth.

This simple model is given by

$$Q_i = \frac{\pi}{4} D^2 (L - L_o) \times \frac{P_H}{P_{atm}} \quad , \tag{C-2}$$

where L is the measured waste level, D is the tank diameter [22.86 m (75 ft)], P_{atm} is the atmospheric pressure, and P_H is the average hydrostatic pressure at which the gas is compressed.

As discussed before, as long as the pump continues routine operation, we do not expect level growth and/or prompt gas releases from the mixed regions. In the future, the mixed regions may contribute to a prompt release if pump operations cease for a period of time and the waste is allowed to resettle. If mixer pump operations resume after the resettling process, we expect induced releases if the level is $>L_0$. In these calculations, we assume that the waste resettles to a 6.35-m (250-in.) NC layer (which was the NC-layer thickness observed after Event G and before the installation of the mixer pump). We assume a 76.2-cm (30-in.) standard deviation for the NC-layer thickness. All other parameters used in computing the average hydrostatic pressure in the NC layer are the same as those reported in Table C-1. If we account for the regions unaffected by pump operation (bottom sludge layer), the choice of parameters for estimating P_H is conservative. The minimum level L_0 may be obtained using historical GRE data and data from the mixer pump tests.

Using these parameters, Eq. (C-2) becomes

$$Q_i = \begin{cases} 755 \times (L - L_0) & \text{if } L > L_0 \\ 0 & \text{if } L \leq L_0 \end{cases} \quad , \tag{C-3}$$

where L and L_0 are in inches to obtain Q_i in cubic feet.

We estimated the standard deviation using a linear propagation of errors. The standard deviation for the level measurement is 38.1 mm (1.5 in.). The standard deviations for the other parameters are the same as those shown in Table C-1. The estimated standard deviation for Q_i is a function of level but varies between 33.8 and 34.9 m^3 (1194 and 1234 ft^3) for waste levels ranging from 10.16 to 10.57 m (400 to 416 in.) [using L_0 = 10.17 m (400.5 in.)]. At a waste level of 10.21 m (402 in.), 99.9% of the variance results from the uncertainties in L and L_0. For a waste level of 10.57 m (416 in.), the contribution of L and L_0 drops to 93%, whereas the remaining contribution to the variance (6%) is a result of the uncertainty in the NC-layer thickness. Hereafter, we assume a constant standard deviation as $\sigma_{Qi} = 34\ m^3$ ($\sigma_{Qi} = 1200\ ft^3$) in the model. Further details of the uncertainty analysis may be found in Ref. 3.

3.2. Gas Release from the Bottom Sludge Layer

We postulate that the layer at the bottom of the tank is not affected by pump operation. This layer continues to retain gas and may roll over, resulting in a prompt gas release. A detailed discussion and analysis of this layer is provided in Ref. 3. The discussion in this appendix indicates that the bottom layer possibly is affected by pump operation. The layer's spontaneous rollover with a large gas release is not very likely but also is not incredible. The analysis shows that the results of the phenomenological modeling are almost equal to the gas release estimates obtained by simple scaling to the largest GRE, the latter estimates being slightly more conservative. For simplicity, we chose to use this scaling approach here to quantify the gas release from the bottom layer. The variation in the hydrostatic pressure is accounted for in this model and is expressed as

$$Q_o = Q_{GRE} \times f \times \left(\frac{H_o}{H_{GRE}} \right) \times \left(\frac{P_o}{P_{GRE}} \right) \quad , \tag{C-4}$$

where Q_{GRE} is the gas release during a large GRE, f is the sludge volume scaling factor compared to a sludge disk of thickness H_o, H_{GRE} is the NC-layer thickness before the GRE, P_o is the average hydrostatic pressure in the sludge layer, and P_{GRE} is the average hydrostatic pressure in the NC layer before the GRE. Currently, the December 1991 (Event E) and September 1992 (Event G) events are believed to have resulted in the largest gas releases. We believe that almost all of the NC layer possibly participated in these GREs. Also, the analysis in Ref. 3 shows that using the data either from Event E or G results in identical results for a 1.016-m (40-in.)-thick sludge. Because the results for Event G are slightly more conservative and Event G is believed to include a larger participation by the NC layer, we used Event G in this analysis. The best-estimate Event G values for Q_{GRE} and H_{GRE} are given as 297.3 m^3 (10,500 ft^3) and 5.59 m (220 in.), respectively. The best-estimate values for P_o range from 2.43 to 2.51 atm (35.7 to 36.9 psi) for sludge thicknesses ≤1.016 m (40 in.) The use of an average value of 2.5 atm (36.7 psi) introduces a small error in the analysis. The best-estimate value for P is obtained as 2.11 atm (31 psi) [corresponding to a 5.59-m (220-in.)-thick NC layer]. Substituting these values into Eq. (C-4), we obtain the following equation for the gas release as a function of sludge thickness:

$$Q_o = 56.6\, f\, H_o \quad , \tag{C-5}$$

where H_o is in inches to provide Q_o in cubic feet.

Using the linear-propagation-of-error method, we estimated the uncertainty associated with Eq. (C-5). The uncertainty associated with Q_{GRE} is ~70.8 m^3 (2500 ft^3). Using the range of NC-layer-thickness observations before and after Event G, the uncertainty in H_{GRE} is ~0.762 m (30 in.) We also estimated the uncertainty in the hydrostatic pressure using the density, crust thickness, layer thickness, and waste level uncertainties (using the same approach as in the induced gas release analysis). As shown in Ref. 3, the hydrostatic pressure contribution to the total variance is <1% within the range of H_o of interest. Neglecting the uncertainty associated with the hydrostatic pressure has an added advantage because it decouples the Q_o model from the Q_i model. The variance of the two models become additive. The standard deviation for Q_o may be obtained as a function of the sludge thickness and its variance as

$$\sigma_{Q_o} = \sqrt{3204\sigma_{H_o}^2 + \left(241 + 3204\sigma_f^2\right)H_o^2} \quad , \tag{C-6}$$

where the sludge thickness and the standard deviation are in inches to obtain the gas release in cubic feet.

Thus, we obtain the bubble release as

$$Q_b = \begin{cases} 755(L - L_o) + 56.6\, f\, H_o & \text{if} \quad L > L_o \\ 56.6\, f\, H_o, & \text{if} \quad L \leq L_o \end{cases} \quad , \tag{C-7}$$

where the variance is given by

$$\sigma_{Q_b}^2 = \begin{cases} (1200)^2 + 3204\sigma_{H_o}^2 + \left(241 + 3204\sigma_f^2\right)H_o^2 & \text{if } L > L_o \\ \left[755(L - L_o + 1.6)\right]^2 + 3025\sigma_{H_o}^2 + \left(241 + 3204\sigma_f^2\right)H_o^2 & \text{if } L_o - 1.6 < L \leq L_o \\ 3025\sigma_{H_o}^2 + \left(241 + 3204\sigma_f^2\right)H_o^2 & \text{if } L \leq L_o - 1.6 \end{cases} \quad . \tag{C-8}$$

3.3. Gas Release as a Result of Mass Transfer

In modeling the mass-transfer contribution to the total release, we make two assumptions:

- Among all the release gases, only the ammonia mass transfer is significant, as discussed in Sec. 2.2 of this appendix.
- The mass-transfer contribution is a constant fraction of the total release, such that

$$Q_m = m \cdot Q \quad , \tag{C-9}$$

where m is a function of waste properties only. As discussed in Refs. 9 and 10, this appears to be a reasonable assumption for gas releases of ≤169.9 m^3 (6000 ft^3) (similar to Event I) and possibly is conservative for larger releases.

The mass transfer includes both the direct transfer from the waste into the dome and the transfer into the bubbles after the bubbles are mobilized and start rising to the surface. By rearranging the terms, we obtain

$$Q = \eta Q_b \quad , \tag{C-10}$$

where

$$\eta = \frac{1-x}{1-a} \quad . \tag{C-11}$$

The mole fraction of ammonia in the retained bubbles (x) may be estimated using the estimated ammonia concentration in the waste (C) and the Henry's law constant (h) as

$$x = \frac{hC}{P_H} \quad . \tag{C-12}$$

We estimate the ammonia concentration in the waste as 0.28 wt % [0.332 moles/l (0.0117 mole/ft^3) of liquid].[9] The Henry's law constant in the waste at 49°C (120°F) also may be obtained from Ref. 9 as 0.325 atm-l/mole (0.169 psi-ft^3/mole). Using an average hydrostatic pressure of 2.05 atm (30.1 psi) (see Sec. 3.1 of this appendix), we obtain x as 0.0526. The fraction of ammonia in the release gas (a) is obtained from Ref. 10 as 0.11. Thus, η is obtained as 1.065.

The standard deviations for the Henry's law constant and the ammonia concentrations are ~30%.[9] For the purpose of this model, maximizing η (minimizing x) is conservative. Kubic's estimate[9] for C (consequently x) is already lower than the estimate by Norton and Pederson.[11] Likewise, our estimate for C is lower than the core sampling data[7,12] when we consider the estimates for the ammonia loss during sampling, transport, and laboratory analyses.[13] Thus, the value we use for C already may be conservative without accounting for additional uncertainty. Nevertheless, in the absence of more detailed data, we use another 30% uncertainty for C. We neglect the uncertainty in P_H because it contributes to <1% of the total variance in η. The standard deviation for a is obtained as 26% from Ref. 10. Thus, using linear propagation of errors, we estimate the standard deviation for η as 0.042.

3.4. Overall Gas Release

The overall gas release at a given level L may be estimated using

$$Q = 1.065 \times \begin{cases} 755(L - L_0) + 56.6\, f\, H_0 & \text{if} \quad L > L_0 \\ 56.6\, f\, H_0, & \text{if} \quad L \le L_0 \end{cases} \tag{C-13}$$

for a given bottom sludge-layer thickness H_0. This equation provides the best-estimate prediction. The associated standard deviation is given by

$$\sigma_Q = \sqrt{(0.042 Q_b)^2 + \left(1.065 \sigma_{Q_b}\right)^2} \quad , \tag{C-14}$$

where Q_b and σ_{Qb} are given by Eqs. (C-7) and (C-8), respectively. The upper-bound, conservative estimate is obtained as $Q + \sigma_Q$.

4.0. SLUDGE THICKNESS AND LEVEL MEASUREMENTS

To quantify the simple gas release model developed above, we need to determine the thickness of the bottom sludge and the associated uncertainty and the appropriate value for the minimum waste level.

4.1. Sludge Thickness and its Uncertainty

The analyses of transient temperature responses on both MITs show that, during pump operation with the jet directed at the MITs, the second TC [0.406 m (16 in.) from the tank bottom] clearly indicates jet motion.[14] Reference 14 also shows that motion is detected at the same TC, even when the jet is oriented 30 deg from the MIT. Based on this information, we estimate that the best-estimate sludge thickness at the MIT locations is 0.254 m (10 in.) (halfway between the first and the second TC). If we assume that the probability distribution for the sludge thickness is uniform between 0.1016 and 0.4064 m (4 and 16 in.) from the bottom, the standard deviation is estimated as 0.0914 m (3.6 in.).

Stewart[14] infers from the crane unloading data during the recent void fraction instrument installation that the sludge thickness below Risers 4A and 11A are between 0.4064 and 0.6096 m (16 and 24 in.). Azimuthally, these risers are located halfway between the normal pump operation directions, which are 30 deg apart. Stewart[14] speculates that scallops may have developed in the regions between the normal pump orientations, where the sludge thickness may be ~0.508 m (20 in.), with a ±0.1016-m (4-in.) uncertainty. Combining these data, we estimate the average sludge thickness as 0.381 m (15 in.), with a standard deviation of 0.1321 m (5.2 in.).

However, the above value of the sludge thickness is valid only at or near the radial position of the MITs, which are 8.5 to 9.1 m (28 to 30 ft) from the pump. We expect radial variations for the sludge thickness to be smaller near the pump and greater between the MITs and the tank wall. For a disk of uniform thickness, 60% of the total volume is inside the 8.84-m (29-ft)-radius circle. The remaining 40% volume is between the 8.84-m (29-ft)-radius circle and the tank wall. Because a larger fraction of the volume corresponds to the region where the thickness is expected to be <0.381 m (15 in.), the error in the radial thickness already may be bounded by the use of a uniform 0.381-m (15-in.) thickness. Nevertheless, we use a standard deviation for the sludge volume estimate as 25% of the volume, which corresponds to a 0.381-m (15-in.)-thick disk. Based on this model, we predict the sludge volume as 156.3 m^3 (5520 ft^3), with a standard deviation of 66.8 m^3 (2360 ft^3).

Stewart[14] provides a detailed analysis of the sludge layer based on the MIT and voidmeter data. In the analysis, numerous assumptions were made in developing the reported 3D profiles. Some of those assumptions cannot be verified easily because the number of data points does not support the detail in the final results and the sludge thickness estimates inferred from the voidmeter are highly uncertain. Nevertheless, Stewart determines the sludge volume to be 178.1 m^3 (6290 ft^3), with an uncertainty of 48.1 m^3 (1700 ft^3). The estimated sludge volume corresponds to an average sludge thickness of 43.4 cm (17.1 in.). Because Stewart's estimate of the average sludge thickness is slightly more conservative than the simple model described previously, we use the best-estimate sludge thickness (H_o) as 43.4 cm (17.1 in.) in this SA.

A schematic of the sludge's approximate profile and uncertainty is shown in Fig. C-1 to illustrate the possible variations in sludge thickness as a function of radius. This figure is generated assuming that the thickness (H_{min}) is 0.1016 m (4 in.) below the pump and monotonically increases with radial distance (r) from the pump such that

$$H - H_{min} \propto r^n \quad ,$$

where n is a positive constant. The profiles in Fig. C-1 are obtained by evaluating n to match the volume of the disk with a constant thickness of 0.434 m (17.1 in.), which is 178.3 m^3 (6295 ft^3). For the upper-bound case, we use an average sludge thickness of 0.605 m (23.8 in.), and the minimum sludge thickness below the pump is maintained at 0.1016 m (4 in.).

Setting H_o = 0.434 m (17.1 in.), σ_{H_o} = 0.132 m (5.2 in.), f = 1 and σ_f = 0.25, the gas release from the sludge layer and the corresponding standard deviation are computed from Eqs. (C-5) and (C-6) as 27.4 m^3 (968 ft^3) and 13.1 m^3 (464 ft^3), respectively. We believe that the degree of conservatism in these calculations is appropriate, considering that the rollover of the entire sludge layer in unison is highly unlikely.[3]

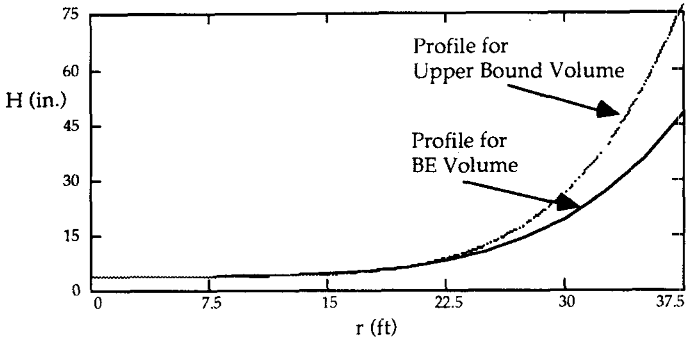

Fig. C-1. Estimated sludge profiles matching the assumed sludge volume.

4.2. Level Measurements

One of the difficulties in applying the proposed model is in determining the minimum level (L_0) and current level (L) because different instruments do not always agree with each other. Four different instruments that provide level measurements are the (1) FIC, (2) manual tape, (3) radar gauge, and (4) ATG (hereafter referred to as Enraf).*

The Enraf is a new instrument that has been used only in the last few months. The other three instruments historically measured levels within a ±38.1-mm (1.5-in.) deviation during quiescent periods between GREs. The difference was attributed mostly to the spatial variations in crust topography. Previously, we did not have a clear bias between the instruments where one instrument always measured greater than or less than the other instrument. The variations appeared to be random in nature, which was in agreement with the possible differences in the crust topography at different regions of the surface. The 38.1-mm (1.5-in.) std dev for the level measurement used in the above model is based on these observations.

Using L_0 = 10.21 m (402 in.), the model is compared to available GRE data in Fig. C-2. The natural GRE data[15] were obtained by a combination of the first three instruments cited above, depending on the availability of the instrument at the time of the specific GRE. The data for the induced GRE[16] were obtained primarily using the FIC data. However, when these GREs occurred (within a few months after pump installation), the FIC measurements were in agreement with the other instruments within the uncertainty range discussed above. The error bars shown in

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* The Enraf-Nonius™ 854 Advanced Technology Gauge, or ATG, is manufactured by the Enraf-Nonius Company of Stafford, Texas.

Fig. C-2 correspond to ±38. 1 mm (1.5 in.) for the level measurement and ±25% for the gas release volume estimates. Based on the comparison shown in Fig. C-2, it appears that 10.21 m (402 in.) is a reasonable estimate for L_O. This choice also is consistent with the fact that even after the largest natural rollovers, the waste level has not dropped below 10.21 m (402 in.), and when the waste level was <10.21 m (402 in.), the pump did not trigger a rollover. At the end of Phase B testing (January 1993), the radar gauge reading leveled off slightly >10.21 m (402 in.) and remained there for a long time. Currently, the radar gauge readings are slightly <10.21 m (402 in.). Thus, using the radar gauge, the minimum level (L_O) may be set to 10.21 m (402 in.).

After mixer pump operations mitigated the tank and eliminated the rollovers, the FIC and the manual tape started deviating from radar gauge readings. The FIC and the manual tape are known to develop stalactites over time and must be flushed periodically. After termination of Phase B testing, there was no rollover resulting in surface motion. Thus, the same spot on the crust was exposed to flush water repeatedly. As a result, a hole appears to have developed on the crust immediately below the FIC. Video observations show that the hole is ~30.5 cm (1 ft) in diameter and may contain a pond. The FIC measures the elevation of this pond surface. It is quite likely that the pond is connected hydraulically to the waste liquid and that the FIC is measuring the true liquid level in the waste (or a small offset from the true liquid level, resulting from the capillary pressure effects if the pond is connected to the liquid waste through small-diamater pores). A schematic of the possible pond configuration is shown in Fig. C-3.

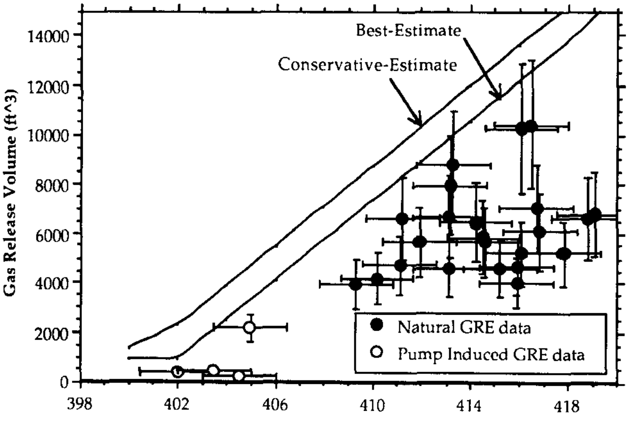

Fig. C-2. Comparison of the present model with the GRE data.

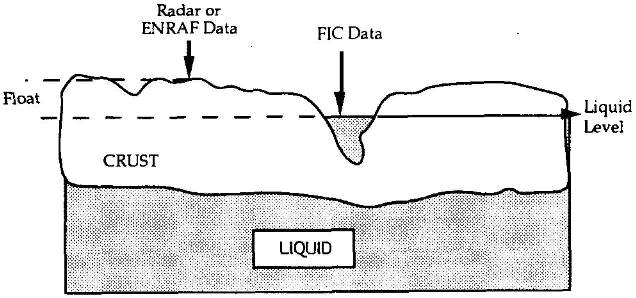

Fig. C-3. Schematic of the possible crust configuration below the level gauges.

If the proposed scenario is correct, the bias between the FIC data and the radar gauge and ENRAF data (which measure the crust surface elevation) would be equal to the float shown in Fig. C-3. Unfortunately, the float is a function of various parameters that do not necessarily remain constant. In a simple model (neglecting the capillary effects), the float is a function of crust thickness, liquid density below the crust, and crust density. Both the liquid density and the crust density are a function of the temperature below the crust, which increased as the mixing progressed. Increasing the temperature immediately below the crust also is likely to have resulted in thinning of the crust. On the other hand, the fact that rollovers have stopped and the crust is no longer being stirred occasionally implies that the crust also may be thickening or that the crust density may be changing as a result of changing moisture content. Gradual degassing of the waste, along with increased inventory of suspended solids below the crust, also increases the liquid density, thus increasing the float. The short-term transient variations of the float during pump operations have an added degree of complexity because the relative surface motion is a function of the pore volume in the crust and capillary resistance to the flow.

Currently, the bias between the FIC and the radar gauge is ~50.8 mm (2 in.). The bias between the FIC and the ENRAF is ~76.2 mm (3 in.). However, as discussed before, this bias may change in the future. If we do not operate the pump for an extended period, the solids may settle and the temperature below the crust may start decreasing. As a result, the macroscopic density of the liquid below the crust may decrease, which in turn may cause the crust to sink. Thus, the difference between the radar gauge (and/or Enraf) and the FIC may decrease. Given all these uncertainties, the level controls must be evaluated carefully because projecting the relative variation in the level data from various instruments into the future requires detailed analysis (which is being performed by the Data Analysis Team).

Controls at levels ≥10.26 m (404 in.) have sufficient conservatism such that if the instruments are used based on a consistent criterion, the controls can be implemented on a conservative basis. Currently, the level measurements from all available instruments are <10.26 m (404 in.); thus, we do not expect the tank level to approach these control limits in the future. The most restrictive level controls are associated with pump removal and installation. Implementing these controls requires special care, as discussed in Sec. 5.2 and 5.3 of this appendix.

5.0. LEVEL CONTROLS

To bound the consequences of various release and burn accidents by the safety envelope defined in this SA, we have many waste level controls. Knowing the allowable maximum release for each case, we determined the corresponding level control. In the following subsections, we determined the level controls for pump operation, pump removal, pump installation, and dome-intrusive operations. As discussed below, all controls are baselined to the FIC readings, where L_0 is set equal to 10.16 m (400 in.) based on recent observations of these readings.

5.1. Maximum Level Control for Pump Operations

The structural analysis documented in App. K shows that the conservative allowable gas release during pump operations should be bounded by 245 m^3 (8650 ft) to meet the structural acceptance criterion. When we substitute 245 m^3 (8650 ft) into the above model, the conservative estimate for the incremental level is obtained as 19.6 cm (7.7 in.). Thus, the level control for pump operation can be set to 10.36 m (407.7 in.) using the FIC and setting L_0 = 10.16 m (400 in.).

However, as discussed later, the level controls for pump replacement are very restrictive. When the current pump fails, if it cannot be replaced, the tank will revert back to its original behavior where the natural rollovers may exceed the structural limit of 245 m^3 (8650 ft). Consequently, the pump must be operated such that the waste levels are kept low. Currently, the FIC level is <10.16 m (400 in.), and the radar gauge level is <10.21 m (402 in.). Thus, we set an alarm for the maximum pump operation at 10.21 m (402 in.) using the FIC data. If the level exceeds the alarm setpoint, the TRG must be notified and must implement an aggressive pump operation schedule until the waste level is lowered to the current level (or lower if possible). Because it is important to keep the tank mitigated and prevent the level from growing, we also lowered the maximum operating level to 10.31 m (406 in.) We expect that pump operations between 10.21 m and 10.31 m (402 in. and 406 in.) will be necessary only if, for some unexpected reason (e.g., limited access to the tank farm), mitigation operations are not performed for an extended period of time while the pump is still operational.

Thus, the pump operation limits (alarm and abort) are set using the FIC. When the FIC is not available, the alarm setpoint when the TRG must be notified should be met assuming a 2-mm/d (0.08-in./d) growth since the last time the FIC data was obtained. The FIC should be made operational as quickly as possible after failure.

Any available instrument can be used to meet the 10.31-m (406-in.) level limit for continued pump operation.

After completion and approval of the level instrument analysis being performed by the PNL data analysis team, the TRG may determine the control setpoints as a function of each level instrument.

5.2. Level Control for Pump Removal

The maximum allowable release for pump removal is determined based on the ejection accident analysis provided in App. M. The conservative estimate (using the conservative-estimate gas composition and gas release rate) is obtained as 70.8 m^3 (2500 ft^3). Substituting into the above model, the incremental level is obtained as 4.57 cm (1.8 in.) using the best-estimate model and 0.25 cm (0.1 in.) using the conservative-estimate model.

Considering that

- there is considerable conservatism in determining the maximum allowable release as 70.8 m^3 (2500 ft) (see the discussion in App. M),
- the inability to remove the pump upon failure would have serious consequences because it would cause the tank to return to its unmitigated state, and
- the frequency of a GRE and a burn is very low ($\sim 10^{-6}$/yr) for the ejection accident to occur,

we feel it is justified to use the best-estimate gas-release-vs-level model. The difference between the best-estimate and conservative-estimate gas release model is primarily the result of the level measurement uncertainties and gas release from a sludge rollover. From the time the pump fails until it is removed, the waste level will be low, and we do not expect a rollover that causes surface motion. Consequently, because the level measurements will be performed at one spot, the uncertainty in the incremental level measurement will be minimal. Also, a unison rollover of the sludge layer is highly unlikely, and the best-estimate model for the sludge rollover possibly already is conservative. As discussed in Sec. 4.1 of this appendix, the larger fraction of the postulated sludge volume is expected to be near the tank walls, away from the tank centerline where the pump is located. Consequently, the sludge is not likely to be disturbed during removal. A coincidental natural rollover of the sludge during the brief period (~1 h) for pump removal is not likely. Finally, as shown in Fig. C-1, even the best-estimate model conservatively predicts all rollover data to date (especially those at low waste level); at waste levels $\leq$10.29 m (405 in.), we have not experienced a rollover with a gas release >56.6 m^3 (2000 ft^3).

Thus, we set the incremental level growth to 4.57 cm (1.8 in.) for pump removal, which results in a level control of 10.21 m (401.8 in.) using the FIC. If the FIC is not operational at the time of pump removal, the TRG may use one of the other level instruments based on a detailed level data evaluation that should be provided by the PNL data analysis team. Currently, this analysis and a detailed understanding of the data from different instruments are not available. Until such an analysis is prepared and approved, we require that time be used as the control parameter. If at the time of pump failure the FIC data is ≤10.16 m (400 in.) or the radar gauge data is ≤10.21 m (402 in.), the pump must be removed within 22 d after failure. Assuming a 2-mm/d (0.08-in./d) growth corresponding to the level growth during the pre-pump operation period, 22 d results in 45.7 mm (1.8 in.) of level growth. The 2-mm/d (0.08-in./d) growth rate is conservative because the waste will not settle instantaneously after pump failure and it would possibly take a few weeks before the waste fully settled and resumed its 2-mm/d (0.08-in./d) growth cycle.

5.3. Level Control for Pump Installation

The maximum allowable release for pump installation is determined based on the ejection accident analysis provided in App. M. The conservative estimate (using conservative-estimate gas composition and gas release rate) is obtained as 103.4 m^3 (3650 ft). Substituting into the above model, the incremental level is 8.64 cm (3.3 in.) using the best-estimate model and 4.32 cm (1.5 in.) using the conservative-estimate model.

During pump removal, there may be crust motion. Also, considerable water may be added to decontaminate the pump, which in turn will result in crust dissolution. Other than the expected surface motion, all other arguments provided above for using the best-estimate gas-release-vs-level model are valid for installation. In addition, there is added conservatism in the "no-motion" criterion used for pump installation because all consequences (structural, toxicological, and radiological) will be bounded by the current safety envelope for pump motion up to 9 ft (3 m) as a result of ejection during installation.

Thus, we set the incremental level growth to 8.38 cm (3.3 in.) for pump installation, which results in a level control of 10.25 m (403.3 in.) using the FIC. This is higher than the pump removal limit, which requires that the probability of an emergency removal be assessed before beginning installation activities. The probability of a rollover at these low waste levels is very low. Considering the successful installation of the first pump, we believe that the necessity of an emergency removal also is very low. Consequently, it is not necessary to impose the removal limit for pump installation.

If considerable water is added during removal such that we cannot accurately predict the actual waste level, or if the FIC is not operational at the time of pump installation, we require that the new pump be installed within 13 d after removal of the current pump. Based on the 2.5-mm/d (0.1-in./d) level growth, 13 d corresponds to 3.3 cm (1.3 in.) of growth, which is equal to the difference between the pump removal and installation limits.

Finally, the TRG may authorize water lancing (see App. U) as the safety basis for pump installation, which is similar to installation of the first pump.

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APPENDIX D
HMS/TRAC DESCRIPTION AND TANK 101-SY MODELING RESULTS

1.0. OBJECTIVE AND SUMMARY OF RESULTS

This appendix discusses the analytical tools, basic assumptions, and thermal-hydraulic results used in support of the Mixer Pump SA. A brief summary of the governing physical equations, numerical algorithms, and constitutive models of the computer codes used to perform the analyses are presented, as well as a description of the computer model of the 241-SY Hanford Tank Farm. Proposed accident scenarios concerning the installation, operation, and removal of the mixer pump in Tank 101-SY were analyzed for the SA.

The HMS/TRAC thermal-hydraulic analysis simulated the injection and mixture of the release gases within the tank dome space, the combustion of the flammable gases, and the resulting gas transport through the various leak paths of the tank. The predicted parameters of interest were the Tank 101-SY dome pressures and vapor temperatures and the radioactive waste material and toxic gases (ammonia) released to the atmosphere. The results of the pressure response of the tank were used as input for the structural analysis of the tank. The entrainment and transport of waste material and toxic gases from the tank were used for the radiological and toxicological consequence analyses.

2.0. HMS/TRAC DESCRIPTION

The analytical tools used to model the thermal-hydraulic phenomena in Tank 101-SY above the waste surface were the combined HMS[1] and TRAC[2] computer codes. HMS is a finite-volume computer code that solves the transient, 3D, compressible-fluid, Navier-Stokes equations with multiple species combined with chemical kinetics. This code was developed at LANL to be a best-estimate tool for predicting the transport, mixing, and combustion of hydrogen gas in nuclear reactor containments. HMS was used in this study to model the gas release into the vapor space of Tank 101-SY. We then postulated that these released gases were transported and mixed in the cover gas volume according to local dynamics (such as convection and turbulent diffusion) before being ignited. After ignition, the flows were driven by the combined fluid-dynamics/chemical kinetics algorithm. TRAC is a finite-volume/lumped-parameter thermal-hydraulics code developed at LANL for deriving advanced best-estimate predictions of postulated accidents involving light-water reactors. The network flow capability of TRAC was used to model the ventilation system associated with the SY Tank Farm. In this context, Tanks 102- and 103-SY were modeled using the lumped volume capability, while the ventilation system, including the in-leakage ports to each tank, was modeled using the 1D, finite-volume capability of TRAC.

The two codes were combined numerically at the physical representation of the boundary to Tank 101-SY. That is, HMS provided TRAC pressures, temperatures, and gas composition at computational cells adjacent to the physical connections for the ventilation system and the in-leakage port. TRAC used these values to compute flow rates throughout the entire system, excluding Tank 101-SY. The resulting TRAC velocities representing the response of the ventilation system then were used as inflow or outflow boundary conditions for HMS. This combination was accomplished in a simultaneously explicit manner that proved to be extremely stable and robust.

2.1. The HMS Mathematical Model

The partial-differential equations that govern the fluid dynamics and species transport, as well as the equations describing the turbulence model and combustion phenomena, are presented in Ref. 1. The specific internal energy of any individual species is related directly to the temperature through a constant coefficient of specific heat at a constant volume. The total specific internal energy then is given by the sum of all of the species' internal energies multiplied by their mass fraction. The equation of state for the fluid pressure is given by the usual ideal gas mixture equation.

The convective heat exchange between the burning gas mixture and the waste surface is given by Newton's heating and cooling law, where the heat-transfer coefficient is calculated according to a modified Reynolds analogy. This expression contains the wall shear stress, which is related to the fluid density and the wall shear speed. We were unable to resolve turbulent boundary layers near solid walls with any practical computing mesh; thus, we matched our solution near solid boundaries with a turbulent law of the wall, which was modified for rough surfaces. When the local Reynolds number is small, the law-of-the-wall formulation is not valid; thus, we used a laminar formulation.

We modeled the radiation heat transfer from the flame in a relatively simple fashion. We assumed that 15% of the total chemical energy of combustion is radiated[3] from a point source at the computational cell center. This energy is radiated spherically away from each computational cell where combustion occurs to solid surfaces such as the crust, with the appropriate geometric view factors. We used a simple algebraic, or mixing length model adapted from the approach of Launder and Spalding[4] for turbulence modeling. In this model, the turbulent viscosity is proportional to the product of the fluid density, turbulent kinetic energy, and length scale of the energy-carrying eddies. Also, it often is estimated that $\leq 10\%$ of the mean flow energy is contained in the turbulent kinetic energy, and the length scale usually is set equal to 0.25 to 0.5 m (9.8 to 19.7 in.) for containment-type problems.

We used a one-step chemical kinetics model that oversimplifies the actual chemical processes. In this model, the only reactions modeled were

$H_2 + N_2O \rightarrow H_2O + N_2 + 77.4$ kcal/mole H_2 consumed

(Reaction A),

$H_2 + 1/2\ O_2 \rightarrow H_2O + 57.8$ kcal/mole H_2 consumed

(Reaction B),

$NH_3 + 3/2\ N_2O \rightarrow 3/2\ H_2O + 2\ N_2 + 105.1$ kcal/mole NH_3 consumed

(Reaction C),

$NH_3 + 3/4\ O_2 \rightarrow 3/2\ H_2O + 1/2\ N_2 + 75.7$ kcal/mole NH_3 consumed

(Reaction D),

$CO + N_2O \rightarrow CO_2 + N_2 + 87.2$ kcal/mole CO consumed

(Reaction E),

$CO + 1/2\ O_2 \rightarrow CO_2 + 67.6$ kcal/mole CO consumed

(Reaction F),

$CH_4 + 4\ N_2O \rightarrow 2\ H_2O + 4\ N_2 + CO_2 + 269.9$ kcal/mole CH_4 consumed

(Reaction G), and

$CH_4 + 2\ O_2 \rightarrow 2\ H_2O + CO_2 + 191.7$ kcal/mole CH_4 consumed

(Reaction H).

The reaction rate in these equations was modeled by a modified Arrhenius law. We have not attempted to quantify the effects of chemical decomposition at elevated temperatures of any gas specie not consumed in the combustion process. In practice, we implicitly solve for the fuel concentration when the fuel-oxidizer mixture is fuel lean and for the oxidizer or reactant concentration when the fuel-oxidizer mixture is fuel rich. This ensures that combustion components will never be driven negative, regardless of the timestep size.

To define the flame interface, which is the region separating the unburned gases from the burned gases, we implemented a modification of the induction parameter model suggested by Oran.[5-6] In fact, the model was reduced to tracking a flame interface very much like the VOF method used for resolving free boundaries.[7-8] A combustion parameter, F, is defined as the ratio of the unburned gas volume in a cell to the cell volume and typically tracks the unburned gas interface. We assumed that in computational cells when F becomes 1/2, the chemical kinetics described above were activated. A zero value of F denotes unburned gases, while a value of one indicates burned gases. By employing a Donor-Acceptor flux approximation,[9] we kept the interface sharp with minimal numerical diffusion.

2.2. The HMS Computational Model

The HMS computational model is described in detail in Ref. 1. Specifically, the solution algorithm follows the LANL ICE'd-ALE[10–14] methodology for solving multidimensional, time-dependent fluid flow equations. For example, a transient fluid-dynamics timestep is broken into three distinct phases (i.e., the explicit Lagrangian, implicit pressure iteration, and the rezone phases).[1]

2.3. TRAC Mathematical Model

The TRAC-PFl/MOD2 computer code solves the two-phase, two-fluid mass, energy, and momentum conservation equations in lumped-parameter and 1-, 2-, and 3D geometries. The code was developed originally for light-water nuclear reactor safety studies. It is directly applicable to the Hanford waste tank ventilation system owing to both its networking capability (i.e., linking together complicated piping networks with different and coupled components) and its fast running speed. A complete description of the conservation equations solved by the TRAC-PFl/ MOD2 computer code can be found in Ref. 2. For the Hanford waste tank ventilation system, the conservation equations solved by TRAC are a reduced set. For example, liquid water conservation equations are not required for the ventilation system because there is no significant amount of water in the ventilation system. Therefore, the single-phase, 1D gas conservation equations are solved by TRAC for the ventilation system analysis. Because the ventilation system is modeled with TRAC, which cannot calculate combustion processes, we were not able to compute ignition of waste gas mixtures in the ventilation system that may propagate back to the tank.

2.4. HMS/TRAC Coupling

The ventilation system for Tank Farm 241 and Tanks 102- and 103-SY were simulated using TRAC, while the dome space in Tank 101-SY was simulated in detail using HMS. Because of the nature of the tank behavior and the ventilation system behavior, it was necessary to combine HMS and TRAC by imposing forced consistent boundary conditions at the physical locations where the two computer models interacted. For these calculations, these locations were (1) where the ventilation ductwork leaves Tank 101-SY and (2) where the inflow leakage paths are above Tank 101-SY. At these locations, TRAC determined the velocity or volumetric flow rate leaving Tank 101-SY, while HMS determined the pressure and temperature in the vicinity of the exit or entrance to Tank 101-SY.

The sequence through which information was passed is given below.

1 At the beginning of a timestep, HMS would use the TRAC boundary condition velocities to advance the time and determine the new time pressure and temperature distribution within Tank 101-SY.

2. The new Tank 101-SY pressure and temperature distributions would be used as boundary conditions for TRAC, which would advance the ventilation system solution and determine current velocities into and out of Tank 101-SY, which would be used as boundary conditions for the next HMS timestep advancement.

This implies that the velocity boundary conditions used by HMS were one timestep behind the pressure and temperature distributions. This is assumed to be an insignificant integration error because, in general, when the velocities, pressures, and temperatures were changing rapidly (i.e., during a burn), the timestep size was reduced to a very small number.

HMS and TRAC were combined by deleting the main driver program in TRAC and replacing it with a subroutine that would run TRAC through its input, initialization, steady-state integration, transient timestep integration, or output phases, depending on a control flag that was passed into the subroutine. The coupling logic in TRAC allowed the pressure and temperature boundary conditions to be passed into TRAC through a BREAK component to store the boundary conditions from HMS. With a BREAK component, the pressure and temperature were fixed as boundary conditions during the TRAC time advancement.

2.5. Validation of Computer Codes

In this section, we give a brief introduction to the quality assurance of the principle analysis computer codes that were used. HMS and TRAC have been assessed independently. LANL has completed an HMS assessment document for the USNRC.[15] In addition, there are many documents and publications that address comparisons between HMS and experimental data and observations.[16-20] LANL also is completing an assessment document for TRAC.[21] The combined computer code HMS/TRAC has been assessed with available Tank Farm data.[22–24] DOE and WHC have requested that the Bureau of Mines Pittsburgh Research Center (Pittsburgh, Pennsylvania) investigate the flammability of mixtures of hydrogen, ammonia, nitrous oxide, and air.[25-26] The resulting experiments were used to benchmark the burn model in HMS.[27]

3.0. HMS/TRAC TANK FARM GEOMETRIC MODEL

In this section, we detail the HMS/TRAC model of the tank and ventilation system used for the thermal-hydraulic analysis for the injection and mixing of the release gases within the tank dome space, the subsequent combustion, and the resulting gas transport. In the following sections, TRAC and HMS models are discussed.

3.1. TRAC Ventilation System Model

The components used to model the ventilation system for Tank Farm 241-SY are shown in the noding diagram in Fig. D-1. A BREAK component in TRAC provides

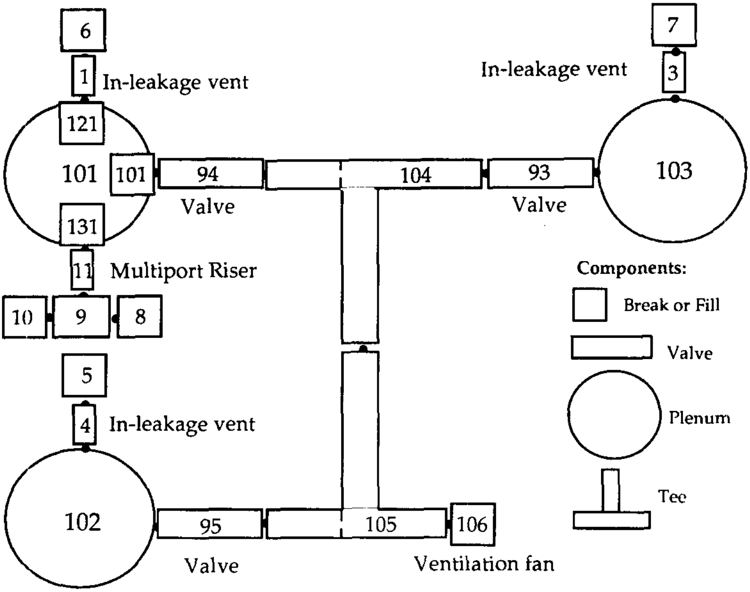

Fig. D-1. TRAC noding diagram. Junctions (connecting labeled components) appear as small dots.

a pressure and temperature boundary condition for the numerical solution of the conservation equations. The flow rates into and out of this component are determined from the solution of the momentum conservation equation given the pressure boundary condition specified in the BREAK component. The density and energy are used as boundary conditions in the mass and energy conservation equations.

For BREAK components 5 through 8 and component 10, atmospheric pressure and temperatures are input as constant values that do not change throughout the analysis. BREAK components 101, 121, and 131 are used to store the Tank 101-SY pressure and temperature information obtained from HMS and therefore will change during the simulation as HMS calculates new pressures and temperatures for the tank. A FILL component in TRAC provides a flow-rate boundary condition for the numerical solution of the conservation equations. The flow rate into a FILL component can be constant, a function of time, or a function of another variable in the TRAC simulation. To simulate the ventilation fan behavior, the flow rate in FILL component 106 was made a function of the fan head, which is the pressure difference between the first fluid cell upstream of the fan and the atmospheric pressure. Fan flow rate as a function of the fan head was supplied by WHC. These fan performance data were used as input to this model. For off-normal conditions, it was necessary to extrapolate the fan flow-rate-vs-head data. We assumed that at large velocities, the fan would fail. To estimate the hydrodynamic behavior of the failed fan, an effective flow resistance was estimated and used to extrapolate the fan flow-rate-vs-head data into the high-velocity region.

VALVE components essentially are special piping or ductwork components that allow the user to change the flow area (i.e., the valve setting) at one location within the component as the calculation is proceeding. As the flow area changes, the effective flow loss through the valve interface in the VALVE component changes based on experimental data for partially closed valves. The valve settings for VALVE components 1, 3, and 4 are adjusted to match the initial pressure in Tanks 101-, 102-, and 103-SY, respectively. The valve settings for VALVE components 94, 95, and 93 are adjusted to match the initial flow rates from Tanks 101-, 102-, and 103-SY, respectively. All six of these VALVE components contain two fluid cells, and the valve interface is the interface between these cells.

A TEE component can be used to represent the branching of a secondary set of piping or ductwork off a primary set of piping or ductwork. The branching can be at any angle relative to the primary leg. The primary and secondary piping can be of varying and arbitrary diameters. For TEE components 104 and 105, the piping is a uniform standard 0.3-m (12-in.)-diam schedule pipe. For these TEE components, the secondary-side piping is assumed to be 90 deg relative to the primary-side piping. The secondary-side piping for component 104 joins Tank 101-SY to the main ventilation line, and the secondary-side piping for component 105 joins Tank 102-SY to the main ventilation line. Tank 103-SY is joined to the main ventilation line by the first cell of the primary side of component 104. Component 9 is a TEE that is used to model the MPR assembly. A complete description of the MPR model is given in Ref. 28.

A PLENUM component is a single-control-volume component that can have multiple inlet and/or outlet connections. A PLENUM component typically is used to represent a large volume (e.g., a waste tank) that has multiple piping connections to it. PLENUM components 102 and 103 are used to simulate Tanks 102- and 103-SY, respectively. Initial volumes, pressures, and temperatures are consistent with the conditions within Tanks 102- and 103-SY.

3.2. HMS Tank 101-SY Model

A 3D Cartesian representation of Tank 101-SY was used to model the dome space region. This mesh is constructed of 7 equally spaced cells in the two horizontal directions and 5 equally spaced cells in the vertical direction, or 245 total computational cells. This mesh is shown in Fig. D-2, with the dimensions given in meters. The crossed-out computational cells are internal obstacles that have been introduced to model the curvature of the tank's surfaces. Obviously, in this coarse mesh, the stepping approximation to the curved surface is not very accurate. Axial elevation level 2 is the same as 1, and axial elevation 4 is the same as 3. In axial elevation level 1, which is located just above the crust, we assume that the waste gases are released through ~60% of the waste surface area. This gas release area consists of cells in columns 4 through 7 and rows 1 through 7, as shown by the shaded area for level 1 in Fig. D-2. Axial elevation level 5 represents the top, or dome, of the tank, where the ventilation system is attached at the cell defined by row 3 and column 3 and designated B. In normal operation, the fan in the ventilation system draws a slightly negative gauge pressure on the tank, and filtered atmospheric air enters the tank through the ventilation in-leakage flow port shown at row 5 and column 5 and designated D. The center 1.07-m (42-in.)-diam riser is designated C and is shown in the center of the model at row 4 and column 4. Components 94, 11, and 1 of the TRAC model are connections B, C, and D, respectively. The appropriate area ratios are used between HMS and TRAC to ensure conservation properties.

4.0. THERMAL-HYDRAULIC ANALYSIS

The thermal-hydraulic analysis simulated the injection and mixing of the release gases within the tank dome space, the combustion of the gas, and the resulting gas transport through the leakage paths and ventilation system. Specific calculations

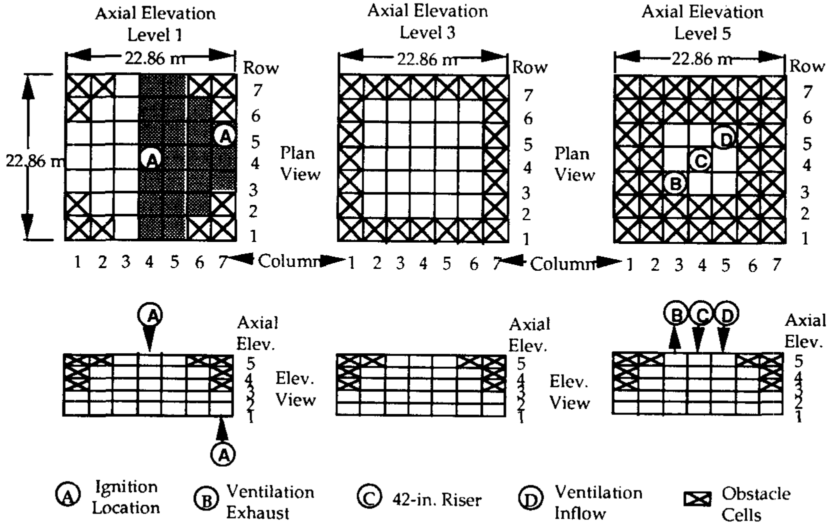

Fig. D-2. HMS 7-X-7-X-5 Cartesian coordinate geometric model for Tank 101-SY showing relative positions of gas injection, tank ventilation connection, and tank in-leakage port.

were performed to provide boundary conditions for determining the structural integrity of the tank and for computing the radiological and toxicological consequences for various tank configurations. The predicted parameters of interest were the tank dome pressures and vapor temperatures and the waste material and toxic gas (ammonia) released to the environment. In Sec. 4.1, the initial setup of the HMS/TRAC models is discussed. The details of the structural calculation and the radiological and toxicological calculations are given in Secs. 4.2 and 4.3, respectively.

4.1. Initial Model Setup

The initial setup for these calculations required some minor coding and input model changes that are dependent on the specific accident scenario being analyzed. For example, parameters we varied for this SA analysis were the magnitude of the gas release, the location of the ignition source, the operability of the ventilation fan, and the configuration of the tank pressure relief system. Parameters or models common to all calculations were the release gas composition, the gas release model, the dome space volume, the deactivation of the compressible waste model, and the initial dome loading of waste particulate before the GRE.

The composition of the release gases was a conservative estimate based on an average tank dome vapor temperature of 307 K (93°F). All calculations considered hydrogen, nitrous oxide, ammonia, methane, carbon monoxide, water vapor, and nitrogen as the release gas composition. The individual gas specie volume fractions and masses of the release gases used for the current calculations are derived in App. B.

A conservative-estimate waste gas release model was used to specify the release rate of the waste gases into the dome space. The HMS/TRAC model assumed that the release gases entered the tank dome space through ~60% of the waste surface of the tank. A TRAC-PF1/MOD3 model of the 241-SY Tank Farm, consisting of Tanks 101-, 102-, and 103-SY and associated ventilation systems, was developed to simulate the December 1991 and September 1992 GREs. The cumulative gas release for each GRE was ~283.2 m^3 (10,000 ft^3). Steady-state ventilation flows and tank pressures were used to balance the system model and obtain consistent flow resistances and flow splits between the three tanks. Measured pressure for Tank 101-SY was used as input to a gas release controller that determined the gas release rate required for the calculation to match the observed pressure. The measured and calculated pressures in the simulation model for Tank 101-SY essentially are the same. Differences of <0.1% occur only during rapid changes in the measured pressure. For the September 1992 GRE, vent header flow-rate data were available, and comparisons between the measured and calculated Tank 101-SY ventilation flows demonstrated that the TRAC simulation matches the ventilation flow rates exceptionally well while being slightly conservative.

Both the December 1991 and the September 1992 GRE simulations indicate that ~60% of the total gas volume was released in the first 200 to 300 s of the GRE, followed by a slow decay at a gas release rate significantly smaller than the average gas release rate during the first 200 to 300 s of the GRE. Although the simulations conservatively were based on comparisons to measured data for ventilation flows during the GRE, an additional conservatism was added to the gas release rate input in the HMS/TRAC calculation by assuming that 70% of the total gas volume was released in the first 200 s of the GRE. The remaining gas volume was released as an exponentially decaying function, as shown in Fig. D-3. This gas release profile is conservative, but it is more representative of the two largest GREs observed to date. The total gas release for the HMS/TRAC model is compared to the cumulative gas releases for the December 1991 and the September 1992 GRE shown in Fig. D-4.

The dome space volume was fixed at 1218 m^3 (43,043 ft^3) for all calculations and was assumed to be filled completely with air before the gas release. The compressible waste model in HMS was deactivated by setting the retained gas volume to zero in the model.

The HMS/TRAC calculations were used to predict the release of dome-space waste particulate and toxic gases to the atmosphere through the tank in-leakage flow path, ventilation system, and pressure relief riser during a burn event. The mass of waste material released to the atmosphere through the riser in-leakage flow path and pressure relief riser was designated as a ground release because the outlets for these ports were at or near ground level. The waste material mass leaving the ventilation system exited through the ventilation stack, the exit of which was located 5 m (16.4 ft) above ground level.

The HMS model preloaded 0.64 kg (1.41 lbm) of waste particulate mass in the dome space at the beginning of a calculation. This amount corresponds to a conservative estimate of particulate density [5.25 x 10^{-4} kg/m^3 (3.28 x 10^{-5} lbm/ft^3)] that remains suspended in the dome as a result of natural circulation. In addition, during a burn,

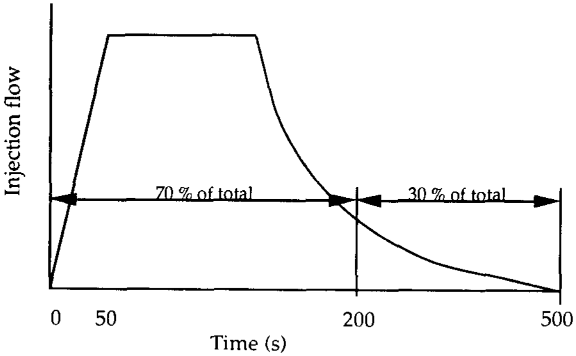

Fig. D-3. Gas injection curve for conservative-estimate analyses.

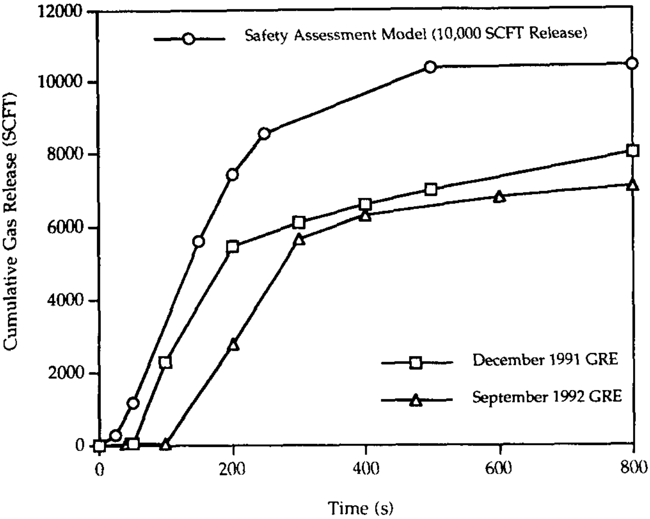

Fig. D-4. Comparison of cumulative gas releases for the HMS/TRAC model with the December 1991 and September 1992 GREs.

there is additional material that is entrained off of the waste surface. The entrainment model of Iversen[29] was implemented into HMS. As the flame sweeps the waste surface, material is entrained from the surface, depending on the sweep velocity. For the simulations performed with 296.8 m^3 (10,480 ft^3) of waste, the entrained material from the waste surface is obtained as ~5.1 kg (11.25 lbm). At gas releases <296.8 m^3 (10,480 ft^3), the flammable gas composition becomes very lean, which results in large fluctuations in the surface velocities. We noticed that at these lean mixtures, the performance of the entrainment model deteriorated and the simulations required special care. Because of these difficulties, we decided to preload the dome space with an additional 5.45 kg (12.02 lbm) of waste particulate before ignition of the waste gases and we deactivated the entrainment model. Therefore, the dome space contained ~6.09 kg (13.43 lbm) of radionuclides at the end of the gas release phase. The 5.45-kg (12.02-lbm) mass entrained from the crust was calculated with a particulate entrainment model developed by Iversen[29] to predict wind pickup of small particles [10 μm (40 mils)] from dry particulate beds. Iversen's model was based on experiments conducted with heavy powders, and using the model for the crust may be very conservative. We assumed a wind speed of 100 m/s (328.1 ft/s) acting over a 0.10-s time period.[30] The 100-m/s (328.1-ft/s) wind speed was determined to be a conservative estimate of the flame speed because flame speeds predicted by HMS are ~46 to 55 m/s (150 to 180 ft/s) (see Sec. 5). In addition, preloading the dome before ignition results in additional material being transported out during the period of burn, which enhances the conservatism. Finally, because the flame speed is expected to decrease with decreasing flammable gas composition, a constant loading in the dome independent of flammable gas concentrations results in added conservatism for gas release volumes <296.8 m^3 (10,480 ft^3).

Calculations were performed with and without an operable ventilation fan. The boundary conditions to simulate the operable ventilation fan cases used a FILL component to simulate the fan behavior based on a WHC-supplied flow-vs-head curve. This FILL component was replaced with a BREAK component that specified the exit ventilation system pressure to atmospheric pressure for the failed ventilation fan cases.

The ignition of the released gases was initiated in a single cell located at two different locations. An ignition point at the top center of the dome space (see Fig. D-2) was used for predictions for structural analysis considerations because the top-down propagation of the flame front maximized the flame area and generally resulted in the highest tank peak pressures and pressure rise times for a given gas release volume. The top-down burn was used for the structural calculation. The other location for the gas ignition location was adjacent to the side of the tank on the surface of the waste. Calculations involving gas ignition located at the waste surface predicted the most conservative radiological consequences because the flame front moving across the waste surface entrained a significant mass of particles and swept them out of the tank. This is in contrast to the top-down burn that tended to force any suspended particles back toward the waste surface.

The flow paths from Tank 101-SY were modeled individually for all cases. For the structural calculation, all MPR instrument ports were assumed to be occupied. This assumption specifies the use of a 66% MPR vent area fraction. During the combustion phase of the calculation, opening of the MPR pressure relief panels reduced the rate and magnitude of tank pressurization. The initial opening of the MPR was initiated by a 0.43-bar (6.0-psig) overpressure of the tank dome region from combustion of the waste gases. This overpressure is the upper limit for the opening of the pressure relief panels on the MPR because the opening limit ranges from 0.36 to 0.43 bar (5.0 to 6.0 psig). The relief panels then were opened fully over a 100-ms period. If we select the 66% MPR vent area fraction and the 0.43 bar (6.0 psig) relief panel opening pressure, the most conservative results with respect to the tank structural integrity based on these MPR parameters are provided.

Three different riser configurations (a closed tank, an open tank, and an open tank with a failed MPR pressure relief panel) were used for the radiological and toxicological release calculations. The closed-tank condition simulated a mixer pump installed in the 1.07-m (42-in.)-diam riser. The open-tank condition simulated an open 1.07-m (42-in.)-diam riser (i.e., the mixer pump is not installed in the riser during a GRE). The open tank with a failed MPR pressure relief panel represented an open 1.07-m (42-in.)-diam riser combined with an MPR pressure relief panel assumed to be in a failed open position. The open 1.07-m (42-in.)-diam riser in all nonburn calculations was simulated with a 100% MPR that was in a fully open configuration at the beginning of the calculation. The nonburn calculations for the combined open 1.07-m (42-in.)-diam riser and failed MPR pressure relief panel assumed that the failed MPR is equivalent to a 50% MPR flow area. Therefore, the 100% MPR flow area used for the open 1.07-m (42-in.)-diam riser calculations was increased by 50% for a total flow area of 1.317 m^2 (14.176 ft^2) to model both flow paths as a single flow path.

For the radiological and toxicological burn analyses, the open 1.07-m (42-in.)-diam riser case was modeled differently from the nonburn cases discussed in the previous paragraph because our tank model was limited to three flow paths from the tank dome to the atmosphere. One flow path was reserved for the 100% MPR vent area opening at 0.43 bar (6.0 psig) overpressure to provide pressure relief during the burn phase of the GRE. This left only two flow paths for normal tank venting that were reserved for the in-leakage duct and the ventilation system duct. Therefore, when we modeled the open 1.07-m (42-in.)-diam riser case, we combined the flow area of the 1.07-m (42-in.)-diam open riser with the 0.305-m (12-in.) in-leakage duct flow area.

Before executing a particular case, the following items were revised or verified to be consistent with the accident of interest:

1. Boundary conditions for the ventilation system are required, i.e., ventilation fan operable or failed;
2. Time and location of release gas ignition must be specified, i.e., either the tank dome apex location or waste surface location;
3. The multiplier (to specify the release gas volume) is applied to the gas mass equivalent to a maximum expected release of 297 m^3 (10,480 ft^3) for any gas release volume different from the 297-m^3 (10,480-ft^3) gas release; and
4. TRAC tank farm ventilation system components must be revised to model properly the pump riser, pressure relief riser, and in-leakage flow paths.

Initially, a long-duration calculation without considering combustion was performed to determine the time at which the maximum fuel concentration exists in the dome space. This calculation showed that the maximum concentration occurred 500 s after the initiation of a gas release. A typical HMS/TRAC calculation for a case with an operable ventilation fan consisted of a 30-s quasi-steady-state period to establish pressures and flows in the tanks and ventilation system. This was followed by a 500-s release gas injection phase, followed by the combustion phase. The run was continued until the tank pressure depressurized to atmospheric pressure. The accident sequences with the failed ventilation fan were run similarly except that the 30-s quasi-steady-state period was not used because the complete system was initialized to atmospheric pressure and thus did not require a steady-state initialization.

4.2. Calculation For Structural Analysis

The calculation for determining the structural consequences was performed for a 245- and 261-m^3 (8650- and 9230-ft^3) GRE, with an inoperable ventilation fan and a top-down burn of the waste gases. The tank pressure response for the 261-m^3 (9230-ft^3) GRE calculation exceeded the structural limitations; therefore, the 245-m^3 (8650-ft^3) GRE was performed. The resulting pressure response met the structural criteria. The peak dome average pressure for the 261-m^3 (9230-ft^3) release and burn was 4.2 bar (60.3 psia), and the peak vapor temperature was 1301 K (1882°F). For the 245-m^3 (8650-ft^3) release, the peak dome pressure was 4.0 bar (58 psia), and the vapor temperature was 1260 K (1808°F). The predicted pressure history during the burn phase is shown in Fig. D-5 because this tank dome pressure response was used for the structural analysis of the tank. The pressure history in Fig. D-5 was expanded from 500.9 s to 501.25 s (as shown in Fig. D-6) to illustrate a pressurization rate of ~15 bar/s (218 psi/s) shortly before the peak pressure was reached.

4.3. Calculations For Radiological and Toxicological Consequence

HMS/TRAC calculations[30] were performed for GREs of 113, 245, and 297 m^3 (4000, 8650, and 10,480 ft^3). A matrix of the HMS/TRAC calculations performed to determine the radiological and toxicological consequences of this SA revision is listed in Table D-1. We selected the 113-, 245-, and 297-m^3 (4000-, 8650- and 10,480-ft^3) GREs based on using these GREs to provide the bounding arguments for the different accidents addressed in the SA. Cases 1a through 2c [297-m^3 (10.480-ft^3) GRE] were run only through the gas release phase to calculate the peak ammonia release rates for determining the toxicological exposures at various locations centered around the tank farm. Cases 3a through 4b are 297-m^3 (10.480-ft^3) GRE burn calculations used to obtain the radiological releases for computing the radiological consequences. Similarly, Cases 5a through 6b [245-m^3 (8650-ft^3) GRE] and Cases 8a through 9b [113-m^3 (4000-ft^3) GRE] were nonburn calculations, whereas Cases 7a and 10a were the corresponding burn calculations.

The results of the HMS/TRAC analyses for this SA are summarized in Table D-2. The peak dome average pressures and vapor temperatures during the gas release or burn phases are given in Table D-2. For a given gas release volume, the greater peak

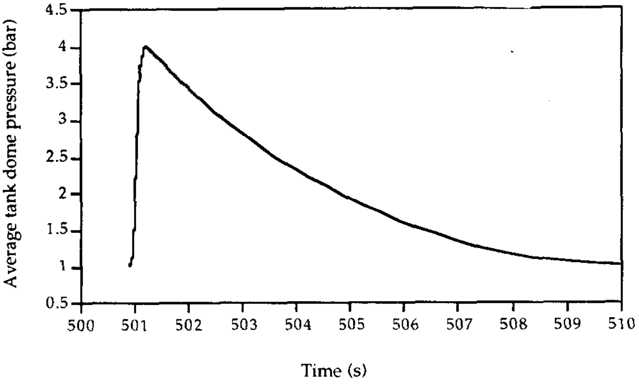

Fig. D-5. Tank 101-SY pressure history for a 245-m^3 (8650-ft^3) release.

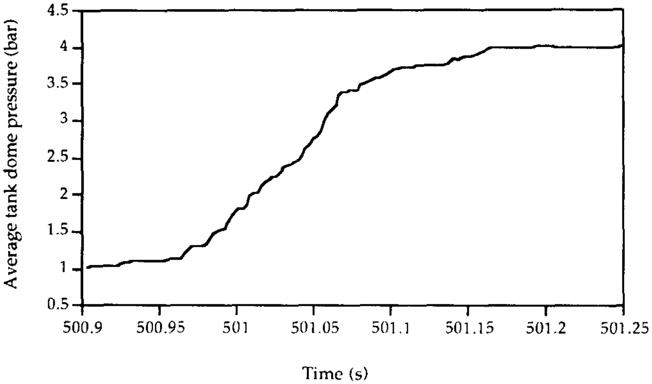

Fig. D-6. Tank 101-SY expanded pressure history for a 245-m^3 (8650-ft^3) release.

pressures and temperatures were predicted for a closed tank with an inoperable ventilation fan. This occurred because the inoperable ventilation fan resulted in a higher flammable gas concentration in the dome space before the burn as compared to the similar case with an operable ventilation fan. When the ventilation fan is operating, a small fraction of the fuel is removed during the gas release phase of the GRE. The maximum ammonia and hydrogen concentrations in the tank dome before the combustion event also are listed in the table. As expected, all cases with an open 1.07-m (42-in.)-diam riser had lower peak pressures and temperatures than their counterpart cases with a closed riser.

The peak ammonia release rates were obtained during the gas release phase of the GRE and are listed in Table D-4. When the 1.07-m (42-in.)-diam riser is opened, the release rates at the three tank exit ducts are altered, as shown in Table D-4 (e.g., Cases 1a and 1b). Failure of the MPR pressure relief panel in the open position during the gas relief phase (Cases 1c and 2c) had an insignificant effect on the release rates. We attribute this phenomenon to the fact that the release of the waste gases into the dome space acts as a piston; because of mass continuity, the waste gases exit the tank ducts at the same mass flow rate, regardless of the magnitude of the duct flow area. For other gas release volumes, we examined only an open 1.07-m (42-in.)-diam riser to quantify the consequences during open-tank conditions.

The ammonia exposures for these cases were computed with the methodology described in App. G of the SA using the peak ammonia release rates given in Table D-3. The toxicological exposure factors have been revised from those reported in previous versions of the SA. The revised factors[31] were used to calculate the ammonia exposures given in Table D-3. For ammonia exposure comparisons to the WHC risk guidelines, the receptor location for the maximum onsite individual is 100 m (328 ft) from the tank and is designated as the SY Farm in Table D-4. The maximum ammonia exposure for all cases analyzed is 333 ppm for Case 2b [i.e., 297-m^3 (10,480-ft^3) GRE with an inoperable ventilation fan and an open 1.07-m (42-in.)-diam riser]. Similar cases with an inoperable ventilation fan and an open 1.07-m (42-in.)-diam riser, but with a different gas release volume, results in the largest ammonia exposures for cases within the double-lined borders in Table D-4.

A summary of the predicted radiological material balance is given in Table D-5 for all burn cases listed in Table D-1. The predicted radiological releases from the tank exit ducts provide the releases necessary to determine the radiological consequences. The material balance for a single nonburn case (i.e., Case 2c) also is given in Table D-5 to provide data to determine the radiological consequences for a gas-release-only event. The maximum radiological mass available for release to the atmosphere is the total dome loading mass either at the beginning of the gas release for Case 2c or before the burn for all other cases listed in Table D-5. During the burn phase, a fraction of the initial dome loading is released to the atmosphere. The last three columns of Table D-5 give the individual releases through the three leakage ducts in the tank dome. These individual releases sum up to the total mass released to the atmosphere (i.e., Column 3 of Table D-5). Comparisons of various tank configurations for the 297-m^3 (10,480-ft^3) GRE are given for Cases 3a through 4b. The total mass released to the atmosphere is very similar for these cases because the difference is only 0.03 kg (0.07 lbm). The differences are minimal between the cases with and without an operable ventilation fan.

TABLE D-1
HMS/TRAC CALCULATION MATRIX

Case ID	Case Description
1a	10,480 ft^3/Ventilation Operable/Closed Tank
1b	10,480 ft^3/Ventilation Operable/Open 42-in. Riser
1c	10,480 ft^3/Ventilation Operable/Open 42-in. Riser/Open MPR Panel
2a	10,480 ft^3/Ventilation Inoperable/Closed Tank
2b	10,480 ft^3/Ventilation Inoperable/Open 42-in. Riser
2c	10,480 ft^3/Ventilation Inoperable/Open 42-in. Riser/Open MPR Panel
3a	10,480 ft^3/Ventilation Operable/Closed Tank/Burn
3b	10,480 ft^3/Ventilation Operable/Open 42-in. Riser/Burn
4a	10,480 ft^3/Ventilation Inoperable/Closed Tank/Burn
4b	10,480 ft^3/Ventilation Inoperable/Open 42-in. Riser/Burn
5a	8650 ft^3/Ventilation Operable/Closed Tank
5b	8650 ft^3/Ventilation Operable/Open 42-in. Riser
6a	8650 ft^3/Ventilation Inoperable/Closed Tank
6b	8650 ft^3/Ventilation Inoperable/Open 42-in. Riser
7a	8650 ft^3/Ventilation Inoperable/Closed Tank/Burn
8a	4000 ft^3/Ventilation Operable/Closed Tank
8b	4000 ft^3/Ventilation Operable/Open 42-in. Riser
9a	4000 ft^3/Ventilation Inoperable/Closed Tank
9b	4000 ft^3/Ventilation Inoperable/Open 42-in. Riser
10a	4000 ft^3/Ventilation Inoperable/Closed Tank/Burn

TABLE D-2
SUMMARY OF HMS/TRAC RESULTS

Case ID	Peak Dome Pressure (bar)	Peak Vapor Temperature (K)	Ammonia Mass before Burn (kg)	Hydrogen Mass before Burn (kg)
1a	1.0344	311.15	25.10	6.12
1b	1.0138	310.78	25.20	6.05
1c	1.0138	310.80	25.20	6.05
2a	1.0366	311.31	25.30	6.25
2b	1.0138	310.82	25.30	6.25
2c	1.0138	310.82	25.40	6.30
3a	4.5020	1440.0	25.05	6.15
3b	4.2600	1410.0	25.30	6.08
4a	4.5060	1450.0	25.30	6.25
4b	4.3010	1430.0	25.30	6.25
5a	1.0274	310.19	21.40	5.20
5b	1.0139	310.22	21.50	5.10
6a	1.0297	310.35	21.50	5.30
6b	1.0138	310.45	21.25	5.30
7a	4.0020	1280.0	21.24	5.30
8a	1.0144	308.24	10.40	2.50
8b	1.0139	307.80	10.40	2.43
9a	1.0173	308.61	10.50	2.60
9b	1.0139	308.64	10.50	2.53
10a	2.4800	798.00	10.50	2.55

TABLE D-3
PEAK AMMONIA RELEASE RATES

Ammonia Release Rate (g/s)			
Case ID	Exhaust Stack	Riser	Inlet HEPA
1a	11.20	0.00	5.70
1b	8.30	12.10	0.74
1c	8.30	12.00	0.74
2a	11.10	0.00	6.02
2b	0.99	16.50	0.00
2c	1.15	15.90	0.32
5a	7.90	0.00	3.89
5b	7.05	8.10	0.63
6a	7.85	0.00	4.20
6b	0.97	10.80	0.23
8a	2.52	0.00	0.41
8b	3.48	0.58	0.32
9a	1.73	0.00	1.00
9b	0.50	2.55	0.06

The radiological consequences were computed with the methodology described in App. G of the current version of the Mixer Pump SA (using the radiological releases given in Table D-5) and are presented in Table D-6. The radiological exposures given in Table D-6 assume an additional source of 0.36 kg (0.79 lbm) of waste released from the HEPA filter during the burn phase.[32]

5.0. CONCLUSIONS

A brief overview of the combined HMS/TRAC code was presented in this appendix, as well as all calculational results of the HMS/TRAC analyses performed for the SA. Maximum onsite (SY Farm) ammonia exposures were computed for the tank configured with an open 1.07-m (42-in.)-diam riser and an inoperable ventilation fan. The tank configuration was not as important for the determination of the maximum radiological doses because all configurations analyzed produced very similar results. The radiological and toxicological exposures are summarized and compared to WHC acceptance limits in Sec. 5 of the SA.

TABLE D-4
AMMONIA EXPOSURES (ppm)

Case ID	SY Farm	242-S Evap.	U Plant	Hwy. 240
1a	63.165	49.357	19.219	2.023
1b	268.131	92.439	26.358	2.566
1c	266.129	91.858	26.222	2.553
2a	64.835	50.450	19.505	2.049
2b	332.962	98.095	23.452	2.147
2c	323.286	96.303	23.207	2.131
5a	43.768	34.275	13.396	1.411
5b	184.150	65.877	19.437	1.911
6a	45.506	35.441	13.723	1.442
6b	220.153	65.900	15.984	1.472
8a	8.958	7.499	3.249	0.349
8b	22.503	12.705	4.970	0.524
9a	10.477	8.118	3.116	0.327
9b	52.713	16.207	4.076	0.380

TABLE D-5
RADIOLOGICAL RELEASES

	Waste Mass Distribution (kg)				
Case ID	Initial Dome Loading	Total Released to Atmosphere	Release through Ventilation Exhaust Stack	Release through Inlet Duct	Release through Relief Riser
2c	0.640	0.167	0.017	0.004	0.146
3a	6.090	3.950	0.272	0.094	3.584
3b	6.090	3.970	0.165	2.400	1.405
4a	6.090	3.940	0.243	0.106	3.591
4b	6.090	3.960	0.068	2.470	1.420
7a	6.090	3.730	0.218	0.095	3.417
10a	6.090	2.840	0.149	0.062	2.629

TABLE D-6
RADIOLOGICAL DOSE EDE (rem)

Case ID	SY Farm	242-S Evap.	U Plant	Hwy. 240	Max. Offsite[a]	Max. Offsite[b]
2c	4.592E-01	9.252E-02	1.858E-02	1.352E-03	2.016E-04	6.672E-03
3a	1.185E+01	2.388E+00	4.796E-01	3.507E-02	5.228E-03	1.731E-01
3b	1.191E+01	2.399E+00	4.956E-01	3.676E-02	5.490E-03	1.817E-01
4a	1.183E+01	2.382E+00	4.785E-01	3.497E-02	5.213E-03	1.726E-01
4b	1.188E+01	2.393E+00	4.948E-01	3.664E-02	5.472E-03	1.811E-01
7a	1.125E+01	2.266E+00	4.551E-01	3.326E-02	4.959E-03	1.641E-01
10a	8.800E+00	1.773E+00	3.561E-01	2.607E-02	3.886E-03	1.286E-01

[a] Acute dose.
[b] 50-yr dose.

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APPENDIX E
DETONATION CONSIDERATIONS IN THE DOME VAPOR SPACE

1.0. OBJECTIVE AND SUMMARY OF RESULTS

In this appendix, we evaluated the likelihood of a detonation in the dome vapor space and ventilation duct. In analyzing the likelihood of detonation, we used the methodology developed at SNL based on the geometric class and mixture sensitivity. The SNL methodology originally was developed for hydrogen/air mixtures. We applied the same methodology to the release gas mixture of interest by using the detonation cell-width concept. We concluded that for gas releases up to 371.7 m^3 (13,100 ft^3), the detonation is possible but very unlikely given that (1) mechanical ignition is difficult, (2) mechanical ignition is unlikely, and (3) all the electrical components comply with the applicable NEC codes.

2.0. BACKGROUND

Two ways that a detonation can occur during a release of waste gases into the dome vapor space are (1) direct initiation of detonation by a powerful ignition source and (2) DDT. The first case involves a strong ignition source of high energy, high power, or large size [roughly 1 g of high explosive (4.6 kJ) for a stoichiometric hydrogen/air mixture][1] to initiate directly a detonation by "shock" initiation. This strong ignition source is enough to be incredible for in-tank ignition sources. The second process involves igniting the released waste gases, which results in a subsonic flame (deflagration) propagating into the unburned combustible gas. The flame accelerates to velocities that cause compression waves to form in front of the deflagration combustion wave. Shock waves may form, and the combustion process may transition to a detonation wave. Flame acceleration is dependent on the "sensitivity" of the mixture and on geometric factors, such as obstacles, scale, and amount of expansion volume near the accelerating wave front.[2]

The sensitivity of the mixture normally is described as the detonation cell width, which usually is investigated for hydrogen/air systems as a function of the equivalence ratio. The equivalence ratio is defined as the ratio of the hydrogen to oxygen mole fractions divided by the same ratio for stoichiometric conditions. Therefore, for stoichiometric conditions, the equivalence ratio is unity; for fuel lean mixtures, it is less than 1; for fuel rich mixtures, it is greater than 1. In fact, the equivalence ratio is an exact measure of the amount of hydrogen that exists in the hydrogen/air system.

The detonation cell width is a length scale associated with detonation waves, which are characterized by an unsteady cellular combustion front. It is well known that detonation waves consist of transverse, reflected, and Mach-stem shock waves all meeting at Mach triple points.[3] These loci of triple points actually produce a traceable diamond-shaped pattern that can be measured. The transverse width of this pattern is called the detonation cell width, which has been experimentally related to detonation limits in various geometries.[4]

3.0. METHODOLOGY

There is no theory that can be used to predict flame acceleration to detonation for all mixture conditions and geometries. However, the work at SNL[4] is an effort to quantify a methodology to examine and give guidelines for predicting DDT. We will summarize the methodology in the following paragraphs. The methodology is based on extensive experimental data and years of research experience; thus, for the validity and justification of the methodology, the reader is referred to the original paper.[4]

The methodology is based on the following assumptions:

1. The likelihood of DDT can be expressed as a function of two variables, one based on the sensitivity of the mixture and the other based on the flame acceleration potential of the geometry through which the deflagration propagates.

2. The sensitivity of the mixture is based on the detonation cell width or equivalence ratio for a hydrogen/air system.

3. The flame acceleration potential in a given geometry can be estimated from such characteristics as obstacles and size by reference to simple guidelines.

Based on the detonation cell width, λ, and equivalence ratio, Φ, mixtures are divided into five sensitivity classes:

1. mixtures that are extremely detonable near stoichiometric;

2. mixtures that are less likely to detonate;

3. mixtures that have been observed to undergo detonations in geometries that favor flame acceleration;

4. mixtures that have been observed to propagate a detonation, but a DDT has not been observed; and

5. mixtures that are unlikely to undergo DDT.

In Table E-1, we present the classification of mixture sensitivity to detonation for dry hydrogen/air mixtures at 20°C and 1-atm pressure.

TABLE E-1
CLASSIFICATION OF HYDROGEN/AIR MIXTURES AT 20°C AND 1 ATM

Mixture Class	Detonation Cell Width (mm)	Equivalence Ratio
1	20 to 15	$0.75 < \Phi \leq 1.5$
2	40 to 20	$0.63 \leq \Phi < 0.75, 1.5 < \Phi \leq 2.2$
3	320 to 40	$0.42 \leq \Phi < 0.63, 2.2 < \Phi \leq 4.1$
4	1200 to 320	$0.37 \leq \Phi < 0.42, 4.1 < \Phi \leq 5.6$
5	No Data	$\Phi < 0.37, \Phi > 5.6$

The flame acceleration potential of a given volume is classified into one of five geometric classes, beginning with geometric Class 1 being the most conducive to flame acceleration to geometric Class 5 being the least conducive. A description of these classes follows.

Geometric Class 1. Large geometries with obstacles in the path of the expanding unburned gases. Partial confinement favors gas expansion past obstacles. An example is a large tube with numerous obstacles and with ignition going from a closed to an open end. Class 1 geometries are the most favorable to large flame acceleration.

Geometric Class 2. Geometries similar to Class 1 but with some features that hinder flame acceleration. Examples would be a tube open on both ends or large amounts of transverse volume for expansion to the direction of the flame propagation.

Geometric Class 3. Geometries that yield moderate flame acceleration but are neutral to DDT. Examples are large tubes without obstacles and small tubes (several inches in diameter) with obstacles.

Geometric Class 4. Geometries unfavorable to flame acceleration. Examples are (1) large volumes with few obstacles and large amounts of transverse expansion to the flame path and (2) small volumes without obstacles. DDT will not usually occur in a Class 4 geometry.

Geometric Class 5. Geometries are so unfavorable to flame acceleration that not even large volumes of stoichiometric hydrogen/air mixtures are likely to detonate. Examples are a totally unconfined geometry at large scale or a small spherical geometry without obstacles and central ignition.

Table E-2 gives the result class as a function of mixture and geometric classes. The entries in this table are based subjectively on investigations of highly experienced detonation physics specialists at SNL.[3]

TABLE E-2
DEPENDENCE OF RESULT CLASS ON MIXTURE AND GEOMETRIC CLASSES

Geometric Classes	Mixture Classes				
	1	2	3	4	5
1	1	1	2	3	4
2	1	2	3	4	5
3	2	3	3	4	5
4	3	4	4	5	5
5	4	5	5	5	5

The entries in Table E-2 can be interpreted as follows:

Result Class 1: DDT is highly likely.
Result Class 2: DDT is likely.
Result Class 3: DDT may occur.
Result Class 4: DDT is possible but unlikely.
Result Class 5: DDT is highly unlikely to impossible.

We intend to use the framework of this methodology to evaluate the potential of detonation occurring in the dome vapor space. A matrix of experiments has been conducted[5] to determine the sensitivity of the waste gas' major components (hydrogen, nitrous oxide, and nitrogen) diluted in air. The ZND model[6] was verified for the purpose of interpolation and extrapolation of these experimental data. In these experiments and calculations, we assumed a given waste gas release volume fraction composition of hydrogen (0.385), nitrous oxide (0.303), and nitrogen (0.312).[6] Using this information and the SNL methodology, we classified the waste gas diluted with dry air into five sensitivity mixture categories, as summarized in Table E-3.

Table E-3 includes the addition of ammonia to the waste gas mixture, but not the trace amounts of methane and carbon monoxide.[7] Both methane and carbon monoxide are relatively insensitive gases compared to hydrogen and ammonia and trace additions of the two are not expected to change the sensitivity of the waste gas mixtures to detonation.

Even though the detonation cell width was used to determine the mixture class, we observe in Table E-3 that the hydrogen volume fraction or percentage serves the same purpose for defining the sensitivity of the mixture.

TABLE E-3
CLASSIFICATION OF CONSERVATIVE GAS RELEASE DILUTED WITH AIR
(Hydrogen, Nitrous Oxide, Ammonia, Nitrogen, and Water Vapor)

Mixture Class	Release Gas Volume Fraction	Air Volume Fraction	Hydrogen Volume Fraction	Detonation Cell Width (mm)
1	>0.45	<0.55	>0.144	<15
2	0.33 to 0.45	0.55 to 0.67	0.105 to 0.144	15 to 100
3	0.26 to 0.33	0.67 to 0.74	0.083 to 0.105	100 to 1000
4	0.22 to 0.26	0.74 to 0.78	0.072 to 0.083	1000 to 10000
5	<0.22	>0.78	<0.072	>10000

3.1. Evaluation of 297.3 m^3 (10,500 ft^3) Release in the Tank Dome

We believe that the geometric class of the waste tank dome is highly unfavorable to flame acceleration. The space is a large open volume of at least 1133 m^3 (40,000 ft^3) with few obstacles; during a waste gas release, there are large volumes for expansion. Experiments have shown[8] that the expansion of combustion waves inhibits flame acceleration. Therefore, the open dome space volume above the waste surface may be classified between a geometric Class 4 and 5.

As the waste gases rise into the dome vapor space, they are quickly diluted with air to mixtures that are less sensitive. In fact, for a 297.3-m^3 (10,500-ft^3) release (ventilation system inoperable, riser closed), we examined the fraction of the total tank volume (as a function of time), which contains accumulated volume fractions of mixture Classes 1, 2, 3, and 4 (Fig. E-1). The predicted mixture classes for this case resulted in no mixture Classes 1 and 2. The presence of mixture Class 3 was negligible. Therefore, as shown in Fig. E-1, the accumulated volume fractions of the shown mixture classes are essentially mixture Class 4.

3.2. Evaluation of a 371.7-m^3 (13,100-ft^3) Release in the Tank Dome

For the 371.7-m^3 (13,100-ft^3) release with an inoperable ventilation system and closed riser, we examined the fraction of the total tank volume (as a function of time), which contains accumulated volume fractions of mixture Classes 1, 2, and 3 (Fig. E-2). The predicted mixture classes for this case resulted in no mixture Classes 1 and 2. Therefore, as shown in Fig. E-2, the accumulated volume fractions of the shown mixture classes are solely a mixture Class 3.

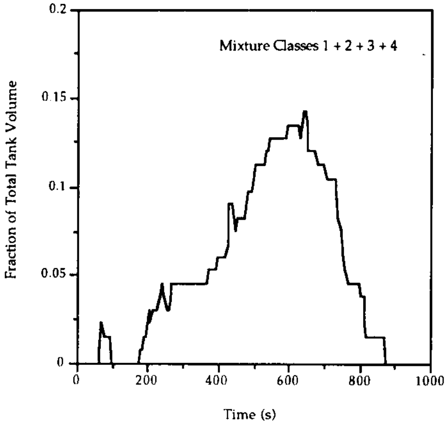

Fig. E-1. Fraction of total tank dome space volume containing mixtures 1, 2, 3, and 4 for a 297.3-m^3 (10,500-ft^3) release with inoperable ventilation system and closed riser.

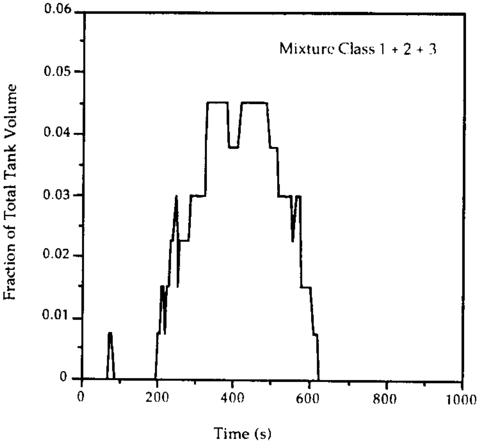

Fig. E-2. Fraction of total tank dome space volume containing mixtures 1, 2, and 3 for a 371.7-m^3 (13,100-ft^3) release with inoperable ventilation system and closed riser.

3.3. Evaluation of a 371.7-m^3 (13,100-ft^3) Release in the Ventilation System

Combustible mixtures of waste gases are drawn through the ventilation system by the operating fan. To analyze the possibility of a detonation or DDT in the duct work of the ventilation system, we calculated the hydrogen volume fraction at the location where the ventilation system is attached to the dome. In Fig. E-3, the hydrogen volume fraction time history is presented and compared to the threshold between mixture Classes 4 and 5 (0.072 to 0.083). During the waste gas release phase, the maximum value remains within mixture Class 4. Even though the ventilation system duct work (30.5-cm, 1-ft-diam pipe) is geometric Class 2, the resulting Class 4 indicates that detonation or DDT is possible but unlikely.

3.4. Summary of Results

Based on work done at SNL and the Explosion Dynamics Laboratory, we have quantified the relative risk of a DDT. The SNL methodology found two parameters to predict the likelihood of DDT. First, the closer a hydrogen/air mixture was to stoichiometric, the more likely the occurrence of a DDT. They listed five categories for mixtures that are related to detonation cell width and equivalence ratios. The second key parameter was the geometry. They found that confined geometries with

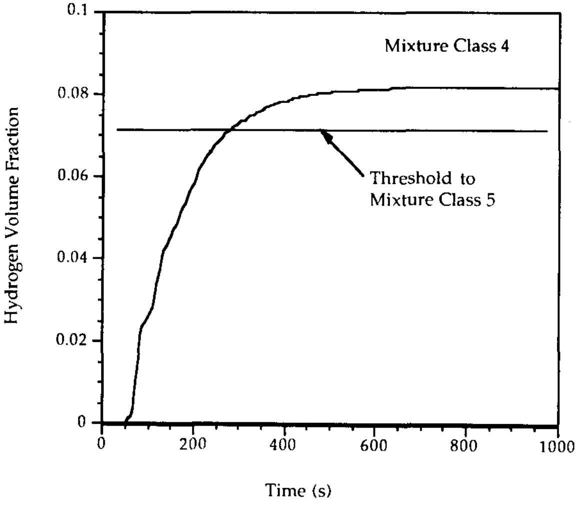

Fig. E-3. Ventilation system hydrogen volume fraction for a 371.7-m^3 (13,100-ft^3) release with operable ventilation system and closed riser.

obstacles promoted flame acceleration and DDT. They had five classes for the geometric effects. The equivalence ratio can be quantitatively calculated, but the geometric effects are subjective. Based on these two parameters, SNL developed a matrix of the likelihood of DDT, as shown in Table E-2. We have updated the SNL methodology for hydrogen in dry air to mixtures of hydrogen, water, and nitrogen diluted with various percentages of air. The Explosion Dynamics Laboratory has obtained experimental data for this more prototypical waste gas composition. This data has been used to calibrate and verify the Shepherd ZND model. Using this model, we were able to interpolate and extrapolate the waste gas composition mixtures to determine the cell widths of each detonation and therefore determine the sensitivity of a given mixture. The waste gas mixture compositions, detonation cell size, and mixture classes are summarized in Table E-3.

For Tank 101-SY, we calculated the volume percentage of the dome vapor space that would contain mixtures in the most sensitive classes for the 297.3-m^3 (10,500-ft^3) release and 371.7-m^3 (13,100-ft^3) release cases with the ventilation system inoperable and with the riser closed. In addition, we calculated the hydrogen volume fraction that would exist in the ventilation system with the ventilation system operable and the riser closed for a 371.7-m^3 (13,100-ft^3) release. For the 297.3-m^3 (11,500-ft^3) release [Fig. (E-1)], up to ~15% of the dome volume was in mixture Class 4, while mixture Classes 1 + 2 + 3 were nearly negligible. This small percentage justifies the assumption that the geometry volume containing the sensitive gas mixtures is open and unrestricted. The geometry therefore is judged to be in the class of least likely to detonate. From result classes in Table E-2, the possibility of DDT is judged to be highly unlikely to impossible.

For the 371.7-m^3 (13,100 -t^3) release, we found (Fig. E-2) that none of the dome vapor space contains Class 1 mixtures and that the dome volume containing the most sensitive mixtures (Classes 1 + 2 + 3) is <5%. From these percentages, we concluded that because the geometry is open and the most sensitive mixtures are unconfined, the geometry is the least sensitive, with the lowest potential for DDT. Using the Table E-2 results, we judged the possibility of DDT to be highly unlikely to impossible.

The ventilation system was examined because it is a confined geometry and is judged to be Class 2. An analysis of waste gas mixtures in the ventilation system showed that the hydrogen volume fraction, and therefore the detonation cell width, is never above Class 4. From Table E-2, considering geometric Class 2 and mixture Class 4, the ventilation system has a result Class 4, which characterizes the DDT probability as possible, but unlikely.

4.0. CONCLUSIONS

In the SNL studies, the experimental data was obtained for dry hydrogen/air mixtures. In the waste gas mixture, hydrogen, nitrous oxide, nitrogen, and ammonia diluted with air, the detonation cell width was measured at the Explosion

Dynamics Laboratory. By using this data to calibrate the Shepherd ZND model, we were able to interpolate and extrapolate the relevant data to determine sensitivity mixture classes and relate them to the SNL methodology. Because the SNL geometric classes are directly applicable, we were able to judge the possibility of DDT based on the two relevant parameters of mixture sensitivity and geometry.

In the tank dome during a 297.3-m^3 (13,100-ft^3) release or 371.7-m^3 (13,100-ft^3) release, the dome volume at any given time containing the most sensitive gas mixtures is negligible. This volume is considered unconfined, and because there are few obstacles in the dome volume, the volume also is considered to be open. An open unconfined volume of this size is in the least likely geometry class for DDT. When the gas mixtures are considered in this geometry, the result class indicates a highly unlikely to impossible, up to mixture Class 3, event of DDT.

The long, 1-ft-diam pipes making up the ventilation system are geometric Class 2. However, because the sensitivity of the gas mixture during the release phase is never less than Class 4, the result class is 4, which indicates DDT is possible, but unlikely.

Based on all of these considerations, we conclude that DDT is possible but unlikely for the integrated waste tank dome vapor volume and ventilation system. This assessment of the likelihood of DDT occurring is based on the assumption that ignition has occurred with a probability of 1. New evidence[9] indicates that waste gas mixtures diluted with air are difficult to ignite with mechanically generated sparks. If we consider that all the electrical equipment complies with the appropriate NEC codes, that the possibility of a mechanical spark ignition is difficult, and that mechanical ignition unlikely, then the probability that detonation will occur is possible but very unlikely.

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APPENDIX F
FLOW AREA BETWEEN THE DOME AND PUMP PIT

1.0. OBJECTIVE AND SUMMARY OF RESULTS

The objective of this analysis is to determine the design controls to prevent flammable gas accumulation in the pit and a burn resulting in cover block launching. The cover blocks may be launched as a result of pressurization of the pit space stemming from (1) a burn in the pit and (2) flow leakage from the dome into the pit.

The results of conservative analyses show that flammable gas accumulation in the pit and damaging cover block motion during a burn may be eliminated if

1. the leak area from the dome to the pit $\leq 3.23 \times 10^{-4}$ m^2 (0.5 $in.^2$) during a GRE without a burn,
2. the leak flow area from the dome to the pit $\leq 2.58 \times 10^{-2}$ m^2 (40 $in.^2$) after the initiation of a burn,
3. the free volume in the pit is ≥ 11.33 m^3 (400 ft^3),
4. the drain pipe remains plugged for dome pressures ≤4.4 atm (63.8 psia), and
5. the vent area to the atmosphere from the pit is ≥ 0.073-m^2 (113-$in.^2$)

This analysis was completed early into the project. A reanalysis using recent knowledge gained from the tank may help remove some of the conservatism in the results if some relief in the above administrative controls is needed.

2.0. GAS ACCUMULATION IN THE PUMP PIT WITHOUT A BURN

This section documents the HMS/TRAC analyses performed to determine the maximum flow area of the pump riser/pump housing annulus in Tank 101-SY such that the gas concentration in the pump pit region remains below the LFL criteria for combustible gases. The Controls section of this SA (Sec. 6) states that the maximum hydrogen concentration allowable is 7500 ppm.

The pump riser/pump housing annulus is a very narrow gap located between the outer pump housing and the energy absorption block/cylinder assembly.[1] This flow path allows the release gases to flow from the tank vapor dome into the pump pit. WHC has calculated the flow area to be 40.84 cm^2 (6.33 $in.^2$) for this annular area.[2] Preliminary HMS/TRAC calculations using this flow area resulted in the hydrogen concentration exceeding 0.75 vol % in the pump pit and cover block region, which resulted in reducing the flow area based on the analysis documented in this section.

2.1. Analytical Methods and Calculations

A series of HMS/TRAC calculations was performed to determine the maximum allowable flow area that will meet the 0.75 vol % H_2 criteria.[3] The HMS/TRAC input model was based on the tank farm model described in App. D and was revised to incorporate some of the details of the pump riser/pump housing and pump pit regions.

A 1D model of the pump pit and pump riser was developed from the original TRAC valve component used to model the 1.07-m (42-in.) pump riser flow path. A noding schematic of the pump pit/riser model is shown in Fig. F-1. All of the modified TRAC input required for the valve component is shown in Fig. F-2. The pump riser annulus flow area (Cell-Edge No. 2) is 40.84 cm^2 (6.33 $in.^2$), as given in Ref. 2. This

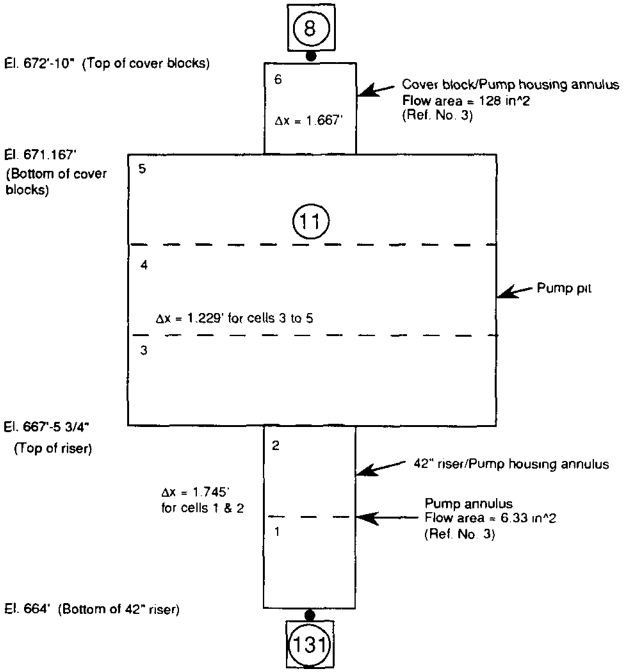

Fig. F-1. TRAC noding schematic for pump riser/pump pit component model.

flow area and the corresponding hydraulic diameter were varied in the TRAC model until the 0.75 vol % H_2 criterion was attained. The valve model treated this annular region as a thin square-edged orifice because our initial assumptions led us to believe that the most limiting flow area in the pump riser was at the location of the hydraulic jack support assembly (see bottom crush plate diagram in Ref. 4).

This assumption later proved to be incorrect after Ref. 4 was obtained. The flow path through the pump riser actually follows a torturous annular path rather than the smooth annular path we used in our model. The calculations

Geometric Data	
Component	in.
Pump housing o.d.	16.00
42-in. riser i.d.	42.00
Cover block i.d.	20.00
42-in. riser height	41.75
Pump pit height	44.25
Cover block height	20.00

	Cell Lengths	
Cell No.	(in.)	(m)
1	20.875	0.5302
2	20.875	0.5302
3	14.750	0.3747
4	14.750	0.3747
5	14.750	0.3747
6	20.000	0.5080

*Lengths from Ref. 4.

	Cell-Edge Flow Areas	
Cell-Edge No.	(in.^{2})	(m^2)
1	1184.38	0.7639
2*	6.33	0.0041
3	1184.38	0.7639
4	15620.34	10.0751
5	15620.34	10.0751
6*	128.00	0.0826
7*	128.00	0.0826

*Flow areas from Ref. 3.

	Cell Volumes	
Cell No.	(in.^{3})	(m^3)
1	24724	0.4052
2	24724	0.4052
3*	230400	3.7756
4*	230400	3.7756
5*	230400	3.7756
6	2560	0.0420

*Cells 3 to 5 based on 400 ft^3 pit volume.

	Hydraulic Diameters		
Cell-Edge No.	(in.)	(m)	Flow Loss Coefficients
1	26.00	0.6604	0.0
2	0.77	0.0196	1.4
3	26.00	0.6604	1.0
4	118.34	3.0057	0.0
5	118.34	3.0057	0.0
6	4.00	0.1016	0.5
7	4.00	0.1016	1.0

Fig. F-2. Data of revised valve component for the 1.07-m (42-in.) pump pit riser.

were completed before this modeling discrepancy was discovered; thus, the model was not revised. Our calculations with the pump riser modeled, as shown in Fig. F-1, will provide conservative predictions for the hydrogen concentrations in the pump pit and above the cover blocks because the actual flow resistances in the pump riser are significantly greater than those used in our model.

The total volume of the pump pit was specified in Ref. 1 as being 14.18 m^3 (500.72 ft^3). We used a pump pit volume of 11.33 m^3 (400 ft^3) in our model to be conservative because informal discussions with WHC personnel indicated that the bottom of the pump pit contains equipment and debris not considered in the WHC-computed pump pit volume.

Table F-1 lists the annulus area and hydraulic diameters used for our calculations. In computing the hydraulic diameters, we assumed that the pump riser annulus flow area was a long narrow slot 40.64 cm (16 in.) in length. The width of the slot was dependent on the annulus flow area. The cell-edge loss coefficients and k factors for the contraction and expansion locations given in Fig. F-2 were based on standard geometric loss coefficients given in Ref. 5. A k factor of 1.4 (given in Ref. 5) was used for the cell edge that simulated the square-edged orifice.

2.2. Results and Discussion

The results of the parametric calculations for the five cases are summarized in Table F-2 and detailed in Ref. 3. The hydrogen concentrations reported for the pump pit are in the center cell (Cell 4 of Fig. F-1) of the pump pit. The hydrogen concentration for the cover block is Cell 6. The hydrogen mass into the pump pit is the total mass of hydrogen leaving the tank vapor dome through the pump riser. This mass does not account for the hydrogen that leaves

TABLE F-1
PUMP HOUSING ANNULUS AREA AND HYDRAULIC DIAMETERS

Run	Annulus Area		Hydraulic Diameter	
Identification	($in.^2$)	(m^2)	(in.)	(m)
A	6.330	0.00408	0.772	0.01961
B	3.165	0.00204	0.391	0.00993
C	1.583	0.00102	0.197	0.00499
D	0.791	0.00051	0.099	0.00250
E	0.500	0.00032	0.062	0.00158

TABLE F-2
SUMMARY OF HMS/TRAC PUMP PIT CALCULATIONS

Run Identification	Area (in.^{2})	H_2 Concentration (%)		H_2 Mass into Pump Pit (kg)
		Pump Pit	Cover Block	
A	6.330	9.95	9.63	0.269
B	3.165	8.80	7.41	0.130
C	1.583	4.87	2.38	0.055
D	0.791	0.89	0.16	0.020
E	0.500	0.075	0.004	0.0075

the pump pit during the calculational period. Run E used an annulus area of 3.23 cm^2 (0.50 in.^{2}), which resulted in acceptable hydrogen concentrations in the pump pit that were below the 0.75 vol % H_2 criteria.

The variation of hydrogen concentrations and the total hydrogen transported into the pump pit as a function of the annulus areas (given in Table F-2) are shown in Figs. F-3 and F-4, respectively. Once the annulus flow area is set to <12.9 cm^2 (2 in.^{2}), the hydrogen concentrations decrease rapidly, as shown in Fig. F-3. The variation of the total mass of hydrogen entering the pump pit is fairly linear with respect to the annular flow area.

The annular flow area between the pump column and energy absorption block/cylinder assembly must be decreased from 40.84 to 3.23 cm^2 (6.33 to 0.5 in.^{2}) so that the hydrogen concentration in the pump pit and above the pump pit cover blocks will not exceed 0.75 vol %. The analysis shows that the hydrogen concentration will be above this limit at the injection location. However, the volume-averaged concentration is much lower than this limit. For the 3.23-cm^2 (0.5-in.^{2}) leak area, the volume-averaged hydrogen concentration is 0.3%.

Also, there are many conservative assumptions made in this model. In addition to conservatively modeling the flow path and the associated losses, the calculations are affected by the following assumptions:

1. At the time of these calculations, we assumed that 371 m^3 (13,100 ft^3) of released gases is injected into the dome space in 200 s. This assumption was later relaxed such that only 70% of the total gases is injected in the first 200 s (see App. D). The discussion provided in App. D shows that this later model is still conservative when compared to the available data.

2. At the time of these calculations, the hydrogen concentration in the release gas was assumed to be 42.8%. Our current model treats ammonia as

additional fuel, and the upper-bound hydrogen concentration is estimated as 31.4% (see App. B). Thus, the volume-averaged hydrogen concentration in the pit can be scaled linearly to yield 0.25%. However, there also will be some ammonia in the pit. Given the relative fractions of hydrogen and ammonia, the LFL for the mixture is discussed in App. B. The results show that the combined LFL is ~3.5% H_2. Thus, the calculated magnitude of 0.25 vol % H_2 is smaller than a quarter of the mixture LFL.

3.0. BURN AND COVER BLOCK MOTION ANALYSIS

The free volume in the pump is estimated to be between 11.33 and 14.16 m^3 (400 and 500 ft^3). The corresponding gas mass is estimated as 13 to 16.25 kg (28.7 to 35.8 lbm).

A drain pipe 7.62 cm (3 in.) in diameter, located between the pump pit and the dome, will remain plugged for gauge pressures <4.4 atm (63.8 psig). However, in addition to the drain pipe, there is a leak path between the dome and the pump pit through the bearings on the pump column. If there is a burn in the dome space, we anticipate that the excess pressure will result in failure of the gaskets around the riser and that leak paths from the dome to the pit will open. The maximum flow area for this leak path corresponds to a 19.05-mm (0.75-in.) gap around the column that is 1.07 m (42 in.) in diameter, resulting in a flow area of 6.4×10^{-2} m^2 (99 $in.^2$). However, once the leak path opens, the minimum flow area is between the pump column (40.5-in. o.d.) and the riser (42-in. i.d.). This corresponds to a flow area of 6.27×10^{-2} m^2 (97.2 $in.^2$). One of the design controls has been to reduce this flow area between the dome and the pit to prevent cover block motion.

The pit is closed by two cover blocks [total mass is 14,500 kg (32,000 lbm)]. At the top, the surface area of the cover blocks is equal to 11.25 m^2 (121 ft^2). There is a vent path to the atmosphere around the pump column where the column sticks out of the cover blocks. This leak is estimated to be 7.3×10^{-2} m^2 (113.1 $in.^2$). This path may be kept open if desired. There is an additional vent area 30.48 cm (12 in.) in diameter, which is covered by a light plate (not bolted) during normal operations. With little excess pressure, this area will open, providing a leak area of 7.3×10^{-2} m^2 (113.1 $in.^2$).

Obviously, if the cover blocks are lifted as a result of excess pressure in the pit, additional vent paths will open. The geometry of the cover block resting on the pit walls is shown in Fig. F-5. As shown, if the cover block displacement is <50.8 cm (20 in.), the vent flow area would be (perimeter) x (displacement) x ($\sin\theta$), where $\theta = 8.5°$.

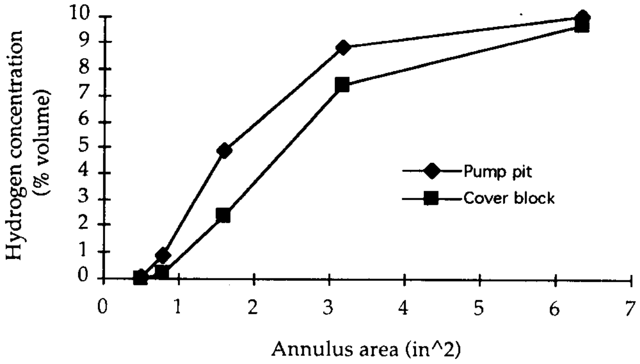

Fig. F-3. Hydrogen concentration in pump pit and top of cover block.

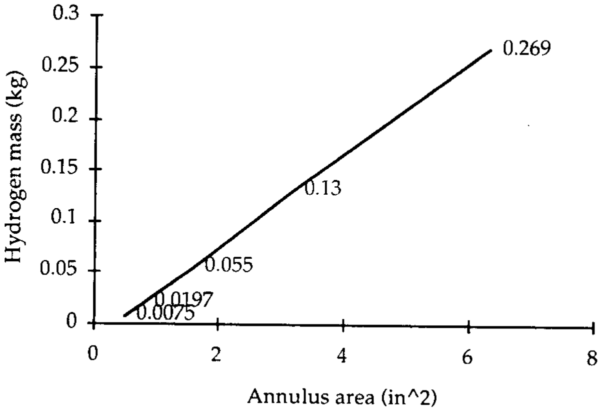

Fig. F-4. Mass of hydrogen transported into pump pit.

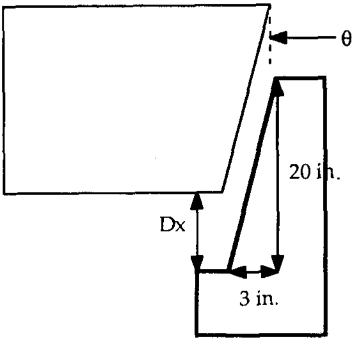

Fig. F-5. Schematic of cover block resting on the pit walls.

3.1. Limiting Dome Conditions and Flammable Gas Flow into the Pit

During a postulated burn in the dome space, the dome pressure will increase. As a result, the gaskets sealing the pump support column may fail, providing an additional leak area between the dome and the pump pit. Because there are no quantitative data on the strength of the gaskets, we assume conservatively that the gaskets will fail immediately after ignition. Using the HMS/TRAC calculations, we can calculate the amount of vented gas during the burn phase. Geometrically scaling the leak area to the total vent area, we estimate the total amount of hydrogen that leaks into the pit. Earlier calculations showed that the maximum hydrogen concentration in the pit was bounded by 2.25%, including the 0.3% that may leak before the burn. Details of these conservative calculations may be found in Ref. 6. Using the current gas compositions provided in App. C, the maximum pit concentrations may be scaled down to 1.75% (half of the LFL for the hydrogen-ammonia mixture).

The jet velocity corresponding to the calculated inflow rates is ~250 ft/s. Considering the close proximity of the pit walls and the small volume of interest, we expect that at such high jet velocities, a complete mixing will occur. Thus, a homogenous mixing assumption is justified.[6]

In the HMS/TRAC calculations discussed so far, we used an ignition location at the waste surface, where the mixture is rich in fuel. As discussed in App. W, we later modified the model and ignited the mixture at the top of the dome because this ignition location is more conservative in terms of resulting peak pressures, and it is more likely that an ignition may be initiated at the top, near one of the risers.

Nevertheless, the new ignition location resulted in very little fuel escaping the dome space during a burn. This is caused primarily by the pressure wave created by the ignition traveling toward the waste surface, thereby trapping the flammable gases in the dome. With this latest model, the amount of hydrogen that escapes the dome during the burn phase is <1 g through all vent paths. Scaling for the flow area and converting to a pit concentration, we find that the pit concentration will increase by <0.02% during the burn. Therefore, for this problem, using the ignition location at the waste surface is more conservative.

In conclusion, we can state that if the leak area between the dome and the pit is restricted to ≤258.1 cm^2 (40 in.^2) during a burn, instantaneous combustion in the pit is unlikely.

3.2. Cover Block Motion Analysis

A simple force balance indicates that the cover blocks will start lifting if the pressure in the pit is >1.14 atm (16.75 psia). However, when the blocks lift, an additional vent area opens and the pit depressurizes. To analyze this dynamic process, we used the simple model shown in Fig. F-6. As shown, a deformable control volume (shown by the dashed line) is defined.

We solve the conservation of mass and the first law of thermodynamics (combined with the equation of motion for the cover block) numerically, using the first principles for compressible gas dynamics and the adiabatic control volume. The details of these calculations are provided in Ref. 6. Many conservative assumptions are made in this analysis. A list of important assumptions are provided in Sec. 3.3.

The following are the important data used for the conservative calculations:

initial pit volume = 12.46 m^3 (440 ft^3),
cover block pressure area = 11.25 m^2 (121 ft^2),
cover block perimeter = 13.4 m (43.96 ft),
pit permanent vent area = 0.073 m^2 (113 in.^2),
dome-to-pit leak flow area = 0.0258 m^2 (40 in.^2),
cover block mass = 14,500 kg (32,200 lbm),
dome pressure = 4.4 x 10^5 Pa (63.8 psia), and
dome temperature = 1550 K (2822°F).

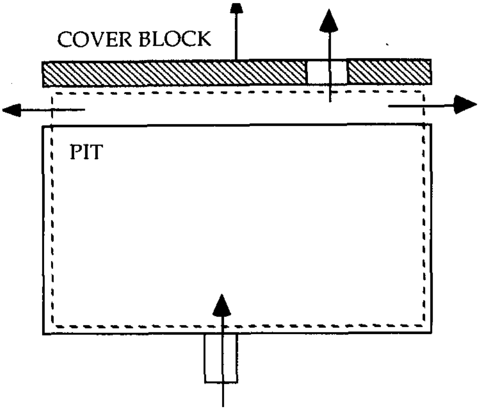

Fig. F-6. Schematic of the pump pit and the control volumes.

3.3. Results and Discussion

The dome peak pressure and temperature values used in the present analysis are obtained from earlier HMS/TRAC calculations for a 371-m^3 (13,100-ft^3) release with burn. The results show that, for the input parameters given above, the maximum cover block displacement is 11 in. (280 mm). Thus, the cover blocks will not clear the pit side walls, and their reimpaction is not a concern. This result was obtained using conservatively bounding magnitudes where there was an uncertainty in the physical dimensions or modeling parameters. Many sensitivity studies were performed to assure a conservative estimate for the maximum displacement.[6] In addition to parametric uncertainties, the model was formulated conservatively. The conservatism of the model is a result of the following:

1. We assume constant pressure and constant temperature in the dome space during a burn. A time-dependent boundary condition would result in lower launch heights.

2. We neglected of the pressure drop through the leak path into the pit. Along this path, the flow goes through narrow channels with very high velocity [>300 m/s (1000 ft/s)]. Thus, the boundary pressure effects are overestimated.

3. We believe, a single stagnant control volume approach overestimates the static pressure forces on the cover blocks.

To assume that the hydrogen that leaks into the pit is homogeneously mixed is not conservative. The hydrogen concentrations near the inlet of the leak into the pit are expected to be high (possibly higher than the LFL). However, in the current analysis, we inject the gas into the pit at the maximum dome temperature. Thus, the energy addition to the dome is maximized, assuming that the flame has propagated through the leak paths. This case also accounts for the possibility of a local burn in the vicinity of the leak into the pit.

Since this analysis was completed, we have revised the release gas composition and the release rates into the dome space. The addition of ammonia, methane, and carbon monoxide into the gas composition results in higher peak pressures for a given gas volume as compared to earlier calculations performed without these gases. On the other hand, the hydrogen fraction in the release gas decreases from the 42.8% used earlier to 31.4% when we add these other species. Thus, the above arguments related to hydrogen concentrations have added conservatism. The peak dome pressure and temperature used in the current analysis bound the values obtained for the peak pressure and temperature corresponding to a 297-m^3 (10,500-ft^3) release with burn using the recent gas composition and injection rate models.

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APPENDIX G
RADIOLOGICAL DOSE AND AMMONIA EXPOSURE FACTORS

1.0. OBJECTIVE AND SUMMARY OF RESULTS

In this appendix, we calculate the radiological dose rates and toxic concentrations at various distances from Tank 101-SY per unit quantity of release during a GRE with or without a burn, using a Gaussian plume model. The calculated radiological doses at different locations for a 1-kg (2.21-lbm) release from the tank are given in Sec. 2.3. The ammonia concentrations at the same locations for a 1-g/s (0.132-lbm/min) release rate are given in Sec. 3.0.

The Gaussian plume model is valid only at distances ≥100 m (328 ft) from the source. In this appendix, we also provide estimates for ammonia and hydrogen concentrations near the vent intake pipe. The results show that under conservative assumptions and most unfavorable weather conditions, ammonia concentrations may be >500 ppm within a radius of 9 m (29.5 ft) from the intake pipe. Hydrogen concentrations do not exceed the 7500-ppm limit outside the pipe.

2.0. RADIOLOGICAL DOSE ESTIMATES

2.1. Model Descriptions and Assumptions

The details of the AI-RISK code, used for performing the dose calculations, are given in Ref. 1. AI-RISK is a tilted Gaussian plume model that tracks the dispersion of particles in five separately sized groups, or bins. Deposition and settling velocities are specified for each size group. Particle size-dependent and solubility class-dependent dose factors for various radionuclides (based on ICRP-30)[2] are used to calculate the EDE. In addition to the acute accident dose, the code calculates appropriate long-term (50-yr) offsite doses resulting from continuous ingestion of contaminated food and water. The code also calculates the long-term (50-yr) occupational dose from postaccident occupancy of a partially contaminated work place; the dose contributors are ground shine and the inhalation of resuspended particulate contamination. This dose contribution is based on user-specified site occupancy factors and postaccident cleanup criteria. AI-RISK also estimates the potential health effects from calculated doses based on ICRP[2]-recommended models and methods. They are presented as lifetime probabilities of (1) latent cancer mortality, (2) genetic effects, or (3) acute mortality, depending on the dose level.

AI-RISK has been under development at LANL since 1990. It has undergone numerous comparisons with other codes, such as GENII,[3] DIFOUT,[4] CAP88,[5] and INPUFF,[6] to verify its dispersion and dose models. Because all features of AI-RISK[1] are not available in any one of these codes, different codes were used to verify different aspects of the modeling. Where direct comparisons of numerical results were possible, the agreement was good (i.e., well within the usual uncertainties for these types of calculations). Several papers[7–9] on the code methodology and calculated results for specific cases have been presented.

The 200-Area Hanford Site meteorology data (1983 to 1991 average for a tower height of 10 m) was input to AI-RISK as a joint frequency wind speed/stability class matrix. For each specified dose receptor, a dose was calculated for each joint frequency combination in the matrix, and a cumulative dose vs frequency curve was constructed for that receptor location. AI-RISK output this curve, as well as the numerical dose values for 50 and 95%—the doses that will be exceeded 50 and 5% of the time, respectively, based on the site meteorological data. In all results presented herein, 95% doses are given.

Dose calculations were performed for release points from the SY Tank Farm ventilation system exhaust stack, inlet stack, and for the 106.7-cm (42-in.) riser near the center of Tank 101-SY. The parameters for the ventilation system stack are:

- stack height 5 m (16.4 ft),
- stack velocity 6 m/s (18.7 ft/s), and
- stack temperature 400 K (127°C) (the calculated concentrations for 25°C are the same as for 127°C because the momentum plume rise dominates).

The parameters for the inlet stack are:

- stack height 5 m (16.4 ft),
- stack velocity 0.5 m/s (1.6 ft/s), and
- stack temperature 400 K (127°C).

The parameters for the riser are

- release height grade level,
- velocity 0.5 m/s (1.6 ft/s), and
- temperature 800 K (527°C) (The calculated concentrations for 25°C are the same as for 527°C, with the exception of a receptor at 100 m, which is 15% higher at the lower temperature. This is well within the overall uncertainty in the calculations).

These source term parameters were selected to envelop a range of possible ground level and stack releases in the SY Tank Farm resulting from various accident scenarios.

2.2. Source Term

The radiological source term composition, derived from the WHC analysis of the Tank 101-SY crust composition,[10] is summarized in Table G-1.

For the accident scenarios developed in the SA, the source terms consist primarily of materials picked up and entrained in high-velocity gas flow across the crust surface. Therefore, for the calculations reported herein, we assumed that the particles all were in the respirable range (<10 µm).

2.3. Dispersion and Dose Calculations

All dose consequences reported in this section were based on a 1-kg (2.21-lb) release of crust material with the composition given in Table G-1. Table G-2 presents the calculated doses to the onsite receptors at the 242-S Evaporator, U Plant, and Highway 240. To obtain the doses for the various accident scenarios, the appropriate

TABLE G-1
RADIOLOGICAL SOURCE TERM USED IN DOSE CALCULATIONS

Radionuclide	Crust (Ci/kg)
^{90}Sr	3.4E-02
^{99}Tc	3.0E-04
^{129}I	2.9E-04
^{137}Cs	4.5E-01
^{237}Np	5.1E-04
^{239}Pu	1.6E-05
^{240}Pu	1.0E-09
^{241}Am	1.5E-04

TABLE G-2
CALCULATED RADIOLOGICAL DOSES FOR 1-kg RELEASE

Receptor Location	Distance (km)	Exhaust Stack Release EDE (rem)	Inlet Stack Release EDE (rem)	Riser Release EDE (rem)
SY Farm Area	0.10	0.342	0.896	2.75
Near 242-S Evap.	0.30 W	0.341	0.476	0.554
U Plant	0.78 NE	0.112	0.117	0.111
Hwy. 240	3.9 SE	0.00894	0.00869	0.00798
Maximum Offsite	13.8 WNW	0.00133 (0.0440)	0.0013 (0.0430)	0.00119 (0.0394)

doses in Table G-2 were multiplied by the respective quantities released in kilograms. The 242-S Evaporator, 300 m (984 ft) due west of the SY Tank Farm, is the nearest location that is continuously occupied by onsite workers, whereas Highway 240 is a public road that has transient occupancy as vehicles pass. The nearest offsite person is located on the site boundary to the west. The downwind distances from Tank 101-SY are given in the second column.

For all receptors, the EDE given in columns 3 through 5 of the table is an acute dose resulting from inhalation and immersion during the accident cloud passage. The number in parentheses for the offsite receptor is the 50-yr dose resulting from continued consumption of contaminated foodstuffs.

Further details of the calculations are provided in Ref. 11.

3.0. TOXIC GAS EXPOSURE LEVEL ESTIMATES

The method for calculating dispersion or estimating toxic gas concentrations is essentially the same as that in AI-RISK. Parameters for the stack and riser releases are the same as those listed for the radiological dose calculations above.

Atmospheric dilution factors (X/Q) for various receptor locations were estimated with AI-RISK (95% meteorology) and are given in Table G-3. These factors were multiplied by the toxic component release rate to obtain the exposure concentration level. Table G-4 gives the estimated ammonia exposure levels for a release rate of 1 g/s (2.2 $\times 10^{-3}$ lbm/s). The exposure levels for the various accident scenarios were obtained by multiplying the release rate by the appropriate values in Table G-4.

Further details of the calculations are provided in Ref. 11.

4.0. AMMONIA AND HYDROGEN CONCENTRATIONS NEAR THE VENT INTAKE PIPE

4.1. Source Description

The ammonia and hydrogen concentrations near the intake pipe were calculated using the GASFLOW code.[12] The maximum values of the mass flows of each gas constituent, as computed by HMS/TRAC, were used to compute the intake vent flow rate. This rate was applied as a constant value for a sufficient time interval to establish a steady-state concentration distribution in the computation space. The gas mixture consists of the following species: nitrogen, oxygen, ammonia, hydrogen, nitrous oxide, water vapor, methane, and carbon monoxide.

TABLE G-3
ATMOSPHERIC DILUTION FACTORS, X/Q

Receptor Location	Distance (km)	Stack Release (s/m^3)	Riser Release (s/m^3)
SY Farm Area	0.10	1.80E-03	1.40E-02
Near 242-S Evap.	0.30 W	1.61E-03	4.06E-03
U Plant	0.78 NE	7.61E-04	9.48E-04
Hwy. 240	3.9 SE	8.32E-05	8.57E-05

TABLE G-4
AMMONIA EXPOSURES FOR 1-g/s RELEASE RATE

Receptor Location	Distance (km)	Exhaust Stack Release Exposure (ppm)	Inlet Stack Release Exposure (ppm)	Riser Release Exposure (ppm)
SY Farm Area	0.10	2.575	6.022	20.025
Near 242-S Evap.	0.30 W	2.303	4.134	5.807
U Plant	0.78 NE	1.089	1.232	1.356
Hwy. 240	3.9 SE	0.119	0.121	0.123

4.2. Model Description

To quantify the concentrations of hydrogen and ammonia near the ground, GASFLOW calculations using the source flow described above were made under a variety of conditions (i.e., different release sizes, different downdraft velocities, and with and without a "rain hat"). The volume under consideration is a cylindrical region 40 ft (1200 cm) high and 40 ft (1200 cm) in diameter centered axially on the vertical vent pipe. The vent flow and mixing in this region were modeled numerically with the axisymmetric 600-cm-x-1200-cm (19.7-ft-x-39.4-ft) domain shown in Fig. G-1.

The hydrodynamics of the model resulted from the effluent venting against a specified downdraft. The upward motion of the vent jet was influenced by the transition from the 30.5-cm (12-in.)-diam pipe to the 61 cm (24-in.)-diam pipe and by interacting with the downdraft above the pipe. In the former case, the pipe expansion caused some spreading of the jet, with higher velocities persisting along the center line (the inner jet) of the 61-cm (24-in.)-diam pipe. The flow at larger radii—the outer jet—was still upward but was, in general, less than half of the center-line value. Above the mouth of the pipe, the inner jet mixed with and was retarded by the downdraft, reaching a maximum height that depended on the respective velocities of the vent and the downdraft. The mixture flowed radially

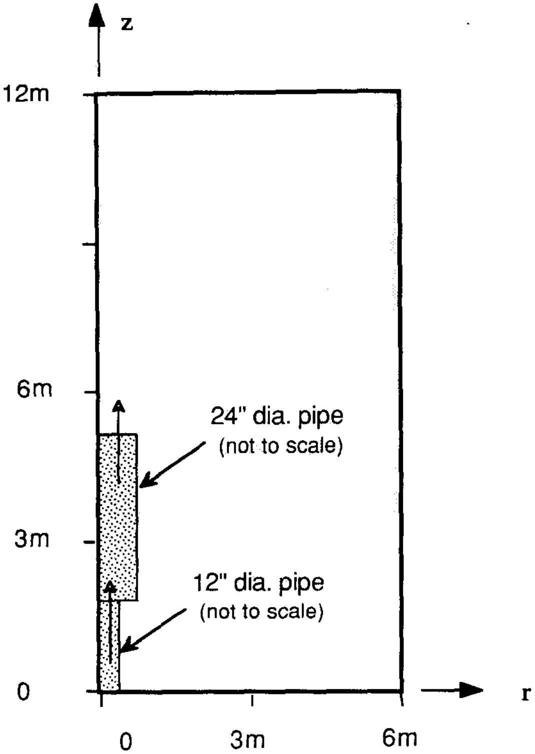

Fig. G-1. Axisymmetric domain used for GASFLOW calculations.

away from the pipe and downward before exiting radially outward. The interaction of the inner jet and the downdraft resulted in a cone-shaped recirculation region [seen in Fig. G-2 as a triangle with vertices at the origin, at the apex of the jet, and on the ground at a radius of 500 cm (16.4 ft)], which entrained some of the release gas pushed downward by the downdraft. The slower-moving outer jet exited the pipe into the recirculation region, adding to the entrained quantities of release gases. The rain hat is a barrier placed 30.5 cm (1 ft) above the end of the stack. It reduces the initial vertical velocity of the effluent jet and directs it radially outward from the stack vent.

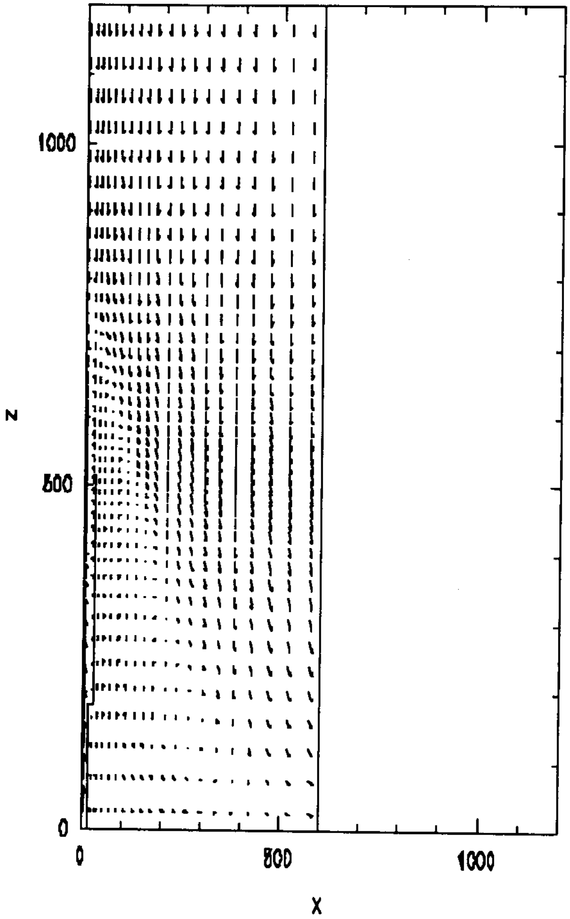

Fig. G-2. Calculation 2, t = 200 s, velocity field.

4.2.1. Boundary Conditions

The axis of symmetry is the west boundary. The east side was modeled as a hydrostatic boundary that allows inflow or outflow as a function of conditions inside the domain. The bottom boundary, representing the ground, was modeled as a free-slip (zero-shear-stress) surface. The top side was modeled with a specified velocity condition simulating an atmospheric downdraft. The inside and outside surfaces of the pipe were modeled with the free-slip condition.

4.2.2. Numerical Discretization

The computational domain was discretized by a grid of 20 cells in the radial direction and 40 cells in the vertical direction. Cell dimensions ranged from 15 cm (5.9 in.) near the mouth of the pipe to 55 cm (21.7 in.) along the top, bottom, and outer radial boundaries.

4.2.3. Turbulence Model

The diffusive transport of mass, momentum, and energy was simulated in the code with an algebraic turbulence model that assumed that (1) 10% of the kinetic energy of the flow was contained in the turbulent fluctuations and (2) a mixing length of 30.48 cm (1 ft) was used.

4.2.4. Approximations

Two significant approximations were used in this analysis.

1. The vent flow was based on the peak flow rate of each gas constituent and was treated as a constant value.

2. The effect of buoyancy in the vent plume was neglected.

The effect of both of these assumptions caused the results of the analysis to be more conservative than if they had been treated more rigorously.

4.3. Results

Five factors influenced concentration levels of hydrogen and ammonia near the ground.

1. The vertical orientation of the vent pipe allowed the momentum of the jet to carry the effluent away from the ground.

2. The height of the vent pipe directed the effluent 5.18 m (17 ft) from the ground before it even could begin to move toward personnel.

3. The turbulent jet mixed the effluent with air, thereby lowering concentration levels.

4. Wind promoted mixing and transported effluent away from the vicinity of the vent pipe. Even if the wind were blowing toward the ground, levels of hydrogen near the ground remained below the LFL.

5. The rain hat reduced the initial upward velocity from the stack, thereby increasing its concentration near ground level. Therefore, the analysis with the rain hat yielded the bounding values for gas concentration.

The results of interest from this analysis were hydrogen concentrations near the ground (location of machinery) and ammonia concentrations at the 1.83-m (6-ft) level (typical personnel height). We wished to determine the radial distance from the vent at which these variables equaled or exceeded permissible levels. In no case did the hydrogen concentration reach its prescribed limit (7500 ppm). However, the ammonia concentration limit (500 ppm) was exceeded for some conditions. The results are listed in Table G-5.

The largest release accompanied by a low downdraft velocity with a rain hat in place was the limiting condition determined by this analysis. The 9-m (29.5-ft) exclusion distance for this condition was considered to be conservative because of the assumptions used in the analysis. At lower down-flow velocities, the actual existence of buoyancy would transport the jet plume upward and away from the regions of concern.

TABLE G-5
GASFLOW ANALYSIS RESULTS

Release Volume (ft^3)	Downdraft Velocity (m/s)	Rain Cap Included	Exclusion Distance for Ammonia (m)
12,500	4	no	none
10,480	4	no	none
5500	4	no	none
12,500	2	no	4.75
10,480	2	no	4.3
5500	2	no	none
12,500	4	yes	3.9
10,480	4	yes	3.55
5500	4	yes	none
12,500	2	yes	4.9
10,480	2	yes	4.55
5500	2	yes	none
12,500	1	yes	6.0
12,500	0.5	yes	9.0

4.4. Conclusions

There was no hazard at ground level from hydrogen because the allowable concentration was never reached at any distance from the vent stack. However, ammonia concentrations were exceeded at the 1.83-m (6-ft) elevation. The results of this analysis show that a radius of 9 m (29.5 ft) from the vent stack will provide a satisfactory exclusion zone. These results were obtained using an ammonia limit of 500 ppm. Later, the IDLH for ammonia was reduced to 300 ppm, which will increase the necessary exclusion zone.

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APPENDIX H
WORKER PROTECTION FROM GAS RELEASE EVENTS

1.0. OBJECTIVE AND SUMMARY OF THE RESULTS

In this appendix we discuss issues related to worker protection from unexpected GREs during open-tank conditions. The discussion focuses primarily on the toxicological effects of ammonia that are known to exist in the release gas. We conclude that controls contained within this SA, combined with additional protective measures required by other safety documents and manuals, provide sufficient protection to the site workers.

2.0. INTRODUCTION

In this appendix, additional detail is provided concerning the hazards from exposure to toxic gases, and typical requirements for worker protection are described. The *Industrial Safety Manual*[1] and the *Tank Farm Health and Safety Plan*[2] give general specifications for personal protective equipment. However, for each particular situation, the proper equipment must be specified by the site safety representative.

The burp gas consists of several gases of toxicological concern, including ammonia, carbon monoxide, nitrous oxide, and methane. The gas of most concern is ammonia; we will show that the controls for limiting the toxicological consequences of ammonia exposure are adequate to control exposure for the other burp gases.

3.0. PROPERTIES OF AMMONIA

Some of the properties of ammonia are as follows:[3]

- alkali;
- colorless gas;
- pungent odor detected as low as 1 ppm;
- flash point = -25°F;
- upper explosive limit (% volume in air) is 28%;
- lower explosive limit (% volume in air) is 15%;
- corrosive to copper, tin, zinc, and galvanized surfaces; and
- reactive with strong oxidizers, acids, halogens, hypochlorite, mercury, calcium, and salts of silver and zinc.

Threshold Limit Value [TLV; level set by American Conference of Governmental Industrial Hygienists (ACGIH)—time-weighted average that should not be exceeded during any 8-h work shift of a 40-h work week] is 25 ppm.

Permissible Exposure Limit (PEL; level set by OSHA—time-weighted average that must not be exceeded during any 8-h work shift of a 40-h work week) = 50 ppm.

Short-Term Exposure Limit (ST; level set by ACGIH and OSHA—15-min TWA exposure that should not be exceeded at any time during a workday) = 35 ppm.

IDLH (Immediately Dangerous to Life or Health) level is 300 ppm. This is the maximum concentration from which, in the event of respirator failure, a person could escape within 30 min without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects.

4.0. HEALTH EFFECTS RELATED TO ACUTE AMMONIA EXPOSURES

Ammonia is a very soluble compound (34%) and thus rapidly is absorbed in the upper respiratory tract. During the initial phases of exposure, ammonia does not penetrate deeply into the lungs. Animal toxicity studies have suggested that some airborne particulates can potentate the effect of ammonia, apparently by carrying adsorbed ammonia deeper into the respiratory tract. The eyes are particularly vulnerable, and ammonia penetrates the eyes more rapidly than other alkalis. Medical first aid in the first 10 s after exposure to the eyes is critical to prevent blindness.

Case reports, epidemiological studies, and animal toxicity studies overall show that exposure to high concentrations of ammonia gas can be fatal. The LC50 (the concentration of a chemical that, when a population of test organisms is exposed to it, is estimated to be fatal to 50% of the organisms under the stated conditions of the test) for mice, rabbits, and cats is ~10,000 ppm. Ammonia gas produced blindness in some guinea pigs exposed for 30 to 120 min at 5000 to 6000 ppm. Humans accidentally exposed to high concentrations of ammonia have experienced blindness and chemical burns to the skin. Exposures to lower concentrations of ammonia have produced chest, eye, nasal, and throat irritation.

A GRE can occur during a window (time period for safe operation with an open tank). At times in the window, the riser or exhaust header is open, and workers are very close to the opening. The radiological release (Ref. 4, p. 15) would be very small. The likelihood of a GRE occurring during a window is discussed in Ref. 5, pp. 11 and 12. Ammonia concentrations for an 8650-ft^3 release near an open riser have been computed to be ~29,000 ppm.

During the February 1991 GRE, ammonia concentrations in the exhaust flow reached 13,000 ppm. The IDLH value of 300 ppm was reached in a few minutes, and the peak value was attained 60 min later,[6] as measured at the stack. The rate of change of ammonia concentration with time between the IDLH value and the peak was constant. A 2000-ppm ammonia release occurred in 1987, and in the May 1991 GRE, workers complained of skin irritation (exhaust concentration was ~1900 ppm, and it was drizzling that evening). The IDLH value and the peak were reached in about the same periods of time as in February. Again, the rate of change of concentration with time was constant. During the June 1993 GRE (before pump installation), ammonia concentrations were measured with the FTIR device at ~13,000 ppm.

For the mitigated tank, the probability of differently sized gas releases as a function of waste level is given in App. J. In App. Y, we discuss the controls applicable to tank intrusion while the mixer pump is operational.

The National Research Council provided the ammonia health effects presented in Table H-1. Ammonia is lighter than air; thus, workers that are further from the release point will be less affected. Table H-1 shows that there is a time dependence to the health effects. For example, 2400 ppm is a threat to life only if breathed for at least 30 min (although Hale[7] shows different results). Therefore, there is reason to believe that the "high mortality rate" from inhalation of 29,000 ppm requires a few minutes of breathing the atmosphere. The time margin provided by the combination of breathing time and the time to reach high concentrations supports the use of evacuation after a release to assure the safety of workers.

5.0. REQUIRED PROTECTIVE MEASURES

Although most of the information presented is not specific to a concentration of ammonia, it is clear that an atmosphere of 29,000 ppm would be life threatening to an unprotected individual. Based on this data and the regulatory criteria establishing 300 ppm as the IDLH, it is clear that the most protective personal equipment must be required.

All work shall be performed using respiratory and eye protection, as specified by an Industrial Hygiene and the Respiratory Protection representative. According to the WHC "Tank Farm Health and Safety Plan" (see Safe Work Practice),[2] monitor readings at the riser or vapor space are not to exceed 12.5 ppm of ammonia. If the OVM readings exceed 20 ppm of the background for 3 min or longer or if the ammonia levels exceed 250 ppm, personnel will stop work and evacuate the tank farm, even if supplied air is worn. A monitoring and alert system (and/or personnel) shall be in place and be functional, an evacuation path shall be cleared of all obstacles, and a designated, upwind staging area shall be defined.

The monitoring system can alert workers both in and near the work vicinity. An evacuation route must be designated and an upwind staging area defined for workers not in the immediate area of the tank. The monitoring personnel must be aware of the potential for ammonia release, the concentration that could be emitted, and the effect on humans of that concentration.

TABLE H-1
AMMONIA EFFECTS[7–9]

Body Parts	Concentration (ppm)	Effects
Skin	10,000	Mild irritation
	30,000	Blisters
Nose	0.7–5.0	Threshold of notice
Lung and Respiratory Tract	25–35	Exposure limit[8]
	300	IDLH limit
	400	Immediate throat irritation
	1700	Cough
	2400	A threat to life after 30 min
	1720[7]	A threat to life in <30 min[7]
	5000–10,000	High mortality rate ("rapidly fatal")[7]
Eyes	140	Slight irritation
	700	Immediate irritation

During pump operation, we do not anticipate that workers will be in the immediate vicinity of the release points. Workers in the vicinity of the tank (e.g., in the DACS trailer) will be trained in proper procedures for self-protection in the event of a gas release. If a gas release occurs, workers will be evacuated according to existing procedures. We anticipate that an Industrial Hygiene and the Respiratory Protection representative will require appropriate respiratory protection for each person in the DACS trailer, appropriate protective clothing, and an approved evacuation plan.

The *Industrial Safety Manual*[1] gives general specifications for personal protective equipment, including respiratory fit testing, training, and maintenance. However, for each particular situation, the proper equipment must be specified by the Occupational Safety and Health Officer. In addition, protective equipment also must comply with requirements for radiation exposure, as specified in "Radiation Protection"[11] and "Radiation Work Requirements and Permits."[12] Protective requirements that would apply to ammonia include the following:

Clothing Full-body impervious suits must be worn; such suits must be completely impervious and be worn over the respirator. These suits must meet requirements for radiation exposure and must be fire retardant (because of fire hazard). Personal cooling devices may be appropriate if work is performed in a hot environment.

Eye goggles normally are required, but the respirator used in this case would be a full facepiece.

Other personal protective equipment is as specified in Ref. 1, including foot protection, eye and face protection, and protective headwear.

Respiratory Protection Respiratory protection must be used in any emergency situation or planned entry into unknown concentrations or IDLH condition (above 300 ppm). Planned entry would include any workers near the breaching of the tank.

The required respiratory protection shall include:

1. a restricted zone, beyond which ammonia levels would not reach 300 ppm in the worst-case scenario; and
2. any SCBA that has a full facepiece and is operated in a pressure-demand (pressure-positive) mode, or any supplied-air respirator that has a full facepiece and is operated in a pressure-demand (pressure-positive) mode in combination with auxiliary (escape) SCBA operated in a pressure-demand mode.

The assigned protection factor for both of these respirator selections is 10,000, the largest value possible. This means that exposure to the wearer will be 1/10,000 of the ambient concentrations. For ambient air ammonia concentrations of 29,000 ppm, a worker wearing a properly functioning and fitting respirator of this type would be exposed to approximately 2.9 ppm, well within acceptable levels.

All respirators must be selected, maintained, and used in accordance with the respiratory protection program (Ref. 1, Vol. III), specifying proper fitting, storage, maintenance, testing, training, etc.

Medical Monitoring Employees are required to receive medical approval to wear a respirator. In addition, however, employees should receive preplacement medical exams, with an examination specific for ammonia directed toward eyes, skin, and upper-respiratory system. Pulmonary function tests should be carried out. Follow-up evaluations should be made for any worker who has signs or symptoms of eye, skin, or respiratory tract irritation.

Site Showers Emergency showers: Showers are specified in Ref. 1, Vol. I. Showers must be set up with clear access such that a worker can wash within 10 s. Skin should be washed immediately upon exposure, and clothing should be removed upon contamination.

Eyewash stations: Eyewash stations are specified in Ref. 1, Vol. I. Stations must be set up with clear access such that a worker can wash within 10 s. Eyes must be washed as soon as possible, preferably within the first 10 s after exposure. Eyes should be flushed with pure water for 15 min, forcibly holding open the lids. Medical attention then should be sought. Contact lenses are allowed under the respiratory program; however, in atmospheres with potential exposures to ammonia, or where positive pressure respirators are used, contact lenses should not be worn.

6.0. AMMONIA RELEASE-RELATED CONTROLS

To provide an adequate level of assurance that ammonia concentrations in the tank farm will be minimized, several controls are provided in Sec. 6.

1. The pump operation shall be terminated if the ammonia level reaches 3000 ppm. This control assures that
    - workers near the tank farm will not be exposed to an ammonia level that exceeds the 8-h average exposure limit of 25 ppm,
    - accident sequences that could provide ammonia exposures near the IDLH limit of 300 ppm will be terminated before unacceptable exposures can occur,
    - initial conditions for gas release analysis with and without a burn analysis will not be invalidated owing to high initial ammonia levels, and
    - the long-term effects owing to pump operation will be minimized.
2. The pump shall not be started if the dome average concentration exceeds 500 ppm. This control assures
    - that workers near the tank farm will not be exposed to an ammonia level that exceeds the 8-h average exposure limit of 25 ppm,
    - against an ammonia release beyond what has been analyzed, and
    - that long-term effects from pump operation will be minimized.

7.0. TOXICOLOGICAL CONSIDERATIONS FOR OTHER RELEASE GASES

Besides ammonia, there are other gases of concern with respect to toxicological consequences, including nitrous oxide, carbon monoxide, and methane. Table H-2 provides information regarding the amount of these gases in the release gas and their relative toxicity. In addition to the gases listed in Table H-2, there are other gases in the burp gases that are simple asphyxiants, such as water vapor, nitrogen, and hydrogen.

TABLE H-2
TOXIC GAS COMPOSITION AND RELATIVE TOXICITY

Gas	% of Burp Gas	TWA (ppm)	IDLH (ppm)
Ammonia	14.95	25	300
Nitrous Oxide	26.69	25–50	None Specified
Carbon Monoxide	0.50	25–35	1500
Methane	0.53	None Specified	None Specified

Of primary concern is ammonia and carbon monoxide because they are the only gases known in the release gas that are immediately dangerous to life and health. The toxicological consequences of carbon monoxide releases are only ~1.3% of the consequences of ammonia; this is because the expected concentrations of carbon monoxide are <4% of the concentrations of ammonia owing to (1) carbon monoxide being a much small fraction of the burp gas, and (2) the IDLH for ammonia being one-fifth that of carbon monoxide. Of secondary importance is that nitrous oxide and carbon monoxide have consequences if long-term exposure is possible. Controls have been established in Sec. 6 of the SA to limit dome ammonia concentrations during pump operation to values that will not approach occupational exposure limits. Controls have also been established in Sec. 6 of the SA to limit acute exposure to ammonia, which is expected to limit both acute and chronic exposure to other gases. Based on the current knowledge of the release gas composition, no additional controls or monitoring of gases other than ammonia were found to be necessary for worker protection.

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APPENDIX I
CRITICALITY AND RADIATION EXPOSURE CALCULATIONS

1.0. OBJECTIVE AND SUMMARY OF RESULTS

This appendix addresses:

- criticality concerns in Tank 101-SY,
- possible radiation exposure associated with mixer pump removal,
- radiation limits (control) for normal withdrawal of the mixer pump, and
- radiological consequences of the pump discharge pressure measurement system failure.

The results in Sec. 2.0 show that criticality is not a concern in Tank 101-SY. The dose calculations for various geometries and scenarios are included in Sec. 3.0. The most important set of dose calculations is related to pump removal and is discussed in Sec. 4.0. Section 4.0 concludes that to bound the amount of waste entrainment, a conservative administrative dose rate control should be set to 10,000 mrem/h during pump removal. Section 5.0 demonstrates that leaks from the pump discharge pressure measurement line are within acceptance guidelines, provided that an ARM with an alarm is placed within 3.05 m (10 ft) of the pump.

2.0. CRITICALITY CONSIDERATIONS

Criticality calculations were performed to investigate the criticality risk of Tank 101-SY. Plutonium is concentrated in the bottom waste layers of the tank, and waste pumping conceivably could reconfigure this plutonium into a critical mass. These calculations examined the possibility of the plutonium criticality and show that such an event is not possible.

2.1. Methodology

Neutron multiplication factor (k_{eff}, k_∞, or eigenvalue) calculations were performed to investigate conservative configurations in which the concentration of plutonium in the tank was varied up to a factor of 10^5 times the reported nominal concentration. Some calculations incorporated a representative sludge composition. The nominal plutonium concentration in the tank was obtained from Ref. 1, which reported measured values of plutonium concentrations from core sample composites taken at various depths. The maximum concentration of plutonium found in the bottom layer of the tank was 0.00165 g/gal. of waste. In other layers, the plutonium concentrations were 0.00010, 0.00016, and 0.00134 g/gal. of waste. Based on these core samples, it was concluded in Ref. 1 that the best estimate of the total tank plutonium inventory was 910 g (2 lb).

The eigenvalue calculations were made with the Sn transport code ONEDANT.[2] Infinite dilute, 69 energy-group cross sections based on ENDF/B data were prepared using the TRANSX[3] code. These codes and data were benchmarked by modeling some of the plutonium-water systems from Fig. 1 of Ref. 4 and comparing eigenvalues. Good agreement was obtained between the calculated eigenvalues and those reported in Ref. 4 for those systems modeled.

2.2. Results

We performed calculations for an infinite configuration (zero leakage) of a plutonium-water solution as a function of plutonium concentration to investigate the criticality issue associated with layering. The zero-leakage assumption is conservative, as is the omission of the sludge constituents, which would produce additional neutron parasitic captures. In addition, all plutonium was assumed to be ^{239}Pu. The results of these calculations are shown in Fig. I-1, which plots the calculated k_{eff} (k_∞ in the case of an infinite configuration) as a function of the plutonium concentration normalized to the maximum measured value of 0.00165 g/gal. At the nominally measured plutonium concentration (concentration factor = 1 in Fig. I-1), the k_∞ was calculated to be 0.00012, an extremely small value. At 100 times the reference concentration, the k_∞ was still only 0.012. A concentration factor of 16,000 is required before the conservative, infinite configuration will become critical ($k_{eff} = 1.00$). We do not believe such concentrations can be achieved.

To address the issue of criticality associated with a reconfiguration in the tank, we investigated a more realistic case in which the total estimated plutonium inventory of 910 g (2 lb) was placed in a sphere of sludge and surrounded by an essentially infinite sludge reflector (without plutonium). The representative sludge composition was taken from Table 2 of Ref. 5. Although listed in the table, mercury was not included in our calculations. Because mercury is a relatively strong neutron absorber and poor moderator, its omission is conservative.

The sphere's radius was reduced as the plutonium concentration was increased from its reference value of 6.25×10^{-6} g/m^3 (4.77×10^{-7} lbm/ft^3) to maintain the total plutonium inventory at 910 g (2 lb). The spherical volumes investigated ranged from 100 L (26.4 gal.) at a concentration factor of 2.1×10^5 to 10,000 L (2640 gal.) at a concentration factor of 210. The results of these calculations are shown in Fig. I-2. For large systems with low concentrations, the k_{eff} values were comparable to the infinite systems previously described. For very high concentrations and correspondingly small dimensions, leakage from the plutonium/sludge sphere became important, and the finite calculations produced lower values of k_{eff} than those obtained for the infinite systems. The calculated k_{eff} peaked at a value of 0.97 at 42,000 times the reference concentration and then decreased as leakage from the

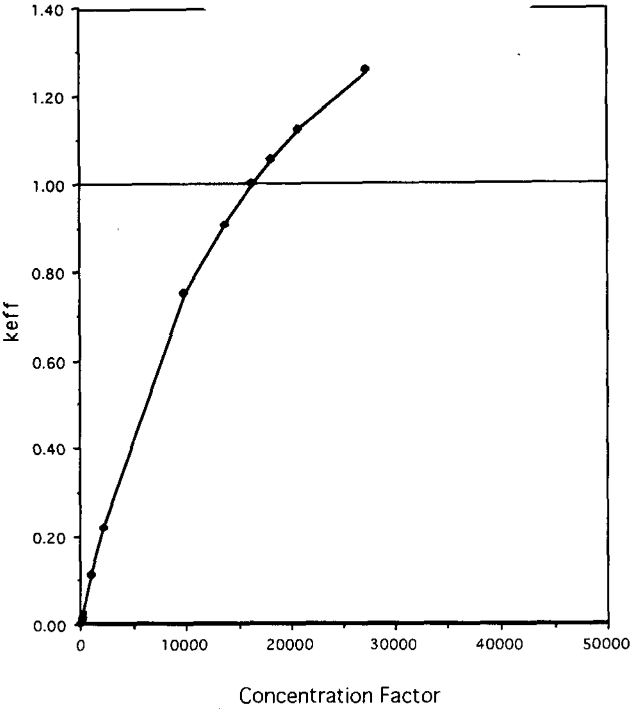

Fig. I-1. Criticality analyses for Tank 101-SY.

small sphere began to predominate. Thus, it appears that 910 g (2 lb) of ^{239}Pu dispersed in a representative sludge composition will not go critical.

Several additional criticality eigenvalues were calculated for criticality associated with a reconfiguration in the tank in which 10 times the total nominal inventory [i.e., 9100 g (20 lb)] is concentrated in a smaller volume. In these calculations, the entire hypothetical inventory of 9100 g (20 lb) was mixed in spheres of either sludge or water. For comparison, the eigenvalues for 910 g (2 lb) in spheres of sludge or water also were determined. A 1-m (3.28-ft)-thick reflector of sludge surrounded the spheres. These results also are shown in Fig. I-2.

These calculations showed that for criticality to occur, the radius of the sphere containing the 9100 g (20 lb) of plutonium must be <70 cm (27.6 in.) if the sphere contained plutonium and water. If the sphere contained plutonium and sludge, the radius must be <30 cm (11.8 in.) for criticality to be achieved. We do not believe that such concentrations can be reached, even if the tank contained 9100 g (20 lb) of plutonium.

2.3. Conclusions

We have calculated k_{eff} values for conservative representations of Tank 101-SY. Based on measurements of plutonium concentrations, the k_{eff} of this tank was extremely small—<0.00012. A very conservative representation of an infinite plutonium-water system would require that the maximum measured plutonium concentration increase by a factor of 16,000 before a critical configuration was obtained. Criticality was not reached when the total plutonium tank inventory of 910 g (2 lb) and the presence of sludge were included in the analysis. If the inventory is increased by a factor of 10 to 9100 g (20 lb), this entire inventory must be contained in a sludge sphere with a radius of <30 cm (11.8 in.) for criticality to occur. We do not believe that this is a credible scenario. Based on these results, we do not believe Tank 101-SY presents a criticality hazard.

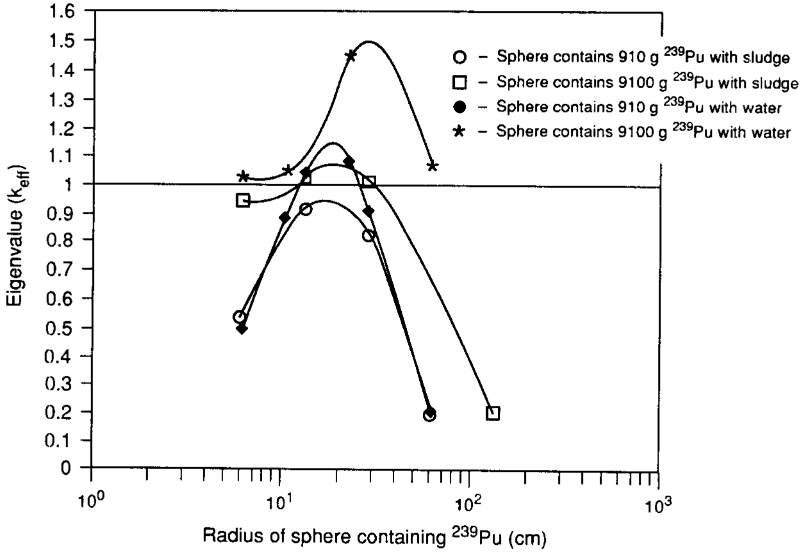

Fig. I-2. Eigenvalues for a ^{239}Pu-containing sphere with a 1-m sludge-containing spherical reflector.

3.0. RADIATION EXPOSURE CONSIDERATIONS

This section describes the calculations made to determine the exposure and source strength for several different situations involving waste from Tank 101-SY. The models used were for exposures from spills of waste (sludge) and for exposures from waste-filled pipes. The source required to produce 100 mrem/h on a surface was determined for three different waste-filled pipe configurations and a fictitious filter.

3.1. Methodology

Calculations were performed for the following models: (1) exposure from a sludge spill from the pump and the two intake pipes; (2) exposure from a sludge-filled intake pipe; (3) exposure from a sludge-filled exhaust pipe; (4) exposure from a sludge spill from the sludge distribution pipe; (5) exposure from the sludge distribution pipe; and (6) source strength required to produce 100 mrem/h on the surface of a fictitious filter, sludge intake pipe, sludge exhaust pipe, and sludge distribution pipe.

The radiation source strength in the sludge was obtained from several documents[6-10] and is composed of the largest value found for each isotope. These values either may have been experimentally or calculationally determined. We assumed that the plutonium found in the sludge consisted only of the isotope ^{239}Pu. For uranium, a value in grams per gram of sludge was given. This value was converted to curies, assuming that all uranium was the isotope ^{235}U. The decay of the daughter, ^{137m}Ba, from the decay of ^{137}Cs dominates the other isotopes in the resultant exposure, and 94.6% of the decays of ^{137}Cs produces ^{137m}Ba, which is in secular equilibrium with ^{137}Cs. The source strength used in the calculations is given in Table I-1.

The constituents of the sludge were obtained from Ref. 10. In these calculations, they were normalized to a density of 1.71 g/cm^3 (106.7 lb/ft^3), which was an experimentally determined value of sludge reported in Ref. 10 and was the largest value found. Because the source strength was reported in microcuries per gram of sludge in the references, the largest sludge density produced the largest source strength. The normalized values of the constituents of the sludge are listed in Table I-2.

The exposure calculations were made using the Microshield code.[11] Several independent hand calculations were performed at various times to compare with the results of the code. The hand calculation results were in reasonable agreement with the code results.

3.2. Results

3.2.1. Exposure from a Sludge Spill from the Pump and the Two Intake Pipes

The two intake pipes are 15.24-cm (6-in.) schedule 40 and are ~7.32 m (24 ft) long. The volume of the two pipes and the pump was calculated to contain 536 L (141.6 gal.) of sludge having a mass of 916 kg (2020 lb). A hypothetical spill could produce a cylinder 73 cm (28.74 in.) in radius and 32 cm (12.6 in.) high. These dimensions would not necessarily produce the highest exposure. Exposure calculations at the top and to the side of the cylinder are give in Table I-3.

3.2.2. Exposure from a Sludge-Filled Intake Pipe

The intake pipe is 15.24-cm (6-in.) schedule 40 and is ~7.32 m (24 ft) long. It contains 136 L (36 gal.) of sludge with a mass of 233 kg (514 lb). Table I-4 gives the exposures at various distances from a point on the pipe 3.66 m (12 ft) from the end.

3.2.3. Exposure from a Sludge-Filled Exhaust Pipe

The exhaust pipe is 40.64 cm (16-in.) schedule 40 and is ~7.32 m (24 ft) long. It contains 835 L (220.6 gal.) of sludge with a mass of 1427 kg (3146 lb). Table I-5 gives the exposures at various distances from a point on the surface pipe 3.66 m (12 ft) from the end.

3.2.4. Source Strength Required to Produce 100 mrem/h on the Surface of a Fictitious Filter, Sludge Intake Pipe, Sludge Exhaust Pipe, or Sludge Distribution Pipe

In Table I-6, the source strengths required to produce 100 mrem/h on the surface of the sludge intake pipe, sludge exhaust pipe, sludge distribution pipe, and a fictitious filter are listed. The sizes of the various pipes were listed in previous sections. The calculation was made for 0.1 cm (0.04 in.) from the surface at a point 1/2 the distance from the end. The fictitious filter is a box 0.3 m by 0.3 m by 15.24 cm (1 ft by 1 ft by 6 in.) and contains carbon at 50% density. For the filter, the calculation was made in the center of the 0.3-m by 0.3-m (1-ft by 1-ft) surface at a point 0.1 cm (0.04 in.) from the surface. The source strength is dominated by the ^{137}Cs.

4.0. MIXER PUMP WITHDRAWAL—RADIATION LIMITS

This section establishes the radiation limits for normal mixer pump withdrawal. These limits are based on the gamma dose measured by the unshielded gamma detectors during normal pump removal. These limits will assure that the inventory of waste that is in the riser during pump removal will be significantly smaller than that assumed in the consequence analysis for a pump ejection accident.

TABLE I-1
SOURCE STRENGTH FOUND IN THE SLUDGE

Isotope	μCi/cm^3
^{90}Sr	70.1
^{99}Tc	0.633
^{129}I	0.496
^{137}Cs	852.0
^{237}Np	0.872
^{239}Pu	0.0291
^{241}Am	0.340
^{235}U	3.81E-04

TABLE I-2
CONSTITUENTS OF THE SLUDGE

Element	Density (g/cm^3)
Aluminum	0.1228
Silicon	0.0430
Chromium	0.0037
Iron	0.1228
Manganese	0.0061
Sodium	0.0614
Nickel	0.0049
Nitrogen	0.0356
Mercury	0.0123
Oxygen	1.1972
Hydrogen	0.1003

TABLE I-3
EXPOSURE FROM SPILL PUMP AND TWO INTAKE PIPES

Distance from Top of Spill (cm)	Exposure (rem/h)	Distance from Side of Spill (cm)	Exposure (rem/h)
0.1	402.0	0.1	344.0
100	63.6	100	14.5
1000	0.948	1000	0.261

TABLE I-4
EXPOSURE FROM INTAKE PIPES

Distance from Surface of Pipe (cm)	Exposure (rem/h)
0.1	132
100	8.6
1000	0.29

TABLE I-5
EXPOSURE FROM EXHAUST PIPE

Distance from Surface of Pipe (cm)	Exposure (rem/h)
0.1	161
100	22.6
1000	0.99

TABLE I-6
SOURCE STRENGTH REQUIRED TO PRODUCE 100 mrem/h AT THE SURFACE

Isotope	Intake Pipe (μCi/cm^3)	Exhaust Pipe (μCi/cm^3)	Distribution Pipe (μCi/cm^3)	Filter (μCi/cm^3)
^{90}Sr	5.31e-2	4.35e-2	1.48e-1	2.19e-2
^{99}Tc	4.80e-4	3.93e-4	1.33e-3	1.98e-4
^{129}I	3.76e-4	3.08e-4	1.04e-3	1.56e-4
^{137}Cs	6.45e-1	5.29e-1	1.79e-0	2.67e-1
^{237}Np	6.61e-4	5.42e-4	1.84e-3	2.73e-4
^{239}Pu	2.20e-5	1.81e-5	6.12e-5	9.11e-6
^{241}Am	2.58e-4	2.11e-4	7.15e-4	1.06e-4
^{235}U	2.87e-7	2.37e-7	8.02e-7	1.19e-7

4.1. Analytical Methods and Calculations

The analysis presented in the SA (Sec. 5 and App. M) indicates that for normal operations and expected cleaning efficiency during pump removal, there will be <12.8 kg (28.2 lbm) of material on the portion of the pump assembly within the riser during the removal process. The SA bounding analysis limited the maximum amount of material that could be released from the riser during a burn event to

12.8 kg (28.2 lbm). To provide the bounding SCO radiation dose rate, we assumed that 12.8 kg (28.2 lbm) of material is in the riser while the pump is being removed. This material could be in the form of chunks, crystals, or a thin film or coating on the pump assembly. We assumed that the wash systems are capable of removing any chunks and that only some form of coated material remains on the pump assembly during the removal process. This approach was consistent with the experience cited in the SA, where in some cases, after an object was high-pressure washed, waste material was found adhering to the object with a thickness of ~1.5 mm (0.06 in.). During a burn event, the majority of material entrained in the escaping gases would originate in the region of the maximum gas velocity. The SA identified this point to be the riser with the pump assembly within it. The pump assembly creates a "choke point"; thus the gas velocities are highest within and just above the outlet of the riser. This analysis[12] therefore assumed that the SCO limiting dose rate was calculated for the condition where the pump assembly is within the riser region during pump removal.

The analysis assumed for waste that:

- waste has adhered uniformly to the pump assembly surfaces to a thickness equivalent to 12.8 kg (28.2 lbm) for that portion of the assembly within the riser (see Fig. I-3).
- this is a normal pump removal and that the pump internals and piping have been flushed adequately; therefore, all radiation detected by the radiation monitors is from waste adhering to the surface areas of the pump assembly.
- large pieces of the waste are removed from the pump exterior by the washing systems.
- all waste adhering to the surface of the pump assembly can and will be removed by the thermal and mechanical shock forces associated with a burn event and that this material becomes an aerosol.

The analysis assumed for a burn event that:

- a burn event can occur with the pump assembly at any position in the riser; however, only the portions of the pump assembly submerged in or just above the surface have any waste adhering to them when the pump is removed. Only the submerged portion of the pump assembly was analyzed for the calculations made in Ref. 12.
- during a burn event, waste in and just above the riser is released. This is the volume represented in the analysis.

- a postulated burn event generates forces less than or equal to the inertial forces (drag, buoyancy, and lifting force) of the pump assembly such that the pump assembly does not lift as result of the burn.

The analysis assumed for dose detection and monitoring that:

- the pump assembly surface is not uniform and that the distance from the radiation monitors (unshielded GM tubes) will vary as the assembly is removed. These irregularities affect the actual dose readings but not the relative range of these readings because the primary source is gamma radiation.

- the overall source geometry is such that the pump assembly can be approximated by three regions sufficient for the calculations.

- the pump assembly is being withdrawn at a rate of ~2 ft/min (1.0 cm/s) and that the communication delay between the crane operator and personnel monitoring the radiation monitors allows pump withdrawal to be suspended within 5 s [the assembly will travel 2 in. (5 cm) before the lift is suspended].

- the material contributing to the dose measurement during removal is of the same thickness or thicker for the portion of the pump assembly below the detectors.

- if radiation levels approaching the limits established herein are detected during removal, removal should be suspended and additional cleaning initiated.

The pump pit and waste geometry is depicted in Fig. I-3. The volume of waste used in this analysis was from the bottom of the riser up to a point ~0.3 m (1 ft) above the top of the riser.

Three waste thicknesses were calculated for the bounding limits of 23.13 kg (51 lb) of waste and a waste density of 1.74 g/cm^3 (108.6 lb/ft^3). Calculations were based on the assumption that the waste uniformly coats the surface of the pump assembly to a thickness that yields a total waste of 12.8 kg (28.2 lbm). This approach is valid in that a thicker (waste) value would yield a higher radiation dose (any waste material shielding can be ignored for gamma rays and the probable thickness involved). If

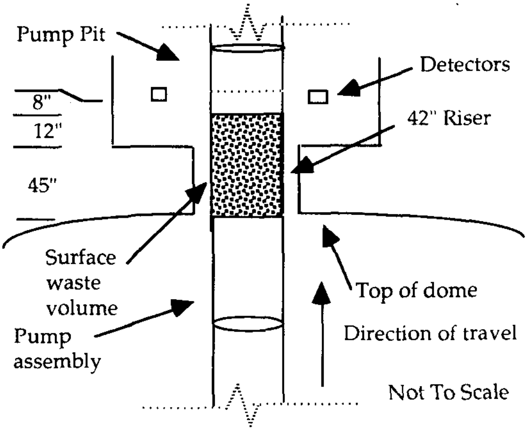

Fig. I-3. Waste volume representation.

the waste thickness is less than the bounding value, the amount released during a postulated burn event would be less than the 12.8-kg (28.2-lbm) waste limit. The SA assumed that during a burn event, small waste particles would be swept off the surface of the waste and then up and out of the tank. In this analysis, we assumed that all material adhering to the surface of the pump in the riser, as shown in Fig. I-3, would be swept off by the force of the explosion and that this material would aerosolize.

The analysis assumed for conservative factors that:

- during a burn event, all of this waste becomes an aerosol, which it would not.
- the surface areas modeled in the three sections of the pump assembly were increased by conservative area factors to account for surface irregularities such as tubing, conduit, fittings, and stiffeners.
- all radiation detected by the radiation monitors is from waste on the surface of the pump assembly. There are two sets of GM detectors: a nonshielded pair and a collimated beam pair. Dose calculations were performed for the unshielded pair.

- the waste material isotopic composition used in the SA is a more conservative formulation than that used by which the dose calculations were made by WHC.[13]
- the calculated peak dose rates in each pump section were used to calculate the limiting does rate for that section.

Dose calculations for various waste thicknesses, performed by WHC,[13] indicated that the expected dose rates vary along the length of the pump assembly (because of component size and distance from the radiation detectors). The WHC dose calculations account for detector locations and geometry relative to the pump assembly during assembly withdrawal. The calculated values assume that the pump internals were cleaned by the flush system and that all of the dose contribution was from a film buildup on the surface of the pump assembly.

These expected dose rates for all waste material thicknesses are somewhat uniform once the submerged portion of the pump assembly enters the sensitivity "window" for the radiation detectors. Because the curves ramp up and stay somewhat constant, these peak values were used for this analysis.

If a limiting value is established above the expected dose rate but below the bounding values established by the SA, enough operational flexibility should be available to allow safe pump removal while still providing sufficient warning if the SA limits are reached. The calculated SA bounding dose limits, the expected dose [for 1.5 mm (0.06 in.) of waste on the surface], and the value recommended for an operational limit are shown in Fig. I-4. After the pump assembly is removed from the riser, the SA dose limit, the administrative dose rate recommendation, and the probable dose rate all trail back to zero. In actual practice, the pump assembly will be suspended over the riser, contained within a plastic "baggie," and allowed to "drip dry," with the drippings returning to the tank.

4.2. Results

The dose rate for the limiting mass is not uniform along the length of the pump assembly, as shown in Fig. I-4. The upper curve in Fig. I-4 provides the bounding dose rates to meet the maximum entrained material constraint in the SA. The administrative control is set to 10,000 mrem/h (see Sec. 6 of the SA), which is at 63% of the minimum predicted dose rate for the maximum entrained material constraint in the SA. The alarm is set at 50% of the SCO (5000 mrem/h). When compared to the expected dose rates, the administrative control provides a considerable margin for operations.

If the dose reading is >10,000 mrem/h, removal operations should be suspended and additional cleaning initiated. If the alarm is exceeded, the pump removal rate must be lowered to allow for additional time for pump cleaning operations.

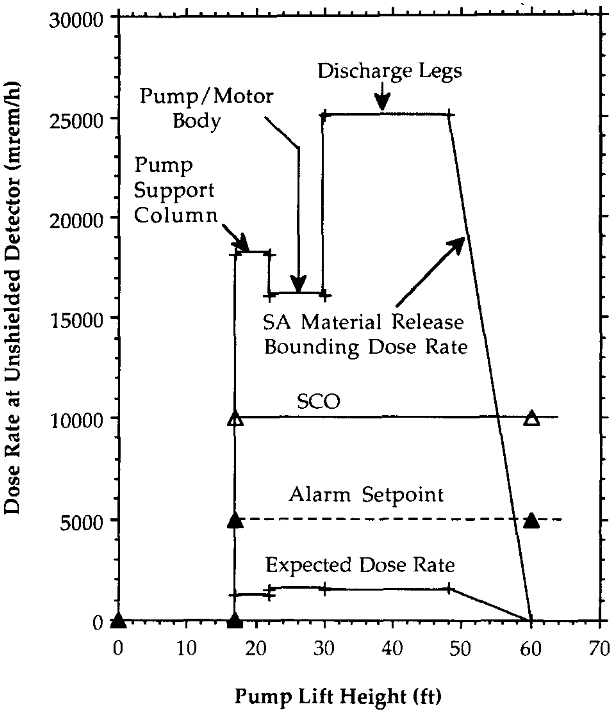

Fig. I-4. Calculated dose rates during pump removal.

4.3. Conclusions

Provided that sufficient administrative controls are established to limit the dose rate reading obtained from the radiation detectors to the above limit, the mixer pump assembly may be withdrawn without exceeding the bounding waste mass values given in the SA.

5.0. SAFETY ANALYSIS OF THE PUMP-DISCHARGE PRESSURE MEASUREMENT SYSTEM

This section summarizes the results of the probability and consequences assessment for waste discharge through the pump-discharge pressure-measurement system.

A pressure-measuring system monitors the pump-discharge pressure. The system consists of a pressure tap at the pump discharge connected to a bellows-seal arrangement that isolates the waste from oil in a 0.64-cm (0.25-in.) SS pressure tube that extends vertically a distance of 18.59 m (61 ft) through the cover block, where it terminates at a pressure transducer. A flush line extends from the waste side of the bellows seal upward through the cover block; the line has a valve and connector at the top end for connection to a source of high-pressure water that can be used to flush the lower end of the pressure-measuring system and pump-discharge nozzle, if necessary. The flush line contains an exit valve and double check valves to prevent waste discharge through the flush line. If these check valves are located inside the tank, a leak cannot occur unless both of the check valves and the exit valve fail simultaneously, an occurrence that is not considered credible.

A discharge of waste into the atmosphere through the oil line is possible only if there is a failure in the above-ground section of tubing or in the connection to the pressure transducer and if the bellows separating the waste from the oil also fails.

5.1. Analysis of Accident Consequences

Calculations were performed to determine the consequence of a break above the cover blocks in the pressure tube accompanied by a bellows failure. The calculations[14] indicated that there would be no waste release for pump speeds <535 rpm. At higher pump speeds, the leak rate and the amount of material aerosolized depended on the pump speed and the effective diameter of the leak. The worst case occurred for a leak diameter of ~0.15 cm (0.06 in.) (Ref. 15). A series of calculations was performed for a break diameter of 0.15 cm (0.06 in.) for pump speeds ranging from 600 to 1200 rpm to determine the pressure upstream of the break. The aerosolization rates in lb_m/h were estimated using results from Ref. 15. At 1200 rpm, the flow rates, aerosolization rates, and fractions aerosolized were obtained as 35.71 g/s (283.4 lb/h), 0.89 g/s (7.032 lb/h), and 2.48%, respectively.

Outdoor ARMs were installed in all DST farms.[16] Each system is comprised of a photo multiplier with a visible and audible alarm set at 5 mrem/h above background. The monitors are sensitive to gamma radiation in the range of 0.1 to 10.0 mrem/h. Alarms are located in the continuously occupied tank farm control rooms and at the CASS control room in the 2750-E Building. Fail-safe alarms are included in each system. The nearest detector is ~15.54 m (51 ft) from the center of Tank 101-SY. Analysis shows that the measured dose rate caused by a leak at that distance would be below the sensitivity of the instrument.

A separate analysis[17] was performed using the Microshield code to determine the radiation level that would be measured by a detector located 0.46 m (1.5 ft) above grade at various distances from the pump. The source for these calculations was a waste-filled SS tube that is 0.64 cm (0.25 in.) in diameter and 0.91 m (3 ft) long. The effect of the material in the air caused by the leak was neglected (conservative). The radiation level as a function of distance is shown in Table I-7.

As a result of this analysis, an additional ARM will be located within 3.05 m (10 ft) of the pump near the midheight of the exposed tubing. The alarm should be set to a value according to Table I-7 and the detector's actual distance from the pump. The pump must be turned off if the system detects high levels of radiation.

A PRA analysis[18] was performed to estimate the accident frequency for this scenario. The point value frequency[18] was found to be 2.78×10^{-7}/yr, with an error factor of 16.7. The 95th percentile value is 4.65×10^{-6}/yr. However, this analysis was based entirely on random failures and did not consider common-cause failures (e.g., impacts or stresses that may occur during pump installation) or secondary failures (failures that cause components to be stressed beyond their design limits in a way that increases their random failure rate). Also, the analysis assumes steady rather than cyclic pressure loading, no human errors in assembly and installation, and testing of the assembly before use. A more detailed analysis accounting for these factors is not possible because of a lack of sufficient statistical data. We therefore considered the accident frequency listed above to be somewhat optimistic and concluded that this accident could not be considered incredible. We have increased the accident frequency by a factor of $\sim 10^3$ for these unanalyzed factors. This value does not have an analytical basis, but the resulting frequency was used mainly to locate the consequences on a frequency-vs-dose plot to evaluate the consequences. As will be seen, acceptability of the results was not particularly sensitive to the frequency.

TABLE I-7
RADIATION LEVEL AT SENSOR CAUSED BY WASTE IN TUBE

Distance from Tube (ft)	Radiation Level (mrem/h)
51.0	0.034
30.0	0.105
20.0	0.242
10.0	0.993
5.0	3.939

Based on the analyses and the additional ARM, dose rates were calculated assuming that the pump is run at maximum speed for 15 min before the condition is detected and the pump is turned off. The doses are listed in Table I-8, and the consequences are acceptable.

5.2. Conclusions

Based on the analysis performed, the consequences of a leak in the external pressure-sensing tubing are acceptable for all pump speeds, provided the requirements of this analysis are met.

The following requirements resulted from this assessment:

- The two check valves in the flush line shall be located inside the tank.
- A radiation detecting sensor shall be installed within 3.05 m (10 ft) of the pump at a height of 0.46 m (1.5 ft) above grade and shall have an alarm set to a value according to Table I-7 and the actual distance of the detector from the pump.
- The ARM system must be operational, and the alarm must be audible in the DACS trailer. Procedures shall be developed such that in the event of an alarm, the operators in the DACS trailer will don respiratory protection equipment and shut down pump operations.

TABLE I-8
DOSES FROM PUMP PRESSURE DETECTOR LEAKS

Location	Frequency[a]	Calculated Dose[b]	Acceptance Criteria[c]
SY Tank Farm	10^{-2}	2.2	5.0 rem[d]
242-S Evaporator	10^{-2}	0.44	5.0 rem[d]
U Plant	10^{-2}	0.09	5.0 rem[d]
Hwy 240	10^{-2}	0.0064	0.5 rem
Offsite (acute)	10^{-2}	0.00095	0.5 rem
Offsite (50 yr)	10^{-2}	0.0315	not specified

[a] Estimated for comparison to acceptance criteria.
[b] Assumes 15-min leak duration at 1200-rpm pump speed.
[c] From Refs. 19 and 20 for a frequency of 0.01/yr.
[d] Ref. 19 specifies the onsite location as the nearest site that is not part of the facility being analyzed.

- The WHC radiation protection organization shall determine the appropriate radiation respiratory protection to be available in the DACS trailer. Any required equipment (e.g., a CAM system) shall be in operation before pump testing, and appropriate procedures shall be developed for response to the alarms.

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APPENDIX J
ACCIDENT FREQUENCY ESTIMATE

1.0. OBJECTIVE AND SUMMARY OF RESULTS

The acceptance criteria used in the SA (presented in Sec. 5) give the allowable consequences of accidental releases as a function of accident frequency. In general, best-estimate frequencies, combined with conservative estimates of the consequences, are used for comparison to the risk acceptance criteria.

This appendix discusses the accident frequencies used in the SA. The frequencies are not based on a rigorous risk analysis. The accidents are based on results of the hazards analysis summarized in Sec. 3 of the SA. Frequencies are based on a combination of best-estimate analysis and conservative assumptions. In some cases, consistency is neglected in favor of conservatism. For example, two mutually exclusive events sometimes are assumed to occur with a probability of 1.0. While logically inconsistent, such assumptions result in conservative estimates of frequency. We do not discuss the uncertainties in the frequency estimates.

2.0. DETERMINATION OF FREQUENCIES

The hazards analyzed are identified in Tables 3-1 and 3-3 in Sec. 3 of this SA. In Sec. 3 of the SA, we do not consider the hazards associated with normal tank farm operations. The consequences of the hazards analyzed in this SA are discussed in detail in Secs. 4 and 5 of the SA. The discussion in this appendix is based on the hazard types identified in Sec. 3 of the SA to maintain consistency, with one exception. Section 3 distinguishes between pump-induced GREs and natural GREs. However, the consequences do not depend on whether an event is induced or natural. Because the safety case presented in this SA is based on consequences, no distinction is made in this appendix between natural and induced GREs.

The accidents discussed in Secs. 3, 4, and 5 of the SA have been developed since the pump mixing was proposed as a method of mitigation. Some of the hazards that were considered initially have been dismissed as a result of additional data and analysis. Although some hazards have been dismissed, it is important to document the reasons. In this appendix, we consider all hazards and accidents discussed in Secs. 4 and 5 of the SA and try to maintain a one-to-one correspondence with these chapters for the sake of consistency and ease of understanding. Thus, hazards that were identified earlier but later determined to be unimportant also are included in this appendix.

2.1. Gas Release Events

Two classes of accidents that can be initiated by a GRE are a flammable or toxicological gas release and a flammable release with a burn. The first step in evaluating the frequencies of these accidents is to estimate the frequency of the various GREs analyzed in this SA.

In the deterministic analysis of the consequences of GREs, a few bounding cases were examined. Because a continuous spectrum of gas release volumes is possible, a probabilistic analysis cannot be based on discrete events. The discrete events in the deterministic analysis must be considered as the bounding case for classes of events or ranges of gas release volumes in the deterministic analysis. These volume ranges must be defined before the probabilities and frequencies can be estimated.

There are four limiting gas release volumes implicit in the analysis of normal operations. The first is a gas release volume of 297.3 m^3 (10,500 ft^3), which is the maximum historical gas release obtained from the GRE data. The second limit is 244.9 m^3 (8650 ft^3), which is the maximum gas release volume for which there is no structural damage to the tank if the flammable gas ignites (see App. K for details). The third limit is ~169.9 m^3 (6000 ft^3), which corresponds to the maximum allowable release during a dome-intrusive activity (see Apps. C and Y). The fourth limit is implicit. This is the gas release volume for which there are insignificant consequences only. The maximum volume for insignificant consequences only is assumed to be the release volume, which results in a dome average hydrogen concentration of 25% of the LFL. This volume is ~28.3 m^3 (1000 ft^3).

The first case in the deterministic analysis bounds all GREs that could cause structural damage. The corresponding class of events in the probabilistic analysis is all gas releases ≥ 244.9 m^3 (8650 ft^3). The deterministic case of 244.9 m^3 (8650 ft^3) bounds all GREs with significant radiological or toxicological consequences but no potential for causing structural damage. The corresponding class for probabilistic analysis is gas release volumes between 28.3 and 244.9 m^3 (1000 and 8650 ft^3). The third class of events is gas releases during dome-intrusive operations; these events are bounded by a 169.9-m^3 (6000-ft^3) gas release. In the probabilistic analysis, the corresponding class of events is gas releases with volumes ranging from 28.3 to 169.9 m^3 (1000 to 6000 ft^3). The final class of events is those with insignificant consequences, which includes all GREs with a gas release volume <28.3 m^3 (1000 ft^3). Because this class has no significant consequences, it is not considered in the analysis.

There are two limiting gas release volumes implicit in the deterministic analysis of pump installation. First is the pump installation limit of 103.4 m^3 (3650 ft^3). This limit is based on the pump ejection accident and is discussed in App. M. Because of the level controls for installation, releases >103.4 m^3 (3650 ft^3) are highly unlikely. The second class of events is those with insignificant consequences. As discussed above, the limit for insignificant consequences is a gas release volume of 28.3 m^3 (1000 ft^3). In the probabilistic analysis, the installation limit of 103.4 m^3 (3650 ft^3) is the bounding case for all gas release volumes between 28.3 and 103.4 m^3 (1000 and

3650 ft^3). Insignificant GREs are all events with a gas release volume <28.3 m^3 (1000 ft^3); however, this class of releases is not considered in the analysis.

There also are two limiting gas release volumes implicit in the deterministic analysis of pump removal. For pump removal, the maximum allowable release is 70.8 m^3 (2500 ft^3), which also is based on the ejection accident analyzed in App. M. In the probabilistic analysis, the installation limit of 70.8 m^3 (2500 ft^3) is the bounding case for all gas release volumes between 28.3 and 70.8 m^3 (1000 and 2500 ft^3). Insignificant GREs are defined as all events with a gas release volume <28.3 m^3 (1000 ft^3); however, this class of releases is not considered in the analysis.

Two possible causes of a GRE that must be considered in evaluating the frequency are (1) natural events and (2) GREs induced by pump operation or waste-intrusive operation. Both natural and induced GREs must be considered during normal operation of the pump. Only natural GREs are considered during dome-intrusive operations because pump operation and other waste-intrusive operations are not permitted (see Sec. 6 of the SA). Only induced events are considered during pump installation and removal. The low waste level prescribed by the controls in Sec. 6 of the SA and the relatively short duration of these operations makes the probability of a natural GRE during installation and removal extremely unlikely.

We assumed that natural GREs will not occur if the pump is operational. In this appendix, we assumed that there is a spare mixing pump available. When the current mixer pump fails, the spare will be installed and fabrication of a second spare will begin. We assume that the time required to fabricate the second spare is 180 d. If the first replacement fails in <180 d, the second replacement pump will not be ready; mitigation by pump mixing will stop, and the natural cycle of GREs that was observed before mixer pump operation began will resume. To estimate the frequency of a natural GRE of a specified size requires the frequency of pump failure, the probability that the first spare pump fails before 180 d, and the probability distribution for the size of a natural GRE.

Induced GREs may occur whenever there is a large disturbance to the waste, such as pump operation, pump installation, or pump removal. The frequency of an induced GRE depends on three factors: frequency of the disturbance, probability of a GRE given the disturbance, and probability of a GRE with the specified gas release volume given that an induced event has occurred. The probability of inducing a GRE with a specified size depends on the level control and not the actual operating level because this SA must consider all allowable operating conditions. Actual operations may be safer.

As stated above, the frequency of GREs during normal operations depends on the frequency of natural events and pump-induced events. A double pump failure must occur for a natural GRE to occur. The failure frequency of the current pump is ~0.125/yr.[1] If the replacement pump is assumed to have the same failure frequency, the frequency of a natural GRE is ~1.2×10^{-2}/yr.[1] The probability of a natural GRE of a given size is based on historical data.[2] During normal operations, the frequency of an induced rollover depends on the frequency of pump operations. If we assume that the pump is operated on an average of once every 3 d, the frequency of pump operation is 122/yr. The frequency of inducing a GRE given pump operation is estimated from pump operating data,[3] and the size distribution of induced events as a function of level is estimated from data for natural and induced GREs.[1,3] The frequency of a GRE during a dome-intrusive operation depends on the frequency of the dome-intrusive operations, the probability of a natural GRE during the operation, and the probability that the release volume is between 28.3 and 169.9 m^3 (1000 and 6000 ft^3). The frequency of dome-intrusive operations is ~10/yr.[1] The probability that a GRE occurs during an intrusive operation is estimated from data.[1–3]

Reference 3 discusses the method used to estimate the frequency of GREs during normal operations. The frequencies of GREs ≥ 244.9 m^3 (8650 ft^3), between 28.3 and 244.9 m^3 (1000 and 8650 ft^3), and between 28.3 and 169.9 m^3 (1000 and 6000 ft^3) during a dome-intrusive operation as a function of level control are given in Table J-1. For high waste level controls, the frequency of a GRE is dominated by the frequency of an induced rollover; at low levels, the frequency is dominated by the frequency of a natural GRE. This result is expected because it is more difficult to induce a GRE at a low waste level. The waste level control for normal operations is 10.31 m (406 in.); thus, the frequency of a GRE with a gas release volume >244.9 m^3 (8650 ft^3) is 4.2×10^{-3}/yr, and the frequency of a GRE with a gas release volume between 28.3 and 244.9 m^3 (1000 and 8650 ft^3) is 5.7/yr. For dome-intrusive operations, the waste level control is 10.26 m (404 in.), so the frequency of a GRE with a gas release volume between 28.3 and 169.9 m^3 (1000 and 6000 ft^3) is 1.0×10^{-3}/yr.

The frequency of an induced GRE during pump installation or removal depends on the frequency of these operations, which is equal to the pump failure frequency of 0.125/yr. As stated above, only induced GREs are considered during pump installation and removal. The frequency of inducing a GRE given installation or removal is estimated from pump operating data,[3] and the size distribution of induced events as a function of level is estimated from data for natural and induced GREs.[1,3] Reference 3 discusses the method used to estimate the frequency of a GRE during installation and removal. The frequency of a GRE with a gas release volume between 28.3 and 103.4 m^3 (1000 and 3650 ft^3) and the frequency of a GRE with a gas release volume between 28.3 and 70.8 m^3 (1000 and 2500 ft^3) are given in Table J-2. The frequency as a function of level is approximately the same for installation and removal because the probability of an event with a release volume between 70.8 m^3 (2500 ft^3) and 103.4 m^3 (3650 ft^3) is very small. As discussed in App. C, the level for pump removal is <10.21 m (402 in.), and the level for pump installation is <10.26 m (404 in.). In Sec. 5 of the SA, where we compare the consequences with the risk

TABLE J-1
FREQUENCY ESTIMATES FOR A GRE DURING PUMP OPERATIONS AND DOME INTRUSION

Waste Level Control (in.)	Frequency of GREs ≥8650 ft^3 (yr^{-1})	Frequency of GREs between 1000 and 8650 ft^3 (yr^{-1})	Frequency of GREs between 1000 and 6000 ft^3 during Dome Intrusion (yr^{-1})
408	4.7 x 10^{-2}	25	9.2 x 10^{-2}
406	4.2 x 10^{-3}	5.7	1.3 x 10^{-2}
404	1.6 x 10^{-3}	1.6	1.0 x 10^{-3}
402	1.4 x 10^{-3}	0.32	5.0 x 10^{-5}

TABLE J-2
FREQUENCY ESTIMATES OF A GRE DURING INSTALLATION OR REMOVAL

Waste Level Control (in.)	Frequency of GREs between 1000 and 3650 ft^3 (yr^{-1})	Frequency of GREs between 1000 and 2500 ft^3 (yr^{-1})
405	2.8 x 10^{-3}	2.8 x 10^{-3}
404	1.5 x 10^{-3}	1.5 x 10^{-3}
403	6.8 x 10^{-4}	6.8 x 10^{-4}
402	3.1 x 10^{-4}	3.0 x 10^{-4}

acceptance guidelines, we evaluate the GRE frequencies for pump installation and removal at 10.26 m (404 in.) to obtain 1.5 x 10^{-3}/yr.

The frequency of a GRE exceeding 244.9 m^3 (8650 ft^3) for the unmitigated tank was ~0.5/yr. Based on the results in Table J-1 and a level control of 10.31 m (406 in.), pump operation has reduced the frequency of large GREs by a factor of ~8000. This frequency comparison shows that the mixer pump has reduced the risk of large GREs significantly.

2.1.1. Flammable or Toxicological Gas Release

This consequences category assumes that no burn occurs. However, there are two other branches on the event tree (see Sec. 4 of the SA) that must be considered during normal operations.

The first branch distinguishes between the ventilation system being operable vs inoperable. The second branch considers inadvertent opening of the MPR vs the

MPR remaining closed. During pump installation, an open MPR is inconsequential because the pump riser is open. During pump removal, no branches on the event tree need to be considered. The pump riser is open; thus, an open MPR is inconsequential, and the ventilation system is expected to be turned off during pump removal.

The risk assessment for Tank 101-SY gives an ignition probability of 1.3×10^{-3} (Ref. 4). Because the probability of an ignition source is very small, the probability of no burn essentially is 1.0.

The unavailability of the ventilation system or probability that the ventilation system is not operating is discussed in detail in Ref. 4. Reference 4 takes credit for an emergency diesel generator. In Ref. 1, an estimate of ventilation system failure probability was obtained. The unavailability or failure probability of the ventilation system without the diesel generator or without an equivalent backup power supply is 4.8×10^{-3}. The major contributors to the unavailability are replacing the deentrainer and prefilter.[4]

The probability of a single panel of the MPR opening during a GRE is $\sim 4.8 \times 10^{-4}$ per event.[5]

2.1.2. Flammable Gas Release with Burn

This consequence category assumes that a hydrogen burn occurs. There is only one branch on the event tree to consider during normal operations and pump installation. This branch distinguishes between the ventilation system being operable vs inoperable. The split fraction for this branch is the same as for a hydrogen or toxicological gas release. During pump installation, the ventilation system must be turned off. The burn pressurizes the tank and causes the MPR to open. Therefore, only the case of an open MPR is considered.

The risk assessment for Tank 101-SY gives an ignition probability of 1.3×10^{-3} (Refs. 4 and 6).

2.2. Flammable Gas Accumulation in Dome, Riser, or Ventilation Duct

There is a possibility of hydrogen accumulation in various stagnant regions in the dome, risers, and ventilation ducts. The discussion in Sec. 4 of the SA indicates that these hazards are inconsequential; thus, the frequencies are not quantified.

2.3. GRE in Neighboring Tank

There are two other tanks in the SY farm. Of these tanks, only Tank 241-SY-103 exhibits GREs. Based on the available data, the frequency of GREs is ~2.5/yr.[1]

2.4. Nuclear Criticality

Discussions in Sec. 4 of the SA and App. I indicate that there is no physical mechanism for producing nuclear criticality in the tank; thus, there are no initiating events for this hazard, and no frequency is assigned.

2.5. Filter System Release

The filter system is assumed to fail as a result of a hydrogen release and a burn. No other accident initiators are considered because these additional initiators are considered to be part of normal tank farm operations.

2.6. Foaming

Excessive foaming was identified as a potential hazard before pump installation and operation. Pump operating experience indicates that foaming does not occur. No initiating events have been identified that cause foaming, so no frequency is assigned to this hazard. An additional discussion of foaming is included in the analysis of long-term issues summarized in App. P.

2.7. Tank Penetration

The analysis of drop accidents summarized in Sec. 4 of the SA and App. L indicates that there is no mechanism for penetrating the tank, provided that the administrative controls in Sec. 6 of the SA are implemented properly. No initiating events have been identified that cause tank penetration; thus, no frequency is assigned to this hazard.

2.8. Flooding the Tank

Based on qualitative arguments in Sec. 4 of the SA, flooding of the tank is not considered to be credible; thus, no attempt has been made to quantify the frequency. External events leading to flooding are not considered credible, and excessive water addition is not considered because adequate controls on water addition have been established.

2.9. Spray of Waste into Dome Region

Sections 3 and 4 of the SA identify splashing during pump installation and removal as a potential mechanism of spraying waste into the dome. The discussion in Sec. 4 of the SA indicates that this accident is bounded by a spill during pump removal. Therefore, no attempt has been made to quantify the frequency of this accident.

Based on the discussion in Sec. 4 of the SA, no credible mechanism has been identified that can cause a spray of waste into the dome other than a GRE. Because there are no credible initiators of a waste spray as a separate accident, no attempt has been made to quantify the frequency of this accident.

2.10. Pump-Induced Waste Release

Section 4 of the SA identifies a discharge through the pressure measurement system as the only credible initiating event for a pump-induced waste release. The frequency of this event is ~5 x 10^{-3}/yr (see App. I).

2.11. Waste Spill during Operation

Several mechanical failures have been identified as a possible cause of waste spill during pump operations. Based on the discussion in Sec. 4 of the SA, these failures are either incredible or inconsequential. Therefore, no attempt has been made to quantify the frequency of this accident.

2.12. Waste Spill or Drop during Removal

Two possible reasons for removing a pump are (1) failure of the current mixer pump, which would necessitate removal and replacement; and (2) emergency removal of the replacement pump during installation. During pump installation, a conservative value of 1.0 is assumed for the probability of emergency removal. The probability of a spill during removal is ~4.8 x 10^{-3}/lift.[7] The probability of a drop during removal is ~3 x 10^{-4}/lift.[8]

2.13. Unfiltered Release through Open Riser

During pump installation and removal, risers are open. If the tank pressurizes during these operations, there will be an unfiltered release through an open riser. Based on data from UORs,[4] possible causes of pressurization are loss of ventilation flow, pressurization of the interfacing system for that tank, inadequate ventilation, filter plugging, and deentrainer plugging.

During installation, the ventilation system is operating, and the frequency of over-pressurization can be estimated from the available data. The estimated frequency of failure is 0.54/yr for continuous operation.[1] During pump removal, the ventilation fan is turned off. To be conservative, the probability of over-pressurization during removal must be assumed to be 1.0.

3.0. SUMMARY

The probabilities and frequencies discussed above are associated either with initiating events or top events. The initiating event is the first event in an accident sequence. The top event is associated with the branches of the event tree. The initiating event frequencies and top event probabilities are summarized in Tables J-3 through J-5. The frequencies of the GREs are based on level controls (Sec. 6 of the SA) for normal pump operation, pump installation, and pump removal.

Tables J-6 through J-8 summarize the accident sequences analyzed in this SA and their frequencies. There is a one-to-one correspondence between these tables and the accident sequence tables in Sec. 4 of the SA.

TABLE J-3
BEST-ESTIMATE ACCIDENT INITIATOR FREQUENCIES FOR EVENT-TREE TOP PROBABILITIES DURING PUMP INSTALLATION

Accident Initiator or Event-Tree Top	Initiator Frequency	Top Probability	Exposure	Reference	Effective Initiator Frequency
GRE during installation window (level ≤404 in.)	1.2×10^{-2}/opn (operation)		0.125 opn/yr	1	1.5×10^{-3}/yr
Ignition source		1.3×10^{-3}		4, 6	
Ventilation system inoperable		4.8×10^{-3}		4	
Pump ejection		1.0		Bounding value	
Filter failure caused by hydrogen release with burn		1.0		Bounding value	
Flammable gas accumulation in dome, riser, or ventilation duct	Not quantified		0.125 opn/yr		Not quantified
GRE in neighboring tank	2.5/yr		1.1×10^{-4} yr/yr	1	2.8×10^{-4}/yr
Failure to install pump	1/opn		0.125 opn/yr	Bounding value	0.125/yr
Spill during pump removal		4.8×10^{-3}		7	
Drop during pump removal		3×10^{-4}		8	
Flooding from external event	Not quantified		1.1×10^{-4} yr/yr		Not quantified
Flooding by inadvertent water addition	Not quantified		0.125 opn/yr		Not quantified
Unfiltered release from ventilation failure	0.54/yr		1.1×10^{-4} yr/yr	1, 4	5.9×10^{-5}/yr
Unfiltered release from external events	1.7×10^{-4}/yr		1.1×10^{-4} yr/yr	6, 9, 10	1.9×10^{-8}/yr
Splashing during pump installation	Not quantified		0.125 opn/yr		Not quantified

TABLE J-4
BEST-ESTIMATE ACCIDENT INITIATOR FREQUENCIES FOR EVENT-TREE TOP PROBABILITIES DURING PUMP OPERATION

Accident Initiator or Event-Tree Top	Initiator Frequency	Top Probability	Exposure	Reference	Effective Initiator Frequency
GRE ≥ 8650-ft^3	4.2×10^{-3}/yr		1 yr/yr	1	4.2×10^{-3}/yr
1000 to 6000-ft^3 GRE during dome intrusion	1.0×10^{-3}		1 yr/yr	1	1.0×10^{-3}
Ignition source		1.3×10^{-3}		4, 6	
Ventilation system inoperable		4.8×10^{-3}		4	
MPR opens with no burn		4.8×10^{-4}		5	
MPR opens with burn		1.0		Bounding value	
Filter failure caused by hydrogen release with burn		1.0		Bounding value	
Flammable gas accumulation in dome, riser, or ventilation duct	Not quantified		1 yr/yr		Not quantified
GRE in neighboring tank	2.5/yr		1 yr/yr	1	2.5/yr
Flooding from external event	Not quantified		1 yr/yr		Not quantified
Flooding by inadvertent water addition	Not quantified		1 yr/yr		Not quantified
Discharge manifold break	Not quantified		1 yr/yr		Not quantified
Pump-induced waste releases	5.0×10^{-3}/yr		1 yr/yr	Judgment	5.0×10^{-3}/yr
Waste spill through auxiliary piping	Not quantified		1 yr/yr		Not quantified
Waste spill through vibrator	Not quantified		1 yr/yr		Not quantified

TABLE J- 5
BEST-ESTIMATE ACCIDENT INITIATOR FREQUENCIES FOR EVENT-TREE TOP PROBABILITIES DURING PUMP REMOVAL

Accident Initiator or Event-Tree Top	Initiator Frequency	Top Probability	Exposure	Reference	Effective Initiator Frequency
GRE during removal window (level ≤404 in.)	1.2×10^{-2}/opn		0.125 opn/yr	1	1.5×10^{-3}/yr
Ignition source		1.3×10^{-3}		4, 6	
Ventilation system inoperable		1		Expected procedure	
Pump ejection		1.0		Bounding value	
Filter failure caused by hydrogen release with burn		1.0		Bounding value	
Flammable gas accumulation in dome, riser, or ventilation duct	Not quantified		0.125 opn/yr		Not quantified
GRE in neighboring tank	2.5/yr		1.1×10^{-4} yr/yr	1	2.8×10^{-4}/yr
Spill during pump removal	4.8×10^{-3}/lift		0.125 lift/yr	7	6.0×10^{-4}/yr
Drop during pump removal	3×10^{-4}/lift		0.125 lift/yr	8	3.8×10^{-5}/yr
Flooding from external event	Not quantified		0.125 opn/yr		Not quantified
Flooding by inadvertent water addition	Not quantified		0.125 opn/yr		Not quantified
Unfiltered release from ventilation failure	0.125/yr		-	1, 4	0.125/yr
Unfiltered release from external events	1.7×10^{-4}/yr		1.1×10^{-4} yr/yr	6, 9, 10	1.9×10^{-8}/yr
Splashing during pump installation	Not quantified		0.125 opn/yr		Not quantified

TABLE J-6
ACCIDENT SEQUENCES DURING PUMP INSTALLATION

Accident Outcome	Accident Initiators	Accident Sequence	Best-Estimate Frequency
Flammable or toxicological gas release	GRE during installation window (level ≤404 in.)	GRE - no ignition source - ventilation operable - no pump ejection	1.5×10^{-3}/yr
Flammable or toxicological gas release	GRE during installation window (level ≤404 in.)	GRE - no ignition source - ventilation inoperable - no pump ejection	7.2×10^{-6}/yr
Flammable gas release with burn	GRE during installation window (level ≤404 in.)	GRE - ignition source - ventilation operable - no pump ejection	2×10^{-6}/yr
Flammable gas release with burn	GRE during installation window (level ≤404 in.)	GRE - ignition source - ventilation inoperable - no pump ejection	9.6×10^{-9}/yr
Flammable gas release with burn	Flammable gas accumulation in dome, riser, or ventilation duct	Flammable gas accumulation - ignition source - ventilation operable - no pump ejection	Not quantified
Flammable or toxicological gas release	GRE in neighboring tank	no longer considered to result in burn	2.8×10^{-4}/yr
Pump ejection	GRE during installation window (level ≤404 in.)	GRE - ignition source - ventilation operable - pump ejection	2×10^{-6}/yr
Filter system release	Flammable gas release with burn		
Tank penetration	None		
Spill during removal	Failure of installation	Failure of installation - Spill from contaminated pump	6.0×10^{-4}/yr
Contamination from dropped pump	Failure of installation	Failure of installation - No spill - Drop of contaminated pump	3.8×10^{-5}/yr
Flooding of tank	- External event - Inadvertent water addition		Not quantified
Unfiltered release through open riser	- Ventilation system failure - External events		7.4×10^{-6}/yr
Spray of waste into dome	Splashing during pump installation		Not quantified

TABLE J-7
ACCIDENT SEQUENCES DURING PUMP OPERATION

Accident Outcome	Accident Initiators	Accident Sequence	Best-Estimate Frequency
Flammable or toxicological gas release	GRE ≥ 8650-ft^3	GRE - no ignition source - ventilation operable - MPR closed	4.2 x 10^{-3}/yr
Flammable or toxicological gas release	GRE ≥ 8650-ft^3	GRE - no ignition source - ventilation inoperable - MPR closed	2.0 x 10^{-5}/yr
Flammable gas release with burn	GRE ≥ 8650-ft^3	GRE - ignition source - ventilation operable - MPR open or closed	5.5 x 10^{-6}/yr
Flammable gas release with burn	GRE ≥ 8650-ft^3	GRE - ignition source - ventilation inoperable - MPR open or closed	2.6 x 10^{-8}/yr
Flammable release with burn	Flammable gas accumulation in dome, riser, or ventilation duct	Flammable gas accumulation - ignition source - ventilation operable - MPR closed or open	Not quantified
Flammable release with burn	Flammable gas accumulation in pump pit	Flammable gas accumulation - ignition source	Not quantified
Flammable or toxicological gas release	GRE in neighboring tank	- No longer considered to result in burn	2.5/yr
Flammable or toxicological gas release	1000- to 6000-ft^3 GRE during dome intrusion	GRE - no ignition source - ventilation operable - MPR closed	1.0 x 10^{-3}/yr
Flammable or toxicological gas release	1000- to 6000-ft^3 GRE during dome intrusion	GRE - no ignition source - ventilation inoperable - MPR closed	4.8 x 10^{-6}/yr
Flammable release with burn	1000-to 6000-ft^3 GRE during dome intrusion	GRE - ignition source - ventilation operable - MPR open or closed	1.3 x 10^{-6}/yr
Flammable release with burn	1000- to 6000-ft^3 GRE during dome intrusion	GRE - ignition source - ventilation inoperable - MPR open or closed	6.2 x 10^{-9}/yr
Flammable or toxicological gas release	GRE ≥8650 ft^3	GRE - no ignition source - ventilation operable - MPR open	2.0 x 10^{-6}/yr

TABLE J-7 (CONT)
ACCIDENT SEQUENCES DURING PUMP OPERATION

Accident Outcome	Accident Initiators	Accident Sequence	Best-Estimate Frequency
Flammable or toxicological gas release	GRE ≥ 8650-ft^3	GRE - no ignition source - ventilation inoperable - MPR open	9.7×10^{-9}/yr
Flammable or toxicological gas release	1000- to 6000-ft^3 GRE during dome intrusion	GRE - no ignition source - ventilation operable - MPR open	4.8×10^{-7}/yr
Flammable or toxicological gas release	1000- to 6000-ft^3 GRE during dome intrusion	GRE - no ignition source - ventilation inoperable - MPR open	2.3×10^{-9}/yr
Nuclear criticality	None		
Filter system release	Flammable gas release with burn		
Foaming	None		
Tank penetration	None		
Flooding of tank	- External event - Inadvertent water addition		Not quantified
Spray of waste into dome region	Discharge manifold break		Not quantified
Waste spill	Pump-induced waste releases - pump control system failures - electrical failures - mechanical failures		5.0×10^{-3}/yr
Waste spill	Waste spill through auxiliary piping - mechanical failures - leak in pump discharge measuring system		Not quantified
Waste spill	Waste spill through vibrator - mechanical failures		Not quantified

TABLE J-8
ACCIDENT SEQUENCES DURING PUMP REMOVAL

Accident Outcome	Accident Initiators	Accident Sequence	Best-Estimate Frequency
Flammable or toxicological gas release	GRE during removal window (level ≤404 in.)	GRE - no ignition source - ventilation inoperable - no pump ejection	1.5×10^{-3}/yr
Flammable gas release with burn	-GRE during removal window (level ≤404 in.)	GRE - ignition source - ventilation inoperable - no pump ejection	2×10^{-6}/yr
Flammable gas release with burn	Flammable gas accumulation in dome, riser, or ventilation duct	Flammable gas accumulation - ignition source - ventilation inoperable - no pump ejection	Not quantified
Flammable or toxicological gas release	GRE in neighboring tank	- no longer considered to result in burn	2.8×10^{-4}/yr
Pump ejection	GRE during removal window (level ≤404 in.)	GRE - ignition source - ventilation inoperable - pump ejection	2×10^{-6}/yr
Filter system release	Flammable gas release with burn		
Tank penetration	None		
Spill during removal	Spill from contaminated pump		6.0×10^{-4}/yr
Contamination from dropped pump	Drop of contaminated pump		3.8×10^{-5}/yr
Flooding of tank	- External event - Inadvertent water addition		Not quantified
Unfiltered release through open riser	- Inoperable ventilation - External events		0.125/yr
Spray of waste into dome	Splashing during pump removal		Not quantified

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APPENDIX K
STRUCTURAL CONSEQUENCES OF TANK 101-SY DURING BURN PRESSURE TRANSIENTS

1.0. OBJECTIVE AND SUMMARY OF RESULTS

This appendix provides details and summary results of structural analyses performed for Tank 101-SY under postulated hydrogen burn conditions. The basis for the structural acceptance criteria discussed in Sec. 5 of the SA also is documented in this appendix.

The results show that the 245-m^3 (8650-ft^3) GRE volume burn satisfies the structural acceptance criteria for Tank 101-SY. The dome and primary liner shell stresses and strains are within allowable limits to preclude structural failure.

Concrete cracking is evident throughout the dome in both burn pressure transients; however, rebar stresses remain below the elastic limit and therefore provide an adequate margin against dome failure. The 261.4-m^3 (9230-ft^3) GRE burn exhibits much higher dome velocities during the transient, exceeding the limiting value of dome velocity to preclude dome failure from soil reimpaction and subsequent collapse.

2.0. BACKGROUND AND INTRODUCTION

The structural response of the tank to a hydrogen burn is determined by the temporal changes in several key parameters, which include

- the concrete side-wall uplift and vertical displacement of the tank dome,
- radial displacement of the primary tank side wall,
- uplift of the primary tank bottom corner, and
- strains throughout the primary and secondary steel tank liners.

Although these parameters are important, the most significant factors are whether the tank maintains its structural integrity below the liquid waste level and whether it maintains its overall structural integrity. The structural consequence analysis summarized herein is based on current LANL documentation.[1]

Previous HMS/TRAC burn analyses and corresponding structural analyses of Tank 101-SY have been evaluated based on a certain percentage of void fraction or on the assumption of a certain amount of compressibility of the waste medium.[2-5] Evaluations of waste samples by WHC using voidmeter instrumentation data have shown recently that the waste may be nearly incompressible after a large GRE. Consequently, we revised our burn model and removed the waste compressibility to assure that the SA remains conservative if or when data from the void fraction instrument are confirmed in the future.

The structural analyses contained in this appendix have been performed with pressure-time histories developed from gas burn analyses conducted with HMS/TRAC (App. D). These burn analyses have been performed for given conditions of vent-flow openings through the MPR. Because the MPR has a full complement of tank monitoring equipment installed, the MPR vent-flow area is reduced to 66% of the total cross-sectional area of the 1.07-m (42-in.)-diam riser. Also, as shown in earlier analyses,[1] burns initiated at the dome apex result in faster pressurization than burns initiated at the waste surface. Faster pressurization becomes more limiting in terms of structural response. Therefore, the analyses reported herein simulate a spark source located at the dome apex. This appendix presents the results of structural analyses as driven by these limiting hydrogen burn conditions, spark source location assumptions, and waste fluid incompressibility.

3.0. ANALYTICAL METHODS AND ASSUMPTIONS

The structural response of the tank to accidental hydrogen burns is determined by the ABAQUS[6] finite element code by imposing the transient burn pressure history to a material nonlinear and geometric nonlinear dynamic FEA model. The FEA structural model was adapted from one developed by WHC and ADVENT Engineering.[7] The basic model is documented thoroughly in the referenced report and documents by Los Alamos National Laboratory.[2] The modeling assumptions and details therefore are not described herein; only the changes that have been made to the FEA model relative to the conditions to be analyzed are described.

Figure 1-1 in Sec. 1 of the SA shows a cross-sectional view of Tank 101-SY and the installed hydrogen mitigation mixer pump. The tank structure comprises a primary steel liner, secondary steel liner, and reinforced concrete containment structure surrounding the tank. The primary liner is made of carbon steel manufactured to specification ASTM-A516 and varies in thickness from 9.53 mm (3/8 in.) in the dome section to 19.05 mm (3/4 in.) at the lower knuckle of the tank bottom. Between the primary and secondary steel liner is the annulus region, which is a 76.2-cm (30-in.) gap primarily used to ventilate the surface of the tank from the waste's internal heat generation and also used to monitor for waste leakage.

The reinforced concrete containment structure has a 24.38-m (80-ft) i.d. and is 14.33 m (47 ft) high to the dome apex, with an inside diameter of the primary liner of 22.86 m (75 ft). The dome is constructed from reinforced concrete in a semi-elliptical geometry, with the primary liner anchored to the concrete with Nelson studs.

Figure K-1 shows the "true" stress-strain relationship for the primary and secondary liner material, as well as the reinforcing bar in the tank's concrete structure. The primary and secondary liners are manufactured from carbon steel to specification ASTM-A516, Gr 65 and have a maximum tensile strength of 450 MPa (65 ksi).

Reinforcing bars are manufactured from carbon billet steel to specification ASTM-A615, Gr 40 or Gr 80, depending on the location of the rebar within the tank. As noted previously, much of the information relative to the structure and analysis assumptions can be obtained from previous evaluations.[1-5,7]

Figure K-2 shows the axisymmetric FEA model of Tank 101-SY depicting certain locations that are of critical interest in the analysis. Soil masses above the dome and soil springs simulating the lateral earth pressure on the concrete side wall are not shown in the figure for the purpose of clarity.

The analysis for the accidental burn assumes that the gas release volume is constant. Two burn cases are studied herein in bounding the structural capacity of the tank. GRE volumes of 261.4 m^3 (9230 ft^3) and 245 m^3 (8650 ft^3) are analyzed and summarized in Table K-1.

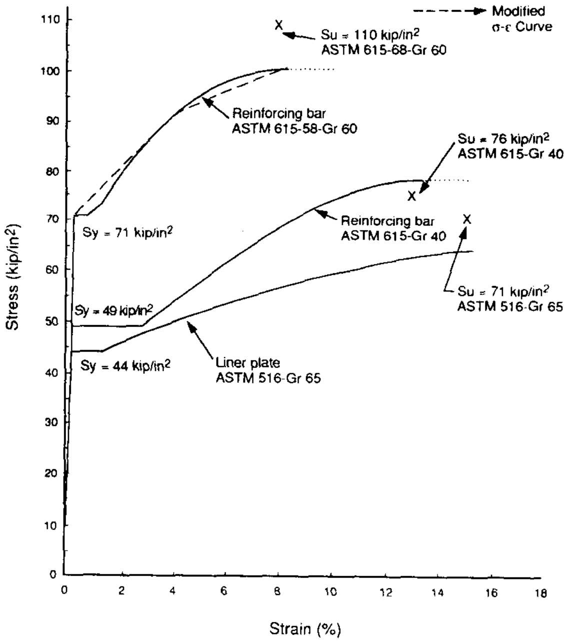

Fig. K-1. Stress-strain curves for steel liner and rebar.

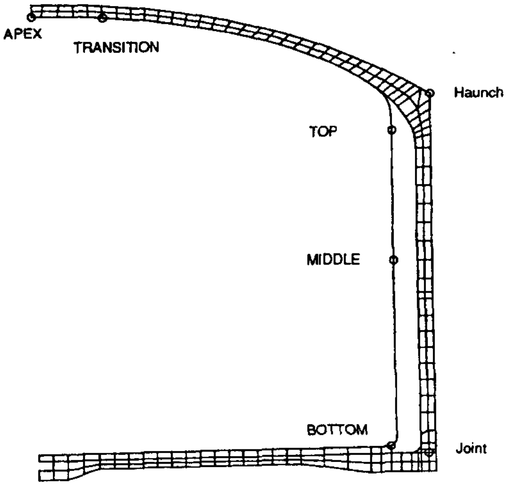

Fig. K-2. Locations on the tank.

TABLE K-1
WASTE LEVEL AND PEAK PRESSURE FOR BURN TRANSIENTS

Case	Gas Volume (ft^3)	Waste Level (in.)	Maximum Pressure (psia)	Maximum Pressure (bar)	Pressure Rate (psia/s)
1	9230	398	60.0	4.14	325.
2	8650	398	58.1	4.01	312.

The MPR is assumed to be venting a capacity equal to 66% of a fully open 1.07-m (42-in.)-diam riser. That is, the MPR has a full complement of equipment installed, thus allowing only a 66% vent flow through the doors. The MPR vent doors open at 41.4 kPa (6.0 psig) and take 100 ms to open fully. We assume that the ventilation fans are inoperable during the full transient.

Both of these GRE burn cases assume a conservative estimate of gas composition and burn rate, as specified in App. D of this SA. Furthermore, the burn is initiated with a spark ignition at the dome apex.

A major change in the modeling of this tank was to increase the soil depth to a 2.13-m (7-ft) minimum above the dome apex, corresponding to the latest figures from the OSD. Also, the soil density was increased from 1760 to 1920 kg/m^3 (110 to 120 lb/ft^3), corresponding to the latest WHC data. These two modifications increased the overall soil mass above the dome from the original 3.06 x 10^6 to 3.44 x 10^6 kg (6.75 x 10^6 to 7.58 x 10^6 lbm). If we include the additional concrete structures (such as the pump pit, cover block, and MPR concrete pad) and the mixer pump weight, the overall mass above the dome is ~3.50 x 10^6 kg (7.72 x 10^6 lbm).

As will be seen later in the summary results, the 261.4-m^3 (9230-ft^3) GRE volume burn did not satisfy the structural acceptance criteria because excessive dome velocities resulted in potential reimpact of soil and consequent collapse of the dome.

4.0. BASIS FOR STRUCTURAL ACCEPTANCE CRITERIA

The technical purpose of the structural acceptance criteria is to maintain confinement of the high-level radioactive waste within the primary liner and prevent uncontrolled releases of tank contents to the environment. Modifications to the acceptance criteria are adopted primarily from the ASME's Boiler and Pressure Vessel Code, Secs. III and XI.[8–9] The area of major concern with the original acceptance criteria is the definition (or lack of definition) of gross structural deformations.

4.1. Maximum Strain

The maximum (or ultimate) tensile strain of 27% for the steel liners is based on uniaxial test specimens. However, the effects of biaxiality must be considered, as well as any localized or global strain-concentrating effects. Biaxiality effects reduce ductility of a material but may be addressed as increasing the far-field global strains. Thus, biaxiality is akin to a strain concentration:

$$\varepsilon_{peak} = \beta K_{\varepsilon} \varepsilon_{global} \ ,$$

where

β = biaxiality factor;
= 2.0 (sphere; $\sigma_1 = \sigma_2$);
= $\sqrt{3}$ (cylinder; $\sigma_1 = 2\sigma_2$);
= 1.0 (uniaxial);

K_{ε} = strain concentration factor, and
ε_{global} = far-field global strain.

For the steel liner in the dome region and the tank cylinder portion, the peak strains would be:

$$\varepsilon_{peak} = 2.0 K_{\varepsilon} \varepsilon_{global}$$

and

$$\varepsilon_{peak} = 1.73 K_{\varepsilon} \varepsilon_{global} \ .$$

The strain concentration in the dome's primary liner thickness transition region, where a 10.16-cm (4-in.) riser penetrates the primary liner, is a function of the far-field strain. Work performed by WHC[7] and ADVENT Engineering[10] shows similar strain concentrations for this region. Based on these two documents, the maximum strain concentration in the transition region with the penetration is between 10.0 and 13.0. Thus, using the upper-bound value and limiting the peak uniaxial strain to 27%, we determined that the far-field global strain from the finite-element model analysis should be <~1.0% to prevent tank failure.

4.2. Gross Deformations

Gross or local deformations (or discontinuities) occur in regions where the stress gradient is nonlinear. These are regions (although the far-field stress may be in the elastic range) where peak stresses in the discontinuous region may be several times the yield strength of the material, thus creating a plastic zone. The fundamental shell theory[11] shows that discontinuity (or local) stresses tend to attenuate over a characteristic length of shell that approaches a value of ~3.0, as shown in Fig. K-3. The functions that define the bending of the shell (moment ϕ, deflection φ, and slope θ) are plotted vs the characteristic length λx. These quantities approach zero as λx becomes large. These functions are related to the shell-bending characteristics as:

displacement: $w = -\frac{1}{2\lambda^3 D}[f(\varphi)]$,

rotation: $\frac{dw}{dx} = \frac{1}{2\lambda^2 D}[f(\theta)]$, and

moment: $\frac{d^2 w}{dx^2} = -\frac{1}{2\lambda D}[f(\phi)]$.

Figure K-3 indicates that the bending produced in the shell is of a local nature because it tends to attenuate to near zero at:

$$\lambda x \approx 3.0.$$

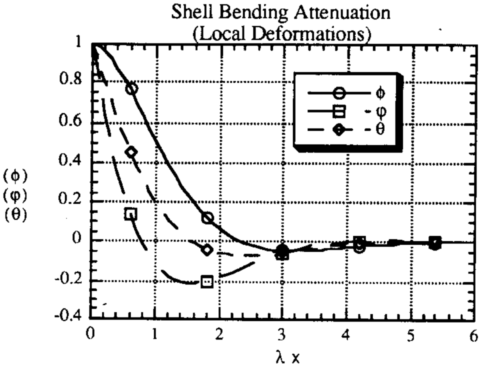

Fig. K-3. Stress attenuation in local shell bending.

The characteristic attenuation factor λ for a cylindrical or spherical shell is:

$$\lambda = \sqrt[4]{\frac{3\left(1-\nu^2\right)}{R^2 t^2}} \quad ,$$

where

ν = Poisson's ratio,
R = radius of the shell,
t = thickness of the shell, and
x = length of the shell required to attenuate stresses.

Solving for the length of shell where discontinuity stresses attenuate out:

$$x \approx \frac{3.0}{\lambda} \quad ,$$

and

$$x \approx 2.33\sqrt{Rt} \quad .$$

For simplicity, we use:

$$x \approx 2.5\sqrt{Rt} \ .$$

From the above derivation for the attenuation length of discontinuity stresses, the limit at which we may consider local or gross deformation is a length of $x \approx 2.5\sqrt{Rt}$ in either planar direction on the shell.

4.3. Gross Discontinuities

Discontinuities in a pressure vessel that are through-thickness imply that the complete circumference of the vessel is plastic across the full thickness. The through-thickness terminology here implies that the model has a full finite depth. Therefore, a gross-type failure could occur from this condition because of large plasticity. As an analogy, consider a cantilever beam with an applied end-load. The cross section at the fixed end of the beam is subjected to a bending moment, thus developing a linear stress gradient. As the load increases, the outer-fiber stress increases past the yield strength and a larger through-thickness section gradually is taken into the plastic range. When the complete cross section is fully plastic, the deformations can be quite large, and gross failure can occur. It should also be noted, however, that the computer model includes the physical characteristic for the primary and secondary liner material's strain-hardening capability. As such, although the complete through-thickness section may be have yielded under the applied loads, or is plastically deformed, the load carrying capability of the structure has potentially increased.

4.4. Local Discontinuities

Discontinuities that do not penetrate through the complete thickness of the material are considered local because the deformations induced are very small and of no consequence to the overall behavior of the structure. Furthermore, if the plastic region does not penetrate through the thickness, the structure will behave as linearly elastic. Thus, a similar analogy of the above cantilever beam with minimal plasticity through its thickness would show that deformations are quite small.

4.5. Intent of Criteria for Limiting Gross Deformations

If we limit gross structural deformations in the tank's steel liner, excessive plasticity throughout large portions of the structure is prevented. That is, gross deformation or discontinuities imply that gross plasticity is occurring over a large region of the tank structure. Therefore, significant overall degradation of the elastic behavior of the tank is expected. This condition obviously would render all current structural analyses invalid, including the burn analysis.

For example, assume that a pump drop on the dome causes a large region of the tank's dome structure to deform grossly without creating a breach. Because the region in question is not localized, we assume that the overall structure will no longer behave elastically. The behavior of the tank, as analyzed under a beyond-design-basis burn event, no longer is valid to predict the correct response because the structural conditions have changed.

Localized deformations or discontinuities are allowed because stresses and strains will redistribute from the localized plastic zones to elastic regions. These localized regions have no significant effect on the overall behavior of the tank structure and therefore are of no concern.

4.6. Extension of Criteria

The philosophy in applying the above criteria to specific locations on the dome must be examined. For example, assume that a 10.16-cm (4-in.)-diam riser has been deformed grossly from an accidentally dropped load, thus implying that the riser-to-liner weld also may be deformed. Given the above descriptions of gross deformations, we cannot allow this condition to occur. However, our concern is whether the gross deformation of a 10.16-cm (4-in.)-diam riser now will have an adverse effect on the overall behavior of the tank dome.

Because the overall state of the tank dome is unaffected by the localized deformation of a 10.16 cm (4-in.)-diam riser, the tank (or dome) behavior would be well predicted by elastic methods. We therefore conclude that gross deformations must be viewed from the overall effect on the tank and dome behavior.

4.7. Steel Liner Tears (Cracks)

We impose limits on steel liner tears (or crack length) to allow for the existence of a crack without the possibility of unstable propagation under load. That is, the basic assumption is to prevent unstable crack growth and subsequent failure of the dome liner under a postulated burn event, given a certain crack size. If we assume that a flaw exists in the dome liner and that membrane stresses are at the elastic limit (yield) during a burn event, then a certain crack size exists that will not propagate in an unstable manner based on the materials' fracture toughness. Using the ASME Boiler and Pressure Vessel Code[8–9] for lower-bound fracture toughness and based on the operating temperature of the material, we derived the critical flaw size under plane strain conditions.

4.8. Flaw Size

From App. G, Sec. III (or Sec. XI) of the ASME Code,[8–9] the following lower-bound reference stress intensity factor K_{IR} (fracture toughness) at the operating temperature of the material (dome temperature) is recommended for ferritic steels with yield strengths <345 MPa (50 ksi):

$$K_{IR} = 26.78 + 1.223\exp\left[0.0145(T - RT_{NDT} + 160)\right] \quad .$$

This curve is based on the lower bound of static, dynamic, and crack-arrest critical K_I values measured as a function of temperature. The reference temperature at the nil-ductility transition region is not known for the primary liner material (the ASTM's material specification is A516-GR 65) but is expected to be ~-73°C (-100°F); therefore, we assume that RT_{NDT} is -18°C (0°F), which should be conservative. The design-operating dome temperature for 241-SY tanks is ~93°C (200°F), but we conservatively assume 66°C (150°F) for the following calculations. Based on this criteria, the lower-bound fracture toughness is:

$$K_{IR} = 136 ksi\sqrt{in} \ .$$

If we assume a through-wall flaw in an infinite plate with a far-field stress σ, as shown in Fig. K-4, the following stress intensity factor is derived:[12]

$$K_I = C\sigma\sqrt{\pi a} \ ,$$

where

K_I = stress intensity factor, $ksi\sqrt{in}$,
C = crack geometry constant
≈ 1.00 (Ref. 12),
σ = far-field stress, ksi
≈ 35 ksi (min. yield strength), and
a = flaw half-length, in.

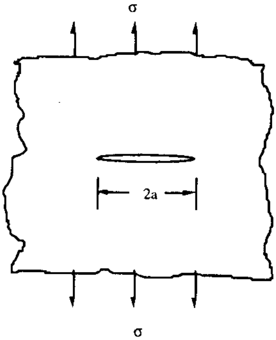

Fig. K-4. Centrally cracked panel.

Solving for the flaw half-length:

$a = 4.8$ in.

Thus, the total flaw length is twice the above value (or $2a$), or 24.4 cm (9.6 in.) Because the operating temperature actually is 93°C (200°F) [rather than the conservative 66°C (150°F)], for simplicity we assume that the critical flaw size is 25.4 cm (10 in.).

5.0. ANALYSIS RESULTS

The results of the structural analyses show that the 261.4-m^3 (9230-ft^3) GRE burn model does not satisfy the structural acceptance criteria. Although the tank suffers from extensive concrete cracking in the dome and the liner strains during the transient are below the allowable peak strains, the maximum dome apex velocity far exceeds the limit to prevent dome collapse from soil reimpaction. The peak pressure attained during this transient is 414 kPa (60.0 psia) at 2.24 MPa/s (325 psia/s). The maximum dome velocity was shown to be ~1.65 m/s (65 in./s), which (as stated previously) exceeds the limiting value.

After soil reimpaction on the dome structure, the actual peak strains developed exceed the failure criteria. A typical deformed shape plot of the tank structure under a burn transient is shown in Fig. K-5.

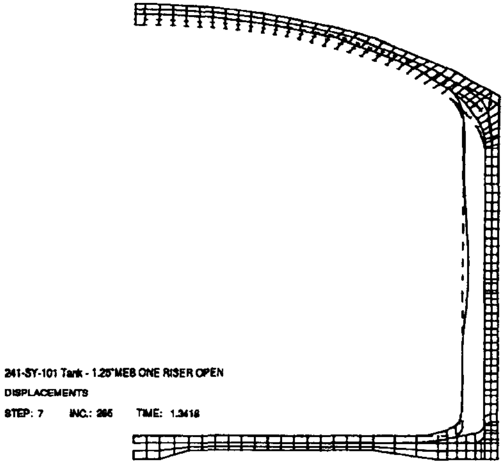

Fig. K-5. Deformed shape of the tank.

A summary of the Tank 101-SY shell and dome primary steel liner stresses and the peak plastic strains for both burn cases are shown in Table K-2. Stresses and strains are well below the bounding structural case of a 371-m^3 (13,100-ft^3) GRE burn documented by LANL for a waste surface burn.[3]

The 245-m^3 (8650-ft^3) GRE burn analysis showed acceptable primary and secondary liner strains and a dome velocity below the allowable limit during the transient.

The maximum strain in the dome is in the vicinity of the thickness transition from the 9.53- to 12.7-mm (3/8- to 1/2-in.)-thick plate. Also in this region is a 10.16-cm (4-in.)-diam riser that tends to increase the strain concentration around the riser/thickness transition. The strain concentration factor in this region has been documented[7,10] to be a maximum of 13.0 (see Sec. 4.0 of this appendix). Therefore, the maximum strain in the dome's thickness transition for the 261.4-m^3 (9230-ft^3) GRE, which is the critical value, is:

$$\varepsilon_{peak} = \beta K_{\varepsilon} \varepsilon_{global}$$

β = biaxiality factor;
K_{ε} = strain concentration factor, and
ε_{global} = far-field global strain.

$\varepsilon_{peak} = 0.150$ in./in. or 15.0% <27% allowable

The total strain also includes a biaxiality factor of 2.0 to the dome to account for ductility reduction based on a biaxial vs uniaxial test specimen. In the main shell of the tank, the strains are somewhat higher, specifically in the vicinity of the lower knuckle. However, the lower-knuckle region does not have the large strain

TABLE K-2
MAXIMUM STRESSES AND STRAINS IN TANK LINER AND REBAR[a]

Case	Waste Level (in.)	Dome Liner Stress (ksi)	Dome Liner Strain (%)	Max. Rebar Stress (ksi)	Max. Shell Stress (ksi)	Max. Shell Strain (%)
1	398	46.2	0.58	65.9	53.9	1.70
2	398	50.0	0.58	71.3	53.3	1.51

[a] Locations of maximum stresses and strains for each case are different. Therefore, there is no correlation between a dome liner strain location for the 245- and 261.4-m^3 (8650- and 9230-ft^3) GREs.

concentration factors. In this vicinity, the biaxiality factor is 1.73, with a strain concentration factor of 1.0.[2] Thus, the maximum peak strain is:

$$\varepsilon_{peak} = 0.029 \text{ in./in.} \qquad \text{or } 2.9\% < 27\% \text{ allowable}$$

The 245-m^3 (8650-ft^3) GRE analysis shows extensive concrete cracking and rebar yielding throughout the tank dome structure. Nevertheless, the stresses and peak strains are well below those for the 261.4-m^3 (9230-ft^3) GRE and therefore are adequate by comparison. Table K-3 provides a listing of the maximum dome apex displacements and velocities for the two cases studied.

Results for the 261.4-m^3 (9230-ft^3) GRE show that the peak dome apex velocity exceeds the overall limiting value of 1.38 m/s (54.5 in./s) to prevent dome collapse from soil reimpaction. The limiting value is estimated as the "average" dome velocity that will cause complete soil separation and subsequent failure from soil reimpact, based on limiting the kinetic energy at impact to the strain energy of the hoop rebar in the haunch region. The mass of the soil, pump pit, cover block, MPR concrete pad, and pump compose a total of 3.5×10^6 kg (7.72×10^6-lbm) distributed over a 24.4-m (80-ft)-diam area. As mentioned previously, the overall mass above the dome has increased because of additional soil/gravel deposited in 1994, as well as from a better estimate of the pump pit and pump mass.

Case 1 shows a maximum dome apex velocity of 1.65 m/s (65.0 in./s), which is greater than the limiting dome velocity of 1.38 m/s (54.5 in./s) to preclude soil separation and reimpaction on the dome that could cause a collapse. The additional liner strains, caused by soil reimpaction on the dome, exceed the limiting value of 27.0% in the thickness transition (accounting for strain concentrations). As such, the 261.4-m^3 (9230-ft^3) GRE with burn does not satisfy the structural acceptance criteria set forth.

Case 2 shows slightly lower dome displacements and peak dome apex velocity. We therefore concluded that, based on the stress and strain resultants and the dome velocity attained during the transient, the 245-m^3 (8650-ft^3) GRE is the upper-bound gas release volume for Tank 101-SY to prevent structural failure.

TABLE K-3
MAXIMUM DISPLACEMENTS AND VELOCITIES AT THE DOME

Case	Waste Level (in.)	GRE Volume (ft^3)	Maximum Apex Displacement (in.)	Maximum Apex Velocity (in./s)
1	398	9230	14.5	65.0
2	398	8650	12.0	50.0

Summary Results for the 245-m^3 (8650-ft^3) GRE

Figures K-6 and K-7 show the pressure-time history for the 245-m^3 (8650-ft^3) GRE burn event. Figure K-8 shows the pressure reduction effect of volume expansion. Figures K-9 through K-13 show the transient response parameters for the dome and other locations within the tank structure.

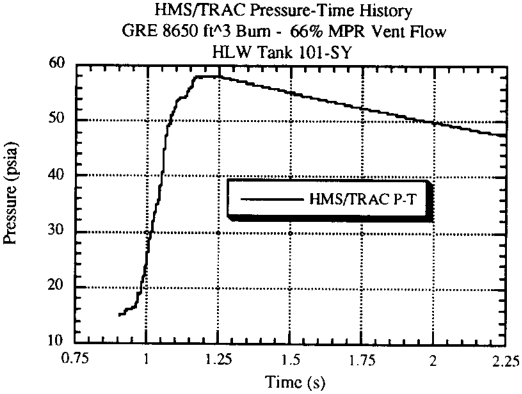

Fig. K-6. Pressure-time history.

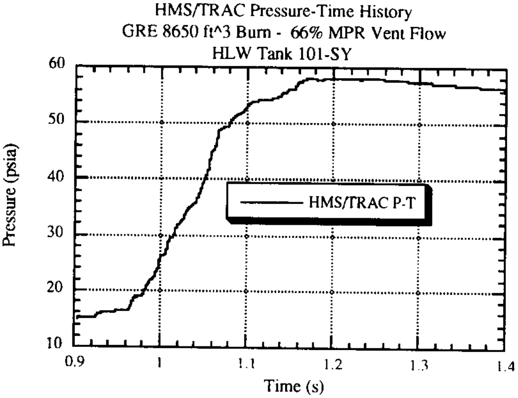

Fig. K-7. Pressure-time history (zoom).

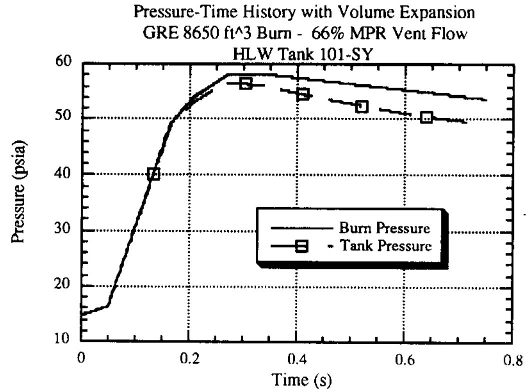

Fig. K-8. Pressure-time history with volume expansion effect.

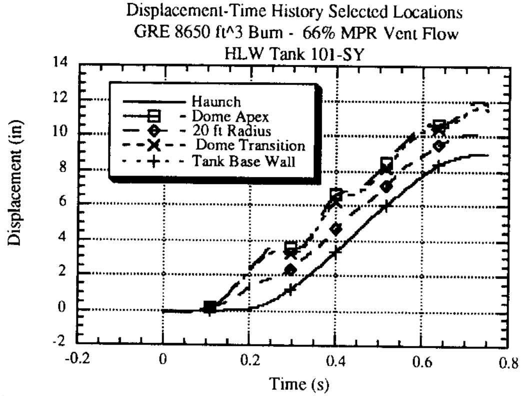

Fig. K-9. Displacement-time history for selected tank locations.

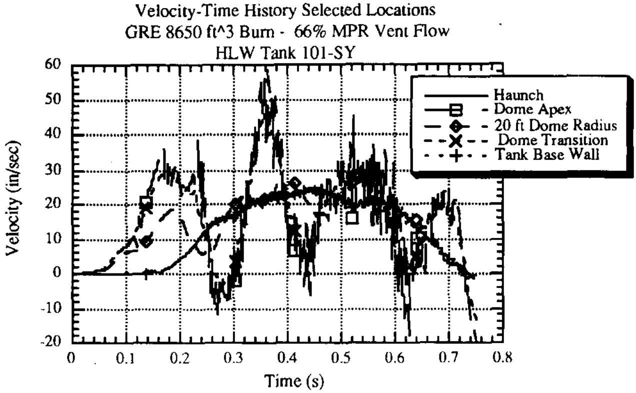

Fig. K-10. Velocity-time history for selected tank locations.

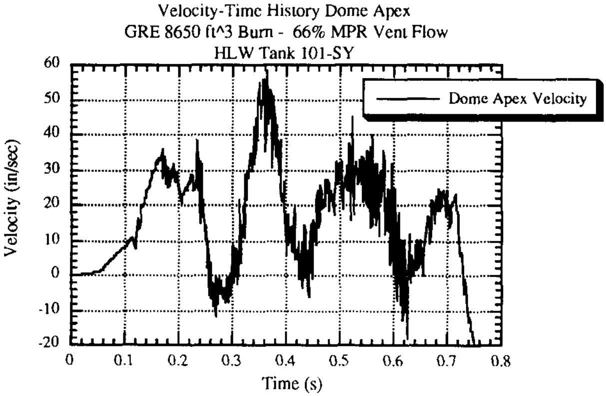

Fig. K-11. Velocity-time history dome apex.

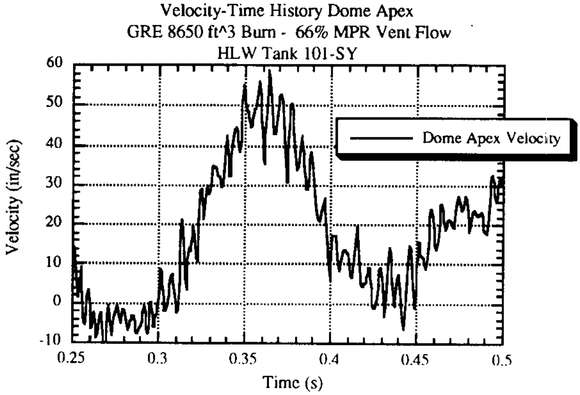

Fig. K-12. Velocity-time history dome apex (zoom).

The high-frequency vibrations shown in the zoom plot above are representative of a dome apex excitation. Fundamental frequencies of attached dome structure may be excited during the transient and exhibit this type of behavior.

Figure K-14 shows a typical displaced shape plot of the tank structure at the maximum pressure during the burn transient.

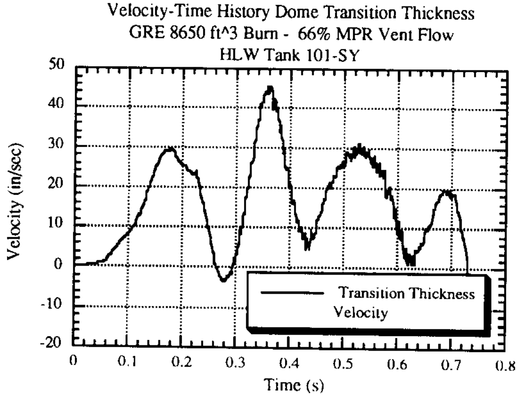

Fig. K-13. Velocity-time history dome thickness transition.

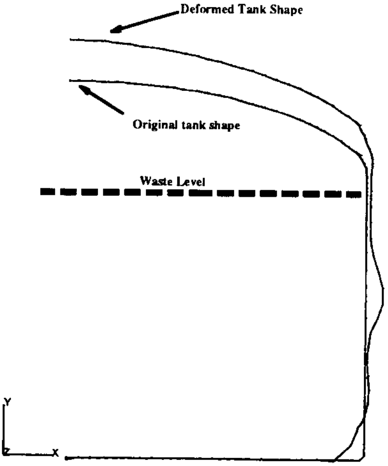

Fig. K-14. Deformed shape of tank at maximum pressure.

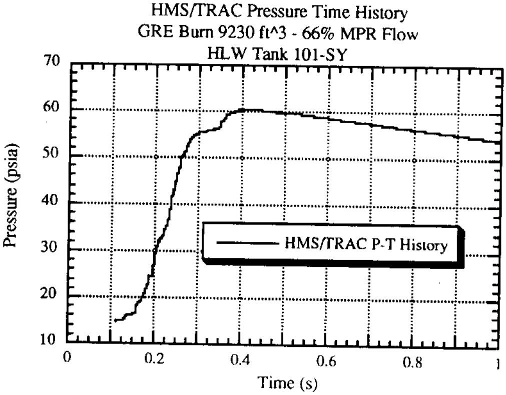

Fig. K-15. Pressure-time history.

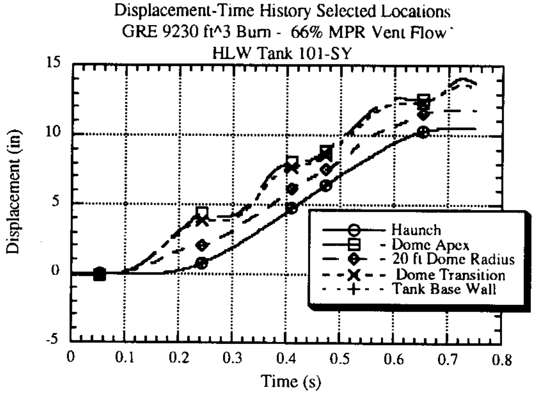

Fig. K-16. Displacement-time history of selected locations on tank.

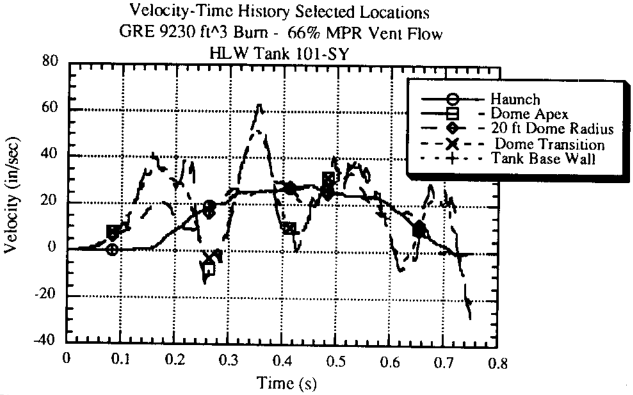

Fig. K-17. Velocity-time history of selected locations on tank.

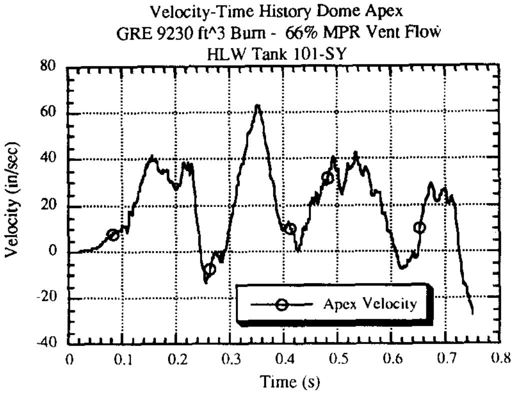

Fig. K-18. Dome apex velocity-time history.

Summary Results for the 261.4-m^3 (9230-ft^3) GRE

This attachment provides all transient response data for the tank based on the 261.4-m^3 (9230-ft^3) GRE burn. The pressure-time history was developed from the burn kinetics model in HMS/TRAC.

Figure K-15 shows the pressure-time history for the 261.4-m^3 (9230-ft^3) GRE burn. Figures K-16 and K-17 show the displacement and velocity time histories, respectively, for several locations within the tank structure. Figure K-18 shows the transient velocity response for the dome apex depicting the maximum velocity at 1.65 m/s (65.0 in./s).

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12. J. M. Barsom and S. T. Rolfe, "Fracture and Fatigue Control in Structures," 2nd ed. (Prentice-Hall Publishing Co., Englewood Cliffs, New Jersey, 1987).

5.0. CONSEQUENCES OF ACCIDENTS

This section discusses the consequences of accidents developed in Sec. 5. As mentioned in Sec. 6, we limit the intrusive waste level to 10.26 m (404 in.) during voidmeter operations. The conservative estimate for the maximum expected gas release at this level is 159.4 m^3 (5630 ft^3) (see Mixer Pump SA, App. C). In this section, we compare the radiological and toxicological consequences of a 245-m^3 (8650-ft^3) gas release. This approach adds more conservatism to our current analysis and allows us to operate the voidmeter at higher waste levels if necessary. The radiological and toxicological consequences of a 245-m^3 (8650-ft^3) release are analyzed in App. D of the Mixer Pump SA and bound the radiological consequences of voidmeter operations.

The radiological consequences of a GRE without a burn are small in comparison to consequences of a burn accident. When the ventilation is operable, the initial peak fuel concentration in the dome before the burn is slightly less as compared to the inoperable ventilation case. However, the differences are very small and are within the uncertainty range of the computations. Consequently, we evaluate only the consequences for the ventilation-inoperable case, which is slightly more conservative than the ventilation-operable case. The radiological consequences associated with the releases were computed using the methodology described in App. G of the Mixer Pump SA.

For toxicological consequences, we are concerned only with ammonia, which burns during the burn phase. Thus, the consequences are evaluated only during the gas release phase (without burn). As discussed in Sec. 5 of the Mixer Pump SA, the analysis showed that the peak ammonia release rate is insensitive to small changes in the available riser area. The toxicological consequences for voidmeter operations are computed using the methodology described in App. G of the Mixer Pump SA. Using the peak ammonia release rates given at a gas release 245 m^3 (8650 ft^3) and using the ammonia exposure factors given in App. G of the Mixer Pump SA, we calculated the peak ammonia concentrations in various locations.

The structural consequences of a GRE and burn with a gas release of 159.4 m^3 (5630 ft^3) are not of concern because structural damage exceeding the acceptance criteria is expected only if the GRE size exceeds 245 m^3 (8650 ft^3) (App. K of the Mixer Pump SA). The structural failure acceptance criteria are the same in this section as in Sec. 5 of the Mixer Pump SA.

The analyses presented in this section demonstrate that there are no credible accident sequences where the consequences exceed the acceptance criteria established in the Mixer Pump SA.

5.1. Summary of Accident Consequences

The consequences of accidents identified in Sec. 4 of this addendum are summarized in Table Add.2.5-1a for radiological effects and in Add.2.5-1b for toxicological effects. Consequences are presented by accident sequence and the phase of voidmeter

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operation. GRE-only conditions, i.e., no burn, may have an additional release quantity because of waste inside the voidmeter that may be entrained, depending on whether waste on the mast or sampler arm can be entrained.

The radiological and toxicological consequences given in Tables Add.2.5-1a and Add.2.5-1b are computed for a gas release of 245 m^3 (8650 ft^3) that can occur at a waste level of 10.26 m (404 in.). The gas release of 245 m^3 (8650 ft^3) is considered to occur in a GRE-burn accident for all phases of voidmeter operations. The burn calculation considered a bottom-up burn of the waste gases, which has been observed to produce the greatest radiological releases and ammonia release rates. The radiological consequences are maximum for this scenario. Toxicological consequences occur during a GRE without a burn.

Figure Add.2.5-1 shows the calculated offsite dose limits for voidmeter operations with the acceptance limits. The calculated offsite doses for the voidmeter operations are well below the guidelines of WHC and therefore are acceptable.

The calculated onsite doses (SY Farm) are shown in Fig. Add.2.5-2 for voidmeter operations with acceptance limits. As shown in this figure, the calculated doses are below the acceptance guidelines.

Appendix G of the Mixer Pump SA describes how to calculate the organ doses. We multiply the onsite radiological doses by a factor of 15. The calculated organ doses are compared to an onsite limit 10 times higher than the acceptance criteria shown in Fig. Add.2.5-2. The results of this comparison are given in Fig. Add.2.5-3 and indicate that all consequences are below the guidelines and therefore are acceptable.

The offsite toxicological consequences at 13.8 km essentially are zero (<1 ppm). The onsite toxicological consequences are shown in Fig. Add.2.5-4, where the toxicological consequences are less than the guidelines. In this figure, we plot only the maximum ammonia release of 45.5 ppm at the SY Farm with various frequencies. The accident sequences listed in Table Add.2.5-1b consider various scenarios for voidmeter spill. As mentioned previously, this spill is not expected to result in an additional ammonia release because the release mass inside the voidmeter is very small. The basis for this assumption is as follows. The maximum possible amount of material released as a result of a spill in the voidmeter, 65 kg (143.3 lbm), is small in comparison to the spill of 916 kg (2019 lbm) considered in the Mixer Pump SA.

A simple scaling based on spill mass indicates that almost no additional practical toxicological consequences can occur from the voidmeter spill. Thus, the maximum ammonia release during voidmeter operation can be only as a result of a GRE-burn accident. We listed the accident sequences in Table Add.2.5-1b for completeness. Only sequences involving a release of tank gases, such as a GRE or a GRE and burn, result in toxicological consequences.

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TABLE ADD.2.5-1a
RADIOLOGICAL CONSEQUENCES OF ACCIDENT SEQUENCES

Radiological Dose EDE for Accident Sequences during Voidmeter Installation							
		Radiological EDE (rem)					
Accident Sequence	**Frequency[c] (1/yr)**	**SY Farm**	**242-S Evaporator**	**U Plant**	**Hwy. 240**	**Max. Offsite[a]**	**Max. Offsite[b]**
Open 10.16-cm (4-in.) riser—GRE and no burn—any size	0.018	3.62E-1	7.29E-2	1.50E-2	1.17E-3	1.74E-4	5.75E-3
Open 10.16-cm (4-in.) riser—GRE and burn	2.34E-5	11.25	2.27	4.55E-1	3.33E-2	4.96E-3	1.64E-1
Unfiltered release from open 10.16-cm (4-in.) riser	2.4E-2	4.675E-1	9.418E-2	1.904E-2	1.520E-3	2.261E-4	7.480E-3
Radiological Dose EDE for Accident Sequences during Voidmeter Operation							
		Radiological EDE (rem)					
Open 10.16-cm (4-in.) riser—GRE and 1% voidmeter release (6.5 g (1.43E-2 lbm)—any size	1.8E-5	3.78E-1	7.62E-2	1.56E-2	1.21E-3	1.81E-4	5.98E-3
Open 10.16-cm (4-in.) riser—GRE and burn and 10% voidmeter release [65 g (0.143 lbm)]	2.34E-8	11.43	2.3	4.62E-1	3.38E-2	5.04E-3	1.67E-1
Radiological Dose EDE for Accident Sequences during Voidmeter Removal							
		Radiological EDE (rem)					
Open 10.16-cm (4-in.) riser—GRE and no burn	0.018	3.62E-1	7.29E-2	1.50E-2	1.17E-3	1.74E-4	5.75E-3
Open 10.16-cm (4-in.) riser—GRE and burn	2.34E-5	11.25	2.27	4.55E-1	3.33E-2	4.96E-3	1.64E-1
Release from physical damage to tank HEPA filter system[0.36 kg (0.794 lbm)]	1.60E-3	9.90E-1	1.99E-1	4.0E-2	2.87E-3	4.28E-4	1.42E-2
Release caused by sudden expansion of pressurized waste in the sampler [0.131 kg (0.289 lbm)]	3.0E-3	3.60E-1	7.26E-2	1.45E-2	1.05E-3	1.56E-4	5.16E-3
Voidmeter drop with release of 10% of 0.65 kg (1.43 lbm) waste film	1.6E-6	1.79E-1	3.60E-2	7.22E-3	5.19E-4	7.74E-5	2.56E-4

[a] Acute dose.

[b] 50-yr dose.

[c] The magnitude of these estimated frequencies are unimportant because they fall below the range of the WHC guidelines.

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TABLE ADD.2.5-1b
TOXICOLOGICAL CONSEQUENCES OF ACCIDENT SEQUENCES

Ammonia Exposures for Accident Sequences during Voidmeter Installation					
		Toxicological (ppm)			
Accident Sequence	**Frequency[a] (1/yr)**	**SY Farm**	**242-S Evap.**	**U Plant**	**Hwy. 240**
Open 10.16-cm (4-in.) riser—GRE and no burn	0.018	45.51	35.44	13.72	1.44
Open 10.16-cm (4-in.)riser—GRE and burn	2.34E-5	45.51	35.44	13.72	1.44
Unfiltered release from open 4-in. riser	2.4E-2	——	——	——	——
Ammonia Exposures for Accident Sequences during Voidmeter Operation					
		Toxicological (ppm)			
Open 10.16-cm (4-in.) riser— GRE and 1% voidmeter release	1.8E-5	45.51	35.44	13.72	1.44
Open 10.16-cm (4-in.) riser—burn and 10% voidmeter release	2.34E-8	45.51	35.44	13.72	1.44
Ammonia Exposures for Accident Sequences during Voidmeter Removal					
		Toxicological (ppm)			
Open 10.16-cm (4-in.) riser—GRE and no burn	0.018	45.51	35.44	13.72	1.44
Open 10.16-cm (4-in.) riser—GRE and burn	2.34E-5	45.51	35.44	13.72	1.44
Release from physical damage to tank HEPA filter system		——	——	——	——
Release from a sudden expansion of pressurized waste in the sampler		——	——	——	——
Release caused by voidmeter drop		——	——	——	——

[a] The magnitude of these estimated frequencies is unimportant because they fall below the range of the WHC guidelines.

In summary, the radiological and toxicological consequences for accidents postulated for voidmeter operations (Tables Add.2.5-1a and Add.2.5-1b) are within the WHC guidelines. In the following sections, we discuss the consequences of each accident in detail.

5.2. Accident Sequences during Voidmeter Installation

This section presents the consequences of the accidents postulated to occur during installation of the voidmeter. The material release conditions governing the evaluation of radiological and toxicological consequences in this assessment are presented below.

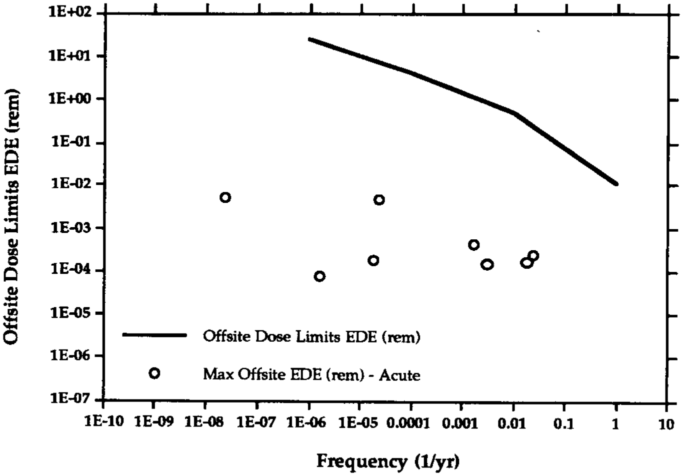

Fig. Add.2.5-1. Offsite radiological dose consequences.

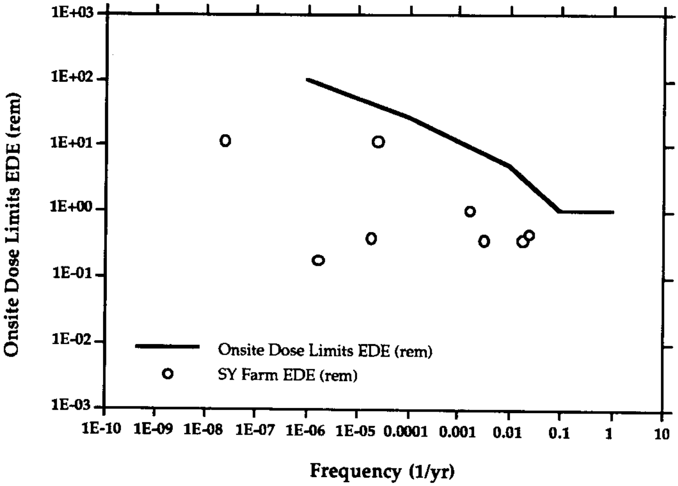

Fig. Add.2.5-2. Onsite radiological dose consequences.

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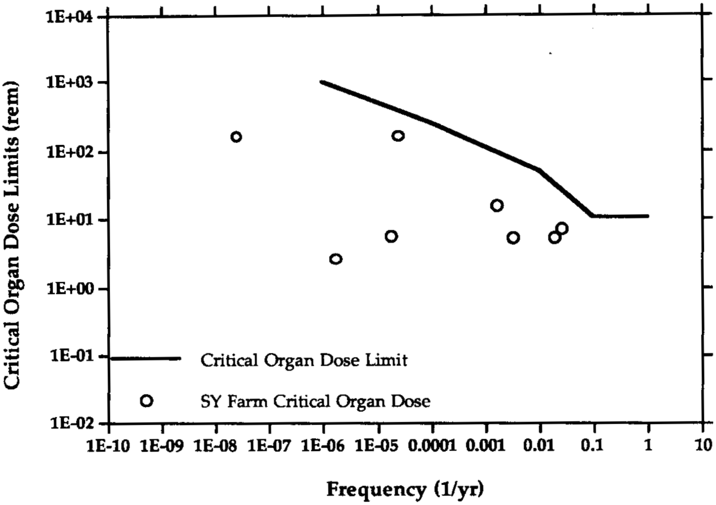

Fig. Add.2.5-3. Critical organ radiological dose consequences.

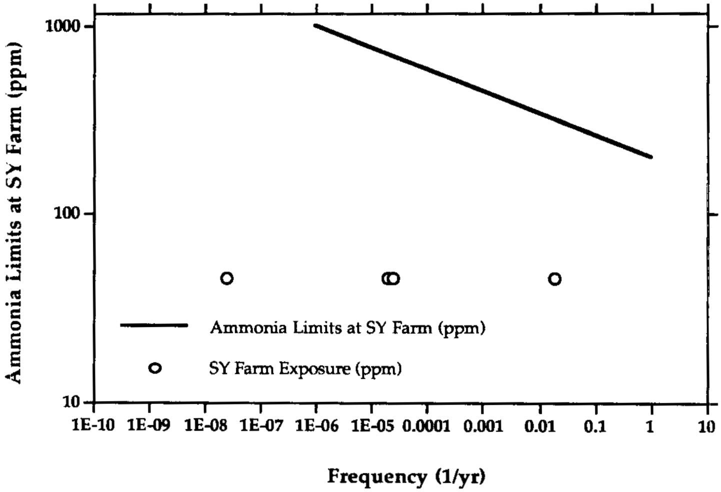

Fig. Add.2.5-4. Toxicological consequences.

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5.2.1. Flammable and Toxic Gas Releases—4-in.-diam Riser Open

During installation of the voidmeter assembly, we assumed that the 10.16-cm (4-in.) riser is completely open to the atmosphere. The consequences of a GRE and burn under a variety of conditions have been evaluated in Sec. 5 of the SA for the 10.7-mm (42-in.) riser. Controls in Sec. 6 of the Mixer Pump SA require that the waste level be limited to ≤10.26 m (404 in.) during voidmeter operations. This level corresponds to a maximum expected gas release of 159.4 m^3 (5630 ft^3) (using the conservative gas release-waste level relation given in App. C of the Mixer Pump SA). To be conservative on the radiological releases, we performed HMS/TRAC calculations for a GRE-burn scenario at a limiting gas release of 8650 ft^3 to estimate the released material. All GRE and burn radiological consequences include the addition of a 0.36-kg (0.794-lbm) ground release caused by tank filter system failure, as discussed in Sec. 5 of the Mixer Pump SA.

The radiological and toxicological consequences were computed using the methodology described in App. G of the Mixer Pump SA and are summarized in Tables Add.2.5-3 and Add.2.5-4, respectively.

The intrusive waste level of the tank for voidmeter installation is 10.26 m (404 in.), as specified in Sec. 6 of the Mixer Pump SA. To assess the radiological consequences of a GRE and burn, we performed an HMS/TRAC calculation with bottom-up burn. The ground and stack releases calculated are 3.417 kg (7.53 lbm) and 0.313 kg (0.69 lbm), respectively.

TABLE ADD.2.5-2
THERMAL-HYDRAULIC RESULTS FOR THE FLAMMABLE OR TOXIC GAS RELEASES DURING VOIDMETER INSTALLATION AND REMOVAL

Accident Sequence	Peak Pressure during Injection (psia)	Peak Pressure during Burn (psia)	Ammonia Released (g/s) Ground Release	Ammonia Released (g/s) Stack Release	Radiological Release (kg) Ground Release	Radiological Release (kg) Stack Release
GRE with 8650-ft^3 release, no burn	14.87	—	7.85	4.2	-	0.131
GRE with 8650-ft^3 release, burn	14.87	58.8	7.85	4.2	3.417	0.313

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TABLE ADD.2.5-3
RADIOLOGICAL DOSE EDE (rem) FOR THE FLAMMABLE OR TOXIC GAS RELEASES DURING VOIDMETER INSTALLATION AND REMOVAL

Accident Sequence	SY Farm	242-S Evap.	U Plant	Hwy. 240	Max. Offsite[a]	Max. Offsite[b]
GRE with 8650-ft^3 release, no burn	3.62E-1	7.29E-2	1.50E-2	1.17E-3	1.74E-4	5.75E-3
GRE with 8650-ft^3 release, burn	11.25	2.27	4.55E-1	3.33E-2	4.96E-3	1.64E-1

[a] Acute dose.
[b] 50-yr dose.

TABLE ADD.2.5-4
AMMONIA EXPOSURES (ppm) FOR THE FLAMMABLE OR TOXIC GAS RELEASES DURING VOIDMETER INSTALLATION AND REMOVAL

Accident Sequence	SY Farm	242-S Evap.	U Plant	Hwy. 240
GRE with 8650-ft^3 release, no burn	45.51	35.44	13.72	1.44
GRE with 8650-ft^3 release, burn	45.51	35.44	13.72	1.44

The releases calculated for the voidmeter installation with an open 10.16-cm (4-in.) riser are bounded by that estimated for a GRE with a 297-m^3 (10,480-ft^3) release with an open 10.7-m (42-in.) riser in the Mixer Pump SA.

5.2.2. Unfiltered Release caused by Loss of Negative Tank Pressure

Section 4.4.1 of this addendum identified conditions under which a release through an open 10.16-cm (4-in.) riser was possible given that the pressure inside the tank dome space was greater than or as great as the atmospheric pressure. If this condition were to occur, tank gases would exit the tank through the 10.16-cm (4-in.) riser and impact the immediate area around the riser. The analyses in Sec. 5 of the SA discuss the unfiltered release through an open 10.7-m (42-in.) riser given a failed ventilation system with a release duration of 1 h.

To determine the release rate from the 10.7-m (42-in.) riser, an HMS/TRAC analysis was performed that assumed a heat generation rate of 12 kW in the waste. The calculated release rate as a result of natural circulation was found to be 0.093 m^3/s. If we assume that the natural circulation rates are not affected by the open-riser area (because the tank dome space is so large), we can scale the gas release from the 10.16-cm (4-in.) riser by the area fraction. However, this assumes that the friction losses are similar in the 10.16-cm (4-in.) and 10.7-m (42-in.) risers. The 10.16-cm (4-in.) riser is 3.35 m (11 ft)

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long; the friction losses are expected to be much higher. Thus, the actual release rate will be less than that obtained from the area scaling. Even when this effect is neglected, the release is expected to be three orders of magnitude smaller. However, the exit velocity from the riser will be the same in both cases because the release is scaled with the area fraction. Thus, a gas release from a 10.16-cm (4-in.) riser and its radiological and toxicological consequences are bounded by the gas release from the 10.7-m (42-in.) riser, as reported in Sec. 5 of the Mixer Pump SA (Table 5-7) and summarized in Table Add.2.5.1a. Gas would continue to be released until the riser was sealed. Because of the ease of covering a 10.16-cm (4-in.) riser, the open time is expected to be less than the 1 h identified in the 10.7-m (42-in.) riser analysis; therefore, the release consequences are reduced even further.

5.3. Accident Sequences during Voidmeter Operation

Two discussions related to radiological consequence assessment for voidmeter accidents during normal voidmeter operations are included. The first establishes the release contribution caused by the voidmeter for those accident conditions where the waste on the voidmeter may be released. The second considers the effect of operational restrictions placed on the allowable waste level for all voidmeter actions (as defined in the controls in Sec. 6 of the Mixer Pump SA). The information in these two discussions is used to compute the radiological consequences of the voidmeter operation accidents presented in Table Add.2.5-1a of this addendum.

When it is in upward motion, the voidmeter could entrain waste. The decontamination system will be operated as the voidmeter is raised. There are no data on the effectiveness of the decontamination system, although previous experience showed reasonably good success. Using a waste simulant with a chemical composition about the same as the waste, we performed experiments[1] to determine how much waste simulant could remain on the voidmeter surface. For these laboratory tests, we used a 3.2-mm (1/8-in.)-thick 304-SS plate and a waste simulant that chemically includes most of the waste chemicals. We inserted the plate into a constant-temperature mixed waste simulant. After the plate was pulled back into the air, we waited until no more drainage was observed. Results showed that 0.0197 g/cm^2 (2.8E-4 $lbm/in.^2$) of waste simulant remained on the plate. Although this number is not directly applicable to predict the amount of waste that could remain on the voidmeter if the decontamination system does not work properly, we believe that it represents a reasonable value for the real waste. We will use it to estimate the expected releases from the voidmeter.

5.3.1. Radiological Consequences caused by Waste on the Voidmeter

The controls will require decontamination of each 4.57-m (15-ft) segment of the voidmeter before it is raised. To estimate the waste on each 4.57-m (15-ft) segment, we need to calculate the total surface area in each segment and multiply that by the entrainment value given above. However, to make the calculation conservative, we will use the total surface area reported by WHC.[2] For this analysis, the voidmeter is assumed to have a radioactive waste inventory of 650 g (1.43 lbm) based on the surface area of the voidmeter. The waste may be released with an associated release fraction of

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either 1% for a GRE or 10% for a GRE with burn, as assumed in Sec. 4.4 of this addendum.

All voidmeter releases are ground releases; thus, the methodology of App. G of the SA for ground releases were used to calculate the EDE associated with the voidmeter portion of the release. The two combinations of voidmeter release consequences for an open 10.16-cm (4-in.) riser during voidmeter operations are presented in Tables Add.2.5-5 and Add.2.5-6 for 1% and 10% release fractions, respectively.

An HMS/TRAC simulation for a 254-m^3 (8650-ft^3) GRE predicted the amount of material at the inlet, exhaust, and MPR (see App. D of the Mixer Pump SA). We added 6.5 g (1.43E-2 lbm) for the GRE accident and 65 g (0.143 lbm) for the GRE-burn accidents to the released values predicted by HMS/TRAC to consider the additional releases by the voidmeter. The total radiological consequences for both combinations are summarized in Table Add.2.5-7.

5.3.2. Radiological Consequences for Operational Restrictions on Allowable Waste Levels

Intrusive criteria presented in App. Y of the SA, which governs open-tank and waste-intrusive operations, specify the conditions that must be satisfied. For voidmeter operations, a maximum waste level of 10.26 m (404 in.) has been chosen, which is consistent with operational needs and safety considerations. The analysis supporting the selection of a maximum waste level of 10.26 m (404 in.) is presented in this section. We will show that the radiological and toxicological consequences of a burn accident during voidmeter operations are bounded by WHC guidelines.

TABLE ADD.2.5-5
CALCULATED RADIOLOGICAL DOSE CONTRIBUTION FROM THE VOIDMETER, 6.5-g (0.0143-lbm) INVENTORY, 1% RELEASE FRACTION

Receptor Location	Distance (km)	Riser Release EDE (rem)
SY Tank Farm	0.10	1.7875E-02
242-S Evaporator	0.30 W	3.6010E-03
U Plant	0.78 NE	7.2150E-04
Hwy. 240	3.9 SE	5.1870E-05
Max. Offsite—Acute Dose	13.8 WNW	7.7350E-06
Max. Offsite—50-yr Dose	13.8 WNW	2.5610E-04

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TABLE ADD.2.5-6
CALCULATED RADIOLOGICAL DOSE CONTRIBUTION FROM THE VOIDMETER, 65-g (0.143-lbm) INVENTORY, 10% RELEASE FRACTION

Receptor Location	Distance (km)	Riser Release EDE (rem)
SY Tank Farm	0.10	1.7875E-01
242-S Evaporator	0.30 W	3.6010E-02
U Plant	0.78 NE	7.2150E-03
Hwy. 240	3.9 SE	5.1870E-04
Max. Offsite—Acute Dose	13.8 WNW	7.7350E-05
Max. Offsite—50-yr Dose	13.8 WNW	2.5610E-03

TABLE ADD.2.5-7
RADIOLOGICAL DOSE EDE (rem) FOR THE HYDROGEN OR TOXIC GAS RELEASES DURING VOIDMETER OPERATION

Accident Sequence	SY Farm	242-S Evap.	U Plant	Hwy 240	Max. Offsite[a]	Max. Offsite[b]
GRE with 245-m^3 (8650-ft^3) release and 1% voidmeter release	3.78E-1	7.62E-2	1.56E-2	1.21E-3	1.81E-4	5.98E-3
GRE with 245-m^3 (8650-ft^3) release and 10% voidmeter release	11.43	2.3	4.62E-1	3.38E-2	5.04E-3	1.67E-1

[a] Acute dose.
[b] 50-yr dose.

We first discuss the effects on the radiological consequences of voidmeter operations with respect to controls on the tank waste level for voidmeter operations. We have shown that by limiting the tank waste level for allowable voidmeter operations to ≤10.26 m (404 in.), the consequences of a gas release involving the additional waste inventory that may be on the voidmeter are bounded by the worst-case releases associated with a GRE of 297 m^3 (10480 ft^3) reported in Sec. 5 of the Mixer Pump SA.

The voidmeter mast and sampler arm may be contaminated with waste that can be entrained given a GRE or GRE and burn if the decontamination system is ineffective in removing waste. Section 4.4.2 considers the condition where a burn occurs and the voidmeter has waste that may be entrained because of a failed decontamination system. In this accident scenario, the material released to the atmosphere will be the sum of the material entrained from the voidmeter, the material released because of a burn in the dome, and the material released from the filter system as a result of burn in the dome.

Because the burn is an energetic event, we will assume that 10% of the waste accumulated on the mast and/or sampler arm will be released during this accident. Thus, for the worst possible case, we add 65 g (0.143 lbm) (10% of the maximum voidmeter inventory of 650 g (1.43 lbm) to the 3.417-kg (7.53-lbm) ground release from

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the GRE and burn, resulting in a total ground release of 3.482 kg (7.68 lbm) for open-riser conditions. The stack release quantity is a function of the GRE size only and is not affected by the additional ground release from the voidmeter. The total ground release, 3.482 kg (7.68 lbm), is less than the maximum ground releases of 3.6 kg (7.94 lbm) for a GRE of 297 m^3 (10480 ft^3), as reported in Sec. 5 of the Mixer Pump SA. Thus, we conclude that when the waste level for voidmeter operation is limited to 10.26 m (404 in.), the worst-case release quantities assessed in Sec. 5 of the Mixer Pump SA will not be exceeded. The radiological consequences are identical to those calculated in Sec. 5.3.1 for the 10% release fraction case.

5.3.3. Toxicological Consequences for Voidmeter Operation

The toxicological consequences for voidmeter operations are identical to those calculated for voidmeter installation (see Table Add.2.5-4). Additional releases from the waste on the surface of the voidmeter are not assumed to contribute to the toxicological consequences. The IDLH limit of 500 ppm also is not violated because the maximum concentration at the SY Farm is 45.5 ppm. The toxicological consequences of voidmeter operation accidents are small and less than the acceptance limits shown in Fig. Add.2.5-4; therefore, they are acceptable.

5.4. Accident Sequences during Voidmeter Removal

This section presents the consequences of the accidents postulated to occur during voidmeter removal. The material release conditions governing the evaluation of radiological and toxicological consequences in this assessment are presented below.

The consequences of flammable and toxic gas releases with a 10.16-cm (4-in.)-diam riser open are identical to those analyzed in Sec. 5.2.1 of this addendum for voidmeter installation.

5.5. Consequence of Release from Filter System

If the tank filter system is damaged during installation or removal of the voidmeter, a release of materials trapped in the filter system is possible. The consequence of a similar event, release of material from the filter system caused by a GRE and burn, is discussed in Sec. 4.3.3 in the Mixer Pump SA. The radiological consequences are assumed to be the same as those considered in the Mixer Pump SA, although a strong case could be made for a reduction of the release fraction to 1% rather than 10% (as used in the SA analysis) because the damage mechanism is not as energetic as the GRE and burn condition assumed in the SA. The radiological consequences of this event are shown in Table Add.2.5-1a, are less than WHC guidelines, and therefore are acceptable.

5.6. Consequences of Accidents Challenging Tank Confinement or Containment

The accident analyses in Sec. 4 demonstrated that there were few credible accident conditions that lead to a breach of confinement provided by the tank and that accidents that lead to breach of containment can be prevented through the application of controls. As a worst case, damage to the 10.16-cm (4-in.) riser during installation or removal of

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the voidmeter caused by dropping the voidmeter on the riser would lead to an open-tank condition where the consequences are bounded by the open riser and GRE-and-burn conditions already discussed.

A breach of confinement caused by a burn in the tank dome is not expected because the gas release is limited to 245 m^3 (8650 ft^3) based on the conclusion given in App. K of the Mixer Pump SA. The probability of drop accidents is low. The critical lift height has been determined to be 36.3 cm (14.3 in.) so as not to damage the riser in the absence of an impact limiter. The use of a limiter further diminishes the possibility of damage to the riser and the tank bottom liner. A drop of the voidmeter or crane boom on the tank dome is found to not exceed the dome capacity (as discussed in Sec. 4.4.4). Critical lift procedures will be put in place to reduce the likelihood of drops.

If the voidmeter is dropped into the tank, it was found that the tank bottom liner will remain intact. Drag loads caused by wind and motion of the voidmeter in the waste were found not to introduce enough moment to damage the riser.

If the forearm were to become debris in the tank and hit the tank wall or other tank components as a result of jet motion, no damage to the tank wall and other components would be expected.

The riser is expected to remain elastic during the DBE scenario. This analysis indicates that no unacceptable damage to the tank will result given the DBE. Further, the elastically calculated bending stresses on the voidmeter for the DBE condition are less than the stresses to cause a plastic hinge at the riser-liner location. In conclusion, the DBE scenario does not present a containment or confinement breach to the tank and riser, and the voidmeter will remain intact.

The breach-of-confinement analysis results indicate that accidents associated with voidmeter operations do not pose a threat to the structural integrity of the riser and tank. The consequences of breach-of-confinement accidents are acceptable, and their likelihoods are low because of the controls in place.

5.7. Consequences of Flooding of Tank

There are several consequences of flooding the tank. As a worst case, the hydrostatic pressure from too much water added [to a waste level of ~10.7 m (422 in.)] will breach the primary confinement and lead to a release of wastes to the environment. This event was determined to be incredible because of the sheer number of gross errors that would be needed and the limits on total quantities of water available for addition.

Increasing the waste level above 10.26 m (404 in.) presents operational consequences because intrusive tank operations controls become more restrictive when the tank level is ≥10.26 m (404 in.).

add 2

5.8. Consequences of Radiation Exposure (Shine)

The radiation field expected at an open 10.16-cm (4-in.) riser has been assessed, along with other radiation field sources expected in normal handling and care of the voidmeter. The analysis demonstrated that the radiation fields were within allowable limits and that normal radiological safety and work planning measures would be adequate to assure that workers were not excessively exposed.

The voidmeter may be contaminated by tank waste during removal or operation phases. The level of waste can add significantly to the radiation fields because of tank shine alone. The amount of waste that could remain on the voidmeter surface was estimated experimentally as 3.316 g (7.31×10^{-3} lbm), with a standard deviation of 0.117 g (2.58×10^{-4} lbm). This results in a waste film density of 0.0197 g/cm^2 (2.8×10^{-4} lbm/in.^{2}).[1]

WHC analyses[4] of radiation fields under the condition of unusual quantities of waste on the voidmeter (see Sec. 4.6.6 of this addendum) showed contact dose rates approaching 1300 mrem/h for the arm assembly, 2100 mrem/h for the mast, and 14,000 mrem/h for the sampling chamber (assuming it is full of waste). At 30 cm (11.8 in.) away, these values drop to 78 mrem/h for the arm assembly, 170 mrem/h for the support mast, and 570 mrem/h for the sampling chamber. All of these levels exceed the 100-mrem/h limit established by WHC. Workers are required to aid in the assessment of decontamination effectiveness during removal actions. Therefore, workers could be exposed to the combined fields from tank waste on the mast and sampler arm assembly, as well as tank shine. The high-radiation conditions require special work controls to limit the exposure.

The accident condition considered in Sec. 4.4.6 of this addendum postulates a failure of both the radiation alarm and the radiation survey to detect the unacceptable radiation levels. Therefore, if exposure through an 8-h shift is possible, the maximum exposure would be 8 h x 1500 mrem/h, or 12 rem for the case that the sampler contains waste. The maximum exposure from waste film on the voidmeter would be 8h*2100 mrem/h, or 16.8 rem. These are far above the allowable annual exposure level of 5 rem but do not pose any immediate threat to health. Controls established in Sec. 6 of the Mixer Pump SA (radiation monitor, decontamination operation, and radiological survey) minimize the possibility of an adverse event.

5.9. Consequences of Hazardous Materials Exposure

Hazardous material may be on the mast or trapped in the sampler. Material on the mast is subject to spills. The material that may be trapped and pressurized inside the sample chamber presents a release hazard because it is under pressure and, if released, may cause the waste to become an aerosol.

Spills of hazardous material can result during removal. A spill analysis for quantities of material in excess of any possible for the voidmeter [910 kg (2019 lbm)] was considered

add 2

in the Mixer Pump SA, Sec. 5, and found to be within radiological and toxicological acceptance criteria. If we consider that the maximum length that the mast can have in the waste is 8.81 m (347 in.) with an internal diameter of 7.62 cm (3 in.), the mast and the sampler could have 65 kg (143 kg) of waste. The spill of this quantity is less than the spill of 916 kg (2019 lbm) of material, which is considered in the Mixer Pump SA (see Sec. 5). Therefore, the toxicological consequences of this hypothetical accident already is bounded by the consequences discussed in Sec. 5 of the SA.

The radiological consequences from a spill accident considers a pressurized sampler chamber as a result of actuator failure. The scenario includes removing the voidmeter from the tank and releasing the waste from the sampler as a result of actuator failure. The release fraction is assumed to be 20%. The release fraction of 20% calculated from the conservative upper-bound curve given in Ref. 3. The effective energy source for Fig. 4.3 of Ref. 3 is evaluated from the maximum expansion work of 800 J and the 0.650-kg waste that could exist in the sampler. The radiological consequences of these spill accidents are summarized in Table Add.2.5-1a. The amounts are lower than the WHC guidelines and are acceptable.

5.10. Consequences of Voidmeter Ejection from the Tank

Analysis of the ejection of an unsecured voidmeter from the riser was discussed in Sec. 4 of this addendum and was shown to be impossible.

REFERENCES

1. C. Unal, "Estimation of Waste On Voidmeter if Decontamination System Is Not Effective or Operable," Los Alamos National Laboratory calc note TSA-CN-WT-SA-TH-50 (June 1994).

2. D. Graves, "Void Fraction Instrument Surface Area," Fax from D. Garves to C. Unal, June 15, 1994.

3. Nuclear Fuel Cycle Facility Accident Analysis Handbook (Nuclear Fuel Cycle Facility Accident Analysis Handbook, NUREG-1320, May 1988).

4. P. Olson, "Void Fraction Instruments Estimate Dose Rates," Westinghouse Hanford Company report WHC-SD-WM-SDD-046, Rev. 0, App. G (October 1994).

add 2

6.0. CONTROLS

The controls for the installation/operation and removal of the voidmeter are provided in Sec. 6 of the Mixer Pump SA. The controls have been developed using WHC standard controls and the results, assumptions, and initial conditions of the analyses presented in this SA addendum. During development of the procedures for each of the activities, the current OSRs and OSDs must be considered. The controls provided in Table 6-11 of the SA can be modified if the appropriate organization grants approval.

Each mitigation activity requires some general standard safety controls, such as controls regarding the ventilation system for certain phases of its operation. Instead of repeating these standard controls applicable to all mitigation activities, we classified them into two general groups: the standard safety controls for all mitigation activities for both the open- and closed-tank operations required by the SA. Tables 6-1 and 6-2 of the SA present these standard safety controls for open- and closed-tank operations, respectively. The controls for voidmeter installation operation and removal found in Table 6-11 reference the Table 6-1 standard controls for open-tank operation for voidmeter installation and removal and Table 6-2 standard controls for closed-tank operation for voidmeter operation.

add 2

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Los Alamos
NATIONAL LABORATORY

Technology & Safety Assessment Division
Nuclear Systems Design & Analysis, MS K575
Los Alamos, New Mexico 87545
(505) 667-0914 FAX (505) 665-4322

e: November 13, 1995
e: TSA-10-95-165

Dr. J. Lentsch
c/o Karen Drury
Westinghouse Hanford Company
P.O. Box 1970, MSIN H5-09
2940 George Washington Way
Richland, WA 99352

Dear Jack:

Enclosed are the copies of all the calc-notes that are directly or indirectly used to support Revision 14 of the Mixer Pump Safety Assessment (LA-UR-92-3196).

When subsequent revisions are submitted for review, we will forward the supporting calc-notes along with the revisions.

If we can be of further assistance, please call me at (505) 667-8893, or you may reach me via e-mail at kop@lanl.gov.

Sincerely,

Kemal O. Pasamehmetoglu

KOP:rhm

Enc. a/s

Cys: J. R. White, Hanford Liaison, WHC MSIN H5-09
J. H. Scott, TSA-10, MS K575 JHS
A. S. Neuls, TSA-10, MS K575
T. J. Hirons, EM/DOE/FP, MS J591
CIC-10, MS A150
TSA-10 File

c:\winword\fy93\hwt\density.doc JMB 7/14/93

From: J.M. Butner, N6, LANL
To: Jack Lensch, WHC
copies: H. Sullivan, A. Neuls, J. Edwards, D. Stack, K. Pasamehmetoglu, R. Jenks, N6, LANL
David Martin, Amanda Clark, Ames Laboratory, 110 Engineering Annex, Ames, Iowa, 50012

Introduction and Evaluation Methods

The purpose of this note is to determine whether the Ames Laboratory density monitors are qualified for waste-environment operation in Tank 241-101-SY. This review is only applicable to the low-powered density monitors and does not include the Ames acoustic ranging transducer; the safe installation of these instruments were considered in an earlier pump mitigation review[1], but their operational safety assessment was excluded from this earlier review. This note reviews the safety aspects relating to the possible hazard from hydrogen ignition caused by the density monitors' portion of the pump-extension instrumentation equipment. With the exception of the acoustic-cavitation analysis, the presented results are qualitative. This safety review considers only an assessment of the of the in-tank portions of the density monitors for their normal operating modes; maintenance of the in-tank assembly is not expected to be possible. Additionally, although we recommend some operational controls, we did not review the operational procedures for these instruments. Finally, because an earlier analysis determined that hydrogen detonation was not likely in the tank[1], this evaluation concerns itself only with ignition.

The evaluation approach is to first consider whether the density monitors have sufficient energy to ignite hydrogen; because the transducers are not located in a hydrogen environment, this initial screening is conservative. If the density monitors are judged to be capable of sustaining a hydrogen burn, we will further judge the instrument transducer design and construction against the criteria for equipment qualified to operate in a hydrogen environment (Class 1, Division 1, Group B location). This approach is more conservative than the one used to qualify the remainder of the pump-mitigation electrical equipment[2] because of the inherent difficulty of sustaining an electrical arc in a liquid medium. Because the instrument wiring raceway passes through a Class 1, Division 1, Group B location, the wiring method does have to meet code specifications; we will evaluate the wiring assembly for adherence to these specifications.

Conclusions

This conclusion drawn from this evaluation is that the Ames Laboratory density monitors (or sensors) can be safely operated in the liquid-waste environment in Tank 241-101-SY based primarily on the conclusion that these instruments are not potential ignition sources, even in a hydrogen atmosphere. Details of the analyses used to make this conclusion are discussed in the remainder of this note. Also, suggested controls that will ensure safe and proper density monitor operation are discussed at the end of this note.

Safety-Issue Meeting

The review process began with a meeting convened at the Engineering Technology Center in Richland on July 7, 1993 where safety issues related to general operation of the Ames density monitors and acoustic ranging transducers (echo rangers) were discussed. A list of attendees is attached to this note. A summary of the meeting discussions relevant to this evaluation is interwoven into each of the note sections.

Systems Descriptions and Location Classifications

The instruments considered in this analysis incorporate Airmar Technology part number B22 density transducers. These transducers are assembled into 2 instrument packages called density monitors (or sensors) that operate in the tank liquid waste, a location not covered by the National Electric Code (NEC)[3], Article 500 classification scheme. The significance of classification in relation to hazards assessment and design criteria will be discussed after brief descriptions of the instrument packages.

Each of the two density monitors consist of an enclosed assembly of transmitting and receiving ultrasonic transducers that face each other across an approximately 3 inch gap. These sensors are driven by a 5V source tuned for maximum expected signal amplitude to approximately 38 kHz sinusoidal; the possible frequency range of the source is 30 to 200 kHz. The lagging phase relationship between the receiving and transmitted signals is a function of the sonic velocity in the waste fluid. The fluid temperature is also measured by a thermistor wired in parallel with the ultrasonic receiver transducers. This thermistor is mounted within the monitor receiver. The 2 density monitors face outward toward the tank and are mounted on opposite sides of the pump at heights of approximately 4.5 and 16.6 ft above the center line of the circulation pump output nozzles.

The density-monitors operate in an basic and radioactive liquid environment whereas their wiring passes through the dome-space atmosphere which is classified as a Class 1, Division 1, Group B location because ignitable concentrations of hydrogen gas can exist under normal conditions. Therefore, the wiring equipment must adhere to the requirements of Article 501 of the NEC primarily because of the potentially small energies required to ignite hydrogen (as low as .017 mJ under some conditions[4]). Wiring specification adherence is discussed later.

In contrast, the density transducers location is such that there are no code standards against which their design, construction, and installation can be judged. We will therefore first consider density monitor safety qualification based on whether these instrument circuits have sufficient energy to ignite a hydrogen atmosphere, a conservative criteria. Based on this criteria, the Ames density monitor is not capable of igniting even a 21% by volume hydrogen atmosphere. As discussed below, this conclusion is based on an examination of ignition-voltage and ignition-current curves for circuits in Group B atmospheres[4] for circuits that are assumed to be capacitive or inductive-impedance circuits. These curves do not treat circuits whose impedances are both capacitive and inductive, so we will consider the density-monitor circuit impedances separately.

The capacitance of the density monitors, including transducers and wiring, has been measured to be approximately 20 nF[5]. The capacitive-ignition curve in Ref 4 indicates that approximately 100 µF is required to ignite a 21% by volume hydrogen atmosphere if the circuit voltage is 10V. The maximum normal operational voltage within the density monitor, generated by amplifying a 1 volt instrumentation power supply voltage, is 5 volts. Even if this level doubles, which is unlikely even if the load current is rapidly interrupted by an open circuit, the density monitor circuit has too low a capacity (by a factor of approximately 50,000) to cause ignition. Therefore, we believe the circuit is safe in regards to voltage level. In regards to ignition current, another Ref. 4 curve indicates an inductive circuit of 100 µH (twice the 50µH inductance of the density monitor power circuit whose main contribution is from the approximately 250 ft of balanced cable[5]) circuit having a maximum open-circuit voltage of 10V requires slightly more than 800 mA short-circuit current to ignite a 21% by volume hydrogen atmosphere. This level is essentially equivalent to the 800 mA maximum the density monitor output amplifier can provide[5]. Given that the tank atmosphere hydrogen concentration is expected to remain well below 21% and that the density monitor circuit has an inductance safety margin of a factor of 2, we believe the density monitor circuit does not have sufficient energy to be an ignition source.

The Ref 4 general guideline curves cannot be easily proven applicable for every situation, but in view of the fact that the monitor is mounted within a submerged enclosure that is not in danger of mechanical failure from cavitation; and that the Class 1 Division 1 wiring to the instrumentation is enclosed and purged, we believe our density monitor transducer safety qualification based on energy consideration is adequate. We will not further evaluate the construction of the density-monitor hardware below the liquid level other than to discuss cavitation. The next section presents the basis for our contention that the density monitor enclosure cannot be damaged by cavitation. The cavitation discussion is adapted from Ref 6.

The Potential Cavitation Hazard

Background

Cavitation can occur only when tensile stresses are present in a liquid. If the tensile stresses which lead to cavitation are high, then locally intense, high frequency spikes of ultrasonic energy are created as bubbles snap into existence; these locally intense ultrasonic pressure fields can lead to the erosion of solids and unusual chemical reactions. If bubbles are already present in the liquid and/or many nuclei for bubble creation exist, then bubbles will grow at low tensile stresses without the attendant release of high intensity ultrasonic energy. In any case, extensive bubble growth in a liquid containing suspended particles can induce macroscopic fluid motion with attendant mechanical abrasion of solid surfaces by the suspended particles.

According to Steve Agnew (LANL), it usually takes some time and relatively large tensile stress (i.e., a high average power level) to induce cavitation and lower levels of stress (i.e. lower average power) to sustain it. The dynamic pressure maxima in a plane acoustic wave are:

$$(1) \qquad P = \pm (W\rho c)^{.5}$$

where P is pressure,
W is rms. power per unit area,
ρ is density, and
c is acoustic wave velocity.

Care must be taken to use mass-based or force-based density in equation (1) as appropriate.

The minimum fluid pressure, P_t, for a submerged transducer will be the sum of the hydrostatic fluid pressure, P_o, and the dynamic tensile pressure:

$$(2) \qquad P_t = P_o - (W\rho c)^{.5}$$

When P_t is less than zero, cavitation is possible.

Assessment of the Potential for Cavitation

There is no cavitation potential at the density monitors. This is because these monitors are operated at low input power levels, resulting in low power density in the fluid. The maximum power density which can be delivered by this system is less than 0.01 watts per square centimeter, resulting in a dynamic pressure variation of less than ± 0.2 atmospheres, assuming worst-case convective-layer conditions ($\rho = 1.54\ kg/m^3$ and $c = 1.9 \times 10^3$ m/s). Since the local hydrostatic pressures at the density monitors exceed 1.9 atmospheres, no net tensile pressure can be generated and cavitation cannot occur. Even if cavitation were an issue, provisions exist to verify the integrity of the instrumentation packages. These provisions are discussed below.

Because the SYSCAN system software recognizes error conditions caused by a loss or degradation of the transmitter or receiver phase signals and the thermistor signal, any transducer physical degradation should be automatically noted. Therefore, no additional electrical measurements should be required to determine the mechanical integrity of the instrument transducers. The following section discusses qualification of the density monitor wiring scheme.

Safety Qualification of the Density Monitor Wiring

Because the instrument wiring raceway passes through a Class 1, Division 1, Group B location, it must meet NEC specifications that allow for very few wiring methods for Class 1, Division 1 locations. The density monitor wiring incorporates the most commonly used method, rigid metal conduit. A minimum of 5 fully engaged threads, made up wrench tight, are required to make for adequate conduit joints. However, the conduit run through the dome space is continuous, so conduit joint quality is not an issue. The NEC also requires conduit leaving Class 1, Division 1 locations to be sealed as discussed in the following paragraph.

The density monitor wiring conduit runs through raceway which is enclosed within 16 inch metal pressurized piping as it feeds through the Class 1, Division 1, Group B classified dome space. We will discuss conduit sealing requirements before considering the aspects of the piping pressure system.

Each conduit run leaving a Class 1, Division 1 location must be sealed on either side of the division boundary except when metal conduit containing no unions, couplings, boxes, or fittings passes completely through a Class 1, Division 1 location with no fittings less than 12 inches (305 mm) beyond each boundary shall not be required to be sealed if the termination points of the unbroken conduit are in unclassified locations[3]. Because the liquid waste is an unclassified location, this exception was followed where the conduit entered the liquid waste; however, couplings or seals are welded at hardware junctions below the liquid level. At the junction where the conduit enters a Class 1, Division 2 location (the 241-101-SY pump pit) the wiring must pass through a seal fitting that is properly assembled and sealed. The sealing compound having a melting point of 200°F that is not affected by the surrounding environment. Also, the thickness of the seal must not be less than the conduit size.

The density monitor wiring conduit passes through 2 seals. First, where the conduit passes through the 16 inch pipe cap, a seal-coupler is welded to the outer conduit wall and a sealing compound fills the gap between the coupler and the pipe cap hole. This sealing compound is rated to 450°F (dry) and 200°F (wet). Where the wiring passes into atmosphere, the conduit is sealed using a NEC/Underwriters Laboratories approved seal-off coupler assembled to the specifications discussed in the paragraph above[7]. It is our opinion that the density monitor wiring is qualified for Class 1, Division 1, Group B location operation.

The Class 1, Division 1 qualified conduit is also enclosed in pressurized metal piping as additional insurance against possible hazard resulting from conduit or fittings leakage. The NEC doesn't specifically define purged equipment, but it recognizes that potential risk may be reduced or that locations may be reclassified as a result of using positive-pressure ventilation as recognized by the National Fire Protection Association (NFPA). The ventilation pressure protection method employed is a NEC recommended variation of the Type Y NFPA purging[8]; the NEC variation suggests the system be initially purged to establish an inert atmosphere and that flow be continued to maintain a enclosure pressure of at least 25 Pa (.004 psig). The conduit piping was initially purged and is constantly maintained at approximately 10 psig using an inert nitrogen atmosphere; 10 psig is twice the maximum anticipated piping hydrostatic pressure load[7]. In accordance with NFPA requirements for Type Y purging, a pressure sensing device trips an alarm when the pressure drops (this alarm-point is 9 psig for the piping), but instrument power is not automatically shut off[5]. It should be noted that the density monitor piping conduit positive-pressure scheme may allow for reduction in the classification of the tank-dome-space equipment, but we have not investigated this possibility. Finally, the last section details controls that will ensure safe and proper density monitor operation.

Operational Controls

This section discusses the level of configuration control suggested for the density monitor system.

Modifications to the Ames Laboratory SYSCAN system and component instruments should not be made without formal Westinghouse Hanford Company (WHC) design configuration and change control and appropriate safety review. To do so could compromise either system effectiveness and/or safety. Specifically, the following instruments must not be replaced , internally modified, or internally adjusted without formal WHC design configuration and change control and appropriate safety review:

the HP Model 467A Power Amplifier,
the BK Precision Model 1541B 40 MHz Dual Trace Oscilloscope,
these Stanford Research Systems Instruments:
    the Model SR620 Universal Time Interval Counter and
    the Model DS345 Synthesized Function Generator,
the AD Data Inc. Model 5600 ATE Switching System, and
the TriValley Technology 486 MS-Dos Computer.

Additionally, the wiring at the terminal barrier strips in the instrumentation cabinet should never be modified without formal WHC design configuration and change control and appropriate safety review[9].

References

(1) Los Alamos National Laboratory, "A Safety Assessment for Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-101-SY: Hanford Site, Richland, Washington," LA-UR-92-3196, revision 4a, July 2, 1993, prepared for the U.S. Department of Energy.

(2) Westinghouse Hanford Company, "100% Design Review of the Mixer Pump Test," WHC-SD-WM-DRR-040, prepared for the U.S. Department of Energy.

(3) The National Fire Protection Association, "National Electrical Code 1990 Edition," NFPA 70-1990.

(4) P.J. Schram and M.W. Earley, "*Electrical Installations in Hazardous Locations*, National Fire Protection Association, Quincy, Massachusetts (1991).

(5) Discussion with Ames Laboratory personnel.

(6) D. Martin and A. Clark, " Response to Safety Concerns Related to Cavitation for Ames Laboratory Equipment as Discussed at Safety Assessment Meeting of July 7," Ames Laboratory memorandum to Jack Edwards and Mike Butner, July 8, 1993.

(7) Discussion with Westinghouse Hanford Company personnel.

(8) National Fire Protection Association, "Standard for Purged and Pressurized Enclosures for Electrical Equipment, National Fire Protection Association Standard NFPA 496-1986, National Fire Protection Association, Quincy, Massachusetts.

(9) D. Martin and A. Clark, " Response to Safety Concerns Related to Controlling Instrumentation in the DACS for Ames Laboratory Equipment," Ames Laboratory memorandum to Jack Edwards and Mike Butner, July 8, 1993.

July 7, 1993 Meeting Attendees

Name	Organization
Jack Edwards	N6, LANL
Mike Butner	N6, LANL
Tony Benegai	Design Engineering, WHC
Amanda Clark	Ames Laboratory
William B. Anderson	Fire Protection Programs, WHC
Dave Martin	Ames Laboratory
Ray Meriman	Electrical Power Systems, WHC
James Robinson	Tank Farms Engineering, WHC
Norton McDuffie	WTS, WHC

Los Alamos
NATIONAL LABORATORY

Technology & Safety Assessment Division
TSA-6, MS K557

Los Alamos, New Mexico 87545
(505) 667-6231
FAX: (505) 665-2897

Calc-Note Approval Sheet

Calc-Note Number TSA6-CN-WT-SA-GR-039 Rev. 1

Document Title: ESTIMATING GAS RELEASE EVENT PROBABILITIES AND FREQUENCIES
Author(s): William L. Kubic, Jr.

Author	**Date**
Supervisor or Peer Reviewer	**Date**
Supervisor or Peer Reviewer	**Date**
Management	**Date**

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Los Alamos, New Mexico 87545

Calc-Note Cover Sheet

Calc-Note Number: TSA6-CN-WT-SA-GR-039 Rev. 1

Calculation Title: **ESTIMATING GAS RELEASE EVENT PROBABILITIES AND FREQUENCIES**	Supersedes Calc-Note Number: N/A

Objective of Calculation:

To estimate the frequencies of accidents initiated by gas release events.

Calculation Method and Key Assumptions:

Analysis of tank data and generic data. See calc-note text for details.

Sources of Data (References):

See calc-note text for list of data and references.

Conclusions:

The probabilities of various gas release events were estimated as a function of level control. The split fractions on the event trees were also estimated. See the calc-note text for a tabulation of the probilitities.

Reasons for Revisions (if applicable):
1 - Correct error in gas release volume
2 - Incorperate additional operating data
3 - Incorperate new pump failure data

QA Category:
☒ I – Nuclear Safety Related
☐ II – Health and Safety Related
☐ III – Other

Comments Provided by		Comments Resolved by		Section Leader Approval	
Signature	Date	Signature	Date	Signature	Date

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Calc-Note Number: TSA6-CN-WT-SA-GR-039 Rev. 1

	Yes	No	N/A
1. Were the inputs correctly selected and incorporated?	☒	☐	☐
2. Was the code under configuration control or a waiver attached to the calc-note?	☐	☐	☒
3. Were the assumptions necessary to perform the analysis adequately described and reasonable?	☒	☐	☐
4. Were the appropriate quality assurance requirements specified?	☒	☐	
5. Was the calculation results reasonable compared to the inputs?	☒	☐	☐
6. Were the references used appropriate and current?	☒	☐	☐
7. Was the calculation neat and of microform quality?	☒	☐	
8. Was a calc-note cover sheet appropriately filled out?	☒	☐	
9. Were your comments adequately satisfied?	☒	☐	☐
10. In your best judgement, is the calculation correct?	☒	☐	

Reviewer's Signature: ____________

Date: ____________

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Calc-Note Number: TSA6-CN-WT-SA-GR-039 Rev. 1

Item	Page	Comment	Response/Resolution

Comments Provided by		Comments Resolved		Resolution Accepted	
Signature	Date	Signature	Date	Signature	Date

Los Alamos National Laboratory
Engineering and Safety Analysis Group

Calc-Note TSA6-CN-WT-SA-GR-039
Revision: 0

ESTIMATING GAS RELEASE EVENT PROBABILITIES AND FREQUENCIES

William L. Kubic, Jr.

February 24, 1994
Revised September 13, 1995

TABLE OF CONTENTS

CHANGES INCORPORATED IN REV. 1

The probability model for gas release events is based on bubble release volume. In Rev. 0, the size of the gas release event was assumed to be equal to bubble release volume. We account for the ammonia released as a result of mass transfer during the gas release event in this revision. We also include new estimates of the pump failure frequency and expanded the analysis to consider the case of zero spares and one spare.

1.0 INTRODUCTION

The purpose of the calculations is to estimate the frequencies and probabilities associated with accident sequences in Tank 241-SY-101 that are initiated by a gas release event. This analysis covers the frequency of gas release events in Tank 241-SY-101, the frequency of gas release events in Tank 241-SY-103, and the reliability of systems that affect the consequences of a gas release event.

2.0 GAS RELEASE EVENTS IN TANK 241-SY-101

2.1 Definition of Release Size Categories

The consequences of a gas release event are a function of the size of a gas release event. This fact is reflected in the deterministic analysis by analysing various bounding gas release events. The implication of this approach is that if the bounding case is acceptable all lesser conditions in that category are acceptable.

The variability in gas release event size is modelled as a continuous random variable; therefore, it is not reasonable to consider the probability of an event of a given size because the probability of an event with a specified size is infinitesimal. In practice, the probability of a bounding event must be the probability of all events in the category. Thus it is necessary to specify the lower bound of the category as well as the upper bound. This section defines the size range for each probability class.

2.1.1 Normal Operations

Normal operations includes all periods other than pump installation and removal. Both periods of normal pump operation and periods of no activity in the event of a pump failure are considered normal operations. The categories of gas release events are:

Inconsequential Events - Inconsequential events are defined as gas release events that do not cause the average hydrogen concentration in the dome to exceed 25 % of the lower flammable limit. Ignition is thought to be very unlikely in this case and the consequences are minor. The bubble release volume needed to reach the lower flammable limit is 1000 scf.[1]

Acceptable Events - Acceptable gas release events release insufficient gas to cause structural damage to the tank in the event of a burn. Acceptable events correspond to a gas release volume of less than 8650 scf.[2] Because no gas release volume less than 8650 scf are analysed for normal operations, the lower bound on this category is the volume require to reach 25 % the lower flammable limit or 1000 scf.

Large Events - The consequences of a gas release greater than the structural limit are analysed. The maximum expected release volume is 10480 scf. This value is based on the maximum observed gas release event. This category of releases represents all expected releases that result in structural damage. Therefore the lower bound for this category is 8560 scf.

Very Large Events - The maximum gas release volume considered in the safety assessment is 13100 scf. This value is based on deterministic arguments. There is an inconsistency between the deterministic and probabilistic analysis. The physics of the deterministic analysis predicts an upper bound to the gas release volume. The probabilistic analysis does not incorporate these physics. It is an empirical approach that assumes the range of gas release event volumes are from zero to infinity. Thus the probabilistic model incorrectly predicts that events can occur with gas release volumes much greater than 13100 scf. In order to obtain consistency between the deterministic and probabilistic models, it is assumed that the 13100 scf release represents all releases greater than the structural limit of 10480 scf. For the purpose of estimating event frequency, very large events are all gas releases with volumes greater than 10480 scf.

Intrusion Windows - During an intrusion, activities, such as a video camera replacement, are permitted. The maximum allowable gas release during an intrusion window is 6000 scf. For probability calculations, a window release is considered all gas release events with a volume between 1000 scf, which is the upper limit of insignificant events, and 6000 scf.

2.1.2 Pump Installation

This phase of operation covers only the period during which a new pump is being installed. This phase does not include the time between pump removal and pump installation or the time between pump installation and the beginning of pump operations. These periods are expected to be relatively short, and they pose no hazards in addition to those that occur during pump operation.

Inconsequential Events - Inconsequential events are defined as gas release events that do not cause the average hydrogen concentration in the dome to exceed 25 % of the lower flammable limit. Ignition is thought to be very unlikely in this case and the consequences are minor. The bubble release volume needed to reach the lower flammable limit is 1000 scf.[1]

Pump Installation Limit- The maximum allowable gas release volume during pump installation is the lower flammable limit, which corresponds to a gas release volume of 3650 scf.[3] The lower limit is the gas release volume that results in a dome concentration of 25% of the lower flammable limit.

Events Larger Than Installation Limit - In a probabilistic analysis, events larger than the maximum window burp must be considered. These events are neglected in this analysis because they are assumed to occur with an extremely small frequency.

2.1.3 Pump Removal

This phase of operation covers only the period during which a new pump is being removed. This phase does not include the period between pump failure and pump removal or the period between pump removal and pump installation. These periods are expected to be relatively short, and they pose no hazards in addition to those that occur during pump operation.

Inconsequential Events - Inconsequential events are defined as gas release events that do not cause the average hydrogen concentration in the dome to exceed 25 % of the lower flammable limit. Ignition is thought to be very unlikely in this case and the consequences are minor. The bubble release volume needed to reach the lower flammable limit is 1000 scf.[1]

Pump Removal Limit- The maximum allowable gas release volume during pump removal is the lower flammable limit, which corresponds to a gas release volume of 2500 scf.[3] The lower limit is the gas release volume that results in a dome concentration of 25% of the lower flammable limit.

Events Larger Than Removal Limit - In a probabilistic analysis, events larger than the maximum window burp must be considered. These events are neglected in this analysis because they are assumed to occur with an extremely small frequency.

2.2 Probabilities of Gas Release Events

The probability of gas release events are evaluated using distributions obtained from the analysis of data. The probability will depend on the size of the release and the level control.

2.2.1 Normal Operations

Two conditions exist that must be considered when evaluating the probability of a gas release event: the mixing pump fails and a natural rollover occurs and mixing pump operation induces a gas release event.

The frequency of pump failure and a natural rollover depends on the number of spare pumps available. The frequency of natural rollovers is estimated to be 1.9/yr if there is no spare pump, 0.22/yr if there is one spare, and 0.0073 if there are two spares.[4] Assuming the pump is operated an average every three days, so the frequency of pump operation is 122/yr. The frequency of a pump induced rollover is the frequency of pump operation times the conditional probability of a rollover given pump operation.

Very Large Events - If the tank reverts to a natural rollover cycle, the size distribution of gas release events is assumed to be the same as for the rollover cycle prior to mitigation. The distribution of level drops for natural rollovers can be represented by a three-parameter Weibull distribution:[5]

$$\Pr(\Delta Z \leq \Delta z) = 1 - \exp\left[-\left(\frac{\Delta z - 4.2\text{ in}}{8.35\text{ in} - 4.2\text{ in}}\right)^{1.3647}\right] . \qquad (1)$$

This distribution implies that all natural gas release events result in level drops greater than 4.2 in. The probability of a natural gas release event with a level drop less than 4.2 in is 0.0. Volume of bubbles released during the event is proportional to level drop. The conversion is 755 scf/in. (App. T of Mixer Pump Safety Assessment Rev. 12) Level drop is related to volume of gas bubble released. Using the conversion given in App. B, the volume of bubbles released corresponding to a 10480 scf release is 9540 scf. The level drop corresponding to the structural limit of 9540 scf is

$$\Delta z_{max} = \frac{(9540\text{ scf})}{(755\text{ scf/in})} = 12.6\text{ in.}$$

The probability of an event greater than 8650 scf is

$$\Pr(Z > \Delta z_{max}) = 1 - \Pr(\Delta Z \leq \Delta z_{max}) . \qquad (2)$$

Based on Eq. (1), $\Pr(\Delta Z \leq \Delta z_{max})$ is 0.928. Based on Eq. (2) the probability of a gas release event that exceeds the maximum allowable release is 0.072 given that an event has occurred.

For pump operation, the waste level must be below the specified control limit. This control or constraint must be considered in evaluating the probability of exceeding an 10480 scf release during pump operations. The conditional probability of a pump induced rollover exceeding the 10480 scf release is the probability of exceeding the 10480 scf release given that the waste level less than or equal to the control limit. This probability has to components. The probability that pump operation induces a gas release and the probability that the induced event exceeds 10480 scf. The probability of inducing a rollover is a function of waste level, and it is given for several discrete level intervals.[1]

$$\Pr(GRE \mid 404 \text{ in} < z \leq 406 \text{ in}) = 0.053 \ .$$

$$\Pr(GRE \mid 402 \text{ in} < z \leq 404 \text{ in}) = 0.023 \ .$$

$$\Pr(GRE \mid z \leq 402 \text{ in}) = 0.0040 \ .$$

The level at which a GRE occurs and the natural log of the gas release volume can be represented by a joint normal distribution.[1] The means and standard deviations of waste level and natural log of gas volume are

Waste Level: $\mu = 413.5$ in $\sigma = 4.9$ in.

ln(Gas Volume): $\mu = 8.37$ $\sigma = 0.93$

The covariance matrix for the waste level and log of gas volume is estimated to be

$$V = \begin{bmatrix} 24.050 & 3.599 \\ 3.599 & 0.871 \end{bmatrix}$$

The first index in this matrix corresponds to waste level and the second corresponds to the log of gas volume.

The joint probability density function for level and log of gas volume is

$$f(z,\ln(q)) = \frac{1}{2\pi\,|V|} \exp\left(-\frac{1}{2} \begin{bmatrix} z-\mu_z \\ \ln(q)-\mu_{\ln(q)} \end{bmatrix}^T V^{-1} \begin{bmatrix} z-\mu_z \\ \ln(q)-\mu_{\ln(q)} \end{bmatrix} \right) , \tag{3}$$

where

z = waste level,
q = volume of gas bubble release,
μ_z = mean waste level,
$\mu_{\ln(q)}$ = mean value of ln(q)
V = covariance matrix.

The symbol | | indicates the determinant. The probability of a GRE with a gas release volume between q_1 and q_2 when the waste level is between z_1 and z_2 is

$$\Pr(q_1<q\le q_2 \mid z_1<z\le z_2) = \frac{\int_{\ln(q_1)}^{\ln(q_2)} \int_{z_1}^{z_2} f(z,\ln(q))\, dz\, d\ln(q)}{\int_{\ln(0)}^{\ln(\infty)} \int_{z_1}^{z_2} f(z,\ln(q))\, dz\, d\ln(q)} \ . \tag{4}$$

This equation can be evaluated using Mathcad (See Appendix A). For releases larger than the maximum allowable release, q_1 is the volume bubbles released during the event; and q_2 is infinity. The results for the three level intervals are:

$$\Pr(q_{GRE} > 10480 \text{ scf} \mid 404 \text{ in} < z \le 406 \text{ in}) = 7.2\text{x}10^{-4} \ .$$

$$\Pr(q_{GRE} > 10480 \text{ scf} \mid 402 \text{ in} < z \le 404 \text{ in}) = 1.1\text{x}10^{-4} \ .$$

$$\Pr(q_{GRE} > 10480 \text{ scf} \mid z \le 402 \text{ in}) = 9.5\text{x}10^{-6} \ .$$

The probability of pump operation inducing an event greater than the MAXIMUM EXPECTED RELEASE is

$$\Pr(q_{GRE}>10480 \text{ scf} \mid \text{Pump Operation}) = \sum_i \Pr(\text{GRE} \mid \text{Level Interval } i)\, \Pr(q_{GRE}>10480 \text{ scf} \mid \text{Level Interval } i) \tag{5}$$

The frequency of exceeding an maximum expected release is the frequency of exceeding maximum expected release due to pump failure plus the frequency of exceeding the maximum expected release due to pump operation.

$$\lambda_{>Max} = \lambda_{failure} \Pr(q_{GRE}>10480 \text{ scf} \mid \text{Natural GRE}) + \lambda_{operation} \Pr(q_{GRE}>10480 \text{ scf} \mid \text{Pump Operation}) \ , \tag{6}$$

where $\lambda_{failure}$ is the frequency of gas release event s as a result of pump failure and $\lambda_{operation}$ is the frequency of pump operation. The frequency of an induced gas release event as a function of waste level is given in Table I.

The level intervals only are defined up to a waste level of 406 in. To obtain results at levels greater than 406 in, probability model must be extrapolated. A linear extrapolation of the logarithm of probability has been shown to be reasonable.[1] Therefore, the cumulative probability for the level 408 in are based on a log-linear extrapolation. The

TABLE I
ESTIMATES OF THE FREQUENCY OF PUMP INDUCED GAS RELEASE EVENTS GREATER THAN 10480 SCF

Waste Level Control (in)	Pr(q>10480 scf) Given Induced GRE and Level Interval	Pr(q>10480 scf) Given Pump Operation and Level Control	Frequency of Pump Induced GRE>10480 scf (yr^{-1})
408	-	$2.1x10^{-4}$	$2.6x10^{-2}$
406	$2.2x10^{-4}$	$1.2x10^{-5}$	$1.5x10^{-3}$
404	$2.9x10^{-5}$	$6.8x10^{-7}$	$8.3x10^{-5}$
402	$2.1x10^{-6}$	$8.4x10^{-9}$	$1.0x10^{-6}$

TABLE II
ESTIMATES OF THE FREQUENCY OF EXCEEDING A 10480 SCF GAS RELEASE EVENT DURING PUMP OPERATION

Waste Level Control (in)	Frequency of GREs >10480 scf (yr^{-1})		
	No Spare	1 Spare	2 Spares
408	**$1.6x10^{-1}$**	**$4.2x10^{-2}$**	**$2.7x10^{-2}$**
406	**$1.4x10^{-1}$**	**$1.7x10^{-2}$**	**$2.0x10^{-3}$**
404	**$1.4x10^{-1}$**	**$1.6x10^{-2}$**	**$6.1x10^{-4}$**

402	1.4×10^{-1}	1.6×10^{-2}	5.3×10^{-4}

The frequency of a large gas release event is dominated by induced rollovers if the high waste level control is selected and there is at least one spare pump. Otherwise, frequency is dominated by pump failure and a return to a natural rollover cycle. These estimates may be optimistic because these estimates are based on past data, which do not reflect the possibility of adverse long term changes.

Large Events - Large events corresponds to releases between 8650 scf and 10480 scf, which correspond to bubble release volumes between 7870 scf and 9450 scf using the conversion factors in App. B. The range of level drops for these releases are between 10.4 in and 12.6 in . Given that a gas release event has occurred, the probability of a level drop between 10.4 in and 12.6 in is

$$\Pr(\text{Large GRE} \mid \text{Natural GRE}) = \Pr(\Delta Z \leq 12.6 \text{ in}) - \Pr(\Delta Z \leq 10.4) . \tag{7}$$

The probabilities in this equation are evaluated using Eq. (1). The probabilities are:

$$\Pr(\Delta Z \leq 12.6 \text{ in}) = 0.928$$

$$\Pr(\Delta Z \leq 10.4 \text{ in}) = 0.824$$

The probability of a very large event given a natural rollover is 0.104.

The probability of a release between 8650 scf and 10480 scf given an induced event for each of the three level categories is determined from Eq. (4). Using the results in App. A, the limits of integration for gas bubble volume are 7870 scf and 9450 scf.

$$\Pr(8650 \text{ scf} < q_{GRE} \leq 10480 \text{ scf} \mid 404 \text{ in} < z \leq 406 \text{ in}) = 4.9\times10^{-4} .$$

$$\Pr(8650 \text{ scf} < q_{GRE} \leq 10480 \text{ scf} \mid 402 \text{ in} < z \leq 404 \text{ in}) = 8.0\times10^{-5} .$$

$$\Pr(8650 \text{ scf} < q_{GRE} \leq 10480 \text{ scf} \mid z \leq 402 \text{ in}) = 7.2\times10^{-6} .$$

The probability of an acceptable release given pump operation is computed in a similar manner to large

$$\Pr(8650 \text{ scf} < q_{GRE} \leq 10480 \text{ scf} \mid \text{Pump Operation}) = \tag{8}$$

$$\sum_i \Pr(\text{GRE} \mid \text{Level Interval i}) \Pr(8650 \text{ scf} < q_{GRE} \leq 10480 \text{ scf} \mid \text{Level Interval i})$$

The frequency of a release between 8650 scf and 10480 scf is the frequency of a release due to pump failure plus the frequency of a release due to pump operation.

$$\lambda_{AE} = \lambda_{failure} \Pr(8650 \text{ scf} < q_{GRE} \leq 10480 \text{ scf} \mid \text{Natural GRE}) + \lambda_{operation} \Pr(8650 \text{ scf} < q_{GRE} \leq 10480 \text{ scf} \mid \text{Pump Operation}) \, . \tag{9}$$

The results for the frequency of pump induced gas release events are given in Table III. The cumulative probability for the level 408 in are based on a log-linear extrapolation. The total frequencies of a GRE with a gas release volume between 8650 and 10480 scf are given in Table IV.

TABLE III
ESTIMATES OF THE FREQUENCY OF PUMP INDUCED GAS RELEASE BETWEEN 8650 AND 10480 SCF

Waste Level Control (in)	Pr(q>10480 scf) Given Induced GRE and Level Interval	Pr(q>10480 scf) Given Pump Operation and Level Control	Frequency of Pump Induced GRE>10480 scf (yr^{-1})
408	-	4.1×10^{-4}	5.0×10^{-2}
406	4.9×10^{-4}	2.8×10^{-5}	3.4×10^{-3}
404	8.0×10^{-5}	1.9×10^{-6}	2.3×10^{-4}
402	7.2×10^{-6}	2.8×10^{-8}	3.5×10^{-6}

TABLE IV
ESTIMATES OF THE FREQUENCY OF GAS RELEASE EVENT BETWEEN 8650 AND 10480 SCF DURING PUMP OPERATION

Waste Level Control (in)	Frequency of GREs between scf (yr^{-1})		
	No Spare	1 Spare	2 Spares
408	2.5×10^{-1}	7.3×10^{-2}	5.1×10^{-2}
406	2.0×10^{-1}	2.6×10^{-2}	4.2×10^{-3}
404	2.0×10^{-1}	2.3×10^{-2}	9.9×10^{-4}
402	2.0×10^{-1}	2.3×10^{-2}	7.6×10^{-4}

The frequency of a large gas release event is dominated by induced rollovers if the high waste level control is selected and there is at least one spare pump. Otherwise, frequency is dominated by pump failure and a return to a natural rollover cycle. These estimates may be optimistic because these estimates are based on past data, which do not reflect the possibility of adverse long term changes.

Acceptable Events - Acceptable events corresponds to releases between 1000 scf and 8650 scf, which correspond to bubble release volumes between 910 scf and 7870 scf. The range of level drops for these releases are between 1.2 in and 10.4 in using the conversion factors in App. C. Given that a gas release event has occurred, the probability of a level drop between 1.2 in and 10.4 in is

$$\Pr(\text{Max. Allow. GRE} \mid \text{Natural GRE}) = \Pr(\Delta Z \leq 10.4 \text{ in}) - \Pr(\Delta Z \leq 1.2)\,. \quad (7)$$

The probabilities in this equation are evaluated using Eq. (1). The probabilities are:

$$\Pr(\Delta Z \leq 10.4 \text{ in}) = 0.824$$

$$\Pr(\Delta Z \leq 1.2 \text{ in}) = 0.0$$

The probability of an acceptable event given a natural rollover is 0.883.

The probability of a release between 1000 scf and 8650 scf given an induced event for each of the three level categories is determined from Eq. (4). Using the results in App. B, the limits of integration for gas bubble volume are 910 scf and 7870 scf.

$$\Pr(1000\ \text{scf} < q_{GRE} \leq 8650\ \text{scf} \mid 404\ \text{in} < z \leq 406\ \text{in}) = 0.70\ .$$

$$\Pr(1000\ \text{scf} < q_{GRE} \leq 8650\ \text{scf} \mid 402\ \text{in} < z \leq 404\ \text{in}) - 0.50\ .$$

$$\Pr(1000\ \text{scf} < q_{GRE} \leq 8650\ \text{scf} \mid z \leq 402\ \text{in}) = 0.26\ .$$

The probability of an acceptable release given pump operation is computed in a similar manner to large

$$\Pr(1000\ \text{scf} < q_{GRE} \leq 8650\ \text{scf} \mid \text{Pump Operation}) = \tag{8}$$

$$\sum_i \Pr(\text{GRE} \mid \text{Level Interval i}) \Pr(1000\ \text{scf} < q_{GRE} \leq 8650\ \text{scf} \mid \text{Level Interval i})$$

The frequency of a release between 1000 scf and 8650 scf is the frequency of a release due to pump failure plus the frequency of a release due to pump operation.

$$\lambda_{AE} = \lambda_{failure} \Pr(1000\ \text{scf} < q_{GRE} \leq 8650\ \text{scf} \mid \text{Pump Failure}) + \lambda_{operation} \Pr(1000\ \text{scf} < q_{GRE} \leq 8650\ \text{scf} \mid \text{Pump Operation})\ . \tag{9}$$

The results for the frequency of pump induced gas release events are given in Table V. The cumulative probability for the level 408 in are based on a log-linear extrapolation. The total frequencies of a GRE with a gas release volume between 8650 and 10480 scf are given in Table VI.

TABLE V
ESTIMATES OF THE FREQUENCY OF PUMP INDUCED GAS RELEASE BETWEEN 1000 AND 8650 SCF

Waste Level Control (in)	$Pr(1000<q_{GRE}\leq$ 8650 scf) Given Induced GRE and Level Interval	$Pr(1000<q_{GRE}\leq$ 8650 scf) Given Pump Operation and Level Control	Frequency of Pump Induced GRE Between 1000 and 8650 scf (yr^{-1})
408	-	1.8×10^{-1}	22
406	0.70	5.2×10^{-2}	6.3
404	0.50	1.5×10^{-2}	1.8
402	0.26	3.1×10^{-3}	0.38

TABLE IV
ESTIMATES OF THE FREQUENCY OF GAS RELEASE EVENT BETWEEN 8650 AND 10480 SCF DURING PUMP OPERATION

Waste Level Control (in)	Frequency of GREs between scf (yr^{-1})		
	No Spare	1 Spare	2 Spares
408	23	22	22
406	7.1	6.5	6.3
404	2.6	2.0	1.8
402	2.0	0.56	0.38

This frequency is dominated by pump operation except for the case of no spare pump. The probability of inducing an event releasing between 1000 scf and 8650 scf is very small but the frequency of pump operation is large. These estimates may be optimistic because these estimates are based on past data, which do not reflect the possibility of adverse long term changes.

Inconsequential Events - By definition, inconsequential events are not a safety concern. Therefore, the frequency of the events is not estimated.

Intrusion Windows - During an intrusion window, activities are permitted in the dome space. No waste intrusive operations are permitted including pump operation and pump bumping. Hence, there is not possibility of inducing a gas release event during an intrusion window. Also, a waiting period of 4 hrs. is required after the last pump operation before an intrusion window can be opened. The waiting period minimises the probability of that an induced gas release event occurs during a window that was initiated as a result of pump operation prior to opening the window. Therefore, the probability of an induced rollover during a window is assumed to be zero.

The frequency of a natural gas release event during a window is comprised of three parts: (1) the frequency of a window operation, (2) the probability of a natural rollover while the window is open, and (3) the probability that the gas release volume is between 1000 scf and 6000 scf.

The frequency of a dome intrusive operation is difficult to quantify because they is not a routine operation. During the 20 month period between the start of pump operation July 1993 and the end of February 1995, there have been between 10 and 15 dome intrusions. These activities include installation of a new video camera, installation of the multi-port riser (MPR), installation and removal of water wands, installation and removal of the viscometer, and installation of a new level measuring instrument. Note, installation and operation of the void meter is not a dome intrusive operation, so it requires a separate safety assessment. Based on experience a conservative estimate of the frequency of intrusion windows is 7.5/yr. A bounding estimate of 10/yr will be used in this analysis.

Various probability distributions for the maximum level prior to a natural rollover are discussed in Ref. 5. The cumulative distribution function (CDF) for the maximum level can be interpreted as follows: given that a gas release event has occurred, the CDF is the probability that the next rollover will occur before the waste level reaches the specified level. If we assume that conditions in during pump operations are similar to conditions after a natural rollover, the probability of a natural rollover during the window is the CDF for maximum level evaluated at the level control for the window. If the window is closed before the level limit is reached, this probability estimate will be conservative.

Reference 5 indicates that the maximum level data can be correlated equally well with normal distribution, a log-normal distribution, and a three-parameter Weibull distribution. The log-normal distribution is used in this analysis because it gives the most conservative extrapolations. Consider a random variable x. If x follows a log-normal distribution, then ln(z) follows a normal distribution. If z is the maximum waste level prior to a gas release, the mean and standard deviation of ln(z) are 769.6079/127.6646 = 6.02840 and 1/127/6646=0.007833 respectively.[5] The probability that the next gas release event occur at level less than Z is

$$\Pr(\text{Natural GRE} \mid z \le Z) = \Phi((\ln(Z) - \mu)/\sigma) \;, \tag{10}$$

where $\Phi(.)$ is the CDF of the standard normal variate; and the values of this function are tabulated in most text books on probability and statistics.

The probability that the gas release volume is between 1000 scf and 6000 scf given the specified level control for a window and a gas release event can be estimated from Eq. (4) because this distribution is based on data for both natural and induced rollovers. The limits of integration for volume are 1000 scf and 6000 scf, and the limits of integration for volume are $-\infty$ and Z. A lower limit of $-\infty$ is used because the control allows a window at all levels less than Z. This probability is evaluated using Mathcad (see App. A).

The frequency of a gas release event during an intrusion window is

$$\begin{aligned} \lambda \quad &= \lambda_{window} \Pr(\text{Natural GRE} \mid z \le Z) \\ &\quad \times \Pr(1000 \text{ scf} < q_{GRE} \le 6000 \text{ scf} \mid \text{GRE and } z \le Z) \;, \end{aligned} \tag{11}$$

where

λ = frequency of a GRE during and intrusion window, and
λ_{window} = frequency of an intrusion window.

The results of the calculations are given in Table VII.

TABLE VII
ESTIMATES OF THE FREQUENCY OF A 1000 SCF TO 6000 SCF GAS RELEASE EVENT DURING AN INTRUSION WINDOW

Level Control for Window (in)	Probability of GRE given Level Control	Probability of Gas Release Between 1000 and 6000 scf given GRE and Level Control	Frequency of GRE Between 1000 and 6000 scf During Window (yr^{-1})
408	$1.4x10^{-2}$	0.71	$9.9x10^{-2}$
406	$2.5x10^{-3}$	0.58	$1.4x10^{-2}$
405	$8.7x10^{-4}$	0.50	$4.4x10^{-3}$
404	$2.9x10^{-4}$	0.41	$1.2x10^{-3}$
402	$2.4x10^{-5}$	0.26	$6.2x10^{-5}$

2.2.2 Pump Installation

The probability of each category of release is considered. Only the case of induced rollovers need to be considered. The duration of the pump installation is very short and the maximum level for pump operation is 402 in, so the probability of a natural rollover is extremely small.

The frequency of pump installation is 0.38/yr, (See Ref. 4) which is the frequency of pump failure.

Events Larger Than Installation Limit - As stated above, events larger than the installation limit are neglected; so the frequency is assumed to be zero.

Pump Installation Limit - Acceptable events for pump installation are releases between 1000 scf and 3650 scf. The probability of a release between 1000 scf and 3650 scf given an induced event for each of the three level categories is determined from Eq. (4). Using the results in App. B, the limits of integration for gas bubble volume are 910 scf and 3320 scf.

$$Pr(1000\ scf<q_{GRE}\leq 3650\ scf\,|\,404\ in<z\leq 406\ in) = 0.65\ .$$

$\Pr(1000\ \text{scf}<q_{GRE}\leq 3650\ \text{scf} \mid 402\ \text{in}<z\leq 404\ \text{in}) = 0.49$.

$\Pr(1000\ \text{scf}<q_{GRE}\leq 3650\ \text{scf} \mid z\leq 402\ \text{in}) = 0.25$.

The probability of a release between 1000 scf and 4000 scf given pump replacement is

$$\Pr(1000\ \text{scf}<q_{GRE}\leq 3650\ \text{scf} \mid \text{Pump Installation}) = \qquad (12)$$

$$\sum_i \Pr(\text{GRE} \mid \text{Level Interval i}) \Pr(1000\ \text{scf}<q\leq 3650\ \text{scf} \mid \text{Level Interval i})$$

The frequency of a release between 1000 scf and 3650 scf during installation is the frequency of a release due to pump failure plus the frequency of a release due to pump operation.

$$\lambda_{GRE} = \lambda_{failure} \Pr(1000\ \text{scf}<q_{GRE}\leq 3650 \mid \text{Pump Operation}) . \qquad (13)$$

The results of the probability and frequency calculations are given in Table VIII. The probabilities and frequencies at waste level controls of 405 in and 403 in were determined by a log-linear interpolation of the results at 420 in, 404 in, and 406 in.

Inconsequential Events - By definition, inconsequential events are not a safety concern. Therefore, the frequency of the events is not estimated.

2.2.3 Pump Removal

The probability of each category of release is considered. Only the case of induced rollovers need to be considered. The duration of the pump removal is very short and the maximum level for pump operation is 403.4 in, so the probability of a natural rollover is extremely small.

The frequency of pump removal is 0.0.38/yr, (See Ref. 4) which is the frequency of pump failure.

Events Larger Than Removal Limit - As stated above, events larger than the installation limit are neglected; so the frequency is assumed to be zero.

Pump Removal Limit - Acceptable events for pump removal are releases between 1000 scf and 2500 scf. The probability of a release between 1000 scf and 2500 scf given an induced event for each of the three level categories is determined from Eq. (4). Using the results in App. B, the limits of integration for gas bubble volume are 910 scf and 2280 scf.

TABLE VIII
ESTIMATES OF THE FREQUENCY OF A 1000 SCF TO 3650 SCF GAS RELEASE EVENT DURING PUMP INSTALLATION

Waste Level Control (in)	$Pr(1000 \le q_{GRE} <$ 3650 scf) Given Induced GRE and Level Interval	$Pr(1000 < q_{GRE} \le$ 3650 scf) Given Pump Installation and Level Control	Frequency of Installation Induced GRE Between 1000 and 3650 scf
406	0.65	4.9×10^{-2}	**1.9×10^{-2}**
405	-	2.6×10^{-2}	**9.9×10^{-3}**
404	0.49	1.4×10^{-2}	**5.3×10^{-3}**
403	-	6.5×10^{-3}	**2.5×10^{-3}**
402	0.25	3.0×10^{-3}	**1.1×10^{-3}**

$$Pr(1000\ \text{scf} < q_{GRE} \le 2500\ \text{scf} \mid 404\ \text{in} < z \le 406\ \text{in}) = 0.55\ .$$

$$Pr(1000\ \text{scf} < q_{GRE} \le 2500\ \text{scf} \mid 402\ \text{in} < z \le 404\ \text{in}) = 0.45\ .$$

$$Pr(1000\ \text{scf} < q_{GRE} \le 2500\ \text{scf} \mid z \le 402\ \text{in}) = 0.25\ .$$

The probability of a release between 1000 scf and 2500 scf given pump replacement is

$$Pr(1000\ \text{scf} < q_{GRE} \le 3650\ \text{scf} \mid \text{Pump Removal}) = \qquad (14)$$

$$\sum_{i} Pr(\text{GRE} \mid \text{Level Interval } i)\ Pr(1000\ \text{scf} < q_{GRE} \le 3650\ \text{scf} \mid \text{Level Interval } i)$$

The frequency of a release between 1000 scf and 2500 scf during removal is the frequency of a release due to pump failure plus the frequency of a release due to pump operation.

$$\lambda_{GRE} = \lambda_{failure} \Pr(1000 \text{ scf} < q_{GRE} \leq 2500 \mid \text{Pump Operation}) . \qquad (15)$$

The results of the probability and frequency calculations are given in Table IX. The probabilities and frequencies at waste level controls of 405 in and 403 in were determined by a log-linear interpolation of the results at 402 in, 404 in, and 406 in.

TABLE IX
ESTIMATES OF THE FREQUENCY OF A 1000 SCF TO 2500 SCF GAS RELEASE EVENT DURING PUMP REMOVAL

Waste Level Control (in)	$\Pr(1000 \leq q_{GRE} <$ 2500 scf) Given Induced GRE and Level Interval	$\Pr(1000 < q_{GRE} \leq$ 2500 scf) Given Pump Removal and Level Control	Frequency of Removal Induced GRE Between 1000 and 2500 scf
406	0.55	4.2×10^{-2}	1.6×10^{-2}
405	-	2.3×10^{-2}	8.7×10^{-3}
404	0.45	1.3×10^{-2}	4.9×10^{-3}
403	-	6.1×10^{-3}	2.3×10^{-3}
402	0.24	2.9×10^{-3}	1.1×10^{-3}

3.0 GAS RELEASE EVENTS IN TANK 241-SY-103

Gas release events also occur in Tank 241-SY-103. Releases for this tank may have an impact on Tank 241-SY-101. The frequency of a release in Tank 241-SY-103 can be estimated from the available data. Table IV list the dates and intervals between gas release events in Tank 241-SY-103.

Based on the data in Table VI, the average period between gas release events is 4.8 mo. The frequency is the inverse of the average period, so the frequency of a gas release event in Tank 241-SY-103 is 0.21/month or 2.5/yr.

The frequency of a simultaneous gas release is the frequency of a gas release event in Tank 241-SY-101 time the probability given by Eq. (16). The frequency of a gas release event is the frequency of a pump induced event and a natural event that occurs in the pump fails. The frequency of a pump induced event given the level control and without regard to size is

$$\lambda_{pi} = \lambda_{operation} \sum_{i} Pr(GRE \mid Level\ Interval\ i) \ . \tag{17}$$

Assuming that there is only one spare pump, the frequency of a gas release event as a result of pump failure is given above as 0.22/yr. The frequency of a gas release event in Tank 241-SY-101 is

$$\lambda_{101} = \lambda_{pi} + \lambda_{failure} \ . \tag{18}$$

The frequency of simultaneous gas release events is

$$\lambda_{2GRE} = \lambda_{101}\, Pr(GRE\ in\ 103 \mid GRE\ in\ 101) \ . \tag{19}$$

The results for various level controls are given in Table X.

TABLE X
FREQUENCY OF SIMULTANEOUS GAS RELEASE EVENTS IN TANK 241-SY-101 AND TANK 241-SY-103

Waste Level Control (in)	Pr(GRE) Given Pump Operation and Level Interval	Frequency of GRE Given Level Control (yr^{-1})	Frequency of Simultaneous GRE (yr^{-1})
406	0.053	10	**2.8×10^{-3}**
404	0.023	3.5	**9.8×10^{-4}**
402	0.004	0.71	**2.0×10^{-4}**

3.2 Pump Installation

In this analysis, it is assumed that a replacement mixer pump can be installed in one 8 hr shift. The exposure of pump installation is the period required for pump installation times the frequency of pump installation. The exposure time is

$$t_{exp} = (8\ \text{hr/operation})(0.38\ \text{operations/yr})/(24\ \text{hr/day})(365\ \text{day/yr})$$
$$= 3.5\text{x}10^{-4}\ \text{yr/yr}\ .$$

The frequency of a gas release event in Tank 241-SY-103 occurring during pump removal is

$$\lambda = \lambda_{103}\, t_{exp} = (2.5/\text{yr})\ (3.5\text{x}10^{-4}\ \text{yr/yr}) = 8.7\text{x}10^{-4}/\text{yr}\ . \qquad (20)$$

3.3 Pump Removal

It is assumed that a failed mixer pump can be removed from the tank in a single 8 hr shift. Therefore, the frequency of an event in Tank 241-SY-103 during pump removal is the same as the frequency for pump installation.

4.0 OTHER PROBABILITY CALCULATIONS

Several accident sequences are initiated by a gas release event. In order to estimate the frequencies of these accidents the split fractions for the various branches of the event tree must be determined. This section summarises the sources and analysis used to obtain the split fractions.

4.1 Ignition Source Probability

The risk assessment for Tank 241-SY-101 gives an ignition probability of $1.3\text{x}10^{-3}$.[7] This study references this probability to a report by Powers and Morales.[8]

4.2 Vent System Failure Probability

The availability of the vent system during a gas release event must be considered. The risk assessment of Tank 241-SY-101 reports the unavailability of the vent system to be $4.5\text{x}10^{-3}$.[7] This estimate takes credit for an emergency diesel generator. The reliability of this generator is reported to be 0.3 failures/demand. Only one cut set for the system unavailability includes loss of tank farm power and failure of the diesel generator. Therefore, the unavailability of the vent system without the diesel generator can be estimated as follows:

$$U_{vent} = U_{w/diesel} - \Pr(\text{Loss of Power})\Pr(\text{Diesel Fails} \mid \text{Loss of Power}) + \Pr(\text{Loss of Power}) \quad (21)$$

The probability of loss of power to the SY Farm is $4.5\text{x}10^{-4}$.[7] The unavailability of the vent system without taking credit for the diesel generator, as calculated from Eq. (19), is $4.8\text{x}10^{-3}$.

4.3 Multi-Port Riser Failure Probability

The probability of a single panel of the Multi-Port Riser opening during a gas release event is estimated to be $4.8\text{x}10^{-4}$ per event.[9]

4.4 Loss of Negative Pressure

Loss of negative pressure in the waste tank is one of the consequences of a gas release event, but there are also other causes of tank pressurisation. Tank pressurisation is not a concern during normal operations because all of the risers are closed. Pressurisation during installation and removal can be a problem because there are open risers.

Analysis of Unusual Occurrence Reports[7] list the following causes of pressurisation: transfer-caused over pressure, accidental loop seal filling, vaporisation, loss of vent fan, interfacing system pressurises tank, inadequate ventilation, filter plugging, and de-entrainer plugging. Accidental loop seal filling is only applicable to aging waste tanks, so it is not pertinent to Tank 241-SY-101. Tank 241-SY-101 is not a high heat tank and does not contain any heater, so vaporisation is not applicable. There will be no transfer to or from Tank 241-SY-101 during pump installation and removal; so transfer-caused over pressure is not applicable. This factor will need to be re-evaluated for the analysis of retrieval operations.

The frequencies of the various cause of pressurisation are listed in Table XI. If all the cause of pressurisation are assumed to be independent, the frequency of vent system failure during pump installation is the sum of the frequencies of the various causes. Combining the frequency gives a total frequency of pressurisation of 0.54/yr. The vent system must be turned off during pump removal, so the probability of release must be assumed to be unity. The frequency of a release during removal is the frequency of removal, which is 0.38/yr.

TABLE XI
FREQUENCIES OF EVENTS CAUSE OVER PRESSURISATION OF TANK 241-SY-101[7]

Cause	Median Frequency (yr^{-1})
Loss of Ventilation Fan	4.1×10^{-1}
Interfacing System Pressurises Tank	7.6×10^{-3}
Inadequate Ventilation	7.6×10^{-3}
Filter Plugging	8.6×10^{-2}
De-entrainer Plugging	3.0×10^{-2}

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APPENDIX A
MATHCAD FILE FOR CALCULATING PROBABILITY THAT AN INDUCED ROLLOVER GIVEN SIZE AS A FUNCTION OF LEVEL

Evaluation of Probabilities of Volumes of Induced Rollovers

The purpose of this calculation is to evaluate the probability that that an induced rollover release a gas bubble volume between q_1 and q_2 given that the level is between z_1 and z_2.

The waste level and the natural log of gas volume can be represented by a joint normal distribution. The means and standard deviations are:

Waste Level (in):	$\mu_1 := 413.5$	$\sigma_1 := 4.9$
ln(Gas Volume) (scf):	$\mu_2 := 8.37$	$\sigma_2 := 0.93$

The covariance matrix of the quantities is:

$$V := \begin{pmatrix} 24.050 & 3.599 \\ 3.599 & 0.871 \end{pmatrix}$$

The joint probability density function is:

$$f(z,q) := \frac{1}{2\cdot\pi\cdot|V|}\cdot\exp\left[\left[-\frac{1}{2}\cdot\begin{pmatrix} z-\mu_1 \\ q-\mu_2 \end{pmatrix}^T\cdot V^{-1}\cdot\begin{pmatrix} z-\mu_1 \\ q-\mu_2 \end{pmatrix}\right]_1\right]$$

Now define the following function need to evaluate the probability:

$$F(q_1,q_2,z_1,z_2) := \int_{z_1}^{z_2}\int_{q_1}^{q_2} f(z,q)\,dq\,dz$$

The probability of the event is

$$\Pr(q_1, q_2, z_1, z_2) := \frac{F(q_1, q_2, z_1, z_2)}{F(\ln(10), \ln(20000), z_1, z_2)}$$

Upper and lower limit for gas volume of 10 scf and 20000 scf are used instead of zero and infinity to prevent numerical problems.

The maximum expected gas release volume is 10480 scf, which corresponds to a bubble release volume of 9540 scf. The coversion from total volume of gas release to volume of bubbles released is given in App. B. The probability of gas bubble release greater than 9540 scf is given below.

$$\Pr(\ln(9540), \ln(20000), 404, 406) = 2.2 \cdot 10^{-4}$$

$$\Pr(\ln(9540), \ln(20000), 402, 404) = 2.9 \cdot 10^{-5}$$

$$\Pr(\ln(9540), \ln(20000), 395, 402) = 2.1 \cdot 10^{-6}$$

The maximum gas release volume for which there is no structural damage in the event of a burn is 8650 scf, which corresponds to a bubble release volume of 7870 scf using the conversion given in App. B. The probability of a gas release event greater than the structural limit but less than the maximum expected release is the probability of a bubble release between 7870 scf and 9450 scf.

$$\Pr(\ln(7870), \ln(9450), 404, 406) = 4.9 \cdot 10^{-4}$$

$$\Pr(\ln(7870), \ln(9450), 402, 404) = 8 \cdot 10^{-5}$$

$$\Pr(\ln(7870), \ln(9450), 395, 402) = 7.2 \cdot 10^{-6}$$

Ignition of the flammable gas is assumed to be impossible if the average concentration in the dome is less than 2% of the lower flammable limit. The gas volume corresponding to 25% of LFL is 1000 scf, which is a 910 scf bubble release. The probability of a gas release between 1000 scf and 8650 scf, which is equivalent to a bubble release between 910 and 7870 scf, is

$$\Pr(\ln(910), \ln(7870), 404, 406) = 0.7$$

$$\Pr(\ln(910), \ln(7870), 402, 404) = 0.5$$

$$\Pr(\ln(910), \ln(7870), 395, 402) = 0.26$$

The maximum allowable gas release during pump installation is 3650 scf. The probability of a release between 1000 and 3650 scf, which as a bubble release between 910 and 3320 scf, is:

$$\Pr(\ln(910), \ln(3320), 404, 406) = 0.65$$

$$\Pr(\ln(910), \ln(3320), 402, 404) = 0.49$$

$$\Pr(\ln(910), \ln(3320), 395, 402) = 0.25$$

The maximum allowable gas release during pump removal is 2500 scf. The probability of a release between 1000 and 2500 scf, which as a bubble release between 910 and 2280 scf, is:

$$\Pr(\ln(910), \ln(2280), 404, 406) = 0.55$$

$$\Pr(\ln(910), \ln(2280), 402, 404) = 0.45$$

$$\Pr(\ln(910), \ln(2280), 395, 402) = 0.24$$

The maximum allowable gas release during window of intrusive operations in the dome is 6000 scf. The release during a window is the result of a natural rollover, so there is no need to divide the release into 2 in segments. The probabilities are conditioned on the level control of ≤Z, which is treated as the interval from 395 in to Z in these calculations. The probability of a release between 1000 and 6000 scf, which as a bubble release between 910 and 5460 scf, is:

$\Pr(\ln(910), \ln(5460), 395, 406) = 0.58$

$\Pr(\ln(910), \ln(5460), 395, 405) = 0.5$

$\Pr(\ln(910), \ln(5460), 395, 404) = 0.41$

$\Pr(\ln(910), \ln(5460), 395, 408) = 0.71$

$\Pr(\ln(910), \ln(5460), 395, 402) = 0.26$

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1. Sullivan, "A Safety Assessment for Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-SY-101: Hanford Site, Richland, Washington," Los Alamos National Laboratory report LA-UR-92-3196 Rev. 14 (March 31, 1995)

2. W. Kubic, "Dissolved Ammonia in Hanford Site Waste Tank 241-SY-101," Los Alamos National Laboratory report LA-UR-94-4235 (October 1994).

2.11. Passwords

GENESIS contains three levels of password entry into the DACS system. These levels are listed below, along with the privileges afforded by each level.

Name	Level	Scope of Permitted Operation
View only	0	No changes or submenus can be displayed, will not exit to DOS
Operator	1	Data entries in user displays can be modified, no submenus can be displayed, will not exit to DOS
Technician	2	Algorithm submenus can be displayed, values on the first page can be changed, mode of operation can be switched between auto and manual
Engineer	3	All values can be changed during the runtime session

2.12. Pump Overspeed Protection

Every AF5000+ motor drive has a parameter field MAXSPD, the maximum speed in the recorded speed unit that can be programmed through the SPDSET command. If an operator tries to command the drive to run at a value greater than the MAXSPD value, the speed setpoint becomes the value stored in MAXSPD. The MAXSPD value is stored in nonvolatile RAM so that the last programmed value is present upon power cycling.

GENESIS also protects the setpoint entry field from being programmed with values out of range. Range extents are entered in AIN blocks in the configurator. These are changed by an operator entering the runtime system at the engineer password level or by a programmer knowing the password for altering the strategy. If an operator tries to over- or underlimit a setpoint, GENESIS restricts the entered value to the appropriate limit.

The AF5000+ variable speed motor drives can be controlled by a manual panel or by the DACS. During pump testing, the control is communicated from the DACS over an RS-232 communications link (see Fig. S-1). The manual control panels were disabled to avoid interference with the DACS. Protection against an inadvertent overspeed command is enabled by setting a MAXSPD in nonvolatile memory in the motor drive. This can be done over the communication link. A command to the speed controller to exceed this speed will be disregarded and the speed set to the value of MAXSPD.