Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

AUG 3 0 1996

96-WSD-173

Mr. John T. Conway, Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, N.W., Suite 700
Washington, D.C. 20004

Dear Mr. Conway:

TRANSMITTAL OF INFORMATION TO COMPLETE MILESTONE 5.4.3.1.B

This letter transmits the document that completes Milestone 5.4.3.1.b, as specified in Revision 1 of the Recommendation 93-5 Implementation Plan (IP). This milestone, scheduled for completion in August 1996, is described in the IP as follows: "Report on lightning evaluation, and if the probability exceeds 1×10^{-6} evaluate potential mitigating options for lightning strikes."

In the IP, the discussion of risks posed by lightning strikes focused on the need for lightning protection. The following work was listed to be completed:

- Check above ground tank penetrations resistance to ground in accordance with Institute of Electrical and Electronics Engineers Standard 142-82, "Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE 1991);"
- Complete a conceptual design on lightning protection; and
- Evaluate the probability of lightning striking a tank with a flammable gas release that exceeds the lower flammability limit in the tank headspace.

The evaluation of lightning strikes to Hanford Site high-level waste tanks is contained in the Westinghouse Hanford Company report titled, "Probability, Consequences, and Mitigation for Lightning Strikes to Hanford Site High-Level Waste Tanks," WHC-SD-WM-ES-387, Revision 1. The evaluation identified the need to install air terminals (lightning rods) on existing light poles in single-shell tank farms and to correct inadequately grounded risers on safety issue tanks. Correction of these items is scheduled for completion during Fiscal Year 1997.

If you have any questions, please contact me or you may contact Jim McClusky on (509) 372-0947.

Sincerely,

John D. Wagoner
Manager

WSD:CAG

Attachment

cc w/attach:
A. Alm, EM-1
R. Guimond, EM-2
J. Tseng, EM-4
S. Cowan, EM-30
M. Hunemuller, EM-38
M. Mikolanis, S-3.1
M. Whitaker, S-3.1
S. Trine, RL DNFSB Liaison

ENGINEERING CHANGE NOTICE

Page 1 of 2

1. ECN 609994

Proj. ECN

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	3a. USQ Required?	4. Date
Supplemental [] Direct Revision [X] Change ECN [] Temporary [] Standby [] Supersedure [] Cancel/Void []	J. M. Zach, Safety Issue Resolution, S7-14, 372-3434	[] Yes [X] No	07/29/96
	5. Project Title/No./Work Order No. Probability, Consequences, and Mitigation for Lightning Strikes to Hanford Site High-Level Waste Tanks	6. Bldg./Sys./Fac. No. 2704HV/200E	7. Approval Designator N/A
	8. Document Numbers Changed by this ECN (includes sheet no. and rev.) WHC-SD-WM-ES-387, Rev. 0A	9. Related ECN No(s). N/A	10. Related PO No. N/A

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

12. Description of Change

1) Document was re-edited to expand the List of Terms, to add a stand-alone chapter of references, and realign Section 2.1.
2) Section 4.6 concerning grounding of tank risers was corrected, information added from WHC-SD-WM-TR-034, Rev. 0.
3) Recommendation 2 was expanded to address prioritization of organic tanks.
4) Refined the numbers in Section 4.9 the degree of protection offered by the addition of air terminals on existing poles.
5) In Section 5 the discussion of SARR-015 revision was updated.
6) Section 5.3 included a statement on review of waste composition data.
7) Statement in the Executive Summary was clarified in response to comments by the DNFSB Staff.
8) Body of report was made consistent with Executive Summary with statement that "Double-Contained Receiver Tanks were not included in the scope of the review."
9) Recommendation 3 was changed to Conclusion 10 since it recommended no action.

13a. Justification (mark one)

Criteria Change	[]	Design Improvement	[]	Environmental	[]	Facility Deactivation	[]
As-Found	[X]	Facilitate Const	[]	Const. Error/Omission	[]	Design Error/Omission	[]

13b. Justification Details

Incorporated reviewers comments to make document easier to read.

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

See Distribution Sheet

RELEASE STAMP

DATE: AUG 01 1996

STA: 4

HANFORD RELEASE

ID:

(3)

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A-7900-013-1 (06/92)

ENGINEERING CHANGE NOTICE	Page 2 of 2	1. ECN (use no. from pg. 1) 609994

15. Design Verification Required	16. Cost Impact				17. Schedule Impact (days)	
	ENGINEERING		CONSTRUCTION			
[] Yes	Additional	[] $	Additional	[] $	Improvement	[]
[X] No	Savings	[] $	Savings	[] $	Delay	[]

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	[]	Inventory Adjustment Request	[]		[]

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

20. Approvals

Signature	Date	Signature	Date
OPERATIONS AND ENGINEERING		ARCHITECT-ENGINEER	
Cog. Eng. J. J. Zach *James Zach*	7/29/96	PE	
Cog. Mgr. R. J. Cash *R J Cash*	7/29/96	QA	
QA		Safety	
Safety		Design	
Environ.		Environ.	
Other		Other	
M. L. Cowen *[signature]*	7/31/96		
J. J. Klos *[signature]*	8/1/96		
E. J. Lipke *[signature]*	7/31/96	DEPARTMENT OF ENERGY	
J. E. Truax *[signature]*	8/1/96	Signature or a Control Number that tracks the Approval Signature	
		ADDITIONAL	

RECORD OF REVISION

(1) Document Number: WHC-SD-WM-ES-387

Page 1

(2) Title
Probability, Consequences, and Mitigation for Lightning Strikes to Hanford Site High-Level Waste Tanks

CHANGE CONTROL RECORD

(3) Revision	(4) Description of Change - Replace, Add, and Delete Pages	Authorized for Release: (5) Cog. Engr.	Authorized for Release: (6) Cog. Mgr. Date
0	(7) WHC-SD-WM-ES-387, REV. 0, EDT 613755 June 5, 1996	J. J. Zach	R. J. Cash
~~0A~~ 1RS	Revision page 1, ECN 609994	James Zach 7/29/96	R. J. Cash 7/29/96

PROBABILITY, CONSEQUENCES, AND MITIGATION FOR LIGHTNING STRIKES TO HANFORD SITE HIGH-LEVEL WASTE TANKS

J. J. Zach
Westinghouse Hanford Company, Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-87RL10930

EDT/ECN: ECN 609994 UC: 2030
Org Code: 79300 Charge Code: E45379
B&R Code: Total Pages: 72

Key Words: Lightning, Lightning Mitigation, Lightning Frequency

Abstract: The purpose of this report is to summarize selected lightning issues concerning the Hanford Waste Tanks. These issues include the probability of a lightning discharge striking the area immediately adjacent to a tank including a riser, the consequences of significant energy deposition from a lightning strike in a tank, and mitigating actions that have been or are being taken. The major conclusion of this report is that the probability of a lightning strike depositing sufficient energy in a tank to cause an effect on employees or the public is unlikely; but there are insufficient, quantitative data on the tanks and waste to prove that. Protection, such as grounding of risers and air terminals on existing light poles, is recommended.

Release Approval 8/1/96 Date

DATE: HANFORD RELEASE STA: 4 ID: 3
AUG 01 1996
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Approved for Public Release

EXECUTIVE SUMMARY

The purpose of this paper is to evaluate the probability and potential consequences of lightning strikes affecting the underground waste storage tanks at Hanford. It does not address Double-Contained Receiver Tanks (DCRTs). These results are used to determine the need for any corrective or mitigative actions in order to provide an acceptable level of safety.

Lightning strike probability is determined on the basis of lightning detection over a 10-yr period, resulting in an assumed strike probability of 0.06 flash/km^2/yr.

While the data support the determination of a strike probability, lightning behavior cannot be easily predicted. A quantitative assessment of the likelihood of specific behaviors or how lightning effects will propagate through the systems or equipment in the vicinity of a strike cannot be performed.

The results of this analysis demonstrate that lightning strikes on or near tanks have the potential of depositing energy in the waste. While it is demonstrated that energy deposited in the waste is reduced as the strike location becomes more removed from the direct tank area, a strike anywhere on the farm can affect a tank.

There are basically two lightning effects of concern: the ignition of flammable gas in the tank head space and the ignition of solid or liquid waste stored in the tanks. Very low energy deposition levels are required to ignite flammable gas, while relatively high deposition levels are required to ignite solid or liquid waste. This report identifies the appropriate target area of concern for both types. The results are as follows:

1. For flammable gas concerns, the assumed area should be the area of each tank farm (including all tanks within the farm), resulting in a frequency of 2 x 10^{-2}/yr for impacting any of the tanks (i.e., once in 50 yr a lightning strike on a farm could cause spark[s] in a tank[s] in that farm). The result is based on the highly conservative assumption that any strike within a farm could affect any or all of the tanks. This does not consider the gas concentration in the head space, only that a spark could occur.

2. For solid and liquid wastes, the assumed area should be the cross-sectional area of the tank, resulting in a frequency of 5 x 10^{-3}/yr for impacting any of the tanks (i.e., one of the tanks may have a strike above it every 200 yr). This is based on the conservative assumptions that all tanks contain dry, fuel-rich waste and that a strike anywhere above the tank could result in a large energy deposition in the waste.

Given these probabilities and a strike in the areas specified, it is appropriate to evaluate the likelihood that waste conditions will exist to support combustion; that sufficient energy will be deposited in the solid, liquid, or gaseous waste to ignite the waste; and that any such ignition will lead to unacceptable results. The results are summarized by the following.

- Analysis and tank head space measurements indicate that the total time the tanks on most farms would exceed the Lower Flammability Limit (LFL) is less than 8 hr/yr (10^{-3}). Although monitoring and analysis continue, and issues such as the likelihood that a storm will cause a gas release-event from the waste have not yet been fully resolved, the evidence clearly supports the conclusion that the probability of a flammable gas mixture existing in a tank is low.

- Not all tanks contain dry, fuel-rich waste and where it exists in tanks, it may not be wide-spread. It appears that there may be organic concerns in about 20% to 30% of the tanks, and the organics may be wet enough to preclude ignition or may be localized within the tank. Characterization and analysis continue. The evidence supports the conclusion that, given a strike on a tank, assuming a value of 1.0 as the probability of lightning energy being in a dry, fuel-rich location may be very conservative.

- It is not possible to determine the likelihood that sufficient energy will be deposited into the waste or gas to cause ignition. Experiments elsewhere and rocket-triggered tests demonstrate that energy from lightning strikes takes many paths. Those penetrations which are well grounded to the tank structure and those risers which do not have instrumentation are very unlikely to deposit energy in the waste. By including all paths (including those which do not communicate with the waste), the likelihood of energy deposition is conservatively assumed to be 1.0.

- Many farms in general and most tanks in particular have a relatively target-free area above them (e.g., few pipes, ducts, risers). There are other structures (light poles, fences, buildings) that may be more likely to send up streamers that connect to the stepped leader (from the lightning bolt) than tank risers. No credit is taken for these other structures, and the cross-sectional area of the largest tanks is assumed as the target area for lightning to affect organic waste. A factor of 10 is conservatively included by using the cross-sectional area of the tank as the target area.

- The ongoing accident analyses have assumed that ignition of flammable gas within the headspace of a tank will cause dome collapse with a very large release of radioactive and toxic material. Ongoing studies of tank dome structural integrity indicate that this is a very conservative assumption.

Because of the uncertainties in many aspects of the assessment of lightning risks, it is not possible to demonstrate quantitatively that an unacceptable lightning-caused event is incredible. The lightning strike probability indicates the possibility of a strike within the tank farms within the remaining life of the tanks. The qualitative factors that are known, however, support the conclusion that the likelihood of igniting the waste is low. Because of the uncertainty associated with this analysis, it is appropriate and necessary to take further steps to reduce this risk.

Potential actions have been assessed quantitatively where possible, and qualitatively when necessary, to identify the range of actions and benefits. On the basis of these results, Westinghouse Hanford Company has developed a recommended set of actions that it believes will provide an acceptable level of safety in a timely manner, while characterization, studies, and analyses are ongoing. These actions include the following.

1. Take the necessary corrective actions of grounding the risers that are not now acceptable and bonding the instrumentation in the risers to meet lightning protection code requirements (NFPA 780). Tanks that are on the organic watch list and those tanks that have similar controls should be corrected first.

2. Consider installation of grounded air terminals on existing power and light poles throughout the tank farms. Depending on the characteristics of the farm, this would provide from 0% (some farms do not have light poles in places to provide protection) to 40% improvement in lightning protection.

Greater protection could be provided by the addition of more poles and grounded air terminals, the use of grounded metal cages, or a catenary system over appropriate farms. As noted in IEEE Std 142 (1991), these systems provide a degree of protection of 99.5% to 99.9%. These protection systems would impact ongoing tank operations and sampling, require a diversion of significant resources, and result in increased occupational exposure for the workers installing the systems. Westinghouse Hanford Company does not recommend the more elaborate protection systems, but rather the corrective actions identified above.

Continuing research, analysis, and discussion concerning the behavior of flammable gas, organic pools, and solid waste are expected to confirm the validity of this approach. However, these results will be closely monitored to determine the need for additional action.

Because of the qualitative nature of much of the available information, others may judge the need for greater or lesser corrective actions. The purpose of this report is to provide the basis for such consideration.

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CONTENTS

CONTENTS (continued)

APPENDICES

LIST OF TABLES

LIST OF TERMS

BLM	Bureau of Land Management
C-G	Cloud-to-ground
DCRT	Double-contained receiver tank
DOE	U. S. Department of Energy
DST	Double-shell tank
FIC	Food Instrument Corporation (level detector)
GAI	Global Atmospherics, Inc.
GRE	Ground Ring Electrode
HEPA	High-efficiency particulate air (filter)
IEEE	Institute of Electrical and Electronics Engineers, Inc.
LFL	Lower Flammability Limit
LPS	Lightning Protection System
NFPA	National Fire Protection Association
NLDN	National Lightning Detection Network™
RF	Radio frequency
SHMS	Standard Hydrogen Monitoring System
SST	Single-shell tank
TA	Target area
TOC	Total organic carbon

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PROBABILITY, CONSEQUENCES, AND MITIGATION FOR LIGHTNING STRIKES TO HANFORD WASTE TANKS

1.0 INTRODUCTION

The purpose of this paper is to evaluate the probability and potential consequences of lightning strikes affecting the underground waste storage tanks. The direct effects of the lightning are considered, and not the radiological analysis resulting from an accident such as a waste fire or dome collapse. General recommendations are made to mitigate potential lightning strikes. It does not address Double-Contained Receiver Tanks (DCRTs).

The safety of the waste stored in the large, underground tanks at Hanford is a concern of the U. S. Department of Energy (DOE). This waste was generated as part of the reprocessing of irradiated fuel from the reactors on the Hanford site to recover the plutonium for the Department of Defense from 1944 until the mid-1980s. Tens of millions of gallons of waste are stored in the 177 tanks that range in capacity from 190,000 L (50,000 gal) to over 3,800,000 L (1,000,000 gal).

The potential hazard is that the chemical composition of certain types of wastes (which varies among and within the tanks) may be susceptible to ignition. For combustion to initiate, three components are necessary: fuel, oxidizer, and ignition source. Wastes having concerns as possible fuels are those which generate flammable gases and those which contain organic complexants and extractants. Waste tanks have a headspace with air above the waste surface and sludge with sodium nitrates/nitrites in many tanks, so an oxidizer can always be assumed to be present. Finally, for the waste to burn, there has to be a credible source of ignition.

It is generally recognized and demonstrated in this report that a lightning strike in a tank farm is an infrequent event. As such, the events of concern are those that can potentially have significant offsite consequences to the health and safety of the public.

For flammable gases the ignition source can have very low energy. The potential consequences of concern are related to dome collapse. In order to assess this hazard, the probability of lightning striking in a manner to cause a spark is analyzed, and the likelihood of the concurrent existence of a flammable gas mixture is also assessed. However, there is presently a lack of definitive data for many tanks to assess how often headspace gas concentrations actually exceed the Lower Flammability Limit (LFL).

Organic complexants and extractants exist in some of the tanks 100% of the time. Controls can be provided to reduce the likelihood of man-made sources of ignition. The only credible naturally-occurring ignition source that can produce enough energy to ignite a waste fire is lightning. Lightning has the potential to ignite the solid and liquid wastes if a significant arc between the waste surface and an object occurs (e.g., a riser or equipment in a riser), or significant energy is deposited in the waste in the form of ohmic heating. As with the flammable gas issue. the lack of definitive tank content data and clear rules for waste susceptibility preclude stating that ignition of organic waste is incredible.

The ultimate question is whether lightning can initiate an accident with unacceptable consequences. For purposes of this report, unacceptable consequences are those which cause a significant release of radioactive or toxic material. A pressure transient from an organic fire or a small flammable gas burn that causes a high-efficiency particulate air (HEPA) filter to rupture would not result in a significant release in this context. However, a dome collapse would result in a significant release of radioactive or toxic material.

While there is quite a bit of conservatism in the existing evaluations, neither a flammable gas nor organic waste ignition can be categorically demonstrated as incredible. Therefore a practical mitigation proposal is made.

Chapter 2.0 of this report describes the site with respect to lightning strike frequency and intensity. Chapter 3.0 gives the characteristics of lightning in general. Chapter 4.0 explains the tank structural issue, the riser configuration, and how they are grounded. It also includes the results of the field walkdowns for grounding adequacy and the recommendations for mitigation. Chapter 5.0 explains the contents of the tanks and their vulnerability to energy deposition from a lightning strike to the ground above a tank, one of its risers, or the equipment associated with the risers. Chapter 6.0 presents the conclusions and recommendations.

2.0 SITE CHARACTERISTICS WITH RESPECT TO LIGHTNING

The Hanford Site is located in southeastern Washington and experiences about ten thunderstorm days per year, with a range of 3 to 23 (Hoitink and Burk 1994). A day is counted as a thunderstorm day when a trained observer hears thunder. The thunder may be from only one lightning flash or may be from hours of storms containing hundreds of such flashes. There are three approaches to determine the frequency of lightning strikes: measurements, calculations, and in-situ reports. This section assesses the state of knowledge for all three approaches to determine the appropriate strike frequency.

2.1 MEASUREMENTS

GAI Global Atmospherics, Inc., (GAI) operates the National Lightning Detection Network™ (NLDN) and is based in Tucson, Arizona. The company is a private enterprise that provides information to the National Weather Service and other government agencies and private businesses. GAI uses over 100 ground-based sensors throughout the United States to detect and locate (through triangulation) ground lightning strikes. At present GAI is able to locate a ground strike within approximately 300 m of the actual location, with a detection efficiency of approximately 80% to 90%. GAI reported that over a 5-yr period (January 1, 1991, through January 1, 1996) there were approximately 600 lightning strikes in the 2,106 km^2 area centered around the tank farms in the 200 East and 200 West Areas (a rectangle approximately 54 km by 39 km). This yields a probability of less than 0.06/km^2 (using 600 strikes for the area over 5 yr). There is some variability across the area in the frequency of strikes, as might be expected considering the geography of the area. The Rattlesnake Hill area, 20 to 30 km to the south and west of the site, has a larger percentage of the strikes than the rest of the area. One 9-km^2 area in that vicinity had more that 0.30 strike/km^2/yr, while the frequency was 0.015 strike/km^2/yr directly over the 200 East and 200 West Areas. The high frequency is probably due to an orographic effect in which the hills "lift" the air, creating better conditions for lightning than if the hills did not exist. If one eliminates the Rattlesnake Hill area from inclusion in the Hanford area data, the 5 yr of data from a smaller area surrounding and including the tank farms, and the 10 yr of data from the Bureau of Land Management (BLM) discussed below, show a consistent value of 0.045 fl/km^2/yr as a value for measured ground strikes. The limited amount of data (10 BLM data points and 5 GAI data points) did not lend itself to a sophisticated mathematical distribution to determine confidence level.

BLM Information was collected from the BLM with respect to lightning strike frequency. Their data (as summarized in Table 2-1) covers 1986 through 1995. BLM was responsible for operating the developing technology within their charter to manage federal forests, including identifying potential forest fire locations. BLM operates a system in the western United States using the same technology (including sensors) as GAI, but with a less sophisticated algorithm for locating the strike precisely.

Table 2-1. Bureau of Land Management Lightning Data.

Year	Number of flashes	Negative flashes	Positive flashes
1986	66	61	2
1987	9	8	1
1988	28	16	11
1989	54	46	8
1990	60	55	5
1991	80	67	9
1992	88	76	5
1993	46	41	1
1994	41	38	0
1995	22	13	8
Total	494	421	50

Note:

The number of flashes is as calculated by the BLM. The negative and positive flashes were manually counted from the plots. The graphics presenting the information are such that a "-" (for a negative flash) could be masked by the longitude and latitude numerals or "+" used to reference points on the maps. The sum of the "negative flashes" and the "positive flashes" may not equal the "number of flashes" because of the manual counting process.

BLM information is for a rectangle of 36 km by 28 km (1008 km^2). Because the area covered is smaller (48%) than the GAI data, it excludes part of the Rattlesnake Ridge. The BLM overall flash frequency is 0.045 fl/km^2/yr compared to the GAI frequency of 0.06 fl/km^2/yr. Over the 5 yr of common data (1991 to 1995), the ratio of positive to negative flashes is about the same (1:9) for the two data sets. The 10 yr of data from BLM would suggest the last 5 yr were not atypical with respect to lightning strikes in the 200 East and 200 West Areas, at least when twice as long a time period is considered.

Detection Efficiency The BLM stated that the system may not detect essentially coincidental flashes and a strike extremely close to a sensor can "saturate" the sensor for a few seconds. During violent weather, there may be more than 1 channel from the cloud to the ground. For example, in Florida there is an average of 1.3 channels to ground that may be kilometers apart. Lightning detection systems could not differentiate the existence of a second channel until recently. Small flashes and those with non-standard waveshapes will not be detected. GAI states the efficiency of detection for the national system was 70% from 1989 to 1991, 65% to 80% from 1992 to 1994, and 80% to 90% in 1995. The BLM did not quote a detection efficiency, although it is assumed to be similar to GAI's. The BLM detection technology is basically the same as GAI's, while the communications link is land-based as opposed to the satellite system of GAI. For the purpose of this report, a detection efficiency of 75% will be assumed.

Hanford-area thunderstorms do not generate very many flashes. There were approximately 120 fl/yr reported by GAI. The BLM reported approximately 50/yr over a smaller land area than GAI reported. The BLM area may not cover the entire area observed to experience 10 thunderstorm days each year, while the GAI area is larger than the area the weather observers at Hanford can realistically hear every thunderclap. There is an average of 10 thunderstorm days per year and between 50 and 100 detected ground flashes each year. If each thunderstorm day is the result of one thunderstorm, the result is that a "typical" thunderstorm may generate 5 to 10 detected cloud-to-ground flashes in the 1,000 to 2,000 km^2 around the Hanford area.

The Pacific Northwest is not a high lightning storm area in general because of the relatively cold temperatures in the ocean coastal waters. Ocean storms do develop lightning as they progress east.

Thunderstorm Days The Hanford Meteorology Office was contacted with respect to thunderstorm days over the past 10 yr. The results are: 1986 - 9 days in the area, 1987 - 7 days, 1988 - 4 days, 1989 - 10 days, 1990 - 11 days, 1991 - 12 days, 1992 - 7 days, 1993 - 13 days, 1994 - 10 days, 1995 - 9 days. This average of greater than 9 thunderstorm days per year is consistent with the 10 thunderstorm days per year assumed in the calculational techniques, and supports the conclusion that the measured data are not skewed by unusual weather conditions over the time period.

As noted earlier, thunderstorm days are based upon human observation. The Hanford weather observatory is located just east of the 200 West Area. Because it is in the center of a large bowl formed by the surrounding ridges, the Hanford observatory may detect thunder at a greater range than the "typical" observer located at an airport or other urban or suburban location. The site's flora (no woods, cornfields, etc.) and few man-made structures also facilitate the sound of thunder travelling farther than in many other locations where there are weather observers.

Additional Information GAI also reported the distribution of the strikes as a function of the months. July has the most lightning strikes of any month, with most strikes annually occurring between May and August. However, in February 1994 there were approximately 15 strikes over the Hanford area, illustrating the occurrence of a thunderstorm or two in that month, which is unusual. The flash data are consistent with reportable occurrences noted in Appendix B. This information can be used to determine optimum times to perform certain evolutions in the tank farms that may place the tanks at a higher risk with respect to lightning events.

If further testing of tank characteristics (such as RF [radio frequency] testing) is done to determine lightning current splitting in the tank, the measured lightning currents may be useful. GAI characterized the peak current of the lightning strikes. The peak current for the average positive polarity flash was approximately 30,000 A, while none of the 600 ground flashes exceeded 83,000 A over the 5-yr period. Approximately 10% of the flashes had positive polarity. The average negative polarity flash had a peak current of approximately 17,500 A with a few scattered above 60,000 A. None exceeded 100,000 A. GAI states the system measures within 30% RMS (root mean square) for lightning current based on measurements of triggered lightning subsequent strokes.

2.2 CALCULATIONS

The following discussion is included in this report for the sake of completeness. Over the years there have been many attempts to fit equations to lightning strike frequency. The various fits resulted in a wide range of predictions as can be seen below. Included in the equations in some cases was a dependency upon latitude. Recent measurements do not support the dependency. While these calculational techniques are of interest, it is more appropriate to use actual data if sufficient, credible information exists.

The number of annual cloud-to-ground lightning discharges is a function of the number of thunderstorms an area has in a given year. The calculations below are based on an average area with a mix of convective and frontal storms. Hasbrouck (1995) presents two equations for ground-flash density. The latitude dependency in the equations has recently been found to not be supported by measurements. Cowley and Stepnewski (1994) used a third equation, similar to the first two.

$$F_g = 0.1 \times (1+\{lat/30\}^2) \times (0.02 \times T_d^{1.7}) \quad (2\text{-}1)$$

lat = latitude of the site in degrees {for Hanford, 47°}
T_d = thunderstorm day/yr (from isokeraunic map) {for Hanford, 10}

$$F_g = 0.1 \times (1+\{lat/30\}^2) \times F_t \times T_d \quad (2\text{-}2)$$

F_t = Total Daily Flash Density ($fl/km^2/T_d$)
0.4 to 1.1 [based upon: 3 fl/min, 1-3 h/storm/T_d, 500 km^2/storm]

$$Fg = 0.1 \times T_d \quad (2\text{-}3)$$

Equation 2-1 gives a ground-flash density for the Hanford area of 0.3 $fl/km^2/yr$. Equation 2-2 gives a range of 1.4 to 3.8 $fl/km^2/yr$, based on assumed storm duration of 1 to 3 hr. Using equation 2-3, a ground-flash density of 1.0 $fl/km^2/yr$ is calculated.

2.3 IN-SITU REPORTED DATA

There has been no formal employee reporting system for cloud-ground flashes at Hanford. Cowley and Stepnewski (1994) report that, "Actual lightning strikes in the tank farms have not been documented. However, conversations with tank farm operations personnel indicate that lightning strikes do occur within the tank farms. This gives credence to the idea that strikes occur within tank farms about once a year." Some of the anecdotal evidence has to do with the loss of instrumentation during a storm. Loss of instrumentation is usually indicative of a power perturbation and does not indicate a direct threat to the waste. (See the descriptions of *RL-WHC-SOLIDWASTE-1991-1002* and *RL-WHC-ANNALLAB-1991-1005* in Appendix B. In each case a power perturbation caused the loss of instruments/ventilation.) It is unknown how much is hearsay as opposed to personal experience. If the actual flash frequency is 0.06 fl/km^2/yr and the area of all the farms [including both the double-shell tank (DST) and single-shell tank (SST) tank farms] is approximately 0.4 km^2, then a frequency of 0.024/yr would be expected for a flash to occur in a tank farm (once every 40 yr). This is significantly less than the once per year or once several years anecdotally noted.

A second source of information is Kelly and Hasbrouck (1995). They note that Hanford had the highest number of reports of "lightning occurrences" per thunderstorm per year of any of the DOE sites. "Lightning occurrences" in this context are any reportable occurrences in which the word "lightning" was in the text. In fact, the ratio was twice as high as the next site (Savannah River). There were approximately 7 valid reports for each year, compared to approximately 15 for Savannah River and approximately 4 for Oak Ridge, who both have approximately five times as many thunderstorm days each year compared to Hanford. Site characteristics probably significantly influence this information. A single passing storm cell has more opportunity to affect a larger area, such as Hanford, than a smaller area, such as Oak Ridge. It is assumed that the basic reporting requirements are similar for each site, although this has not been investigated for this report. Appendix B presents a review of 33 occurrence reports associated with lightning from 1990 through 1995. It points out that there were three cases in which a single lightning flash likely resulted in multiple lightning occurrences (13 of the 16 reports associated with the 200 East and 200 West Areas were probably related to these three flashes).

The reported information confirms the fact that a lightning strike may occur approximately once per year in the tens of square kilometers surrounding and including the 200 East and 200 West Areas (including tank farms). Equipment is most often affected through the electrical distribution system. Loss of an instrument does not mean that it was directly struck by lightning, and it cannot directly cause combustion. No documented reports or evidence of lightning striking a tank farm exist.

2.4 CONCLUSION

A ground flash frequency of 0.06/km^2/yr can be assumed. This is arrived at by dividing the measured values (0.045 fl/km^2/yr) by the detection efficiency (75%). The frequency is conservative since it includes some areas that experience more lightning strikes on the average than the tank farm areas. To add additional conservatism for multiple ground strokes affecting divergent targets, 0.1 fl/km^2/yr could be assumed. This is more than one order of magnitude less than the frequency previously assumed. (Cowley and Stepnewski 1994)

3.0 LIGHTNING FLASH CHARACTERISTICS

3.1 GENERAL LIGHTNING CHARACTERISTICS

Lightning can be caused by thunderstorms, snow storms, volcanos, and dust storms. Hanford is too distant from any active volcano to have lightning caused by volcanic activity. Dust storm lightning is relatively rare and does not have currents as high as thunderstorm lightning.

To understand the hazard lightning presents, it is necessary to understand the characteristics of lightning. Of the several types of lightning that are produced in a thunderstorm [e.g., intracloud, cloud-to-ionosphere, intercloud, cloud-to-air, and cloud-to-ground (C-G)], the only one of concern to the safety of the waste in the storage tanks is C-G. Hasbrouck and Majumdar (1995) report that a typical flash lasts approximately 1/2 to 1 s.

The severity of a lightning strike is normally measured by the magnitude of the peak current, charge transfer, and action integral. Based on data collected over decades around the world, for negative lightning 200,000 A is generally accepted as the 99th percentile value. In other words, 99% of C-G negative lightning flashes have less than 200,000 A. As noted in Chapter 2.0, data collected using indirect measurements over the past 5 yr for the Hanford area indicate that, of the 600 C-G flashes, no negative lightning flashes exceeded 100,000 A with a 30% measurement accuracy.

Hasbrouck (1989) describes the phenomenology of a lightning strike. A "stepped leader" or ionized channel moves toward the earth in increments of approximately 50 m. The current may peak at -1000 A, while the average may be approximately -100 A. These steps take approximately 1 μs and are separated by a 50-μs pause. Positively charged streamers start moving up from the earth, particularly from tall, grounded, pointed objects. One or more streamers may be formed. As the distance between the stepped leader and streamers narrows, breakdown of the intervening gap will occur when the field is greater than the dielectric strength of the air. This "striking distance" is normally in the range of 30 to 100 m.

The positive "return stroke" seeks to neutralize the ionized channel's negative charge following the channel at 35 to 100 m/μs to its upper end. It is possible that in a single flash, more than one streamer may be involved with one or more return strokes. The potential breakdown may occur across parallel paths. There may be two to three ground strike points separated by up to 10 m. Or there may be a cluster of several points within a few centimeters, partly dependent upon the geometry (e.g., a flat roof or a pointed air terminal).

As the potential of 50,000,000 to 100,000,000 V approaches earth, it makes the final jump to a streamer, determining the location of the strike and the magnitude of the return current. Typically one considers the "cone of protection" of a structure as the area bounded by a circle with a radius of the height of the structure. The "cone of protection" for more energetic strokes (200,000 A) is more effective than for the less severe strokes (50,000 A) because the former have a greater striking distance than the latter. This is because the more energetic stepped leader can seek a streamer from a more distant, taller, more conductive structure than the less energetic flash.

The current for the return stroke will flow through parallel paths to the point of connection(s) between the stepped leader and one or more streamers.

3.2 LIGHTNING EFFECTS

The effects of a lightning flash can be either direct or indirect. Physical damage to a structure is a direct effect and occurs when the return-stroke current flows through material that is relatively non-conductive, and significant ohmic heating or arcing occurs. The current may be contained within the concrete wall of a tank using reinforcing bar as the conductor. Where gaps exist, arcing may occur, vaporizing moisture in the concrete. Arcing may occur in the tank between the metal tank walls and the waste, between the tank dome reinforcing bar and a riser that is not well bonded electrically to the rebar, between equipment passing through the riser and the riser itself, and between equipment passing through a riser and the waste surface (including low energy sparks that could ignite flammable gas).

Indirect effects of a lightning flash are electrical interference and fires that result from arcs. The energy from a flash may melt metal items in a tank which could fall into the waste. If the item were large enough and hot enough (i.e., contained a significant amount of energy), certain types of waste may be ignited.

Lightning is unpredictable in its path and tremendous in its effects. It is the leading weather-related cause of injuries and deaths in the United States. The American Petroleum Institute states, "Even when all known precautions are employed, prevention or safe dissipation of direct-strike lightning cannot be absolutely assured...The methods provided in this section have been successful except on the rare occasions when lightning acted in an unpredictable fashion...Prevention of direct-stroke lightning is generally impossible." (API 1991)

As discussed in Chapter 4.0, it is accepted that a lightning strike in the vicinity of a tank(s) on a farm will lead to an electrical current in the concrete. Also discussed at length in Chapter 4.0 is the fact that the underground storage tanks will act as electrodes with respect to electricity, including lightning.

3.3 TYPICAL LIGHTNING PROTECTION

IEEE Std 142 (1991) states, "Lightning cannot be prevented; it can only be intercepted or diverted to a path which will, if well designed and constructed, not result in damage. Even this is not positive, providing only 99.5% to 99.9% protection." At the 99.5% protection level, the probability of a strike on the area of a farm with an area of 0.04 km^2 would change from 0.002 fl/yr (one strike in 500 yr) to 0.00001 fl/yr (one strike in 100,000 yr).

Typical lightning protection takes one of two forms: structure design or air terminal (lightning rod/tower or overhead ground wires). For example, the appropriate grounding of a steel tank provides protection through the structural design. A lightning rod on a barn or light pole is one example of an air terminal. Wires above high voltage lines and a catenary design are examples of overhead ground wires. The goal is to guide the lightning current to ground without adversely passing through something that could be affected (such as a person, house, weapons bunker, tank waste). NFPA 780 provides "...lightning protection system installation requirements for:...(e) structures containing flammable vapors, flammable gases, or liquids that can give off flammable vapors." (NFPA 780 1995)

Lightning protection does present an attractive target for lightning since it is designed to intercept lightning. Therefore, any installed system in the tank farms does present the possibility that a lightning strike may occur at that location, which otherwise would have struck outside the area. If the lightning protection ground system does not successfully divert the current away from the tanks, it is possible that a small spark could occur in a tank with flammable materials, creating ignition. The "footprint" of the farm is expanded slightly. Since lightning is so infrequent and there has been no evidence that lightning has been attracted to the existing targets (light poles, fences, radiation monitoring poles, etc.) within the farms, the argument that any mitigation will adversely affect the farms is not persuasive.

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4.0 TANK CHARACTERISTICS WITH RESPECT TO LIGHTNING

For a lightning strike to have the potential of igniting tank waste, it must somehow pass through the waste or heat a part of the tank that is in contact with the waste. The various paths that lightning may take to affect the waste are discussed below. The tank structure is a second concern and is discussed at length in Section 4.8. The electrical current will choose the paths of least impedance. Besides the tanks and risers there are wooden light poles on most farms, chain link fences surrounding most farms that are periodically grounded, some power poles, and other metallic protrubances. The fence and poles are likely sources for upward streamers.

Since the tanks are buried under 1.8 to 2.1 m (6 ft to 8 ft) of overburden, a ground strike is unlikely to result in significant current penetrating the tank to the waste. This is because the current will form fulgurites in the highly resistive soil and pass to the concrete shells of the underground tanks, which may act as ground electrodes (as discussed below). For solid/liquid ignition, the question then becomes what targets exist for lightning to strike such that energy can penetrate a tank to affect the contents.

Since the DSTs are completely enclosed containers, their vulnerabilities to lightning effects are significantly less than SSTs. Uman notes in Cowley and Stepnewski (1994), "The metal double-wall tanks provide effective lightning protection...<u>if</u> all tank apertures and penetrations can be properly protected from current and electromagnetic field entry. The tanks, being buried and having large surface area (concrete over metal), are inherently grounded." Since the metallic dome risers are reportedly welded to the metal tank roof, there is not the concern that the riser is not electrically bonded to the tank.

For simplicity of discussion in this section, unless otherwise noted, the word "riser" will include all penetrations into a tank which may be a lightning target. This includes the riser proper; equipment in the riser such as instruments, ventilation, pumps, etc.; and interconnecting underground piping with associated valves. There may also be a target somewhat remote from the riser proper, such as an instrument cabinet with a conduit containing wires attached to a riser. Depending on the electrical characteristics of the connections, such as resistivity, inductance, capacitance, and current-carrying capacity, a remote "target" could receive a strike that could affect one or more tanks.

4.1 POTENTIAL RESULTS OF LIGHTNING STRIKES

To assure that all the potential accidents related to lightning and the underground storage tanks are addressed, a review of Buck (1993) was done.

Buck (1993) identified farm-specific and tank-specific potential lightning strike events as listed in Cowley and Stepnewski (1994). Table 1 (Cowley and Stepnewski 1994) lists 33 events which could be initiated by a lightning strike on a farm, ranging from loss of instrumentation, to ignition internal to a tank, to a portable air compressor fire. Table 2 (Cowley and Stepnewski 1994) lists 48 tank-specific events if lightning were to strike the ground, a riser, an open pit, a closed pit, or other tank component. Since this report is concerned with only those events which lead to a significant release of radioactive or toxic material, the events associated with loss of instruments and fires external to the tanks are not considered further here. There are 12 identified sequences that lead to a short term "loss of confinement" (e.g., powered ventilation system shutdown). These events are not peculiar to lightning initiation and, without a spark/ignition in the tank, are not serious since there would be no motive force to lift a plume several hundred feet into the atmosphere such that it could be dispersed to distant workers or offsite.

Of the 24 events that have a hazard of "spark or ignition source internal to the tank," 5 are associated with the installation or removal of equipment (including crane usage), activities that are controlled to preclude the event. The control of these activities is not included in the scope of this report. If a pit is open, there are five events in which a lightning strike may cause a spark or ignition of material in the pit, and the secondary effect is burning material falling into the vapor space. There are three events in which lightning is postulated to cause ignition of combustible material that is hypothesized to have been left in a closed pit, and the ignited material enters the vapor space. There are two events (pump or leak detection control panel and heat trace panel) similar to the pit concerns, in which a lightning strike leads to flaming material, including sparks, falling through an open riser. The nine remaining events are associated with specific risers (passive ventilation, active ventilation, flake box, camera, FIC, thermocouple tree, additional passive ventilation, level observation well, solids level detector). These risers have been evaluated for grounding by Kiewert (1996).

Buck's review (1993) of potential events affecting the waste is inclusive. Analysis of the list of events indicates the scope of significant lightning-initiated events is limited to those discussed in this report. These events are riser-specific for events that may affect solid or liquid waste, such as ignition of flammable material that falls into the tank or sparks, or specific risers being struck. This review allows proceeding to the next step of determining the paths for lightning to affect the tank.

4.2 GENERAL TANK TARGET AREA

One of the more difficult issues with respect to tank vulnerability to lightning is the question of how large an area is the applicable target area for a tank. That is, a strike in what area will affect the tank. Before determining that, the meaning of "affect" must be considered, because there are several effects a tank and its waste can experience.

On the one hand, the whole tank farm could be considered as a lightning target. In some cases this is appropriate, since there are interconnections of equipment scattered throughout the farm and the tanks. The tanks can be considered as tied together electrically underground through interconnecting pipes and the cathodic protection system. As discussed in Section 4.8, the concrete has less resistivity than the backfill around the tanks. One way to consider the tanks is as 12 huge, concrete-encased electrodes (for a farm with 12 tanks).

The farms take various geometries, but in general are rectangles 120 m by 180 m (400 ft by 600 ft). This results in an area of approximately 0.02 km^2 per farm, or less than 0.25 km^2 total for the 12 SST farms. (Including the DST farms would increase the area to 0.40 km^2.) This approach of using farm area as the target is appropriate for consideration of structural effects, because all tanks can be somewhat affected by a single flash through the interconnections. It is also used in the consideration of flammable gas, because of the low energy threshold required for ignition of flammable gas and the possiblilty of a small spark being generated in a tank from a strike on equipment even indirectly connected to the tank.

4.3 TANK WASTE TARGET AREA

For sufficient energy to be deposited in liquid or solid waste to cause ignition, the strike must affect specific equipment that is not well bonded to a riser and the riser is not well bonded to the tank. In this case the tank farm area is not a concern, because the lightning energy does not have a path to the waste. The division of lightning current paths in the riser and the tank will depend on the relative resistance and inductance between the poorly-bonded equipment and riser, and the resistance and inductance through the equipment, the waste, and into the metal tank wall.

The cross-sectional area of a tank can be considered as the strike target area. A tank with a diameter of 24.4 m (80 ft) has an area of 465 m^2 (5,026 ft^2), or approximately $5x10^{-4}$ km^2. If there is 0.06 fl/km^2/yr, then the probability that the cross-sectional area of a tank will be struck is $3x10^{-5}$/yr. This approach would suggest that the chances of energy travelling through the overburden to a riser, being carried on pipes or conduits to a riser, or going down to the tank and circulating through the tank to a riser, could result in enough energy reaching the waste as to be a threat.

A detailed review of riser configuration on the tanks determined that the ground surface above many tanks is relatively free of pipes and conduits, particularly the SST farms. As discussed in Section 4.5, the interconnecting pipes are not likely paths to the waste. As part of WHC-SD-WM-TR-034, *Single Shell Tank Riser Resistance to Ground Test Report* (Kiewert 1996), an inventory of riser size (both cross-sectional area and height) was done. For example, each of the 12 tanks in T Farm (1,850,000 L or 500,000 gal), and 4 smaller tanks, have from 3 to 11 risers. By using the riser radius and the height (high, conductive structures are more attractive to lightning than no structure), an equivalent target area, TA, can be calculated for each riser in square meters.

$$TA = 3.14159 \times (r + h)^2 \quad (4\text{-}1)$$

where r = radius of the riser in meters, and h = height of the riser in meters. If r and h are be expressed in inches, the multiplication factor is 0.002 [3.14159 x (0.0254 m/in.)2]).

This does not consider the shadowing effect of a tall riser next to a low riser. It also does not take into account the conduit to pump control station, ENRAF unistrut or instrument cabinet, or those structures themselves.

A detailed review of the risers on three SST farms was done to determine how conservative the assumed target area was. Among the six A Farm tanks, A-105 was by far the tank with the largest target area (91.0 m^2), because of the several relatively tall risers it has. Even including A-105, the average area for the six A Farm tanks was less than 40 m^2.

The BX Farm target areas were influenced by tall risers for breather units. For example, BX-104 (R-1) and BX-106 (R-2) are the tallest structures on the three farms shown in Table 4-1. While these were the tallest risers at 2.4 m and 2.7 m (8 ft and 9 ft) respectively, the breather risers for the other BX tanks were between 1.5 m and 1.8 m (5 ft and 6 ft). Including BX-106, with its area of 47 m^2 due to the breather and instrument risers, the average area of the 12 tanks is 31.2 m^2.

For the T Farm tanks, the ones with the largest target areas were T-203 (33.5 m^2), T-107 (33.4 m^2), T-106 (32.8 m^2), and T-112 (31.5 m^2). T-102 has the smallest area with 12.8 m^2. Therefore, the target area for each tank in T Farm is less than 40 m^2, at least less than 0.1 of the cross-sectional area of the tank.

Table 4-1 provides the detailed information, tank-by-tank, riser-by-riser, for the A, BX, and TFarms. Assuming that each of the 34 tanks had a target area of 500 m^2, the area for the tanks on the three farms would be 17,000 m^2. The detailed riser-by-riser review calculates a total area of less than 1,100 m^2, or 1/15 of the previous value for the 34 tanks.

Further evaluation of specific risers can be made. Particular attention is paid to risers that contain equipment that reaches or penetrates the waste surface. Thermocouple trees and level detectors are normally among the tallest targets [nominally 1.9 m (75 in.) or less] on tanks in the A, BX, and T Farms. This results in a target of 12.1 m^2 or less for each of those risers. This area is included in the tank target area.

Other risers may be observation ports, breather pipes, spares, etc. These (as well as those identified above as having equipment that reach the waste) are of concern for two reasons. If a lightning strike current could enter the riser, it could cause a spark in a flammable gas mixture in the dome head space or pass into the rebar and cause damage. The structural effects on the concrete and rebar are discussed in Section 4.8. The potential for significant flammable gas ignition is covered by the assumption of the whole tank farm as the target.

An effort is underway to get the tank farms to a "controlled, clean, and stable" condition including removing the equipment that had been abandoned in place over the years. Connections of unused instruments to risers are being removed. This ongoing project, which has been successfully completed in the TX farm, further reduces the surface targets of a tank.

For target area of a tank with respect to significant energy deposition in the waste, the most straight-forward approach for this report is to assume the cross-sectional area of a tank (5×10^{-4} km^2). This value is quite conservative for the SST farms. There is a technical basis to assume a target area of less than 5×10^{-5} km^2 per tank based on field measurements.

4.4 MISCELLANEOUS OBJECTS WITHIN THE TANKS

In the future there may be additional equipment permanently installed into a tank that may be in contact with the waste, without the removal of existing equipment.

In addition to the active equipment in or near the waste, photos, videos, and records verify other conductive material extending out of the waste toward the tank dome. This includes instruments or equipment (e.g., thermocouples, lances, etc.) abandoned in place over the years. Some of these were disconnected and dropped into the waste, so there is no direct connection to a riser providing a path for lightning current. Others may have been disconnected at the flange and left in place, so there is a direct electrical path from the riser to the waste. It is impractical to try to identify each such object and categorize it with respect to its ability to act as a grounding rod.

It is possible for a lightning strike, if channeled down a riser, to spark across 1 to 2 m of head space to objects protruding out of the waste or to equipment in nearby risers. A rule of thumb is that an air gap of approximately 0.3 m (1 ft) normally precludes a spark between metal objects for potentials up to 140 kV. Schnetzer et al. (1995) report voltage transients as high as 200 kV within a building during rocket-triggered lightning experiments on a reinforced concrete structure. This information is intended to present some order of magnitude values of what can occur in a structure struck by lightning to better relate to metal objects in the tanks.

When there is a lightning strike in the vicinity of a tank, either to the ground or to a structure, the reinforced concrete tank will develop an electrical charge until the charge can dissipate into the ground. Equipment hanging into the waste from a riser can develop an induced charge, such that it could spark in the waste to the metal tank that is connected to interconnecting pipes, if that path has low enough resistance and inductive impedance to support the arc.

By including the "inactive" risers (those which do not have any equipment normally installed) in the riser target area discussed in Section 4.3, the tank target includes those known and unknown items that are in the tanks, as well as future additions.

4.5 INTERCONNECTING PIPES

There are underground interconnections for the tanks in the form of fill lines, cascade lines, etc. There are valve operators near the surface with reach rods to the valves in the pipes.

These valve operators are normally in valve pits with covers over the pits. The valve operators are not plausible targets for a direct strike because the covers shield them.

The pipes are under 10 m (30 ft) or more of very resistive soil. It is very improbable that a lightning strike on the ground will lead to a significant energy transport to the tank through the pipes, although it is possible a pipe could be charged by such a strike.

If lightning current were to be drawn through an interconnecting pipe from the ground or another tank, it could enter the metal tank to which it is connected through a "nozzle" arrangement above the waste. However, the solid/liquid waste would probably not be affected, since the current would have to find a path from the metal tank through the waste, to some equipment out of the top of the tank, through a riser to ground. It is highly unlikely that such a path could introduce a significant amount of energy or cause a large spark. It is more likely that ground would be found through another pipe that is connected to the tank or through the concrete-tank/metal-tank interface [1,000 to 1,400 m^2 (10,000 to 15,000 ft^2) of contact surface], even though there is "insulating" material (Gunite) between the metal tank and the concrete tank. The interface has a large cross-sectional area. The condition of the waste in the tank is analogous to a person in a metal car or a metal cage (Faraday cage), with millions of volts from a Van de Graaff generator passing through the cage (Newcott 1993).

Because of the low energy required to ignite flammable gas mixtures, it is reasonable to make the conservative assumption that any strike within a farm, including over buried pipes, will cause one or more sparks within each tank within the farm. Because of the higher energy required for ignition and the need for the energy to be deposited in the waste, that conservatism with respect to solid/liquid wastes is unnecessary.

4.6 RISER GROUND CHARACTERISTICS

There are several guides in effect for resistance to earth measurements that provide an acceptable level of protection from lightning for industrial facilities, including hazardous storage facilities. Note that these standards and guides are based upon a measurement of direct current or low frequency alternating current, while lightning is high frequency.

IEEE Std 142 (1991) states, "System ground resistances of less than 1 Ω may...only be required for large substations, transmission lines, or generating stations. Resistances in the 1 to 5 Ω range are generally found suitable for industrial plant substations and buildings and large commercial installations."

NFPA 780 (1995) presently does not address the specific resistance acceptable for lightning protection systems. But its predecessor, NFPA 78 (1989), states, "System ground resistances of less than 1 Ω may be obtained by the use of individual electrodes connected together. Such a low resistance may only be required for large substations or generating stations.

Resistances in the 25-Ω range are generally found suitable for industrial plant substations and buildings and large commercial installations."

NAVFAC DM 4.6 states that maximum ground resistance for any lightning protection shall not exceed 10 Ω. (Department of Navy 1979)

Article 250-84 of the National Electrical Code states that if a made electrode does not have a resistance-to-ground of 25 Ω or less, it shall be augmented with an additional electrode (NEC 1993). This is for the grounding of electrical systems. In Section 250-71(b), the code notes in an example, "Also assume that the power ground has a resistance (Rp) of 10 Ω, a *very* low value in most circumstances."

To determine the riser-to-ground resistance, a test was done on each accessible riser (some are under covers or cut off and capped below grade level) for each SST (Kiewert 1996). This test did not measure all characteristics of the tanks, such as inductance. Five major conclusions regarding the risers could be drawn:

- Approximately 48% of the 100-series tanks have all risers grounded adequately.

- The vast majority (> 98%) of the 775 originally-installed risers in the 100-series tanks are well grounded, meet the acceptance criteria of less than 5 Ω, and most have a resistance of less than 2 Ω.

- Those risers that were added to the 100-series tanks after original construction are incidently grounded, if at all. Approximately 40% of those 319 risers had resistances in excess of the acceptance limit. All are considered suspect.

- The 200-series tanks [nominal capacity of 190,000 L (50,000 gal)] had a different construction technique for risers than the 100-series tanks. Approximately 54% of the 97 risers on those 16 tanks were classified as ungrounded.

These trends were not apparent from the work on SY-101 (Carlos 1992) because of the limited scope of the investigation. Corrective actions, such as grounding straps, are being implemented on the risers that present a risk to the waste.

Appendix A presents more detail on applicable codes and guides.

4.7 EQUIPMENT/RISER BONDING CHARACTERISTICS

The next item to consider is how well the equipment within the riser is bonded to the riser electrically, to assure that it does not serve as a conduit for current into the waste or to its surface. In Cowley and Stepnewski (1994), Uman notes that a direct strike on equipment-riser bonds or welds with a standard value of 2.5×10^{-3} Ω may generate voltages in the range of 10^3 to 10^4 V or "reasonable" values of 10^1 to 10^2 V. There may also be sparks at bolted flanges. If there is a small pocket of flammable gas in the riser, it is conceivable that it could ignite. However, since these effects are relatively localized and small or external to the tank, it is not of direct concern to the waste or structure.

However, inadequate bonding would "guide" the current down the equipment into the tank. where it would seek its way to ground through the waste, into the metal tank wall, and into the concrete (which is a moderate conductor, similar in conductivity to earth). In taking this path, the lightning strike is capable of depositing significant amounts of energy in the waste, either through ohmic heating or an arc. Kiewert (1996) is proposing corrective actions to assure adequate bonding.

4.8 TANK STRUCTURAL RESPONSE

The following discussion addresses the issue of the potential direct effect of lightning upon the tank structure. It does not consider the pressure transient from a fire. It is applicable to tanks that do not have flammable gas concerns or organic concerns, as well as those that do. For this purpose, the tank farm area is considered as the target for lightning, since there are many paths to the tank structure and even low energy effects should be considered. The specific concern is whether rebar that is wired-tied together may create sparks with concrete spalling leading to structural effects.

While the paths that lightning may chose to take through a structure are becoming better understood through the emerging RF testing technique and computer analysis (which have not yet been done at Hanford), the Hanford waste tanks are not well enough understood to say with certainty what percentage of the current from a strike may pass from the riser to the rebar, either through connections or arcs. Research, as described below, tends to demonstrate that rebar functions very well as a conductor. However, when it comes to detailed and specific analysis, Schnetzer et al. (1995) point out the difficulties of predicting a the response of a building to lightning, even when the building was built specifically for testing. In this case two subtle items caused responses that were unexpected. PVC pipe sleeves were installed on conduits to insulate the conduits from the building. But instead of extending the sleeves away from the building, they were cut off flush at the outer wall, allowing an unintended current path from the building to the exposed conduit at the point of exit. One of the two underground conduits used to evaluate the structure was buried 3 cm (1.125 in.) under a metal post for a steel fence surrounding the building. When the conduit was excavated, substantial arcing spots were found on the top of the conduit, confirming consistent arcing had occurred during the tests. With respect to the test, the authors say, "This outcome clearly demonstrates the difficulty in making definitive analytical assessments of the lightning responses of arbitrary complex structures or facilities." This experience points out the difficulty that would be encountered in modelling the 149 SSTs, including the attached pipes and surrounding fences; light poles on the farms; and other pipes, ducts, and conduits on the farms. But in the absence of further information, it is safe to assume that in addition to the charge that a tank receives through a riser, it is quite probable that the tank will be charged from a strike in the vicinity (since it acts like a big electrode).

The rebar in the dome consists of two layers, one near the inner surface and one near the outer surface. Each layer consists of concentric rings and radial bars, like the spokes of a wheel. At some distance from the center, two bars were added for each one of the "spokes", to account for the ever-enlarging circumferences of the concentric circles. The bars were not welded, but the radial and circumferential bars were tied to each other to assure proper spacing between rings and spokes. So while there may be gaps at the joints between the radial lengths of rebar and other gaps where the circumferential lengths were joined, there are many effective paths for the current from radial to circumferential rebar and back, wherever low impedance exists.

Uman notes in Cowley and Stepnewski (1994), that given gaps between rebar and risers, and rebar and rebar, and concrete and the metal tank wall, and given lightning current passing through the reinforced concrete structure (including the waste tanks), it is probable that some sparks would occur. This sparking could cause damage to the concrete where the spark creates mini-explosions that press the concrete outward, leading to cracks and/or spalling. This is a possibility particularly in structures in which the rebar network is limited.

Fagan and Lee (1970) discuss the grounding systems for buildings. They state, "...(T)hat concrete-encased metal objects were effective in providing improved grounding under adverse soil conditions, suggesting that the reinforcing framework of footings for the columns of structural steel buildings would provide effective grounding function and means...The steel framework of such buildings, if electrically connected at each column base to an inherent grounding electrode, then functions as a very efficient grounding network for system, lightning, and static grounding...All the rebar elements are held together before concrete pouring only by twisted-steel tie wires. As such, these fastenings would not be considered electrically adequate...At the same time, it has been found that these wire ties are surprisingly effective electrical connections...(T)here are a large number of these junctions (no. 8 or larger steel wire) effectively in parallel, cinched tightly together to support heavy rebar structures before and during the pouring of the concrete. They are also embedded in the concrete so corrosion is not a factor."

Assuming the reinforcing bar in a concrete reinforced structure is grounded, NFPA 780 (1995) states in Section 3-18.3, "Conductors...concealed in steel-reinforced concrete units shall be connected to the reinforcing steel." "Conductors" are the down conductors from air terminals to ground. This connection is done to preclude inadvertent flashing between the down-conductors and the structural steel. In other words, industry recognizes the ability of the rebar to be a pseudo down conductor without significant effects on the structure. Using this construction technique has not caused significant or unacceptable effects in the thousands of reinforced structures world-wide, including spalling caused by entrapped moisture vaporization.

IEEE Std 142 (1991) states, "Naturally, the greater the number of down conductors and grounding electrodes, the lower will be the voltage within the protection system, and the better it will perform. This is one of the great advantages of the steelframed building. It has as many down conductors as it has columns, or one about every 4.57 m (15 ft). Also at the bottom of each column it has a footing, which is a very effective electrode." With respect to ground electrodes, it states, "Made electrodes may be subdivided into ...steel reinforcing bars in below-grade concrete..." These statements are applicable to a reinforced concrete structure with its web of rebar. And for an underground, reinforced concrete tank, the whole structure is the equivalent of a foundation.

As is the case with any electrical current, current associated with a lightning strike will take the path of least impedance. The case of lightning strike is a very dynamic situation with the large current, resistive, inductive, and capacitive effects in the many possible paths. If a strike were to occur on a tank riser that is not well grounded to earth ground, and instead the primary path of the current is through reinforcing bars that are joined but not welded, the current would tend to go through the paths where the connection is better, as opposed to where significant gaps exist. In the case of an above-ground building that has the lightning current pass through the reinforcing steel and/or rebar, it is anticipated that the rebar is integral with the foundation where the current will be dissipated into the ground with no damage to the building. In the case of the underground tanks at Hanford, the rebar is not only tied into the foundation, but the concrete walls (which have a conductivity lower than the backfill around the tank) will dissipate the current through the large surface area of 1,900 m^2 (20,000 ft^2).

Two papers concerning rocket-triggered lightning relate to reinforced concrete structures. Morris et al. (1994) confirmed computer modelling of weapons storage igloos with respect to lightning, including rebar and a Lightning Protection System (LPS). They state in the conclusions, "...direct-strike lightning appears to pose no safety threat to properly stored explosives inside the structure...The surge impedance through the structure rebar is so small compared to the surge impedance of the counterpoise or other LPS conductors, that the LPS serves principally to conduct the lightning current into the rebar...Only a small percentage of the total current flows on LPS conductors, so most of the total current flows to infinity through the rebar, concrete, earth, and possibly large diameter metallic conduits...The voltages inside the structure are determined principally by the inductance and connectivity of the rebar in the walls and floor, and the current flowing in conductors connected to the grounding system is determined by the parallel inductance of the rebar."

A second paper, by Schnetzer et al. (1995), evaluated the response of a structure specifically constructed to be struck by rocket-triggered lightning. The walls were isolated from the ground and the building footing by a phenolic insulating material and were bonded to the floor rebar for some tests and isolated from the floor rebar for other tests. The structure had an LPS including five air terminals, two down conductors, and a Ground Ring Electrode (GRE). The air terminals were bonded to the corrugated metal roof, which was bonded to the rebar in the walls. The building was built on 0.15 m (6 in.) limestone gravel base, eliminating intimate contact with the underlying red clay soil. As noted in the previous paper, this paper concludes, "In this type of steel-reinforced concrete structure, structural members carry to earth the major fraction of incident lightning current...With wall-to-floor bonding jumpers removed, it was expected that the majority of the current would be carried to earth by the down conductors. In fact, this path carried no more than one-half to one-third of the incident stroke current." Even though the walls were intentionally insulated from the footings and the ground, this significant amount of current was carried by the rebar through unanticipated paths to ground.

IEEE Std 142 (1991) reports in the paragraph about concrete encased electrodes. "Concrete below ground is a semi-conductive median of approximately 3,000 Ω-cm resistivity at 20 °C, or somewhat lower than the average loam soil. Consequently, in earth of average to high resistivity, the encasement of rod or wire electrodes in concrete results in lower resistance than when a similar electrode is placed directly in the earth." The measured resistivity of Hanford's soil is 15,000 to 50,000 Ω-cm (Kiewert 1996). By visualizing the layers of an onion with an electrode buried in the center, it can be seen that, even though the resistance of each layer has the same value for each square centimeter, the folded back layers have smaller areas. This means that the resistances of the shells increase as the shells are peeled away one-by-one toward the electrode at the center. By having material immediately around the electrode with a relatively low resistivity (such as concrete) instead of high resistivity (such as Hanford soil), the resistance of the first shell of soil is reduced because the area is larger than if it were immediately around the electrode (not displaced by the concrete).

API (1991) recognizes that there are underground storage tanks that are used to store petroleum products, including tanks in non-conductive, plastic shells. With respect to a concern about static charges, they state,"...the outside of a buried plastic tank is in contact with a conducting medium and any accumulated charges are dissipated."

Weiner (1996) reviewed the structural aspects of potential lightning effects on a tank. He concludes that, "Dome collapse as a direct result of a strike is considered very unlikely." The bases for the statement are practical experience, the fact the domes have at least double the normal structural margin implied by code practice, and that any damage would be local spalling. In addition, the multiplicity of conducting paths tends to minimize any localized reactions.

Based on the historical information of experience of buildings of similar construction, testing (mostly reported in IEEE documents), and a review of design features of the waste tanks, the tank structure will not be directly affected by a lightning strike. This section does not address the consequences of a secondary effect if a detonation or deflagration were to occur.

4.9 MITIGATION

For a system like the tank farms, there are several possible methods to reduce the threat from lightning. These methods include:

1. Improved grounding of the risers and bonding of the equipment that passes through them to the waste;

2. Grounded air terminals around the tanks;

3. Shielding that covers the tanks, such as a catenary system;

4. Mitigative steps to reduce the vulnerabilities of the waste, such as ventilation or assuring that the waste is wet;

5. Operational controls which prevent or mitigate enhanced lightning vulnerabilities during normal and special operations.

Grounding and Bonding The 100-series SSTs were constructed (albeit possibly inadvertently) as rather effective Faraday Cages, since the original risers are tied into the rebar network in general. Those risers added after original construction and those of the 200-series tanks can be grounded through the addition of cables that better couple the riser to ground. The cables should be as short and fat as reasonable to reduce the impedance as much as possible, or more than one cable should be used. There are some instruments that contact the waste and are apparently grounded through the waste instead of through the riser. These instruments have to be carefully considered with respect to the waste in the particular tank, the need for the instrument, its design and installation, and the ability to bond the instrument better to the riser or other path to ground.

Grounded Air Terminals The existing light fixtures on the poles within the farms already present attractive lightning targets. However, there is no engineered protection to keep a streamer from initiating from a riser, ventilation system, earth ground, etc., and jumping to a conduit affixed to a light pole. A system of partial protection on existing poles would serve to intercept and divert some of the infrequent flashes that might otherwise affect a tank with its contained waste, particularly for those farms with waste that is most susceptible to ignition. The T Farm does not have poles close enough to the tanks to have protection value. The C Farm has new, tall, metal light poles that have air terminals installed already. The grounding of the lightning protection needs to be checked to assure that it is independent of the electrical system. One can assume the "rolling ball" as the zone of protection, or the more restrictive "cone of protection" for an air terminal on a pole. Because of the configuration of the existing light poles, the B, BY, S, SX, TY, and U Farms can achieve 40% protection using the "rolling ball" concept, while the A, AX, BX, and TX Farms can achieve 15% to 25% protection of the cross-sectional area of the associated tanks. Using the "cone of protection," that coverage is reduced to 0-16%, with most farms being on the order of 10%. Of the risers that contain thermocouple trees (i.e., a potential conductor into the waste), approximately 40% are covered by the "rolling ball" and 10% by the "cone of protection." ICF Kaiser Hanford provided an estimate of $350,000 to install air terminals on approximately 40 existing light poles on the nine farms (Koellermeier 1996).

Additional poles with attached grounded air terminals could be installed where existing light poles do not provide 100% coverage. This would be more costly in resources and occupational exposure and disruptive to ongoing work than limiting the work to existing poles. This is not recommended for the incremental benefit received.

Catenary System A review of previous mitigation activities was done. Because of the concern of gas-release events in 101-SY in the early 90s, consultants were brought onsite to propose appropriate lightning mitigation. Two meteorological towers were put into place as air terminal towers. Eventually they were removed so that certain work could take place and because the system was not fully effective as installed. While they were more than tall enough to provide protection, there was a question of the cone of protection coverage. Because the lightning season had passed and the mixer pump was subsequently installed, no mitigation system was reinstalled.

This episode was a learning process since it became evident that any significant mitigation scheme would have to be carefully considered, to not present a hazard to the workers or a significant barrier to accomplishing work in the farms.

ABB Impell Corporation; TLC, Incorporated; and EBASCO Incorporated provided input to the decision for SY-101. Johns (1991) presented the review of the proposals. The consensus was that installation of a catenary system for the SY Farm instead of the air terminal towers would provide better protection for SY-101. The estimate for this protection was $200,000. Engelhardt (1992) stated that the cost of a catenary system for SY Farm was $400,000. In view of the complexity of work access, the estimate for the installation of the commonly accepted "best" protection would be hundreds of thousands of dollars for each of the 12 SST farms. Installation of catenary systems for all tanks would itself entail some risk due to digging activities for installation. An evaluation of this risk was beyond the scope of this report.

Waste Controls Most of this report has focussed on what happens outside of the tank when there is a lightning strike. Another mitigative action would be to protect the waste in such a way that a lightning strike that does impact the waste does not create an ignition. If tanks have flammable gas concentrations for an unacceptably high amount of time, ventilation may be used to control the gas levels. If there are fuel-rich pockets of organic waste that are dry enough to ignite, depending on the leak integrity of the tank, it may be possible to add water to the waste to keep it above the required moisture level. Waste controls are not recommended if they are only for prevention of ignition from lightning, unless there is some new analysis of waste vulnerability that warrants the controls.

Operational Controls Operational controls, such as posted weather watchers, contacts with the Hanford Weather Observatory, termination of work, bonding of in-use equipment, are not within the scope of this report. Those controls are imposed in the work control process. While this report recognizes that controls exist, it is limited to protection for storage conditions.

Recommendation To address lightning mitigation across all of the SST farms, the National Lightning Safety Institute was contracted to review the farms, tanks, and nearby area, to propose a practical mitigation approach. Among other things, they strongly recommend grounding and bonding. They also recommended the addition of grounded air terminals atop existing wooden light masts/poles, correctly mounted and grounded. (Kithill and Collier

1996) For the newer steel poles in C Farm, they recommended verifying that the lightning ground system is not tied into the electrical ground system. It is recognized that this is not "100% protection." But it is a balanced approach considering the relatively low frequency of a lightning strike affecting a tank, and the cost and risk of constructing a more elaborate system.

4.10 CONCLUSIONS

For considerations of either structural or flammable gas issues, any strike on a farm should be assumed as an event initiator, with a target of approximately 0.02 km^2 for each farm. For concerns for organic issues (either solvents or complexants), the target for each tank is less than 500 m^2 (5×10^{-4} km^2), the cross-sectional area of the tank. This is conservative by a factor of 10 because on most SST farms the ground above the tanks is relatively clear of pipes, ducts, and conduits. The tank risers either are adequately grounded or will be grounded in accordance with code acceptance criteria. The tank structures are not significantly affected by a lightning-initiated event because of the many paths through the rebar and to ground through the concrete. Structural failure caused directly by lightning is incredible. Full mitigation, such as a catenary system for the 12 SST farms, would cost several million dollars. A more cost-effective approach would be to install air terminals on existing light poles.

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in²	Target Area, m²	Notes
Tank A-101					
R-20	2	76	19113	12.4	
R-2	4	24	2463	1.6	Temperature
R-6	2	70	16286	10.6	ENRAF
R-3	4	2	113	0.1	
R-7	2	32	3632	2.3	
R-12	2	48	7854	5.1	Temperature
R-11	2	30	3217	2.0	
R-10	3	8	380	0.2	
R-19	2	12	616	0.4	
Tank Total				34.7	
Tank A-102					
R-9	10	2	452	0.3	
R-14	3	43	6648	4.3	
R-2	4	6	314	0.2	
R-6	2	68	15394	10.0	FIC
R-3	4	2	113	0.1	
R-7	2	48	7854	5.1	Temperature
R-16	5	12	707	0.5	
R-17	5	12	707	0.5	
R-19	6	12	1018	0.7	
R-18	2	50	8495	5.5	
Tank Total				27.2	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in^2	Target Area, m^2	Notes
Tank A-103					
R-15	2	54	9852	6.4	Temperature
R-2	4	18	1810	1.2	Temperature
R-6	2	67	14957	9.7	FIC
R-17	2	56	10568	6.9	
R-12	6	24	2827	1.8	
R-3	4	2	113	0.1	
R-7	2	24	2124	1.4	
R-11	4	6	314	0.2	
R-19	2	8	314	0.2	Liq. Observ. Well
Tank Total				27.9	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in^2	Target Area, m^2	Notes
Tank A-104					
R-15	2	30	3217	2.1	
R-20	2	18	1257	0.8	
R-5	2	40	5542	3.6	
R-1	4	18	1521	1.0	
R-14	2	48	7854	5.1	
R-10	2	14	804	0.5	
R-6	2	52	9161	6.0	Reel
R-2	4	18	1521	1.0	Temperature
R-11	2	15	908	0.6	
R-18	2	12	616	0.4	Temperature
R-12	2	12	616	0.4	Temperature
R-4	6	8	616	0.4	
R-17	6	22	2463	1.6	
Tank Total				23.5	
Tank A-105					
R-11	1	24	1963	1.3	
R-5	2	56	10568	6.9	Reel
R-1	4	10	616	0.4	
R-14	2	6	201	0.1	Temperature
R-15	2	52	9160	6.0	Temperature
R-6	2	24	2124	1.4	
R-16	2	84	23235	15.1	Temperature
R-17	2	68	15395	10.0	Temperature
R-18	2	3	79	0.1	
R-19	2	72	17203	11.2	Temperature
R-9	4	98	32685	21.2	Temperature
R-20	2	6	201	0.1	
R-4	6	10	804	0.5	
R-8	2	12	616	0.4	Pressure Gauge
R-21	2	72	17203	11.2	Vapor Sampler
R-22	2	48	7854	5.1	Temperature
Tank Total				91.0	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in^2	Target Area, m^2	Notes
Tank A-106					
R-20	3	18	1385	0.9	
R-1	4	2	113	0.1	
R-14	2	48	7854	5.1	Temperature
R-10	3	24	2290	1.5	
R-6	2	62	12868	8.4	ENRAF
R-2	4	16	1257	0.8	Temperature
R-11	3	24	2290	1.5	
R-18	2	48	7854	5.1	
R-12	3	16	1134	0.7	
R-17	6	16	1521	1.0	
Tank Total				25.1	
FARM TOTAL/AVE PER TANK				229.4/38.2	
Tank BX-101					
R-7	6	20	2123	0.4	
R-8	2	57	10936	7.1	Reel
R-2	2	62	12868	8.4	Temperature
R-1	2	69	15837	10.3	
Tank Total				26.2	
Tank BX-102					
R-7	6	72	19113	12.4	
R-8	2	44	6648	4.3	Temperature
R-2	2	59	11690	7.6	Reel
R-1	2	28	2827	1.8	Temperature
Tank Total				26.1	
Tank BX-103					
R-7	6	16	1521	1.0	
R-8	2	69	15837	10.3	FIC
R-2	2	60	12076	7.8	
R-1	2	45	6940	4.5	Temperature
Tank Total				23.6	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in^2	Target Area, m^2	Notes
Tank BX-104					
R-7	6	12	1018	0.7	
R-8	2	69	15837	10.3	ENRAF
R-1	2	96	30172	19.6	
Tank Total				30.6	
Tank BX-105					
R-7	6	65	15837	10.3	Temperature
R-8	2	58	11310	7.4	
R-2	6	18	1810	1.2	
R-1	2	69	15837	10.3	ENRAF
Tank Total				29.2	
Tank BX-106					
R-8	2	65	14103	9.2	ENRAF
R-7	6	69	17671	11.5	Temperature
R-1	2	26	2463	1.6	Temperature
R-2	2	108	38013	24.7	
Tank Total				47.0	
Tank BX-107					
R-5	2	20	1521	1.0	
R-6	6	22	2463	1.6	
R-7	6	22	2463	1.6	
R-8	2	72	17203	11.2	FIC
R-2	6	68	17203	11.2	
R-3	6	40	6648	4.3	
R-4	2	65	14103	9.2	Temperature
Tank Total				40.0	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in^2	Target Area, m^2	Notes
Tank BX-108					
R-8	2	26	2463	1.6	
R-7	6	58	12868	8.4	Reel
R-6	6	26	3217	2.1	
R-5	2	72	17203	11.2	Temperature
R-13	6	26	3217	2.1	
R-1	2	56	10568	6.9	
R-2	6	26	3217	2.1	
Tank Total				34.4	
Tank BX-109					
R-5	2	40	5542	3.6	Temperature
R-6	6	12	1018	0.7	
R-7	6	17	1662	1.1	
R-8	2	65	14103	9.2	ENRAF
R-1	2	14	804	0.5	
R-2	6	20	2123	1.4	
R-3	6	42	7238	4.7	Temperature
R-4	2	65	14103	9.2	
Tank Total				30.4	
Tank BX-110					
R-6	6	18	1810	1.2	
R-5	2	22	1810	1.2	
R-4	2	58	11310	7.4	
R-3	6	36	5281	3.4	
R-2	6	55	11690	7.6	Reel
R-1	2	58	11310	7.4	Temperature
R-R1	2	6	210	0.1	
R-R2	2	8	314	0.2	
Tank Total				28.5	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in²	Target Area, m²	Notes
Tank BX-111					
R-5	2	24	2124	1.4	Liq. Observ. Well
R-6	6	26	3217	2.1	
R-1	2	60	12076	7.8	Temperature
R-2	6	58	12868	8.4	Reel
R-3	6	26	3217	2.1	
R-4	2	70	16286	10.6	
R-R3	2	6	201	0.1	
R-R4	2	6	201	0.1	
Tank Total				32.6	
Tank BX-112					
R-8	2	73	17671	11.5	ENRAF
R-7	6	28	3632	2.4	
R-1	2	56	10568	6.9	Temperature
R-2	6	12	1018	0.7	
R-3	6	14	1257	0.8	
R-4	2	58	11310	7.4	
R-R1	2	4	113	0.1	
R-R2	2	6	201	0.1	
Tank Total				29.9	
FARM TOTAL/AVE PER TANK				378.5/31.2	
Tank T-101					
R-1	2	56	10568	6.9	ENRAF
R-2	6	10	804	0.5	
R-7	6	63	14957	9.7	Temperature
R-8	2	58	11310	7.4	
Tank Total				24.5	
Tank T-102					
R-1	2	54	9852	6.4	
R-2	6	8	616	0.4	
R-8	2	52	9161	6.0	ENRAF
Tank Total				12.8	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in^2	Target Area, m^2	Notes
Tank T-103					
R-1	2	63	13273	8.6	ENRAF
R-2	6	8	616	0.4	
R-7	6	61	14103	9.2	
R-8	2	59	11690	7.6	Temperature
Tank Total				25.8	
Tank T-104					
R-1	2	10	452	0.3	Liq. Observ. Well
R-2	6	28	3632	2.4	
R-3	6	20	2124	1.4	Vap. Temp. Probe
R-4	2	53	9503	6.2	Temperature
R-5	2	60	12076	7.8	ENRAF
R-6	6	12	1018	0.7	
R-7	6	31	4301	2.8	
R-8	2	50	8495	5.5	
Tank Total				27.1	
Tank T-105					
R-1	2	60	12076	7.8	ENRAF
R-2	6	9	707	0.5	
R-3	6	5	380	0.2	
R-4	2	7	254	0.2	Temperature (cut)
R-5	2	54	9852	6.4	
R-6	6	31	4301	2.8	
R-8	2	12	616	0.4	
Tank Total				18.3	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in²	Target Area, m²	Notes
Tank T-106					
R-1	2	60	12076	7.8	ENRAF
R-2	6	16	1520	1.0	
R-3	6	12	1018	0.7	
R-4	2	4	113	0.1	
R-13	6	71	18626	12.1	
R-5	2	10	452	0.3	
R-6	6	10	804	0.5	
R-7	6	32	4536	2.9	
R-8	2	58	11310	7.4	Temperature
Tank Total				32.8	
Tank T-107					
R-R1	2	2	50	0.0	
R-1	2	63	13273	8.6	ENRAF
R-2	6	12	1018	0.7	
R-3	6	16	1520	1.0	Dip Tubes
R-4	2	58	11310	7.4	Temperature
R-5	2	38	5027	3.3	
R-6	6	20	2124	1.4	
R-7	6	36	5542	3.6	
R-8	2	58	11310	7.4	
Tank Total				33.4	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in²	Target Area, m²	Notes
Tank T-108					
R-1	2	14	804	0.5	
R-2	6	16	1520	1.0	
R-3	6	14	1257	0.8	
R-4	2	41	5809	3.8	Temperature
R-13	6	60	13685	8.9	ENRAF
R-5	2	14	804	0.5	
R-6	6	16	1520	1.0	
R-7	6	18	1810	1.2	
R-8	2	54	9852	6.4	
Tank Total				24.1	
Tank T-109					
R-1	2	64	13685	8.9	ENRAF
R-2	6	16	1520	1.0	Dip Tubes
R-3	6	51	10207	6.6	
R-4	2	11	531	0.3	
R-5	2	10	452	0.3	
R-6	6	11	908	0.6	
R-7	6	11	908	0.6	
R-8	2	65	14103	9.2	Temperature
Tank Total					27.5
Tank T-110					
R-1	2	65	14103	9.2	ENRAF
R-2	6	20	2124	1.4	Dip Tubes/SHMS
R-3	6	55	11690	7.6	
R-5	2	14	804	0.5	
R-6	6	18	1810	1.2	
R-9	2	29	3019	2.0	
R-8	2	60	12076	7.8	Temperature
Tank Total				29.7	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in^2	Target Area, m^2	Notes
Tank T-111					
R-2	6	12	1018	0.7	
R-8	2	19	1385	0.9	
R-3	6	54	11310	7.4	
R-4	2	61	12469	8.1	ENRAF
R-5	2	64	13685	8.9	Temperature
R-6	6	25	3019	2.0	
R-7	6	16	1520	1.0	Liq. Observ. Well
Tank Total				29.0	
Tank T-112					
R-1	2	10	452	0.3	
R-2	6	12	1018	0.7	
R-11	2	26	2463	1.6	
R-3	6	22	2463	1.6	Dip Tubes
R-4	2	4	113	0.1	
R-10	1	54	9503	6.2	
R-13	6	61	14103	9.2	ENRAF
R-5	2	4	113	0.1	
R-6	6	46	8495	5.5	
R-7	6	3	254	0.2	
R-8	2	52	9161	6.0	Temperature
Tank Total				31.5	
Tank T-201					
R-6	6	53	10936	7.1	
R-5	2	59	11690	7.6	Temperature
R-7	6	14	1257	0.8	
R-8	2	9	380	0.2	
R-4	2	36	4536	2.9	Reel
R-3	6	3	254	0.2	
Tank Total				18.8	

Table 4-1. Riser Configuration with Respect to Lightning for A, BX, and T Farms. (12 sheets)

Riser	Radius, in.	Height, in.	Target Area, in^2	Target Area, m^2	Notes
Tank T-202					
R-6	6	61	14103	9.2	
R-5	2	66	14527	9.4	Temperature
R-7	6	19	1963	1.3	
R-8	2	13	707	0.5	
R-4	2	36	4536	2.9	Reel
R-3	6	12	1018	0.7	
Tank Total				24.0	
Tank T-203					
R-6	6	57	12469	8.1	
R-5	2	63	13273	8.6	Temperature
R-7	6	19	1963	1.3	
R-8	2	63	13273	8.6	Temperature
R-4	2	38	5027	3.3	Reel
R-3	6	36	5542	3.6	
Tank Total				33.5	
Tank T-204					
R-6	6	58	12868	8.4	
R-7	6	20	2124	1.4	
R-8	2	67	14957	9.7	Temperature
R-4	2	39	5281	3.4	Reel
R-3	6	39	6362	4.1	
Tank Total				27.0	
FARM TOTAL/AVE PER TANK				419.8/26.2	

Notes:

ENRAF is a level detector manufactured by the ENRAF Corporation.

FIC is a level detector manufactured by the Food Instrument Corporation.

Temperature is a thermocouple tree or other temperature monitoring device.

Reel is a manual liquid level detector.

SHMS is Standard Hydrogen Monitoring System.

5.0 LIGHTNING-RELATED ATTRIBUTES OF TANK WASTE

This document is not intended to be an all encompassing review of waste characteristics; it is to identify those special issues that are related to lightning.

There are three issues of concern with respect to the waste: flammable gas, liquid organic complexants on the waste surface, and organic complexants in the sludge. There is ongoing work to further understand the behavior of the waste with respect to each issue. The methodology of how flammable gas may be generated in the tanks is being revised. This may better bound the frequency of how often a tank can have concentrations of flammable gas in the headspace that is either in excess of the LFL during steady state conditions. Brown and Stout (1996) reported headspace measurements of flammable gas concentrations in 22 SSTs using grab sample results, Standard Hydrogen Monitoring System (SHMS) data, and sniff data from industrial hygiene data sheets. Of 253 grab samples, 37 samples in six of the tanks exceeded 500 ppm, while only 8 samples in two of the tanks exceeded 1,000 ppm. While this data may be encouraging, not enough information is available to definitively quantify the amount of time that head space concentrations in excess of 25% of the LFL exist under normal conditions. Waste analysis is finding the organic waste is moist enough to preclude ignition, in most cases.

5.1 GAS-RELEASE EVENTS AND WEATHER/WASTE OBSERVATIONS

Lightning is associated with thunderstorms that occur during low atmospheric pressure. It has been observed from instrument response and verified mathematically that some tanks have level increases when atmospheric pressure is low, because the gas contained in the waste expands. Some information was collected from SY-101 from late 1989 to 1991 (Strachan 1991). The conclusion drawn was "...there is no correlation between the pressure variations and the start of a gas-release event." Among other things, Whitney et al. (1996) presented a series of graphs in Appendix F that tracked atmospheric pressure and waste level in 1995. In particular, F-7 (S-103 for October 18 to November 19), F-8 (S-106 for October 18 to November 19), F-10 (S-107 for November 1 to November 29), F-13 (S-111 for October 31 to December 1), F-20 (U-103 for November 14 to December 30), F-23 (U-105 for November 14 to December 15), and F-28 (U-109 for October 9 to November 21) show the relationship. In general, the changes are on the order of 0.5 in. in an 80-ft-dia tank. If the level change is uniform across the tank, 0.5 in. is equal to approximately 200 ft^3 of increased waste volume. In general most of the barometric pressure changes were 0.2 in. Hg. However, between December 9, 1995, and December 12, 1995, a very large pressure swing (almost 1.5 in. Hg) occurred. Waste level increased with decreasing pressure, consistent with previous data. Four of the DSTs (103-AN, 104-AN, 105-AN, 101-AW) experienced increased H_2 concentrations on December 12. The first three tanks had increases on the order of 200 ppm, while 101-AW went from 790 ppm to 2,110 ppm. (As apoint of reference, 10,000 ppm is roughly equivalent to 25% of the LFL.) There was no thunderstorm activity associated with this low pressure system.

While there is a cause-effect relationship between atmospheric pressure and entrained gas, it does not appear that even significant weather perturbations alone would cause a single SST to release adequate volumes of gas to cause the head space concentrations to reach the LFL. The viscosity of the waste, as well as the surface tension and the diffused nature of entrained flammable gas in the waste, tend to keep the gas from creating a gas release event when barometric pressure changes.

Since the phenomenology of gas-release events is not yet fully understood, this report assumes a lightning strike anywhere on a farm with a flammable gas tank can cause ignition in a tank with dome space concentration in excess of the LFL. It also presents the methodology for calculating the probability of ignition. Further work needs to be done to determine which tanks have a credible ignition scenario.

5.2 EQUATIONS

A second aspect of lightning and potential flammable gas is the calculational technique to determine whether ignition is credible. The probability of any of the 149 SSTs having dome space concentration in excess of the LFL coincident with a lightning flash is the summation of each of the tanks' probabilities. In other words:

$$P_{ig} = \sum_{i=1}^{i=149} Freq_{ti} \times P_{ti} \qquad (5\text{-}1)$$

Where: P_{ig} is the probability of ignition of any tank, $Freq_{ti}$ is the flash frequency affecting tank *i* in flash/tank/year, P_{ti} is the probability of tank *i* having a concentration of greater than the LFL (e.g., the fraction of a year that the concentration exists in the tank). A uniform frequency can be assumed and $Freq_{ti}$ is a constant for all the tanks. Or a tank-by-tank calculation can be done, with tank-specific target areas. It can also be calculated on a farm-by-farm basis. In this case, using 0.06 fl/km²/yr and 0.02 km² for a farm, Freq is 0.001 fl/farm/yr. Using this frequency, equation (5-1) can be simplified to:

$$P_{ig} = Freq \times \sum_{i=1}^{i=149} P_{ti} \qquad (5\text{-}2)$$

A probability can be assigned that is a limit, such that P_{ig} must be less than 10^{-6}. If the frequency of any one tank being affected because of a strike on the farm is 10^{-3}, and if the summation of the probability of each of the 149 SSTs exceeding LFL is less than 10^{-3} (less than approximately 8 h/yr), then the probability of any tank ignition is incredible.

The same general approach can be used with respect to the possibility of initiation of an organic-nitrate reaction.

$$P_{acc} > (1.0 - P_d) \times Freq \qquad (5\text{-}3)$$

Where P_{acc} is an acceptable probability of an occurrence of initiation of an organic-nitrate reaction (e.g., 10^{-6}), P_d is the probability that the energy of a lightning strike will be dissipated without ignition, and Freq is the assumed frequency of a lightning strike on a tank. If Freq is less than 10^{-6} fl/km^2/yr, then it does not matter if the waste can effectively dissipate the energy without ignition. Or if P_d is greater than 999,999/1,000,000 (the characteristics of the waste are such that the energy is essentially always dissipated), it does not matter if a tank is struck once a year. Equation 5-3 can be solved for either Freq or P_d.

Based upon a Hanford-area flash frequency of 0.06 fl/km^2/yr and a tank target area of 5×10^{-4} km^2, the probability of a tank riser being struck is 3×10^{-5}/yr. Because most risers are adequately grounded and mitigative actions are underway, the factor of 10 conservatism could be removed (the more realistic target area of the risers versus the cross-sectional area of the tank). The probability is reduced to 3×10^{-6}/yr. That would suggest that if the energy can be dissipated 2/3 of the time without ignition striking a riser that does not have anything connecting to the waste, being directed from the riser to ground, or slightly heating some moist organic waste, then the overall result is acceptable.

5.3 ORGANIC PHENOMENOLOGY

Solvents. There are few tanks with identified organic solvent. Of the 68 tanks that have had vapor space sampling analysis done through April 1996, up to 7 have had indications of a solvent pool of 2 m^2 or greater. Of these, one has been verified through photography as having an organic pool on its surface (C-103). Photographs of the surface of a second tank (BY-108) show a dry surface suggesting that organic solvents may be contained within the solid waste. There are no photographs of the other tank surfaces. The sampling program is set up to first sample those tanks and farms that are more likely to contain organic solvents based on historical data. The vapor sampling program is scheduled to continue for about two more years, until all SSTs have been sampled. Even assuming the same rate of finding tanks with possible organic pools, only eight or nine more tanks would be expected to be found (7/68 or 10% of the 81 remaining SSTs).

Fauske (1996) notes that a spark of a modest amount of energy (10 J) is required to ignite an organic solvent pool. While a typical lightning stroke would generate a spark larger than that needed for ignition, it is extremely improbable that the bulk of the energy would be applied to this one, critical gap. But given the critical gap and spark in one of the few tanks with organic solvent on the waste surface, Meacham et al. (1995) demonstrated that for at least one tank (C-103), the fire self-extinguishes at the oxygen extinguishment limit.

Organic Complexants. As discussed below, ignition in an organic complexant tank requires a fuel-rich, low-moisture condition. The issue of what an appropriate criteria should be for evaluating the safety of organic tanks is being evaluated. There are 20 SSTs which are on the Organic Watch List because it is assumed they have greater than 3 wt% total organic carbon (TOC). Webb et al. (1995) determined that all except 13 SSTs were *safe* and those 13 were *conditionally safe.*

A review of the results of waste sampling from 10 of the 20 tanks that are on the existing Organic Watch List demonstrated that none had fuel-rich (>600 J/gm) and dry (<5 wt%) waste. Information on the other 10 tanks was not available for review.

For purposes of this report, 30 tanks (20% of the SSTs) are assumed to have the requisite conditions for potential ignition.

Fauske (1996) points out that a spark of 3.3 J is required to ignite organic complexant in the waste. He goes further to state, "...the short duration (microsecond time scale) prevents sustained combustion prior to the dissipation of the spark energy." For one example, "...the critical ignition time is of the order of 1 s." And he further states, "...the waste must be essentially dry for such ignition sources to be effective. Small quantities of water will prevent the contact temperatures from reaching the ignition temperature, even for stoichiometric mixtures." With respect to waste moisture content, Fauske et al. (1995) state, "Again, a moisture concentration greater than 20 wt% will prevent combustion for all fuel-oxidizer concentrations." If the moisture content is less than 5 wt%, an ignition source of 1200 J/gm would initiate sustained combustion. A fuel-moisture relationship is defined by a line:

$$\text{wt\% TOC} = 4.5 + 17(x_W)$$

where wt% TOC is the weight per cent of total organic carbon (on a wet basis) and x_W is the fraction of free water in the waste. Values of the relationship above the line are susceptible to ignition while combinations below the line are unlikely to ignite.

The fact that the waste is in general moist serves to temper energy deposition from lightning. Approximately 968 Btu/lb_m is the latent heat of vaporization. Since 1,056 J equals 1 Btu, approximately 1 MJ (10^6 J) is required to vaporize 1 lb_m (453 g) of water, not including the energy required to heat the water from ambient to the boiling temperature. This is approximately 1,000 J for 0.5 g. Uman, in Appendix A to Cowley and Stepnewski (1994), discusses the two forms of energy deposition: arc and ohmic heating. He notes, "A typical lightning transfers 25 coulombs of charge and thus an arc due to lightning between metal electrodes could liberate 250 J of energy at the arc spot, in a volume certainly less than a cubic centimeter, perhaps as small as a cubic millimeter." While a spark, with 250 J concentrated in a very small volume and short duration, may not do much vaporization, it is of interest that the amount of energy Uman uses is the amount required to vaporize 0.1 g of water (100 mm^3). Ohmic heating is different in that a time integral of current squared is used to calculate the energy. Uman notes, "The time integral...is typically 5 x 10^4 A^2s for negative flashes to earth..." Ninety per cent of the energy [which would range from 100 to 10^7 J (depending upon waste conductivity)], would be deposited in approximately 2 L of waste. For the upper limit of 10 MJ, 5 kg of water could be vaporized.

Spark. It was noted in Chapter 3.0 that an indirect effect of a lightning flash could be the ohmic heating of metal in the tank, leading to melting and the subsequent dropping of a piece of molten metal into the waste. Fauske (1996) considers that, "... 250 J alone would be required to produce a molten steel droplet 4 mm in diameter, which is less than the capillary size of approximately 6 mm (i.e., the melted material would quickly refreeze in place)." A falling spark does not contain enough energy to ignite the organic waste.

Summary. Although there are still refinements ongoing with respect to tanks contents and waste susceptibility to ignition, it can be assumed that 20% of the SSTs may have organic waste (either solvent or extractant) that could be susceptible to ignition. Concentrated lightning energy precisely deposited in the correct tank is more than adequate to create a spark in excess of that which could cause ignition in a tank with either organic solvents on the waste surface or organic complexants in the waste. A surface fire would burn itself out or moisture in the waste in excess of 20 wt% would preclude propagation. In addition, some mitigation is recommended.

5.4 TANK CLASSIFICATION

For the purposes of determining the proper type of electrical equipment to be used in certain applications, NFPA 497A (1992) has provided a methodology. Huckfeldt (1996) performed the classification for the flammable gas watch list tanks since the question was raised as to what equipment could be used in the tanks during intrusive activities. While this is not directly applicable to the concern over lightning-initiated events, the logic used can be carried over to this evaluation. NFPA 497A (1992) classifies as Class I those areas where flammable concentration of vapors "...may be present...in sufficient concentration to produce an ignitible mixture." Division 1, which is a subcategory of Class I, includes locations where an "...ignitible mixture is likely to be present continuously or intermittently under normal conditions of operation, repair, maintenance, or leakage." Division 2 locations are those where "...ignitible mixture is likely to be present under abnormal conditions, such as failure of process equipment." Flammable mixtures of hydrogen are Group B (group is the categorization of the type of combustible present in the location.)

Huckfeldt (1996) recommends that new equipment that is installed in the vapor space of the flammable gas watch list tanks be designed and constructed in accordance with Class I, Division 2, Group B, requirements (for locations where the ignitible mixture is present under abnormal conditions). He states, "This is a conservative position," because electrical breakdowns are rare even for equipment that has not been designed as rigorously as his recommended type.

Equipment that communicates directly "...with the waste where flammable gases may accumulate during operations should be installed to meet the requirements for Class I, Division 1, Group B locations." This approach is consistent with the concept that, even for flammable gas watch list tanks, the risk of a spark occurring when there is an ignitible mixture is small.

While this evaluation has focussed on organic extractants in the waste, Huckfeldt expresses the concern over retained gas in the waste. The basis for the controls Huckfeldt recommends imposing on intrusive work is consistent with lightning issues presented in this report.

5.5 CONCLUSIONS

Based on observations over the past year, it appears that low pressure weather systems will not cause a gas-release event coincident with a lightning storm. Further evaluation needs to be completed with respect to the amount of time that tanks have gas concentrations in excess of the LFL. This report presents the methodology to evaluate the data.

There are few tanks with known organic solvent. The probability of lightning striking a riser of a tank with an organic solvent pool is approximately 3×10^{-6}/yr for each tank (3×10^{-5}/yr if there are 10 such tanks). If the tank cross-sectional area is assumed to be the target area, the probabilities increase by a factor of 10. The probability of a pool ignition is less than the strike frequency because strike frequency includes all risers on a tank with organic solvent. But, as discussed in Sections 4.3 and 4.6, strikes on most risers will not lead to energy entering the waste because of configuration and grounding. This conservatism has not been quantified.

If the moisture content in the organic extractant waste is greater than 20%, a fire will not be initiated by lightning energy being deposited in the waste. There is a critical relationship between moisture content and fuel that will support a fire if a lightning strike were to deposit sufficient energy in the waste. The probability of lightning striking a tank with organic-fuel-rich, dry waste is the same as striking a tank with organic solvent. If 20% of the tanks have susceptible organic extractants, the probability of any of those tanks being struck in a year is less than 10^{-4}. As with the solvent tanks, the chance of ignition is less than the strike frequency, but not quantified. Again, using the cross-sectional area of the tank as the target area, the probability increases by a factor of 10.

6.0 CONCLUSIONS/RECOMMENDATIONS

6.1 CONCLUSIONS

1. Lightning flashes in the 200 East and 200 West Areas are less than 0.06 fl/km^2/yr. This is based on 10 yr of actual data from the BLM and GAI.

2. Based on over 600 ground flashes, peak current for the 99th percentile flash is 100,000 A.

3. The tanks probably serve as electrodes during a lightning event and, as such, can be affected by a strike anywhere on the farm. The effect of particular concern is for flammable gas.

4. With respect to organics, the paths into tanks that lead directly to waste do not present very large targets for lightning. Detailed evaluation of the risers demonstrates that a farm-by-farm approach yields realistic target area values and allows a focussed approach on potential mitigation for those few tank-riser combinations that could represent a direct path for a significant portion of lightning current into the waste.

5. While the waste shows some response to changing weather (i.e., level changes in response to atmospheric pressure), it appears quite unlikely that a low pressure system can cause a significant gas-release event coincidental with lightning creating a spark in an affected tank.

6. Although a detailed cost and schedule estimate for a complete lightning protection system for each tank farm was not done, based on the experience at 101-SY, such a system would cost several million dollars and may create operational challenges for daily operations, characterization, and retrieval of tank waste.

7. Because of the extremely low probability of a lightning strike creating an unacceptable event (such as an organic fire) in a tank, complete lightning protection (such as a catenary system) is not warranted.

8. The construction industry practice of bonding down conductors to reinforcing steel in concrete structures, combined with the few reported incidents of significant problems with lightning affecting such buildings, allows the conclusion that the likelihood of dome collapse or other major structural problem directly from a lightning strike is extremely unlikely or incredible.

9. A review of industry standards and guides, in conjunction with field measurements, points out that the lightning protection for the waste tanks meets the intent of appropriate standards, in particular NFPA 780 (1995). It is anticipated that future activities will continue in compliance with codes and standards.

10. Further evaluation of the tank characteristics with respect to lightning in the form of RF testing should not be done at this time, because of the uncertainty added by subtle as-built differences among the tanks. These differences can cause significant structure response variations, as pointed out in Schnetzer et al. (1995).

6.2 RECOMMENDATIONS

1. Lightning mitigation should be done in a cost-effective manner. This includes putting air terminals on appropriate light poles and assuring adequate clearances between the electrical ground for any of the farms and the existing lightning ground system. This would provide incremental protection for the tank contents.

2. Tank risers with unacceptable riser-to-ground resistance measurements (particularly those which communicate with the waste) should be corrected. This will provide some assurance that the risers will divert the energy from a lightning strike to the ground rather than to the tank and/or waste. Since this is mainly an issue with respect to organic waste, the repairs should be prioritized based on whether the tank is *unsafe, conditionally safe*, or *safe.*

3. For those tanks that have waste that is very susceptible to ignition and that have risers that do not meet the acceptance criteria for ground resistance, consideration should be given to putting a grounded, metal structure or an air terminal over those risers that have equipment extending into the waste.

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APPENDIX A

CODE APPLICABILITY

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APPENDIX A

CODE APPLICABILITY

In reviewing a list of codes, standards, and recommendations, it appears that the most applicable is National Fire Protection Association (NFPA) 780, *Standard for the Installation of Lightning Protection Systems*, 1995 Edition.

DOE ORDER 6430.1, *General Design Criteria*

Paragraph 1630-5 of Section 1630, "Exterior Electrical Utility Services," states, "Lightning protection systems shall comply with NFPA-78...A risk assessment using the guide in Appendix I of NFPA-78 shall be made of these buildings to determine the risk of loss due to lightning." Note that Appendix I in NFPA 78 has become Appendix H of NFPA 780.

AMERICAN PETROLEUM INSTITUTE RECOMMENDED PRACTICE 2003

This practice addresses tank vehicles, marine operations, storage tanks, miscellaneous electrostatic hazards, lightning and stray currents. It does not address underground storage tanks explicitly.

The petroleum industry tanks are generally metal and above ground, so most of the discussion revolves around masts and overhead ground wires. It mentions wood, brick, tile, and concrete structures in the final paragraph of Section 6.4, and suggests the protection techniques used for tanks, tankers, etc., is applicable for these other types of structures. Once again, it does not address underground facilities specifically. It notes the protection-zone concept is consistent with NFPA 78 (the predecessor to NFPA 780).

NFPA 780, *Standard for the Installation of Lightning Protection Systems*

The following are some applicable definitions quoted from this standard:

> **Authority Having Jurisdiction.** The organization, office, or individual responsible for approving equipment, an installation, or a procedure. (This is further discussed in Appendix A, "Explanatory Material." Section A-2-2 states, "The phrase 'authority having jurisdiction' is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual...")
>
> **Listed.** Equipment or materials included in a list published by an organization acceptable to the authority having jurisdiction and concerned with product evaluation that maintains periodic inspection of production of listed equipment or materials and

whose listing states either that the equipment or materials meets appropriate standards or has been tested and found suitable for use in a specific manner.

Metal-framed Structure. A structure with electrically continuous structural members of sufficient size to provide an electrical path equivalent to that of the lightning conductors covered in this standard.

Vapor Openings. Openings through a tank shell or roof above the surface of the stored liquid. Such openings might be provided for tank breathing, tank gauging, fire fighting, or other operating purposes.

Zone of Protection. The zone of protection is that space adjacent to a lightning protection system that is substantially immune to direct lightning flashes.

The following are specific, applicable paragraphs of the standard:

Chapter 4.0, "Protection for Miscellaneous Structures and Special Occupancies. 4-6 Concrete Tanks and Silos." Lightning protection systems for concrete (including prestressed concrete) tanks containing flammable vapors, flammable gases, liquids that can produce flammable vapors...shall be provided with either external conductors or with conductors embedded in the concrete in accordance with Chapters 3.0 or 6.0.

Chapter 6.0, "Protection for Structures Containing Flammable Vapors, Flammable Gases or Liquids that Can Give Off Flammable Vapors."

6-1 Reduction of Damage.

6-1.1 This chapter applies to the protection of structures containing flammable vapors, flammable gases or liquids that can give off flammable vapors. (Appendix A, "Explanatory Material", notes in Section A-6-1.1, "This chapter applies to flammable or combustible liquids such as gasoline, diesel, jet fuel, fuel oil, or crude oil stored at atmospheric pressure.")

6-1.2. Certain types of structures used for the storage of liquids that can produce flammable vapors, or used to store flammable gases are essentially self-protecting against damage from lightning strokes and need no additional protection. Metallic structures that are electrically continuous, tightly sealed to prevent the escape of liquids, vapors, or gases, and of adequate thickness to withstand directs strokes (sheet steel 3/8 in. or greater)...are inherently self-protecting...

6-2 Fundamental Principles of Protection. Protection of these structures and their contents from lightning damage requires adherence to the following principles:

(c) Structures and all appurtenances (e.g., gauge hatches, vent valves) shall be maintained in good operating order.

(e) Potential spark gaps between metallic conductors shall be avoided at points where flammable vapors can escape or accumulate.

6-3.3 Rods, Masts, and Overhead Ground Wires.

6-3.3.1. The zone of protection of a lightning mast is based on the striking distance of the lightning stroke (the distance over which the final breakdown of the initial stroke to ground, or to a grounded object, occurs). Since the lightning stroke can strike any grounded object within the striking distance of the point from which final breakdown to ground occurs, the zone of protection is defined by a circular arc concave upward. The radius of the arc is the striking distance and the arc passes through the tip of the mast and is tangent to the ground....The striking distance is related to the peak stroke current and thus to the severity of the lightning stroke; the greater the severity of the stroke, the greater the striking distance. In the vast majority of cases, the striking distance exceeds 30 m (100 ft). Accordingly, the zone based on a striking distance of 30 m (100 ft) is considered to be adequately protected...Increasing the height of a mast above the striking distance will not increase the zone of protection. [The zone of protection can be calculated algebraically by the following equation: $d^2 = h \times (200 - h)$, where d is the horizontal distance from the mast to the edge of the zone of protection and h is the height of the mast.]

6-3.3.4. Masts of wood, used either separately or with ground wires, shall have an air terminal extending at least 0.6 m (2 ft) above the top of the pole, securely attached to the pole, and connected to the grounding system...For metallic masts, the air terminal and the down conductor shall not be required.

APPENDIX H RISK ASSESSMENT GUIDE

H-1, "General."

H-1.1. This lightning risk assessment guide is prepared to assist in the analysis of various criteria to determine the risk of loss due to lightning. As a guide, it is not possible to cover each special design element that may render a structure more or less susceptible to lightning damage. In special cases, personal and economic factors may be very important and should be considered in addition to the assessment obtained by using the guide.

H-2, "Determining the Risk." *{Values are reasonable for Hanford Waste Tanks.}*

$$R \text{ (Risk)} = \frac{A + B + C + D + E}{F}$$

A-Type of Structure = building housing the storage of hazardous material {10}

B-Type of Construction = reinforced concrete {1}

C-Relative Location = underground/structures in areas with higher structures {1}

D-Topography = On flat land {1}

E-Occupancy and Contents = Explosive ingredients {10}
Combustible materials {5}

F-Lightning Frequency Isokeraunic Level = 0-5 {9}

$$R = \frac{10 + 1 + 1 + 1 + 10 \text{ (or 5)}}{9} = 2 \text{ to } 2.5 = \text{Light to Moderate Risk Value}$$

NFPA 30, ***Flammable and Combustible Liquids***

NFPA 30 directs the user to NFPA 78 (the predecessor of NFPA 780) to obtain information on lightning protection for tank storage, both above ground and underground. (Section 2-7, "Sources of Ignition.")

NFPA 50A, ***Gaseous Hydrogen Systems at Consumer Sites*****/50B,** ***Liquefied Hydrogen Systems at Consumer Sites***

Neither code addresses lightning protection.

APPENDIX B

LIGHTNING-RELATED OCCURRENCE REPORTS

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APPENDIX B

LIGHTNING-RELATED OCCURRENCE REPORTS

A search of the occurrence report database was conducted on the word "lightning." It resulted in 33 reports over six years (1990 to 1995). Two were discounted because they were work-practice related. One had to do with a lightning arrestor. Four were reports of grass fires. Ten were associated with power outages elsewhere on site or inadvertent activation of a railroad track grade crossing barricade arm. (Three spurious activations of an arm from May 20 through May 23, 1994, were noted in *RL-WHC-KHFLEETOP-1994-0006* because of failed diodes possibly due to ..."heavy rain/lightning...") Sixteen reports were identified as being related to the 200 East and 200 West Areas.

On June 29, 1991, shortly after 1500, five events related to a passing storm caused occurrence reports. At 1510, electrical power was lost to all East Tank Farm facilities (*RL-WHC-TANKFARM-1991-1026*). On page 4 of the report, the evaluation includes a note, "The 200 East Area power failure is also documented from a site wide perspective in an Occurrence Report (*RL-WHC-200EM-1991-1025*) issued by Operational Site Services." Also at 1510, "lightning struck and disrupted the main power to the grout processing facility causing the ventilation system to shutdown (sic)." (*RL-WHC-GROUT-1991-1003*) The description of the cause includes, "Lightning struck and knocked down the main power that was supplying the 200 East area and Grout." The description of the occurrence identified the power supply as 243-G9. At 1515, it was noted in *RL-WHC-WHC200EM-1991-1025* (the report referred to above), "...lightning apparently struck near the 13.8 kV overhead lines C8-L6 and C8-L7." At 1535, " All facilities at B Plant/WESF had a loss of primary electrical power supply. Lightning from an electrical storm disrupted feeders C8-L6 and C8-L7." (*RL-WHC-BPLANT-1991-1014*) These are the same feeders identified in the previous report. There is a 20-min discrepancy in the times of the reports. Ten minutes later, at 1540, "Following the lightning storm, Tank Farm personnel checked the status of facilities and discovered that the 213-W building exhauster was shut down." (*RL-WHC-SOLIDWASTE-1991-1002*) From the time of the first report (1510) until this report (1540), the operators were touring facilities and there would be a lag before some items could be identified and reported to the shift manager, who would then determine reportability. It appears very likely that all five of these reportable occurrences are from a single strike on the 13.8 kV line.

On August 6, 1991, five more reportable occurrences happened in the late afternoon. At 1730, "Electrical storm activity caused power loss at several facilities in the 200 East and 200 West Areas." (*RL-WHC-ANNALLAB-1991-1015*) This included the laboratory where "A total momentary power loss due to an electrical storm resulted in a low intake vent alarm...Building evacuated as precautionary measure due to no air supply to CAMs." As noted at 1743, "...at approximately 1740, B Plant experienced a momentary power fluctuation due to a lightning strike on a site main feeder system." (*RL-WHC-BPLANT-1991-1023*) At the same time, "Lightning caused the 13.8 KV breakers

C8X1 and C8X4 to trip, relay action closed breakers C8X1 and C8X4." (*RL-WHC-WHC200EM-1991-1035*) At 1747, "...a power interruption at the UO3 Plant had occurred." (*RL-WHC-PUREX-1991-1039*) When the plant contacted the PFP Power Operators Control Room, they were, "...informed that all of the 200 West area had suffered the power interruption..." Finally, at 1754, "...lightning disrupted the main power to the grout processing facility." (*RL-WHC-GROUT-1991-1006*) The report states the event occurred at 1745, very close to the same time as the event at the UO3 Plant (1747). Without further investigation it is difficult to say whether one or two flashes caused the five reports.

Unrelated to the other ten reports from 1991 is *RL-WHC-WHC200EM-1991-1027*, which occurred at 0255 on July 13, 1991. In this instance, "Lightning caused the 13.8 KV breaker C4x18 to trip, relay action close breaker C4x18."

On June 28, 1992, a late evening storm resulted in three occurrence reports. At 2107, "...13.8 kV breakers were tripped by protective relay action and successfully reclosed. This caused momentary power outage to all connected loads on the 13.8 kV lines C8-L3 and C8-L4. The facilities involved were...242 UA,...284 W 241 Tank Farm..." (*RL-WHC-WHC200EM-1992-0038*) The next event was discovered at 2150 (*RL-WHC-PUREX-1992-0073*). However, the text states that alarms were received at 2113, closer to the time of the previous report. Also, it notes the tie breaker between the main power feed lines for the 224-UA building has closed. It is probably the case that in the previous report, the reference to 242-UA should have been to 224-UA. In a fashion similar to the previous report, the discovery time is 2150 for *RL-WHC-TANKFARM-1992-0051*. In the report, it notes that, "...at 2107 hours, a lightning strike on a 500 KVA transformer caused a 45-s power loss on the C8-L3 and C8-L4 power lines serving the 200 West Area." This is identical to the description of the first case. The reason for the later discovery time is the fact the operations personnel surveyed the area and found equipment not operating. As in previous events, it appears that a single lightning strike caused three events.

The following occurrence reports also were associated with the June 28, 1992 storm, but not in the 200 Area. They are included here for information:

> *RL-WHC-WHC300EM-1992-0030* "At 2015... 13.8 kV breaker...tripped by protective relay action. This caused a power outage to all connected loads on 13.8 kV lines C3-L2, C3-L3, C3-L5."
>
> *RL-WHC-WHC600EM-1992-022* "A total building primary power failure occurred due to a power outage...Lightning struck a transformer causing a power outage."
>
> *RL-WHC-WHC600EM-1992-0023* "At 2220...the 100 Area Fire Station notified the Dispatcher that there was a loss of power to their facility...(L)ightning struck a section of 13.8 kV line C8-L6..."
>
> *RL-WHC-WHC600EM-1992-0025* The June 28, 1992, thunderstorm resulted in range fires that caused the generation of an occurrence the next day.

> *RL-WHC-UO3-1994-0003* This occurrence may not have been a direct result of lightning. On February 13, 1994, at 1040, management discovered that some recorders were not operating and a report needed to be generated. However, the cause of the malfunction was not known. "Several electrical, wind, and rain storms have occurred at the UO3 facility within the last month. During these weather disturbances, spiking has been observed on the two (2) recorder channels..." There is an additional statement, "On Thursday afternoon, 2/17/94, during a lightning storm, the chart recorders R-1, R-2 and R-3 noted spikes..."

Finally, an occurrence was reported October 4, 1995, at 0900 (*RL-WHC-BPLANT-1995-0047*). However, the event occurred on September 28, 1995, at approximately 1420. "...(A) lightning bolt was seen near the front of the 271-B facility...The investigation...determined that the cause (of the alarms) was due to failure of the I/P controller..."

There have been at least six separate lightning strikes over a 6-yr period that resulted in 16 occurrence reports in the 200 East and 200 West Areas. One report does not identify a specific time to narrow in on a certain storm, but does include references to electrical storms in the area, *RL-WHC-UO3-1994-0003*. Thunderstorms in the Hanford area in February are rare. GAI detected 15 to 20 flashes in February 1994, but none in February of any other year.

As noted, there were six occurrence reports from the 200 Area on June 28, 1992, and four more from the rest of the site that were related to lightning. There are two other days on which multiple reports were generated identifying lightning as a cause. These were not in the 200 Area.

> *RL-WHC-308-1990-0025* On September 7, 1990, "Lightning strike on BPA grid resulted in a power fluctuation that automatically shut down the facility HVAC computer."
>
> *RL-WHC-FFTF-1990-0026* Also on September 7, 1990, "Lightning strikes on the Bonneville Power Administration 230 KV power distribution grid led to the interruption of electrical power to the plant..."
>
> *RL-WHC-WHC100EM-1992-0006* On July 20, 1992, "At 0721...lightning apparently struck an insulator on the 13.8 kV Line C4-L18."
>
> *RL-WHC-WHC600EM-1992-026* Also on July 20, 1992, "A lightning storm ignited a small grass fire at the intersection of Route 2 North and Route 11A..."

Of the 30 valid lightning-related reports, 16 are discussed here as associated with the 200 Area, 8 are identified as being related with common storms or strikes, and the grade crossing was mentioned because of the ambiguity of the cause. The other five occurrence reports for the site included two for grass fires (August 20, 1993, and August 7, 1994) and three for power outages (May 15, 1993, June 11, 1994, and July 10, 1995).

While it appears that there is a high number of lightning-related occurrence reports for the Hanford site considering the relatively few thunderstorm days in an average year (30 over 6 yr, including 16 related to the 200 Area), a more indepth review of the information would suggest the site is required to generate multiple reports from events which were initiated by a single flash, because of the design of the electrical power distribution system.

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